PhD THESIS

The Contribution of Complexity Theory in Resolving Energy Losses in Electrical Smart Grid Systems:

A Case Study of Electricity Supply and Use in Regional New South Wales – Australia

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A thesis submitted in fulfilment of the requirements for the degree

Doctor of Philosophy

August 2017

Table of Contents

List of Figures

List of Tables

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Acknowledgements

First and foremost, I owe my gratitude to my Principal Supervisor Professor Vernon Ireland for the genuine privilege of his excellent supervision, support, direction, advice, and wisdom to complete this study satisfactorily. Without his guidance, encouragement, and instruction, this thesis would never be achieved.

My thanks must go to my Associate Supervisor Dr Barry Elsey who has shown faith in my work and supported my journey in complexity study. His constant support, patience, and encouragement is immeasurable to me and without him, this thesis could not have been done. My deep appreciation is extended to my Associate Supervisor, Professor Frank Schultmann, for being such a helpful supervisor.

My appreciation also goes to my beloved Professor Vernon Ireland and my beloved, Entrepreneurship, Commercialisation, & Innovation Centre at the University of Adelaide. Thanks for your support during my research and for providing me with a priceless chance for a PhD scholarship.

I owe a deep sense of gratitude to "Dr Graciela Corral de Zubielqui" for her keen interest in my Master‘s research topic. Her prompt inspirations, timely suggestions, with kindness, dynamism and enthusiasm, have enabled me to successfully complete my Master‘s thesis, and win the chance of a PhD scholarship. To my beloved kids and wife ‘Thank you’. To my brothers and sisters, I love you all. My prayers and gratitude go to my parents’ spirits who have bequeathed me endless peace of mind and were always standing beside me throughout their lifetimes.

This study is dedicated to my supervisor, Professor Vernon Ireland, and to the ECIC, for their generous and endless kindness and support during my Master’s and PhD studies.

Abstract

The PhD research addresses the longstanding and unresolved global problem of energy losses from electrical smart grid systems. In particular, it focuses on the potential for a productive new role for end users of electricity at the household level. The research provides a complex systems perspective in approaching this problem, which recognises the benefits of emergence and self-organisation by homeowners in understanding and seeking to contribute to the large networked power distribution system.

A case study use of power by 300 houses in NSW, Australia, is used to address the current inconsistencies between electricity tariff policies and stakeholders, and the lack of knowledge and methodology needed to resolve the phenomena of peak and off-peak demand of electricity, which together, create unfavourable energy losses. A further issue is the inequity of financial benefits for electricity grid power suppliers, retailers and end-users.

A study of homeowners' patterns of use of grid supplied power, of a sample of home owners, over a three year period, was conducted, with usage data at 30 minute intervals, The research used mathematical programming methods, including Python programming software. The resulting calculations are used to devise a model, drawing on complexity theory, which significantly mitigates against energy losses, both to the electricity generators and distributers, and to end users, by factoring in the new element of renewable energy sources.

The contribution to knowledge is primarily the reduction of peak power usage in the grid by reducing maxima by use of home generated power through solar and wind, supplemented by individual battery systems. The research also indicates the business benefits of such an approach.

The research provides a way forward for future research and for a sustainable energy sector, with significant benefits to energy suppliers, retailers and end users at the household level.

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Chapter 1

Introduction

Acronyms

AEMC: Australian Energy Market Commission
AER: Australian Energy Regulator
AGL Energy: Electricity Retailer
Ausgrid: Electricity Retailer
BREE: Bureau of Resources and Energy Economics
DSP: demand side participation
EnergyAustralia: Electricity Retailer
Kw.hr: Kilo Watt Hour
LRMC: long-run marginal cost
MWh: Mega Watt Hour
NEM: National Electricity Market
NSW: New South Wales
Matlab: A multi-paradigm numerical computing environment and fourth-generation programming language
Origin Energy: Electricity Retailer
Snowy Hydro: Electricity Retailer
TIEs: tiny initiated events
TWh: terawatt-hours = billion Kilo Watt Hour

Chapter Outline

The key aim of this chapter is to provide a general introduction to the research problem and to provide an overview of the research that is to be fully developed through the body of this work. This chapter has been divided into three sections. The first part of this chapter provides an overview of the role of complexity theory and how it will guide this study to answer the research questions. The second part of this chapter provides the background to the research problem and the reasons this study is needed. The third part of this chapter presents the research questions, hypothesis, objective, the research rationale, contribution to knowledge and introduces the coming chapters of the thesis.

1.1 Focus of the thesis

This thesis explores the extent of human behaviour as an example of non - linear dynamic behaviour in a complex system, by using a case study of an electrical smart grid system. This study uses the complex systems and focuses on the spontaneous emergence of human's actions to understand the consequences of events scalability and the clustering dynamic of non-linearity.

Complexity theory has become a popular approach to address system dynamic and framing of complex networks, yet there is more to learn about how to link simple events created by human behaviour, which leads to a complex end and influences the outcomes of organisations. Particularly, when focusing on a subjective people in a complex system, it would be expected to have the highest influence on developing that system. In spite of the work done in this area of research, there is still a gap in the general conceptualisation of subjective human behaviours in electrical smart grid systems. A lack of integration of the subjective end-user behaviours into accepted models of system operation similar to that one illustrated in Fig 1.1, and a lack of agreement on facilitating a 'micro grid system' are obstacles to increasing system efficiency.

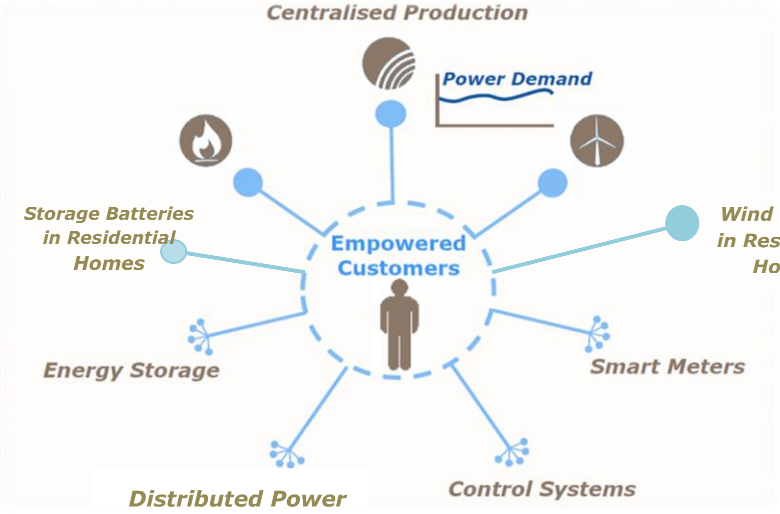

Figure 1.1 Empowered Consumers (Peak Energy 2016)

The interaction between complexity theory and human behaviour in moderating and optimising responsibilities and reducing losses of non-linear dynamic behaviours are evident and significant. However, the norms of scalability of human behaviours concerning the nature of complex systems that may provide positive operational outcomes, remain under development and are not yet well addressed in complex theories.

No conceptual model has yet been produced to explain the relationship between the tiny initiated events of human behaviours and the role of moderating/optimising a complex system, such as an electrical smart grid system. This study inscribes this shortcoming and a possible way to resolve it (Maguire, S, McKelvey, B, Allen, P, 2011).

This research is an attempt to verify the individual and clustering effect of human behaviours while consuming electricity in a complex grid system in Australia, supported by non-traditional power generation. This would, therefore, providing a greater understanding of those chaotic interactions which, in turn, will facilitate efficiency improvement (Platt, 2013). To achieve such a goal, a conceptual model has been hypothesised, theoretically discussed, and empirically tested, using simulation modelling covering number of ’47,304,000’ data elements. The subjective human behaviour targeted in this research consists of a residential group of people located on the demand side of electricity through a segment of residential houses in NSW in Australia.

1.2 Background of the Research

The electrical industry contributes significantly to the notion of the economic growth in Australia. The electricity industry of multi-generators and multi-users on a grid system is unique and differs from other industries due to the dynamic intensity of its prototypical nature. An estimated 36 per cent of Australian energy consumption is used for electricity power generation (Analysis Of Demand Side Management Opportunities 2014). The Australian government is aware that Australia’s electrical energy markets are going forward through significant transformations. The environment, energy prices, and customer welfare are major players which affect the expectation of future changes in the Australian market. There must be changes made to both the supply – and demand – of ways electricity is consumed and priced, as well as, being environmentally-friendly. Changing patterns of demand and supply have an effect also out of Australia on development in international markets for better future.

The electricity networks in Australia were built between the 1960s and ‘70s and have probably reached the end of their service life. Australia has nearly the same amount of network infrastructure as that installed in the United Kingdom. The difference, however, is that Australia has less than one tenth of the population of the population to share the costs (Department of Industry 2016). Consequences, the Australian Energy Regulator (AER) and the National Electricity Market (NEM) set the electricity network businesses prices and revenues regarding the nature of assets. Thus, new investments are needed and new operational environments should be considered. The goal is to assure efficient and conscious network investment to introduce a more reliable energy supply with less cost possible to consumers.

The National Electricity Market (NEM) expected such an investment would exceed $7 billion for transmission lines and $36 billion for an area distribution network. The forecast has been overtaken by approximately 27 per cent for transmission and 60 per cent for distribution as a rise in investment from the previous estimation made by NEM. Taking into account the investment drivers in NSW distribution network it found that $14 billion capital expenditure due to 42 per cent growth in energy demand, 31 per cent for asset replacement, 9 per cent for reliability and quality and 18 per cent for IT, climate change, environmental, safety and statutory obligations. It is considered to be too much money for uncertain outcomes (Department of Industry 2016).

1.3 Why Are Electricity Prices Increasing?

Many constraints are responsible for delivering an answer to the single objective in this complicated question, for which it is hard to introduce one simple answer *(Futures Knowledge 2015); (Gregory Basheda Marc W. Chupka, Peter Fox-Penner, Johannes P. Pfeifenberger, Adam Schumacher 2006); (U.S. Energy Information Administration (eia) 2015); (Fact Check 2016); (World Nuclear Association 2016); (Ontario Energy Board Consumers 2016); (Residential Electricity Price Trends 2015); (Possible future retail electricity price movements: [1 July 2012 to 30 June 2015] 2013); (Electricity Prices and Cost Factors 2001); (AER Electricity Report 2016); (Electricity tariff reform in NSW 2015); (An Introduction To Australia's National Electricity Market 2010); (Distribution Losses in Expenditure Forecasts 2012); (National Electricity Market 2016); (Analysis Of Demand Side Management Opportunities 2014).* The long-run marginal cost (LRMC) ranges for each National Electricity Market (NEM) region in Australia, depending on the type of loss either at transmission that is within $71–$150/MWh; or at distribution and that is in between $71–$262/MWh (Department of Resources Energy and Tourism, 2013; Grid Australia, 2012).

In this sense, the retail prices of electricity have risen roughly 60% since 2007. Although, the consumption of electricity is due to complex causes that differ in nature from one state to another. However, one underlying reason lies at the heart of the problem and that it is the ‘end-users’ consumption behaviours of electricity.

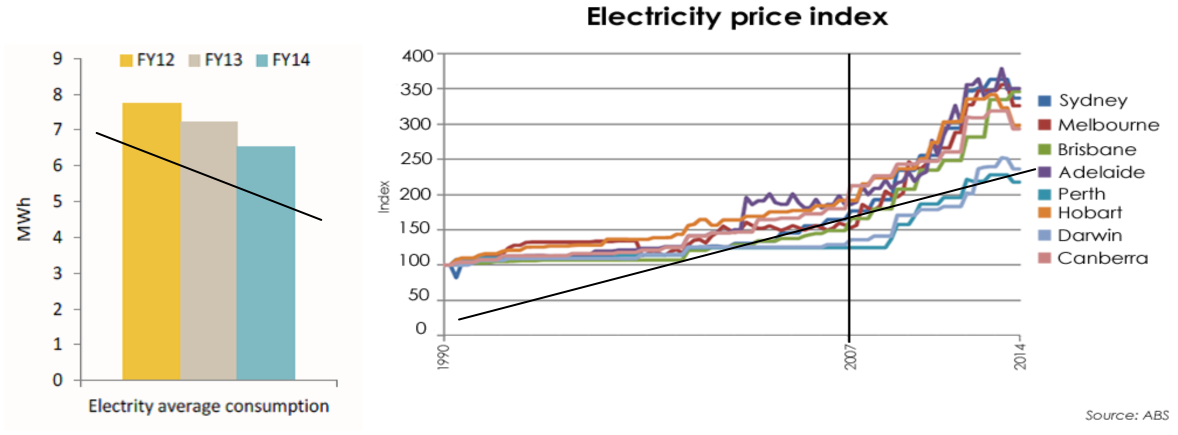

Figure 1.2: Average Consumption - Electricity Price Index (Peak Energy 2016)

The wholesale price of electricity is concurrent with the cost of producing electricity using power generators, with an average elasticity between peak and off-peak times (Zafar, 2015). The structural indicators of the electricity market illustrate high levels of incentives of the market power linked to the state where generators are exposed to contract or spot prices. Indicators explore the major relationship between a generator's bidding and spot price outcomes. Volatility in electricity spot prices can increase the cost of electricity usage and pose significant risks to market stakeholders. While electricity retailers face a risk of spot prices rising to levels at which they have no option but pass increased prices on to customers; generators also face a risk when low spot prices occur which reduce their earnings (see Figure 1.2).

Therefore, it is problematic for market participants to manage their exposure to price risk and ensure appropriate financial solvency. The complex financial relationships between retailers, generators and other businesses create financial interdependency, meaning that financial risks for one stakeholder can affect others. One solution supporting volatility in electricity prices was proposed by NEM, including Origin Energy, EnergyAustralia, AGL Energy, and Snowy Hydro, through vertical integration between electricity generators and retailers, which aims to balance the risks in each market.

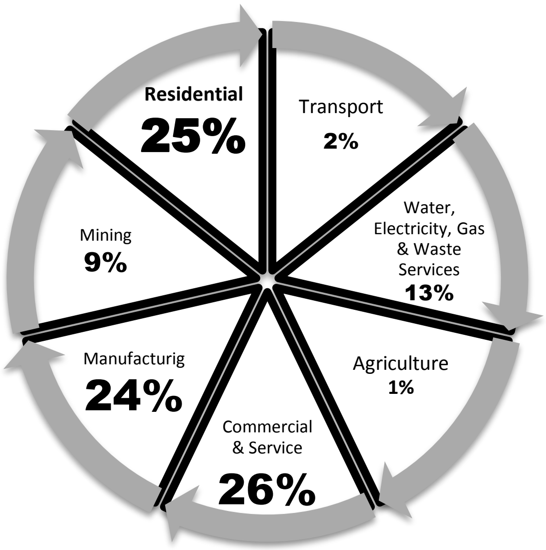

Figure 1.3: Bureau of Resources & Energy Economics (National Electricity Market 2016)

An estimated 247 billion kilowatt hours (TWh) of electricity are generated annually in Australia. Of these, 15 TWh are used by generators and 234 TWh are delivered as a net production of the grid system. The losses are 12 TWh in the energy consumption sector and another 12 TWh in transmission lines (World Nuclear Association, 2015). Assuming that distribution network service providers (DNSP) and transmission network service providers (DNSP) are the same in network topology, then we will find the following results:

Transported (Native) Energy = 50,000 GWHrs* (1 year)

Total Losses = 1,900 x 2 GWhrs* (1 year), 7.6% of Transported & distributed Energy

Value of Losses @ $55/MWhr = $210M

An old issue of the instability of electricity supply increases concurrently with the increase in electricity demand. One factor which causes losses in the grid system is the volatility clustering of electricity demand that results from instantaneous emergence of end-user behaviours which influence the performance of electricity supply and are also influenced by the following factors:

- Generation fuels cost.
- Operation and maintenance of power plants.
- Electricity bidding prices.
- Electricity spot prices.
- Weather conditions.

- Regulations and policies.
- Extra pressure on generators at peak times, which increases fuel consumption and reduce performance.
- Increased line load leads to increased losses through heat radiation.
- Lack of forecasting or analysing electric timely flow leading to wastage of electricity.

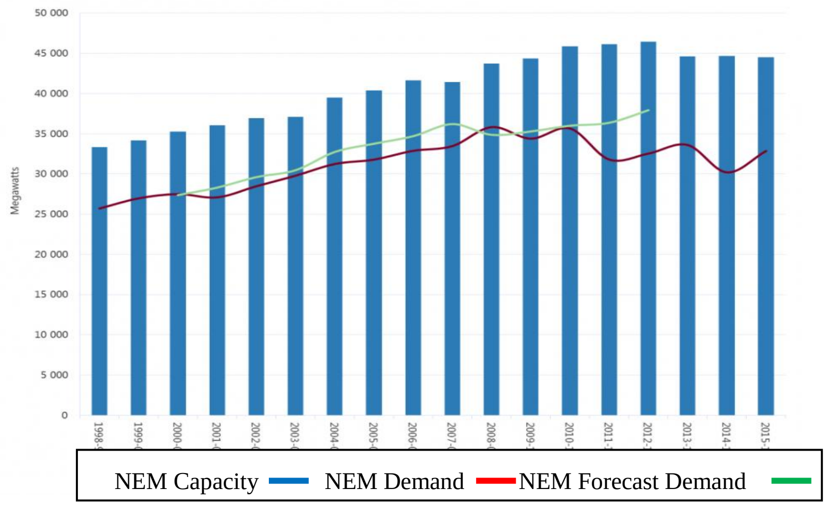

Figure 1.4: NEM Demand, Capacity & forecast Demand (Australian Energy Regulator 2016)

The economic solutions can be in part measured by recognising the trend in electricity demand to provide solutions which aim to reconcile the demand and supply of electricity and to reduce the gap between them. Electrical smart grid systems become more complex by involving renewable energy such as solar panels, windmills and storage batteries (see Figure 1.5). Therefore the level of success will depend greatly on the quality of managing these resources to match the consumption behaviour of end-users. Even though recent technology provides multiple energy sources of electricity, the issue still exists of how these sources are being managed to derive more stability to meet the demands of end-users of electricity (Colson et al. 2009, p. 3).

Figures 1.3 & 1.4 illustrate that people have become more addicted to using electricity in order to meet their daily needs and this leads to an increase in electricity prices. Electricity generation increased recently by up to 59% above the figure of electricity produced in 1990. The rate of electricity demands grows by 2.4 per cent per year and will double in 2030 compared with the demand in 1990. Therefore, in the future, the grid system needs more transmission lines and distribution networks to cater for the peak electricity demands of consumers. Peak demand typically occurs during cold snaps and heat waves. The estimation of Ausgrid, a major electricity distributor, revealed $11 billion worth of network infrastructure in the national electricity market (NEM) needed to deliver a usage benefit for just 100 hours per year, which is approximately one per cent of the needs to meet periods of peak demand. Thus, the economic saving for each dollar invested in reducing losses will be around 1.6c a year. For these economies, the payback period exceeds the life of the asset (50yrs at an 8% discount rate), and the investment is negative NPV. This is similar to building an extra eight lanes on the Sydney Harbour Bridge just to cater for the few peak hours during the year.

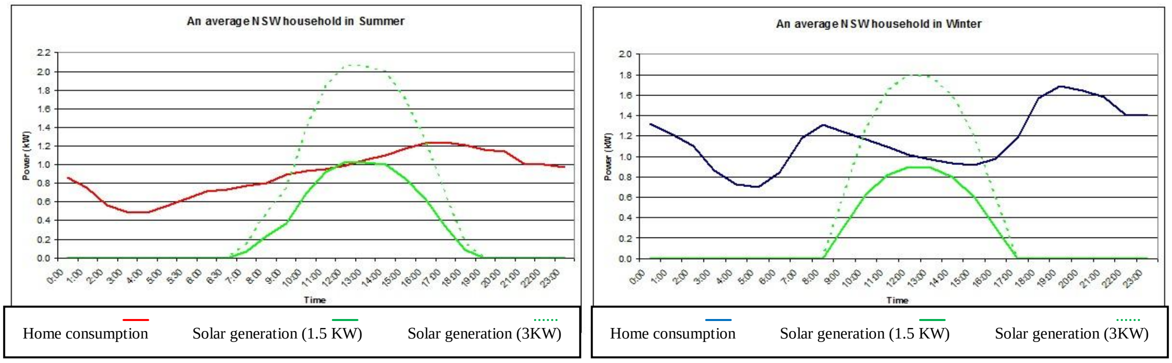

Figure 1.5: Average NSW household in Summer/winter (Australian Energy Regulator 2016)

Real challenges rise with the increase of the usage capacity and the numbers of subjective consumers over time, that the electrical system will gradually undergo greater complexity. As shown in Figure 1.6, the losses (Kw.hr) of electric power transmission and distribution in Australia was last measured in 2011 at 13,313,000000 Kw.hr, according to The World Bank. The satisfaction with electricity systems in meeting the needs of future daily life requires continuously adding robust concepts for demand system planning. This will never be done without considering more robust optimisation approaches to enlarge the number of alternatives and to achieve the optimal involvement of the subjective end users by allocating and using the resources optimally.

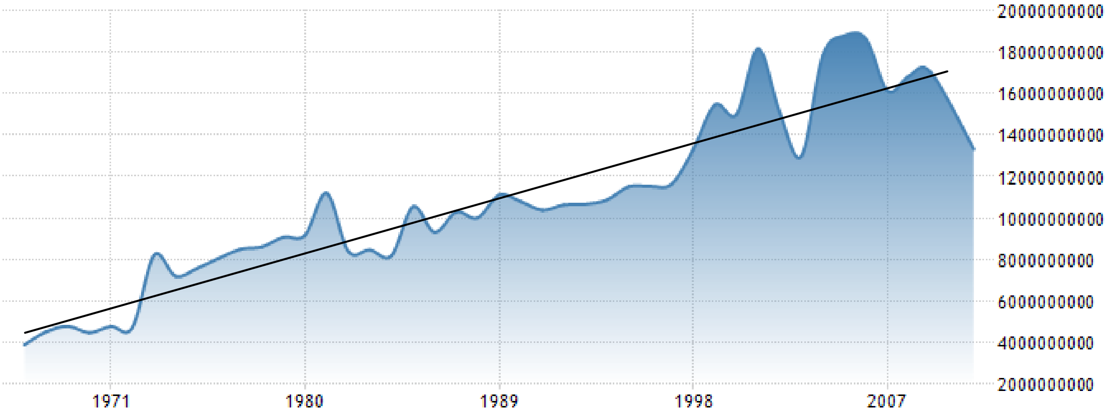

Figure 1.6: **The losses (Kw.hr) of electric power transmission and distribution in Australia (World Nuclear Association 2016)**

The structural indicators of the electricity market illustrate high levels of incentives of market power linked to the state of generators‘ exposure to contract or spot prices. Indicators explore the major relationship between a generator’s bidding and spot price outcomes. Currently, the AER runs a scheme of ‘the power of choice reconditions‘ including a focus on demand management for innovative projects and for finding non-network approaches to managing demand. The approaches include measures to reduce and moderate demand or to provide alternative ways to meet supply. In August 2015, the AEMC also released a rule change that intensifies incentives for distribution businesses to assure demand management solutions that deliver a net benefit (Australian Energy Regulator, 2015).

Along the same lines, the Australian Energy Regulatory (AER) runs a scheme of the ‘ power of choice reconditions’ focused on demand management for innovative projects and finding non-network approaches to penetrate renewable energy. The approaches include measures to reduce and moderate demand or to provide alternative ways to meet supply. The opportunity of the rule change proposal is discussed at length under the title “Distribution Losses in Expenditure Forecasts” (Grid Australia, 2016). A rule change of the AEMC has also been made to intensify incentives for distribution businesses to assure demand management solutions that deliver a net benefit (Australian Energy Regulator, 2015). Therefore, one factor of success of the electricity industry massively depends on an understanding and centralising of the end-users’ timely behaviour on the demand side.

Electrical distribution utilities will need to make major investments in generation and transmission capacity in the future. The need for such a capacity will be highly controlled and mitigated through more demand agility. In addition, energy monitoring and reduction will be achieved through a variety of conservation, energy efficiency, and demand-response programs, all related into a better understanding of different consumer behaviours.

Complexity theory focuses on the individual needs for a common goal and The delivery of intrinsic interventions to meet supreme global needs. The philosophy of complexity concerns self-actualisation to develop a self-governance capability for improving holistic well-being (Gilbert 2012, p. 16). From this aspect, the complexity way of thinking sets very challenging expectations to achieve extraordinary results for continuity and and sustaining at the moment of emergence events.

Recently, complexity theory has received considerable attention for its emphasis on adapting the intricacies of the interoperability environment among diverse industries (Werhane and Painter-Morland 2011, p. 117). Thus, the research will aim to identify in depth how to improve the complex system's interoperability by understanding the characteristics of the chaos paradox as a part of the complex environment.

1.4 The Research Problem

Human behaviour is a complex and a non-linear dynamic behaviour. Discussion of the nature of the non-linearity of human behaviour still needs further research by using the lenses of complex philosophy. Individual behaviours need more in-depth studies to distinguish their models of changeability, similarity and dissimilarity in order to understand the influential clustering of individual's behaviours in a complex system. Complexity theory will be used to present a justification and to build a comprehensive conceptual model to fill this gap.

Since the 1800s, several theories of societal aspects have academically evolved in an attempt to explain how to understand and alter human behaviour. The widest applied theories and approaches that make sense of human behaviours are:

- Self-determination theory (Trépanier, S-G, Fernet, C & Austin, S 2012)
- Charismatic theory (Kark, Shamir & Chen, 2003)
- Transformational theory (Rafferty & Griffin, 2004) (Yukl, 1999) (Bass, B.M. 1995) (Hooijberg, R. & Choi, J. 2000)
- Motivational theory in respect to social identification (Kark, Shamir & Chen, 2003)
- Self-concept theory (Lord, Brown & Freiberg, 1999)
- Exchange theory (Blau's, 1964) (Gerstner, C.R. & Day, D.V. 1997)

- Theory of Individual Differences (Chan, K. & Drasgow, F. 2001)
- Contextual theory of leadership (Osborn, R.N., Hunt, J.G. & Jauch, L.R. 2002)
- Leadership theory (Shondrick, S.J., Dinh, J.E. & Lord, R.G. 2010)
- Transactional Theory (Tyssen, Ana K, et. al 2014); (Junker, N.M, Dick, R.V, 2014)
- Great Man Theory (Halaychik, C. S 2016); (Cawthon, DL 1996)
- Trait Theory (Halaychik, C. S 2016); (Amy E. C, et. al 2012)
- Behavioural Theory (Stelmokiene, A, & Endriulaitiene, A 2015); (Raes, A, et. al. 2013)
- Situational Theory (Thompson, G, Robert P. Vecchio, R. P 2009); (Kruger-Ross, M.J & Waters, R.D 2013)
- Contingency Theory (Kriger, M & Seng, Y 2005); (Heller, FA 1973); (Mark Van Vugt, M, Grabo, A.E 2015)
- Cognitive Theory (Swearer, S, Wang, C, Berry, B, & Myers, Z 2014).

Those theories illustrate hierarchical organisational structures (Lichtenstein, Uhl-Bien, Marion et al. 2007, p. 129). They have differently defined human behaviours to improve their integration, but only within the limitations of a particular boundary, which does not cover the concept of network-based interactions. Consequently, traditional models are insufficient and incapable of enhancing effective practices that need to react immediately and sufficiently to tackle emergences (Ancillotti, E., Bruno, R. & Conti, M 2013); (Colson, Member, Nehrir, & Member, 2009, p. 3); (Kroposki, Basso, Deblasio, & Friedman, 2006, p. 354); (Goldberger, A 1996, p. 1312); (Shafiullah, Oo, Ali, & Wolfs, 2013); (Basso, T. S., Deblasio, R., & Member, S, 2004); (Stötzer, Member, Stein, & Member, 2012); (Urken, Arnold B., “buck” Nimz, Arthur & Schuck, Tod M, 2012); (Halliday S, Beggs C, Muneer T 1999).

Traditional management science is less than required to meet the practical interests, as focused on in analysis, prediction and management. Regarding the environment of impermanence, a new science of management is focusing on chaos, complexity and self-organisation (Francis, 2007, p. 2). Today scientists create methods by which complex systems can effectively cope with uncertainty and rapid change. This opens the possibility of fruitful dialogue between science and management practices, and the successful use of science in practice.

Therefore, the traditional management models that existed over the past century, are not capable of coping with the non-linear dynamics of firms operating in the current knowledge-based era (Uhl-Bien et al. 2007, p. 298). Complexity theory, by contrast, casts a light on the non-linear behaviours and their dynamics. Complexity theory examines the ever-changing, complex procedures and systems that constitute a high level of interoperability (Ramalingam et al. 2008, p. 8).

Complexity theory proposes the studies of network-based interactions to embrace emergence events (Allahverdyan, A E ; Steeg, G Ver ; Galstyan, A 2015); (Urken, Arnold B. ; “buck” Nimz, Arthur & Schuck, Tod M. 2012); (Agostinho, C & Jardim-Goncalves, R 2015); (Stötzer, M., Member, S., Stein, J., & Member, N, 2012); (Lin, C Y-Y 2004, p. 3), concern knowledge distribution, learning, creativity to positively embrace change (Werhane & Painter-Morland 2011, p. 115). Thus, complexity theory is more suited to the cases that other theories can no longer adequately explore, because it goes beyond individual needs, focusing on a common goal, delivering intrinsic interventions, self-organisation, and develops a self-governance capability (Gilbert 2012, p. 16).

Complexity theory grew out of the General Systems Theory, of the 1960s. The fundamentals of complex managerial perspectives were drawn from natural science when it examines non-linearity and uncertainty. The philosophy of complexity is an interdisciplinary theory emphasising interactions and accompanying loops of feedback that constantly observe and change the system. The application objectives of complexity theory aim to cope with diverse conditions of uncertainty to adapt their environments.

Collecting information over a wide range of data recorded has been introduced as a new contributing factor to complex networks to adapt the mutation of individual and clustering behaviours produced by a collection of events that originated from changes of initiating micro events (Grobman, GM 2005). Since then, traditional management has been questioned for lack of its appropriate implementations for behaviours of non-linear systems (Medvinsky, A, Petrovskii, S, Tikhonova, I, Malchow, H & Li, B 2002).

As an important issue facing the complexity system’s adaptability is whether the quantitative resource flow is restrained or not-restricted. This may affect how capable the adaptive system is in coping with new changes. The enabling trait’s role in complex systems is how to provide resources and to enhance access to information for needed change. Changing to improve the system is a complexity approach which could be achieved by implementing a mechanism that is tailored to interact with heterogeneous agents to catalyse activities and deal with non-linear emergence.

Australia is in the midst of a complicated set of electricity demands and regulatory proceedings. This research supports incorporating distributed energy into a utility grid planning, and in the end stimulating the growth of distributed energy that enhances grid imperatives and customers' needs alike. The attempt will be made to provide a new comprehensive overview of Australia's advancement to achieve a perfect union between demand and supply of electricity. The research will have a close eye on the future of electricity rates in a distributed energy market and add to the knowledge needed to customise what tomorrow's grid edge may look like.

In today's business world of the electricity industry, which is often uncertain and uncontrollable, traditional mechanisms of "scientific management" become unproductive (see Figure 1.7). This is problematic because to build ‘Electrical Smart Grid systems’ for the future requires adding to the meaning of a modernised electric system that is suitable to provide smoother energy distribution and production (Ancillotti et al. 2013). The Government of Australia continues to push the states and territories to improve the governance of corporations of electricity businesses and to become more customer oriented. The Australian Government is also concerned to progress ‘the packaging of energy market reforms’ seeking greater efficiency. Currently a carbon tax remains the most convenient means of alerting consumers to ensure that they pay no more than necessary for electricity.

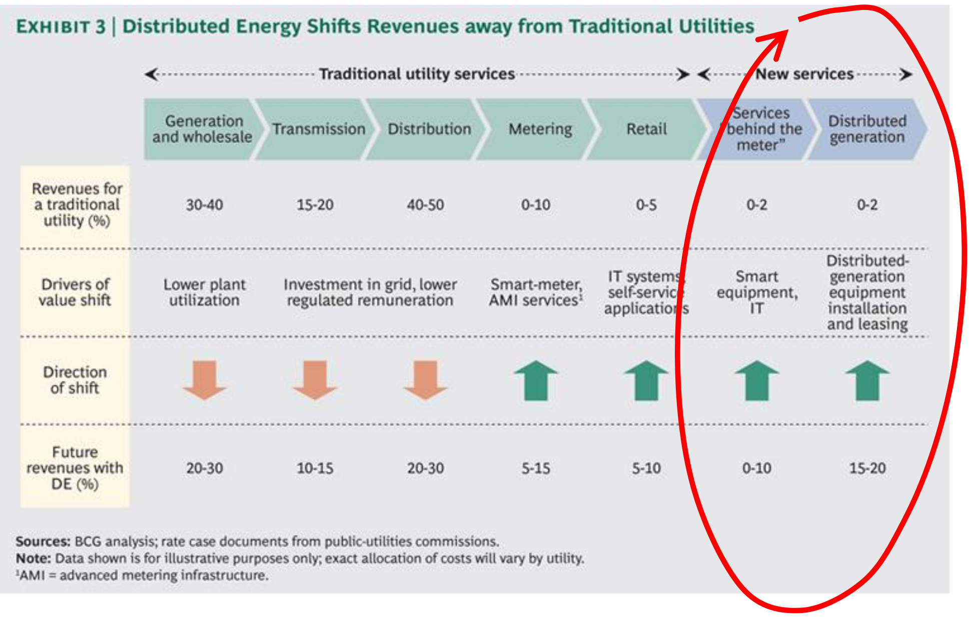

EXHIBIT 3 | Distributed Energy Shifts Revenues away from Traditional Utilities

	Traditional utility services					New services	
	Generation and wholesale	Transmission	Distribution	Metering	Retail	Services "behind the meter"	Distributed generation
Revenues for a traditional utility (%)	30-40	15-20	40-50	0-10	0-5	0-2	0-2
Drivers of value shift	Lower plant utilization	Investment in grid, lower regulated remuneration		Smart-meter, AMI services[1]	IT systems, self-service applications	Smart equipment, IT	Distributed-generation equipment installation and leasing
Direction of shift	⬇	⬇	⬇	⬆	⬆	⬆	⬆
Future revenues with DE (%)	20-30	10-15	20-30	5-15	5-10	0-10	15-20

Sources: BCG analysis; rate case documents from public-utilities commissions.
Note: Data shown is for illustrative purposes only; exact allocation of costs will vary by utility.
[1]AMI = advanced metering infrastructure.

Figure 1.7: The Utility Shift To Energy Solution Provision (Peak Energy 2016)

Human behaviour is an essential consideration because, in all technical, societal, and economic models of complexity systems, end-users often have the most influence on the model. For this reason, business models described by the stakeholders' theory state that once consumers are better off, the whole system and other stakeholders are better off, too (Greenwood & Freeman 2011). Using the philosophy of complexity theory in relation to end-users in the shared process between supply and demand of electricity sees end-users at the centre and at the same time, independently involved.

Although end-users are not the sole cause of the problem of smart-grid optimisation, they comprise a significant problem in optimising smart-grid systems. This is due to end-users' non-linear consumption behaviour. Enhancing the ability of end-users' to manage their energy use better is a substantial factor in addressing issues around rising peak demand and pricing pressures and the necessary expected future investment. Therefore, the objective of building a pricing structure and metering technologies must be derived through greater demand side participation (DSP). This is a critical step and must be taken.

A case study of an electrical smart grid system was used in this research to focus on the non-linearity of human behaviours that cause peaks and troughs, lead to enlarging the gap between supply and demand of electricity. "Peak demand periods" are overwhelming the electrical grid system and only resolved by providing better management for end-users' behaviour (Su & Wang 2012).

The importance of qualitative research methods is argued in complexity science as essential for researchers to disconnect the elements of complication, emergence and dynamic among a system’s agents (Begun, J, Zimmerman, B & Dooley, K 2003). However, to understand the complexity of a system, it is important to use quantitative research methods through a number of diverse tools.

To date, there has been very little effort made to understand complexity philosophy as a way to discuss the problem of human behaviour and uncertainties. An Australian electricity system is used in this research as a case study with which to identify solutions for optimising the complexity of end user’s incorporation in order to mitigate the gap between demand and supply of electricity. Therefore, in the current research, complexity theory has been adapted and conceptualised with the human behaviour model. The attempt is made in order to understand and to improve the relationship between the complexity of human behaviours and the complexity of a system. The research also attempts to define the usefulness of preventing losses and balancing the interaction between demand and supply of electricity by relying on understanding the complexity of end-users’ behaviour.

1.5 Research Questions, Hypothesis, and Objectives

The fundamentals of a smart grid system rely on moving the energy systems from a centrally controlled to a more consumer driven, iterative system (see Figure 1.8). Smart grids are operating, but still, we need to find out how far we are able to produce, deliver, and consume energy to reach the concept of “change for the better.” Changes for the better will occur by involving the end-users and by discussing the following:

- Can we create ways for the end-users of electricity to make a major contribution via smart grids?
- Can we, at household levels, directly optimise non-technical information into technical information?
- Can we leverage our understanding of social complexity into B2B financial services and products?
- Can end-users’ behaviour be tuned to make the best use of smart-grid system effectiveness?
- How can complexity theory help to understand end-users‘ behaviour in decision-making in relation to electricity consumption?

The research in this thesis aims to answer the following research questions:

Q1 = Does the combination of sustainable homes and fossil fuel power that comes from the grid help to mitigate and control energy losses during peak and off-peak consumption?

Q2 = Do sustainable houses that are equipped with renewable energy capacity (solar + storage battery) help to offset losses during peak and off-peak electricity consumption?

Q3 = Do individual houses better manage energy losses, thereby supporting the grid system to reduce and control the peak and off-peak electricity consumption?

Q4 = Does the use of solar and storage battery in residential homes help to stabilise the peak and off-peak consumption of electricity?

Q5 = Does the use of renewable energy (solar + storage battery) in residential houses help the electrical grid systems to control and mitigate the peak and off-peak consumption of electricity?

Q6 = Does the use of renewable energy (solar + battery) in homes provide greater benefits than using renewable energy from macro levels (supply + transmission)?

1.6 Research hypothesis

H1 = Electrical grid systems using fossil fuels to deliver electricity to sustainable houses (installed specific capacity of solar + battery) can reduce and control grid energy losses.

H2 = Sustainable houses that have separately installed renewable energy (solar + storage battery) can reduce energy losses in the grid system.

H3 = Theorise the capacity of renewable energy of each residential home to reduce the effects of peak/off-peak consumption, is better able to minimise energy loss in electrical smart grid systems.

consumption, is better able to minimise energy loss in electrical smart grid systems.

H4 = Solar and/or wind generation capability, supported by storage battery, helps to reduce energy losses that occur during peak and off-peak consumption times.

H5 = Residential houses that have installed renewable energy sources better support the electrical grid to control and reduce peak and off-peak electricity consumption, based on the demand of the inhabitants.

H6 = The use of renewable energy in residential homes provides greater benefit than using renewable energy at the macro level (from supply and transmission to distribution to homes).

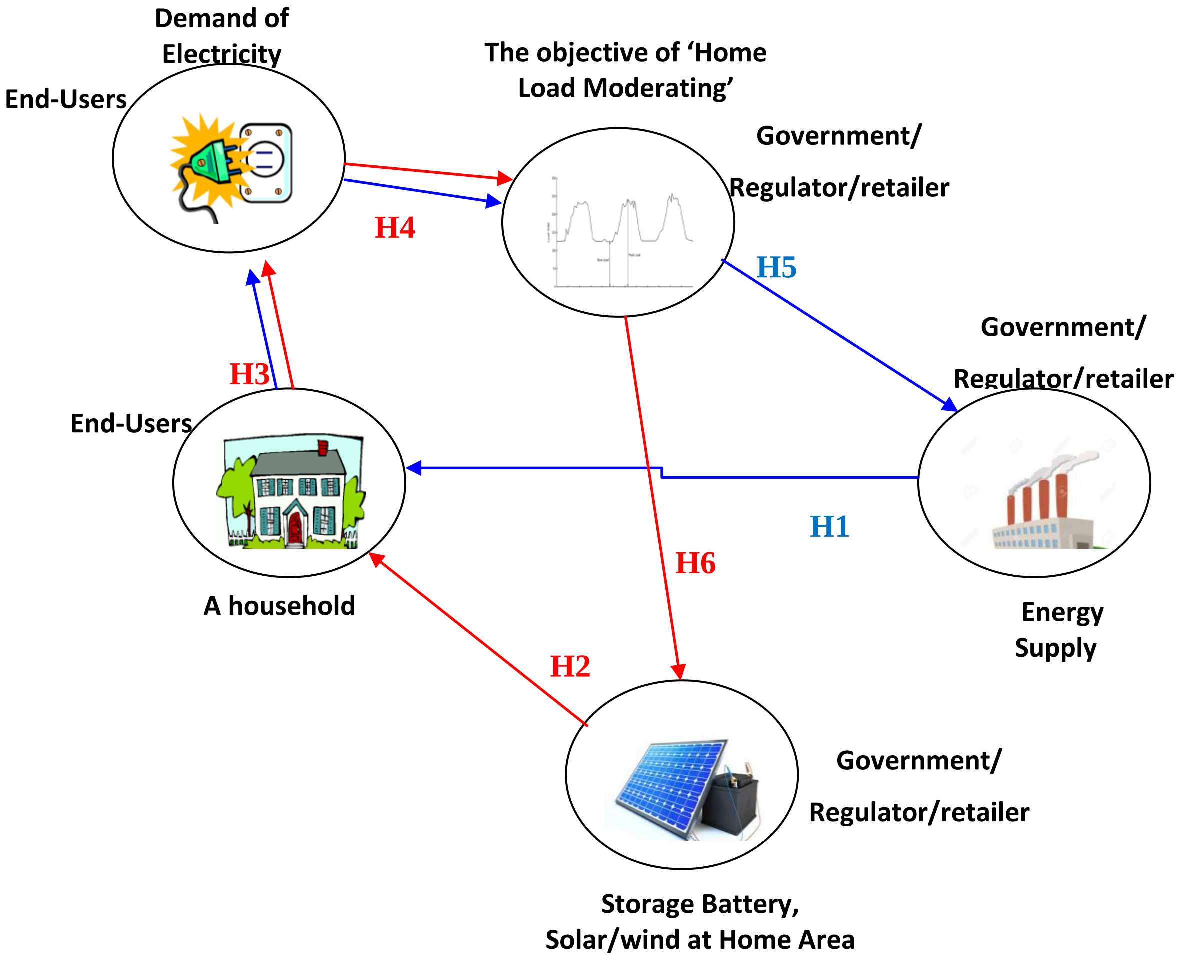

Figure 1.8: Home Load Moderating (Combined by the Author)

The main aim of the research questions is to determine theoretically and analytically, the extent to which end-users' behaviours have potential impacts on the losses of energy incurred in electrical smart grid systems, and how the nature of that impact could be understood to develop a model that might help to reduce the extent of the energy losses within the electrical smart grid systems in Australia. Theoretically, revising the literature of complexity theory will build a picture upon the following goals:

- To establish a deep understanding of the nature of the relationship between end user's behaviour and a complex system, concerning how end-users' behaviour is understood from the angle of magnifying the places of strength and weaknesses and dealing with them to grow and influence the efficiency of a complex system.
- To compare the degree and the impact of end-users' behaviour at micro levels in electrical smart grid systems. These end-users are currently unrelated and have no linkages between them in relation to the electricity consumption. This research will

explore evidence that leads to failure due to the non - linear dynamic behaviour of end-users at the micro levels of the demand side of electricity.

- To generate insights on how complexity theory is able to enforce needed changes in a complex system with respect to addressing internal problems and fostering new solutions so that the system can realise higher levels of performance in the present and the future.
- To identify areas for future research in relation to the scalability of human behaviours in respect to spontaneous emergence and non-linear dynamic behaviour.

1.7 Objectives

- To mitigate the gap between the supply and demand of electricity (see Figure 1.8).
- To get rid of peaks and fill off-peak times at household scale.
- To identify interventions based on end- users' behaviour for smart grid improvement initiatives.
- To investigate the home influence for load stability in the management of non-linear dynamic symptoms (see Figure 1.8).

The literature review systematically explores the evidence from various writers on whether there is a way of making subjective human behaviour influence the improvement of complex systems and increase the total efficiency, or whether there is no way to avoid hindering the complex system's outputs.

1.8 Rationale of the Research

The basic reason for this research is to review how subjective human behaviours are managed in a complex system in order to improve outcomes. Firstly, this research focuses on adding possible ways of electricity regulation (e.g. government, retailers) to enforce appropriate change in an electrical smart grid system by understanding the nature of non-linearity and examining the circumstances under which the implementation of a concurrent deterministic model for change in a complex system, is advantageous.

This research also investigates the essential characteristics of good household modelling. In a similar way, this research sets out to investigate how the understanding of unrelated end-users can play a successful role in mitigating complex system losses.

Compared with other nations, such as Germany and the United States, the inadequacies of the gap between supply and demand of electricity in the Australian market are characterised by many factors. One is a lack of awareness of end-users' behaviour, which ought to be more manageable as a matter of decreasing losses and costs for both demand and supply sides in the electricity industry. The cost of consumed electricity for end-users is a result of multiple constraints on the side of demand and supply of electricity. Impacts such as when fuel costs vary based on the per unit cost, different power plant properties regarding construction, operation and maintenance, transmission and distribution systems, weather conditions, and regulated/unregulated prices of generations.

Annual announcements for the Australian federal, state, and the local governments aim to deliver environmental outcomes for the people of NSW (EAP, 2015). Research and development in Australia call for new cost-effective techniques focusing on reducing gas emissions, and enabling systems for very high penetration of renewable energy generation to reduce and balance the electricity consumption. This objective needs more research efforts to draw clearer directions and with greater linkages to science, technology and innovation in Australia, along with better defining the roles of universities, government, industry, and society at large.

The strategic plan of enabling a very high penetration of renewable energy generation will serve the concept of well-being in the community and test the relationship between supply and demand of electricity. The research testing of this will use data for 300 end-users in NSW in order to fulfil the constraints of non-linear dynamic behaviours of consuming electricity and provide options for reach the research objectives. One of the main goals in the 21st century is considering the promotion of grid systems to become more intelligent systems. Research communities, governmental efforts and other utilities are jointly working together to derive smart grid systems with the follow advantages (Shafiullah et al., 2013):

- High, consistent service;
- Highly reliable service;
- Practical, suitable management to derive efficient energy;
- Self-healing facilities;
- Automated systems and accurate decision;
- Support systems;
- Smart metering integration; and
- A very high penetration of renewable energy generation.

However, Australia and the rest of the world still have space for further academic research to address further solutions concerning unavoidable consumer behaviours to improve the environmental figure and the economic outcomes within the electricity industry.

1.9 Contribution to Knowledge

This research study goal is to use complex theory to understand the complex practice of human non-linear dynamic behaviour in electrical smart grid systems in Australia. Although a large number of studies having centralised subjective human behaviour, there remains a gap in which to apply the unused lenses of complexity philosophy to better understand and improve the non-linear dynamic behaviour of humans in complex systems, with particular reference to an electrical smart grid system in Australia.

Among the massive number. of existing studies, the researchers have generally taken two paths, either replicating other existing models for adequacy improvement or developing a new model to solve the system's issue. To the best of the author's knowledge, a few among past studies have discussed the non-linear dynamic behaviour of electricity consumers by using complex system theory to demonstrate the influence of non-linearity and to moderate the system's efficiency. This study reviews and examines the socio-technical concepts of complex management theories in relation to the micro-scales in electrical smart grid systems.

The purpose of this study is an attempt to use complexity tools to assess the influence of end users‘ non-linear behaviours. Subsequently, this study adds to a growing body of theoretical and empirical research related to the influence of diverse human behaviours in complex systems. The most notable contribution of this study is in investigating the roots of the strengths and weaknesses of the non-linear dynamic behaviours of consumers with the objective of improving the system outcomes. It opens up future research areas by considering complex theory in the context of avoiding chaotic outcomes, by organising tiny initiated events and small changes for desirable outcomes.

1.10 Methodology

Regarding research methods, the philosophical level is linked to more general aspects, for instance, the nature of knowledge, the proof of knowledge, mind, truth, matter, reality and reasons (Zikmund 2000, p. 234). Grasping the philosophical issues behind the research methodology is a crucial procedure. This clarifies which insights suit what kind of evidence, thus identifying what data needs to be collected and ways of doing the analysis. The knowledge based on the research design philosophy is necessary to clarify which research methodology is more suitable and which is not a good choice and does not work with the nature of the study (Zikmund, 2000, p. 59).

This research is designed to review the literature in regard to complexity theory to identify the nature of tiny initiated events (TIEs) and the influence of scalability. Following that, it develops an appropriate model to indicate whether or not the collected data will fit the assumed hypotheses. Having completed these steps, longitudinal data of the demand and supply of electricity will be gathered from a historical database, from electricity retailers and the Australian government.

In this research, I will use the research design that is most expedient in finding answers to the research questions. The ontological premise in this research method is an expressed reality that can be described by the use of a mixed qualitative and quantitative method. This approach is significantly aimed at determining the nature of a particular reality (Picard & Velautham 2014, p. 5). From this perspective, the secondary data collected relates to the complexity theory from a literature review, thus providing subjective realism to fulfil my desire to achieve what is possible in this research journey. Objective realism will describe the appearance of things as they are in observable surface phenomena. Based on the sample statistics used in the analysis, one unifying aspect that will follow is that the sample selected will lead to inferences about the non-linearity phenomena.

This research takes into account four areas while deciding to choose a particular research method. The first area is the philosophical paradigm and the objective of the established research. The second area is the nature of the phenomenon of interest. The third area is the nature and level of both the research questions and practical considerations in relation to the research environment. Lastly, this research will consider the efficient use of resources. The secondary data of electricity consumption is quite difficult to find and collect, but it costs nothing and is considered cheaper than the questionnaire and interview approaches. The interview and survey approaches would not be simple as the missed data and incomplete answers would need further filtration.

To achieve the research objective, a conceptual model was hypothesised and tested in stochastic and deterministic ways. This will give full attention to the societal behaviour problem that affects the technical, environmental and economical aspects. The concept of complexity theory needs to be collected from the different literatures. For this study, I have considered the simulation modelling approach.

Using a simulation modelling approach allows scientific methods of data analysis to be incorporated as multiple tools can be employed for a large sample size. A Matlab simulation kit has been used for the collected historical data to answer the research questions in more efficient ways than the questionnaire and interview approaches. At 48 interval times, a day and over three years 15873120 items of data have been collected and analysed to go in depth through end-users' behaviours.

The procedure and simulation modelling methods used in the research were assumed appropriate in order to get rid of biases, deliver accurate results and validate the research outcomes.

1.11 Outline of the Thesis

A short overview for each chapter will be presented in this introduction chapter as follows:

Chapter 1: This chapter introduces the research problem and exhibits the research background and the research questions. Chapter 1 also represents the research approach and methods and rationalises the research into particular contributions. The limitations and key assumptions are also described in brief in this chapter.

Chapter 2: The methodology and typology of the case study in this chapter will be described in depth including the data collection and the way of promoting the right way of analysis and why nominating a particular data. The chosen analysis will serve the goal of answering the research questions of this thesis.

Chapter 3: A brief background will be described in this chapter of the electricity industry in Australia and its history of economic growth. Further details will also explain the mechanism of electricity supply chains from suppliers to end-users and the losses incurred during the last few years. This chapter will also show the efforts of the Australian government to solve the problems of the electricity grid systems concerning the technical, environmental, economical and societal factors. There follows an explanation of the residential segment of end-users in the distribution area of electricity based on their trends in electricity consumption and how that affects on the grid system. The socio-technical aspects of the electricity industry are exhibited and discussed concerning the influence of consumers' behaviours during the day.

Chapter 4: Through this chapter, a comprehensive literature review describes the theoretical complexity philosophy that forms the framework of this thesis to tackle the problems identified through the chosen case study. The sustainability perspective proposed in this chapter to define a theoretical framework is intended to integrate the demand and supply aspects at residential homes for optimisation purposes (Miller, B 2005). The circle of thinking uses the lens of how to immediately enable household environments to understand and take action on the non-linear dynamic behaviour of end-users while consuming electricity (Mason, M 2009). This chapter shows how using the theory of complexity will produce a set of heuristics that can be aggregated and applied to support the dynamic of networks (Agostinho, C & Jardim-Goncalves, R 2015); (Matthew Deems, E, Xabier E, B & Xabier E B 2014); (Knutsen, W L 2013).

This chapter will give evidence on how complexity philosophy from the physics phenomenon to social behaviours discusses the sensitivity of the initial conditions that have the nature of randomness and unexpected behaviour (Mason, M 2009). The extended discussion in this chapter will pay more attention to other fields of Biology, Economics, Chemistry, Physics and Sociology, showing that complexity theory based on the phenomena of initial conditions leads to subsequent outcomes that are shaping nonlinear dynamic behaviours which are hard to predict (Mason, M 2009). Therefore, this chapter and drawing on the complexity literature, will propose a novel metaphor on which to build a model and to apply the mechanism for sustainability purposes (Agostinho, C & Jardim-Goncalves, R 2015).

Chapter 5: Factors influencing the formation of electricity costs and prices are discussed in this chapter to describe the relationship between Australian electricity customers and their different consumption demands for peak and off-peak of electricity. Therefore, in this chapter the influential nature of consumers' behaviour is discussed in regard to energy losses and possible solutions, and their significance for policy and regulatory reforms. An attempt in this chapter is made to build a relationship between social factors and technical aspects. This chapter also discusses the issue that has emerged from the lack of leverage between end-users and suppliers of electricity.

Chapter 6: This chapter will investigate the inner social relations in electrical smart grid systems, and steps to decomposing it into smaller scales to be controlled and to commanding non-linear dynamic behaviour. Following in the light of complexity theory, this chapter will focus on the sensitivity of the initial conditions that has the nature of randomness and unexpected behaviour. Following that and from the complexity literature the study will propose a novel metaphor on which to build an objective functional model with which to apply the concept of ‘homes’ sustainability’.

Chapter 7: The analysis will be divided into two parts. One part will use the technique of stochastic analysis to stress the issue that plausibly exists on behalf of the non-linearity of end-users’ behaviour. This chapter will describe the result analysis of stage one by using simulation modelling techniques. Advanced data analysis will be undertaken by using particular tools from the Matlab programming kit to test the nominated variables.

Chapter 8: This chapter will exhibit the second part of the deterministic analysis. The analysis will consider the losses of energy caused by peak and off-peak phenomena. These phenomena will be managed by designing a sustainable average scheduling model for residential households to use solar and storage batteries at residential homes. This chapter will present the quantitative results of the analysis by using the Python programming kit of simulation modelling, where deterministic analysis is carried out by using different tools. The evolution of the testing model undertook a test of over 47,304,000 data items to evaluate the developed hypothesis. This chapter summarises the major theoretical and analytical findings of the research based on the influence of end-users’ behaviour in the grid system. Thus, the contribution to knowledge of this research will be defined through practical implications and theory building, delivering recommendations to regulatory and policy makers. Suggestions will be made about what further research is needed to complement this thesis.

1.12 Key Assumptions and Limitations

There is a broad range of technologies, which exist in electrical grid systems, but we cannot deny that there is a lack of a directive guidance to develop and facilitate efficient levels of using them against the non-linearity of human consumption behaviours. Electricity, along with its history is built in a way that keeps the end-users in a passive mode, still exists and has its extension even through the modern grid systems.

Although there is a growing body of literature covering many aspects of end user behaviour in the electricity industry, it is still widely understood that the empirical validation of demand management and optimisation with the supply of electricity in electrical systems, is limited, and the contribution of complexity theory to such an issue is rarely studied. The scalability of electricity consumption and the clustering interactions among the consumers‘ behaviours appear to be ignored and need further focus. The study in this research attempts to centralise the consumer’s behaviour to get rid of peaks and troughs and to mitigate the gap between supply and demand of electricity. Thus, it will provide a greater understanding of end-users‘ demand, which in turn, will improve the total performance of the grid systems.

Recently, some academic literature has significantly concentrated on consumers’ behaviour. However, this research uses the concepts of complexity theory not to debate the role of end-users, but to investigate how to understand the clustering of different consumer’s behaviours when consuming electricity. The purpose of using complexity theory is to define appropriate solutions to reduce the energy losses in the grid systems by understanding the electricity consumptions and the transition between peak and off-peak times by diverse consumers (Francis, 2007).

A limitation of this research study is that it focus on a segment of residential households in the state of New South Wales. The limited sample size and the demographic and weather circumstances will be considered as restrictions that inevitably influence the results. In the future, the same perspective of complexity philosophy will need to be applied to further analysis in other national locations to make sure that the findings might be used in the same manner around Australia.

1.13 Summary

Energy trading in smart grid system relies heavily on the degree of autonomy of end-users. Thus, the focus in smart grid systems needs to be on how do provide features in the system to enhance the end-users‘ role in managing and storing energy by incorporating both traditional energy and sustainable energy (Changsong, C, Shanxu, D, Tao, C, Bangyin, L & Jinjun, Y, 2009, p. 2139). This research attempts to centralise end-users in an electrical smart grid system and to build a model simultaneously to provide solutions that help to mitigate the gap between demand and supply of electricity.

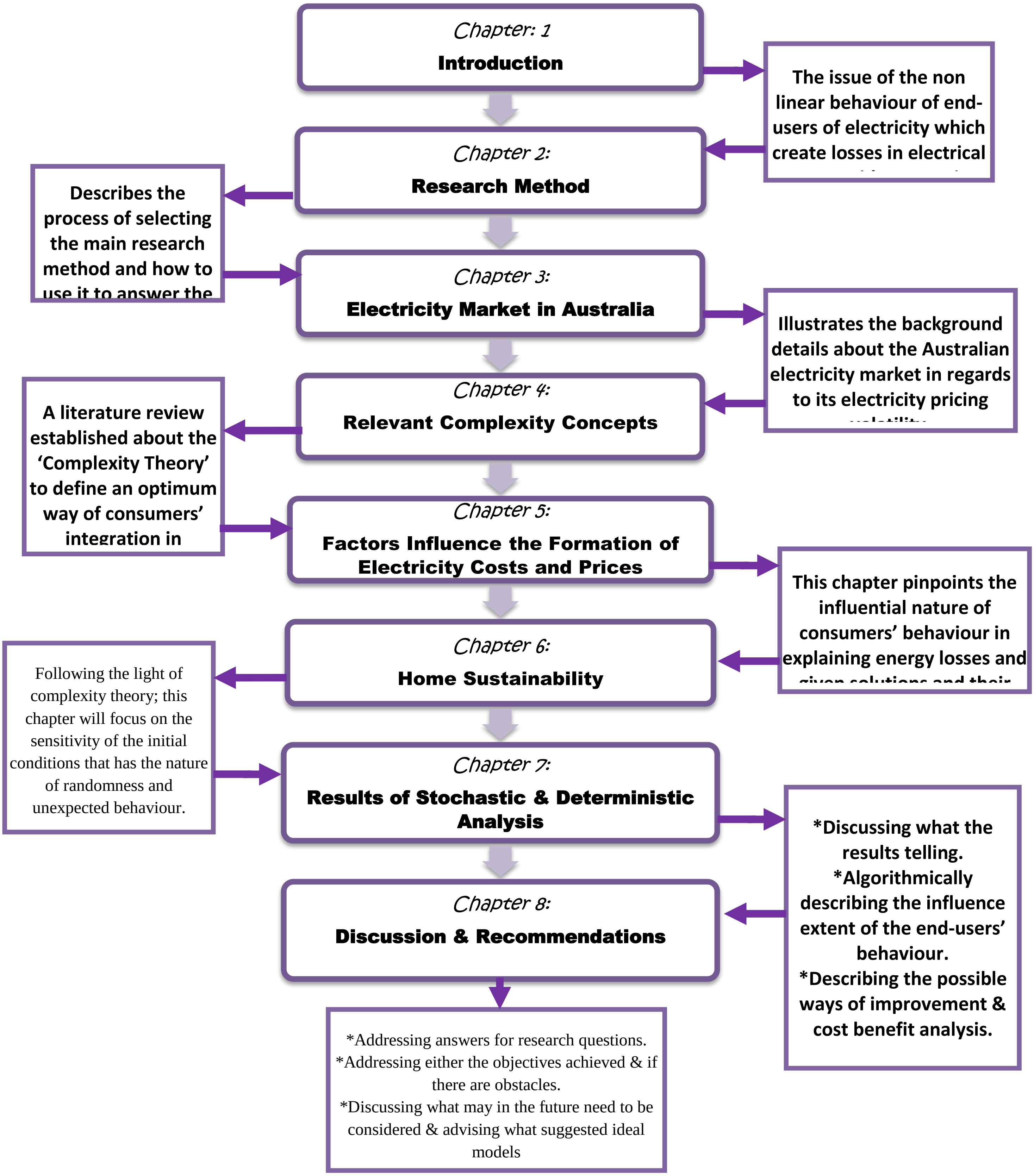

Figure 1.9: Overview of the Research Thesis

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Chapter 2

Research Method

Acronyms

AEMO: Australian Energy Market Operator

AMI: Automated Metering Infrastructure

CCGT: Combined Cycle of Gas Turbine

CL: Controlled Load Data of Electricity Consumption for Residential Homes

DM: Deterministic Model

DR: Demand Response Program

EC: Electricity Cost

Efergy: Real time home energy use

EL: Energy Losses

FLUKE: Energy Logger Instrument

GC: General Consumption data for residential homes

GG: Solar Generation at Residential Homes

HAN: Home Area Network

IES: Intelligent Energy System

Kw.hr: Kilo Watt Hour

Matlab: A multi-paradigm numerical computing environment & fourth-generation programming language

NSW: New South Wales

OCGT: Open Cycle for Gas Turbine

Python: A high level general purpose programming language

REC: Renewable Energy needed Capacity

TIEs: tiny initiated events

ToU: Time of Use Tariff

Lessons Learned from Chapter One

The research problem of energy losses incurred in electrical smart grid systems in Australia has been identified in this chapter. It forms the basis for an interdisciplinary study which uses the lens of complex systems science to explore both answers for the problem and to show the way forward. This chapter specifically offers an accessible, yet technically-oriented overview of the research problem of energy losses in electrical smart grid systems. It sheds light on the importance of changing the patterns of demand and supply of electricity for a better future. The topics covered include the basic facts of energy demand losses, the fundamentals of end-users' dynamic networks, and the perspective of complexity theory, used to identify appropriate techniques and tools to investigate the research problem, its objectives, hypothesis and possible solutions.

Chapter outline

This chapter describes the process of selecting the main research method and how to use it to answer the research questions. This is important because a single piece of research requires a combination of different methods to analyse a movement between paradigms at the level of epistemology and theory (Brannen, J 1992). Whether or not transferring between paradigms is needed, this chapter highlights the significance of choosing the appropriate methods for the adopted theory and research questions. An adequate match between the research and the selected methodological approach is vital to the effectiveness of the research (Davidsson, P 2005). A positivism based research methodology and case study method were selected to fulfil the research objectives and to explore the stated research questions. This chapter on research methodology will clarify the reason behind this choice and will primarily exhibit that through a theoretical framework.

2.1 Research Purpose

It can be overwhelming for those who are selling, owning, and consuming electricity that business-as-usual is not a future option. In this research, I seek to provide incentives to reduce the influence of peak and off-peak phenomena including, but not exclusively, renewables. Therefore, the purpose of this research is explanatory and aims to meet the following objectives:

- To investigate complexity theory as a meaningful theory in this context;
- To understand the role of complexity theory in complex management practice;
- To analyse how complexity theory can be used to understand the management of complex systems such as electrical smart grid systems;
- To research how the complex approach can help in understanding problems of complex systems when these systems do not work according to plan;
- To assess how the problems of unpredictability and unknowns in complex systems can be addressed with the help of the complex behaviour approach;
- To analyse the problems of unpredictability and unknowns in complex systems through complex narrative analysis;
- To create a model for exploring the feasibility of building unpredictability and unknown problems into complex systems.

Table 2.1: Research Report Purpose and Classifications (Vitug 2014)

Purpose	Aims		Sources	Samples
		Yes/No		
Exploratory	To explore a new issue or topic to learn about it	No	- Survey - Secondary data - Case studies - Pilot studies - Focus group	Study on what demand of electricity is all about
	To satisfy the researchers' desire for better understanding	No		
	To examine the feasibility of undertaking a more extensive study	No		
	Addresses the 'what' is this phenomena really about?	Yes		
Descriptive	To describe particular situations and events	Yes	-Data gathering techniques -Surveys -Field research -Content analysis	-Labor force survey -Educational survey -Population census (race, sex, age, gender, ethnicity, income, home size)
	To exhibit or gather details of relationships or a situation	Yes		
	Interest on who, what; when; where & how, but not why?	No		
Explanatory	To know why & explain things, causes & reasons	Yes	All of the above (However, in this research the sources used are case study, secondary data, field research & content analysis)	Reporting the peak and off-peak consumption rates by residential consumers is descriptive, but identifying why these phenomena occur involves explanation. Likewise, identifying the variables that influence all stakeholders to unify their goals upon losses and benefits & involves explanation.
	Builds on descriptive & exploratory research & goes on to define the reasons why that occurs	Yes		
	To extend a theory to new areas, new issues & new topics	Yes		
	To provide evidence to support or refute an explanation or prediction.	Yes		
	To test a theory's principle or predictions	Yes		

The options for the research 'purposes, with regard to sources and samples as in the above table, are limited by the aims of the research problem. From the above table, the selection of the research purpose under study is purely explanatory, and is needed to explain variables that should be considered in order to decrease the influence of peak and off-peak phenomena. Exploratory and descriptive purposes were also found useful and important to explain and gather the chronic weaknesses of the dynamic structural trend between electricity demand, suppliers and retailers. These integrated trends have undermined electricity grid performance at a time when electricity grid is running above the levels prevailing during peak and off-peak times.

The descriptive and exploratory evidence is needed to show the previous efforts to demonstrate how the recent concurrent extra spending on the governance of peak and off-peak phenomena will not avoid higher spending in the future is recent have not only solved, but the spending is expectedly rising in the future to higher rates. As a result of all of this and some of other factors not related to our current research that wastefully sprayed money around this demand issue need to be undertaking through a descriptive approach. It is also important to explain why the technical system has been and will remain in this particular deficit until this matter is solved. To describe why, as long as the grid system is in deficit, gross operational losses will result and continue to rise from these issues, leading to increased losses of electricity demands.

2.2 Data Collection

When collecting data on electrical consumption to embrace analytics, it is tempting to assume that it will provide the decisive insight, disclose the overlooked explanation, or crisply discern key solutions within a swamp of muddled information. The data collection process involves a number of key considerations that necessarily arise with regard to how data should be gathered and analysed. Data gathering must carefully use accepted technique to protect and enhance the reliability and credibility of data. In this research, the factors are the context, the issue to be monitored and addressed, the goal of the data collection and the size and nature of the data in relation to a specific electricity home area network (HAN).

Consideration is also taken to ensure that the collected information is provided in a way that complies and is consistent with customer privacy protection legislation (Australian Competition & Consumer Commission 2017). This research aims:

- To provide a larger picture of the complex phenomena of electrical smart grid systems.
- To define instant electricity consumption data in order to investigate the trends of end-users’ behaviour and how they might be integrated to serve the grid goal of sustainability (that is, electricity consumption per seconds, minutes, hours, days, months, years – achieving smaller measurement scale is preferable for accuracy reasons).
- To compare different cases of end-users’ consumption behaviours, and investigate their similarity and dissimilarity trends.
- To test the replication of end-users' demands and justify their variation.
- To provide solutions to avoid the emergence of extraneous variation under the name of peak & off-peak demand.

Therefore, six strategic steps were involved to collect data and these are as follow:

2.2.1 Defining Industrial Issues & Opportunities

To do this, it was essential to review industrial and governmental reports related to the assumed issuance of electricity demand concerning peak and off-peak phenomena of end-users of electricity. This step was necessary to understand what happens inside and outside the electricity industry and electrical smart grid systems. As a result, chapters one, three, four, and five of my thesis are provided with particular directions on the variables related to peak/off-peak issues that should be explored and how the data must be collected to achieve certain goals.

2.2.2 Prioritize an Issue & Opportunity for Gathering Data

This task reviewed the proposed issue and opportunity through a small sample assessment to deliver a fundamental reason behind why the data must be collected in a particular way.

2.2.3 Plan Methods & Approaches for Collecting Data

Collection of data will depend on step two above, regarding the best method of collecting data that suit who will be surveyed, the sources of data that will be used, and the duration of the data collection. Thus, many factors influence collecting data, including but not limited to the context of residential houses‘ use of electricity, the size of electrical smart grid systems, resources, the complexity of the issues and the opportunity selected.

2.2.4 Collect Data

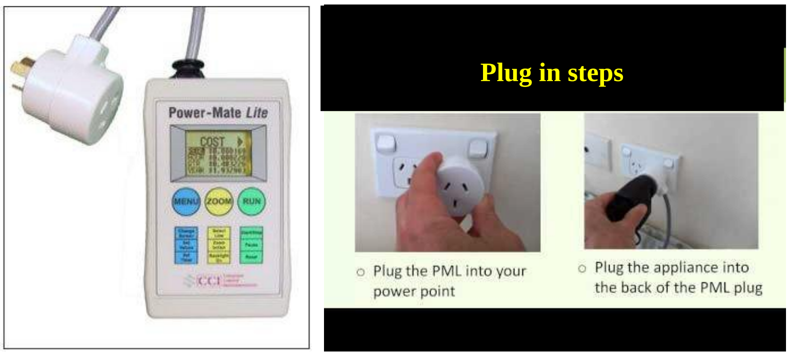
In this step, there were many challenges related to the data that needed to be collected from key stakeholders, which in my research case, are well defined as the residential consumers in New South Wales (NSW) - Australia. The author of this thesis first attempted to collect data by selecting persons to be involved and held accountable for recording their electricity consumption via smart meters installed in their houses. Determining who would collect the data was managed by contacting the technical department of the Fluke company through a face to face meeting with an expert, to discuss what sort of data need to be collected from residential homes. Fluke company specialising in manufacturing digital smart meters for multiple measurements of electricity. A specific digital logger, the "Fluke 1730/US Three-Phase Energy Logger" was recommended for the required purpose that aims to document information on the electrical energy waste, load study and energy usage analysis (FLUKE 2017) in households. However, this was problematic, in that the while the proposed logger could perform the following functions:

- Recording when and where energy is being consumed in a residential household’s utilities.
- Comparing multiple data points over time and building an accurate picture of energy usage.

The problem was that the FLUKE digital logger as shown in Figure 2.1 need to collect electrical consumption data at the same time, from all nominated houses which would cost a great deal of money, since a large number of digital loggers and staff would be needed. Further, the measuring of houses‘ electricity consumption should be managed by electricity experts, involving many technicians in the same measuring time, also very difficult to manage and also very costly. One digital logger unit costs $3000 AUD, and my research needs to test at least one hundred houses to generalise the results. The consumption record should be for at least one year to track the consumption behaviour of residential end-users in different seasons and demand circumstances, and identify the usefulness of data for investigating the problem of peak and off-peak phenomena. The Fluke company was happy to provide only one technician for training and measuring the electricity consumption of a single household. Therefore, it was practicably impossible to collect data by using the above digital logger for obvious financial and technical reasons.

Figure 2.1: Fluke 1730/US Three-Phase Energy Logger

The second attempt to collect data was by using digital loggers for homes’ electricity consumption provided by another local Australian company named ‘Reduction Revolution’ (See below). This “Power-Mate Lite” meter was selected because it is easy to install and use with home power points as per the figure 2.2.



Plug in steps

- Plug the PML into your power point
- Plug the appliance into the back of the PML plug

Figure 2.2: Power Mate Lite Digital Logger (Reduction Revolution 2017)

The obstacles to using this second meter were first, cost (one unit costs $120), and each home would need 10-20 units to cover all power points of that powered appliances. The third problem was that the lighting system could not be measured when using these types of metres. However, it could be calculated referring to electricity bills and data collected from the above meter. In addition, along with the above “Power-Mate Lite” meter, it was also necessary to use an additional device, the “Efergy” (see Figure 2.3), since the housing sample for data analysis is residential homes with installed solar panels and at the same time using grid power. The purpose of using the “Efergy” was to view the daily consumption of electricity from both grid and solar in easy-to-read graphics.

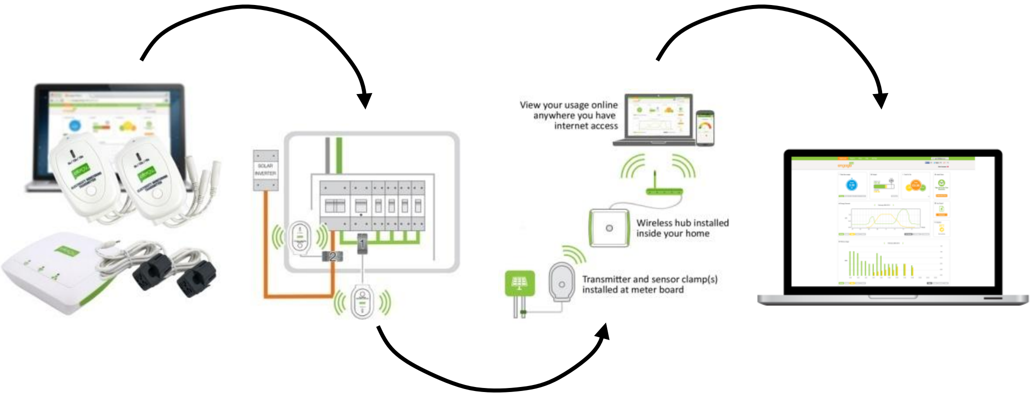


Figure 2.3: Power Sharing Recorder (Reduction Revolution 2017)

Although a set of these meters was bought to install in one home as a start, it remains problematic to manage to buy, install and operate all the meters at the same time for multiple houses. These obstacles were faced with the above two attempts at collecting data leading to added awareness of which best practices must be assumed to gather the targeted data. Therefore, the data collection plan changed from collecting ‘first data’ to finding a way to collect ‘second data’. Luckily, the second regional data could be identified and gathered from both the “Australian Energy Market Operator” (AEMO) and from the “Ausgrid” electricity provider in the New South Wales (NSW); for 300 consumers. Data details as following:

- Data collected from 300 consumers for three years of electricity consumption of residential houses in New South Wales in Australia.
- Data recorded in Kilo-Watt hours (KWh is the unit of measuring electrical energy) and has three categories recorded at 48 interval times during every day.
- General consumption data (GC) which flows from the grid to the houses.
- Controlled load data (CL) which also flows feed from the grid to the homes but is used for controlling purposes in some houses‘ systems, such as irrigation systems, swimming pools, air conditioning and some lighting systems.
- Solar panels generating data (GG); this power was generated from the PV panels on the houses.
- Regional consumption data for New South Wales over three years.
- Australia total consumption data for the same three years.
-

The consumers’ data have three categories, and those are determined as follows:

- Total consumers’ data items used in this research analysis an estimated 47,304,000 million (300 consumers x 365 days x 3 years x 3 categories [GC, CL, GG] × 48 interval recording times = 47,304,000 million).
- Regional demand data of New South Wales (NSW) = 3 years x 365 days x 48 interval recording times = 52,560.
- Country demand data items = 3 years x 365 days x 48 interval recording times = 52,560.
- Total data used in this research analysis = 47,304,000 + 52,560 + 52,560 = 47,409,120 million data items.

2.2.5 Analyse & Interpret Data

Two research methods used to explain the technical steps of data interpretation of this research: stochastic and deterministic analysis. These methods are as follows:

2.2.5.1 Stage One “Stochastic Analysis”

- Examine the consumption demand for households to better understand the influence of different behaviours of consumers/end-users/houses.

- Magnify the uncertainty that is created by end-users to quantify the levels of dissimilarity, diversity and non-linearity of different consumers to reveal their consuming influences. The purpose of this analysis is to approve that the micro levels, where residential houses were located, to reveal different facts about managing electricity demand than the macro view of solutions.
- Investigate uncertainty as important for the following reasons:
    - Uncertainty is the range of possible values where the optimum value of the measurement lies. An uncertain consumption of electricity leads to involving imperfect and/or unknown information.
    - Therefore, uncertainty is a consequence, an extent or a magnitude of circumstances, conditions or events that cannot be entirely predictable.
    - The analysis will help to understand the ambiguity and uncertainty sit in the future which we can know more about it by using a plausible method to observe facts and reveal a surprising phenomenon.
    - Any macro phenomenon is an inflation of the tiny events that go through a reshaping process until they reach integrated maturity. It is believed that it is possible to find a meaningful indicator and deal with these uncertainties at micro levels for the electricity market and commentate on the effect on the wholesale value of electricity.
- Compare different consumptions of houses to provide a better understanding of the significance of different consumers behaviours.
- Compare the consumption of households with regional and country figure of consumption.
- Compare the peak consumption times for regional and country data with the consumers who are truly consuming electricity at peak demand.
- Compare the off-peak consumption times for regional and country data against single consumers from the sample of consumers that will be used for analysis and while they are consuming electricity at off-peak times.
- Compare the scale of actual consumption demand for individual consumers against the chart of tariff (Time of Use) that is shown in the Table 2.2 below. In this tariff/contract, the cost of electricity varies by time and the cost of electricity will be highest at peak times and lowest at off-peak times. The purpose of doing this is to compare the actual demand of each consumer with the ‘Time of Use’ tariff.

Table 2.2: Time of Use Tariff (ToU) (Network Tariff 2015)

Time Period	Day of Week	Time of Day
Peak	*Monday to Friday*	*7am to 9am* *5pm to 8pm*
Shoulder	*Monday to Friday*	*9am to 5pm* *8pm to 10pm*
Off-Peak	*Monday to Friday*	*10pm to midnight* *Midnight to 7am*
	Saturday, Sunday & Public Holidays	*All*

2.2.5.2 Stage Two 'Deterministic Analysis'

This stage of the analysis seeks the optimal operational method when adding renewable energy "solar & storage batteries" at each home. Renewable energy sources will be a complement to the traditional energy used from the grid.

New South Wales Government Officials and the 'Independent Pricing & Regulatory Tribunal' provided the average consumption levels of residential consumers in NSW as shown in the Table 2.3 below. The average consumption levels are the single factor that influences the capacity design for the generation power plants. The high capacity explained in the table is one of the causes of peak demand phenomena while the low consumption capacity affects the demand load and drags it into off-peak demand events. These demand facts were taken into consideration to downscale the concept of peak, off-peak and average demands into the residential home levels. For more details see chapter three.

Table 2.3: Influence of Consumption Levels on Average Prices of Electricity (AEMC 2014)

Annual Consumption Level	2013/14 Average market Offer (cents per KWh)	2013/14 Annual household bill
Low (2,500 KWh)	36.12	$903
New South Wales-specific average (6,500 KWh)	28.76	$1,869
High (9,500 KWh)	27.77	$2,638

Cost of the electricity load in New South Wales (NSW) varies based on the load status either at peak, average or off-peak, is summarised in Table 2.4. The cost of the electricity generation load will be assumed in the analysis to make sense of the losses that occur during different consuming times.

Table 2.4: NSW Cost of Load during Peak, Shoulder/Average & Off-Peak (Intelligent Energy System 2004)

Long Run Marginal Costs (LRMC) ($/MWh) for Peak, Shoulder & Off-Peak times			
Electricity Generation	**Peak**	**Shoulder**	**Off-Peak**
Total NSW Cost of Load	$89.59 MWh	$47.25MWh	$22.66MWh
Total NSW Franchise Price of Load for Retailers	$123.77 MWh	$33.99 MWh	$30.92 MWh

As illustrated in Table 2.5, coal remained the primary fuel source to generate electricity in 2014-15 however its use also recently fell to 63 per cent. Natural gas-fired generation accounts for 21 per cent of total electricity generation in Australia. Renewable energy makes up approximately 17 per cent of the total Australian electricity generation (Department of Industry and Science 2016). Therefore, and from the above facts, coal represents 75 per cent and natural gas 25 per cent of the total traditional fuel use for generating electricity. The analysis undertaken in this thesis assumed that the power generation index would be achieved according to the above ratios at all generation capacities. The calculation also neglected the power generated from renewable energy since it has different operational characteristics avoided in this research. The assumption used referred to the facts collected from the literature as follows:

- Maximum consumption of individual NSW residential homes = 10,000 kWh (found in the literature = 9,500KWh, but for analysis, consideration was counted as 10,000 KWh).
- The cost of power generation = 75% coal + 12.5% OCGT + 12.5% CCGT (natural gas generates 25% of total traditional power generation. See table 2.5.
- NSW used two types of gas generators, OCGT (open cycle gas turbine) and CCGT (combined cycle gas turbine) which assumed each of these gas generators responsible for generating the half of power generated by natural gas (Department of Industry and Science 2016).

Table 2.5: Average Annual Growth of Traditional & Renewable Power Generation (Department of Industry & Science 2016)

	2014–15		Average annual growth	
	GWh	**Share (per cent)**	**2014–15 (per cent)**	**10 years (per cent)**
Fossil fuels	217,871	86.3	3.1	0.4
Black coal	107,639	42.7	1.8	-2.1
Brown coal	50,970	20.2	10.6	-0.8
Gas	52,463	20.8	-3.6	9.7
Oil	6,799	2.7	35.6	9.3
Renewables	34,488	13.7	-6.9	5.3
Hydro	13,445	5.3	-27.0	-1.9
Wind	11,467	4.5	11.8	23.5
Bioenergy	3,608	1.4	11.4	-1.0
Solar PV	5,968	2.4	22.9	59.3
Geothermal	1	0.0	27.3	2.7
Total	252,359	100.0	1.6	0.9

- New South Wales-specific demand averages for residential homes approximately 6,500 kWh per year (AEMC 2014). When scaling down this capacity to per half hour, we then calculate it as follow: 6500 kWh per Year / yeas/365 days / day/24 hours = 0.74 kWh per hour.

- The data collected from the Australian Energy Market Operator (AEMO) recorded every half an hour. Thus, 0.74 kWh divided by 2 to get the consumption per half hour is equal to 0.371 KWh. This rate of consumption is assumed as optimal one (see the previous point).

- Reference to the literature concluded that the maximum ranges of annual consumption in NSW at 8000 KWh and the minimum average consumption at 5000 KWh. The value of 1500 kWh has been added and deducted to and from the optimal defined average (6500 KWh) to achieve the minimum and maximum averages. This provided an agile range of average to make the monitor and control system considered as the desired range and support the home electrical system to comply with these ranges. Keeping the residential homes within these ranges will avoid them operating at unfavourable peak and off-peak consumption rates. For more details see chapter four.

- The average amount of electricity at residential houses is defined as follow:

    - Assumed the minimum average of consumption = 5000 kWh per year that equal 0.29kWh per half hour.
    - Assumed the maximum average of consumption = 8000 kWh per year that equal 0.459KWh per half hour scale of consumption. The reason behind using this standard has been answered in detail in chapter four.

- The losses of electricity of a household are assumed when the consumption falls above or below the desired average ranges (0.29-0.459 KWh).

- The responsibility for losses occurring above the maximum average of assumed consumption is mainly attributed to massive increase in the heat radiation rate that comes from electricity flow through transmission conductors and distribution lines which have been plotted and calculated, based on the data available from the report of the ‘Intelligent Energy System’ (IES 2004).

- The responsibility for losses occurring below the minimum average of consumption mainly attributed to a massive increase in the specific fuel consumption per kWh of power generation which has been plotted and calculated based on the data available from the report of the ‘Intelligent Energy System’ (Department of Industry and Science 2016).

- The purpose of using renewable energy in this research project is mainly to make the homes pivot within average range to eliminate of the losses occurring at peak and off-peak demand levels which are assumed as the desired consumption ranges (0.29KWh – 0.459KWh) (see Figure 2.4).

- A cost-benefit analysis will be calculated to compare the cost of losses which will be discarded (Cent/KWh) and the cost of installed renewable energy designed to make the homes’ demand fall within average levels and reduce the out of range losses.

- The installed capacity of renewable energy (Solar & Storage Battery) will be dependent on the nature of the homes’ demand. Therefore, different houses will be unequal and consequent to that, the nature and capacity of renewable energy and the way of operating of these resources, will be slightly different from one home to another.

Table 2.6 shows the cost of the various parameters used in residential homes including solar panels, storage batteries, inverters, advanced smart meters.

Table 2. 6: The Cost Installations of Renewable Energy at Residential Homes (Gellings, C, Horst, G, McGranaghan, M, Myrda, P, Seal. B, & Siddiqui, O 2011)

Solar per 1 KW System (with inverter & installation)	**Life cycle**	**30 Years**
	Average daily production	3.9KWh
	Cost $/KW	1400
Lithium-Ion Battery with installation	Life cycle	10 years
	O&M / 5 years	$300
	Charging time	1 hour
	Discharging time	1 hour
	Cost $/KWh	$443
Battery Inverter with installation	Life cycle	10 years
	O&M / 5 years	$300
	Cost $/kW	$514
	Installation Cost	$400
* Advanced Meter Infrastructure (AMI)	Life cycle	10 Years
	Cost/Customer	***$70 (low) - $140 (high)
	Installation of Residential Meters	***$7 (low) - $15 (high)
	Ongoing System Maintenance	***$3 (low) – $11(high)
In-home displays	Life Cycle	10 Years
	Cost	***$20 (low) – $50 (high)
**Direct Load Control (not integrated with AMI)	Life Cycle	10 Years
	Cost	***$100 (low) – $100 (high)

**AMI: Automated Metering Infrastructure*
***DR: Demand Response program*
**** Low and high scenarios of cost*

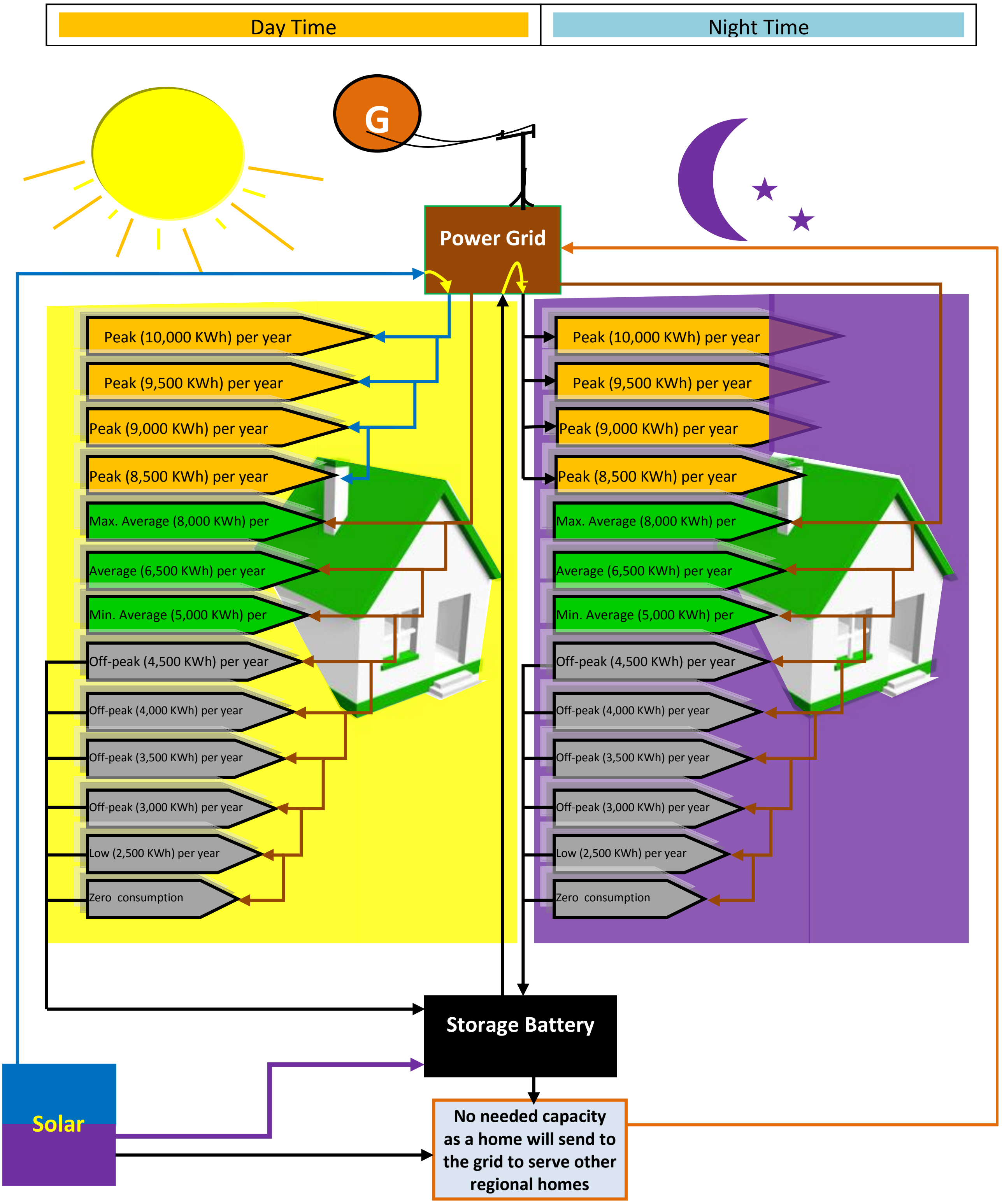


Figure 2. 4: Solar & Storage Battery to preserve the home consumption within average capacity

2.2.6 Act on Results

The analysis plan is limited within two types of analysis, ‘stochastic’ and ‘deterministic’. The assumed further future action on the analysis result adds another analytical approach known as “Machine Learning” to design a smart device able to implement the principle of the outcome findings on any other houses not included in the sample of analysis to achieve the same proposed solution. In all cases, it is also decided that it would be necessary to collect further information because there are gaps in relation to the accuracy of some data collected (for example, a precise cost of electricity losses and cost of generation at all operational circumstances of the grid).

2.3 Research Philosophy “Paradigm”

A paradigm is defined as a model that has a particular research framework. The aim of the research philosophy is to deliver a flexible evolving research design. Most researchers set the development of research proposals in connection with the implications of the ‘research philosophy’ which comes under one of the following three reasons:

- Research philosophy leads researchers to select the most appropriate methodology to achieve the research objectives.
- Research philosophy leads to define the boundaries and limitations of selected research approaches.
- Research philosophy stimulates creativity and innovation to examine the research problem.

Referring to Morin (1977, p. 44), a paradigm is also defined as “a set of fundamental relationships of association and opposition to a limited number of central ideas, links which will order/ control all thoughts, all speeches, all theories.” The paradigmatic framework is provided according to three aspects:

1) Seeking to describe something, or to understand or explain, something.
2) Trying to assess the effectiveness of something.
3) In response to some concern or problem for which solutions are sought (Robson 2011).

Figure 2.5:Research Paradigm

The three combinations of the elements, illustrated in Figure 2.5, highlight research 'paradigm' as a broad and essential concept in all areas of study. A paradigm is also described as a framework based on ? "people's value judgments, norms, standards, frames of reference, perspectives, ideologies, myths, theories, and approved procedures that govern their thinking and action" (Mangan, J, et. al. 2004). A paradigm also refers to how all elements of the research fit together because people relate to the findings as they indicate a valuable thing that is worthwhile to discover (Wood, M & Welch, C 2010). Using either of the terms "philosophy" or "paradigm" means that we aim to use a researchers' method of thinking to develop knowledge. Overall, a paradigm is a matrix of perceptions and beliefs embracing the power of action, implications and relationships. This may be depicted as a matrix of a paradigm that has a nature of scientific endeavour related to undertaking a particular enquiry (Mangan et al. 2004). In this study, the research design will use a quantitative approach to test the existence of the influence of tiny initiated events (TIEs). The knowledge of complexity theory will be used to recognise the degrees of chaos characteristics by which the proposed unexpected tiny initiated events (TIEs) may be discovered. In this method, the research will follow an experimental approach design for a demographical group and collect data according to certain criteria. In this method also, the research will develop dependent variables of a quantitative approach regarding the perceptions of the complexity theory on complex systems such as electrical smart grid systems.

2.4 Theoretical Framework

The initial purpose of this research is to define how complexity theory is able to help organisations in complex systems, such as electrical smart grid systems, to increase the levels of the systems' predictability, adaptability and speed in reacting to instant events. Firstly, this research focuses on the role of complexity theory in discovering a new methodology to heighten the level of sensitivity towards unexpected events, by examining the circumstances under which the implementation of complexity theory in complex systems, such as smart grid systems, is vital.

The general alignment of the research method is overlaid on the synthesis integrated strategy as shown in Figure 2.6. The object of this research is to investigate how can we make Household Area Networks (HANs) of electricity introduce a significant contribution to the smart grids of electricity, with exceptional reference to New South Wales (NSW) in Australia. The large 47 million data items used is a real data set of half hourly consumption of electricity by residential houses. Using this data mainly to provide a micro picture of the electricity consumption behaviour of end-users/ homes in an electrical smart grid system. At each household level, the data will be used to reveal the total losses in the electrical grid system association between end-users' behaviour in the decision-making of consuming electricity and the emergence of the phenomena of peak and off-peak electricity demand.

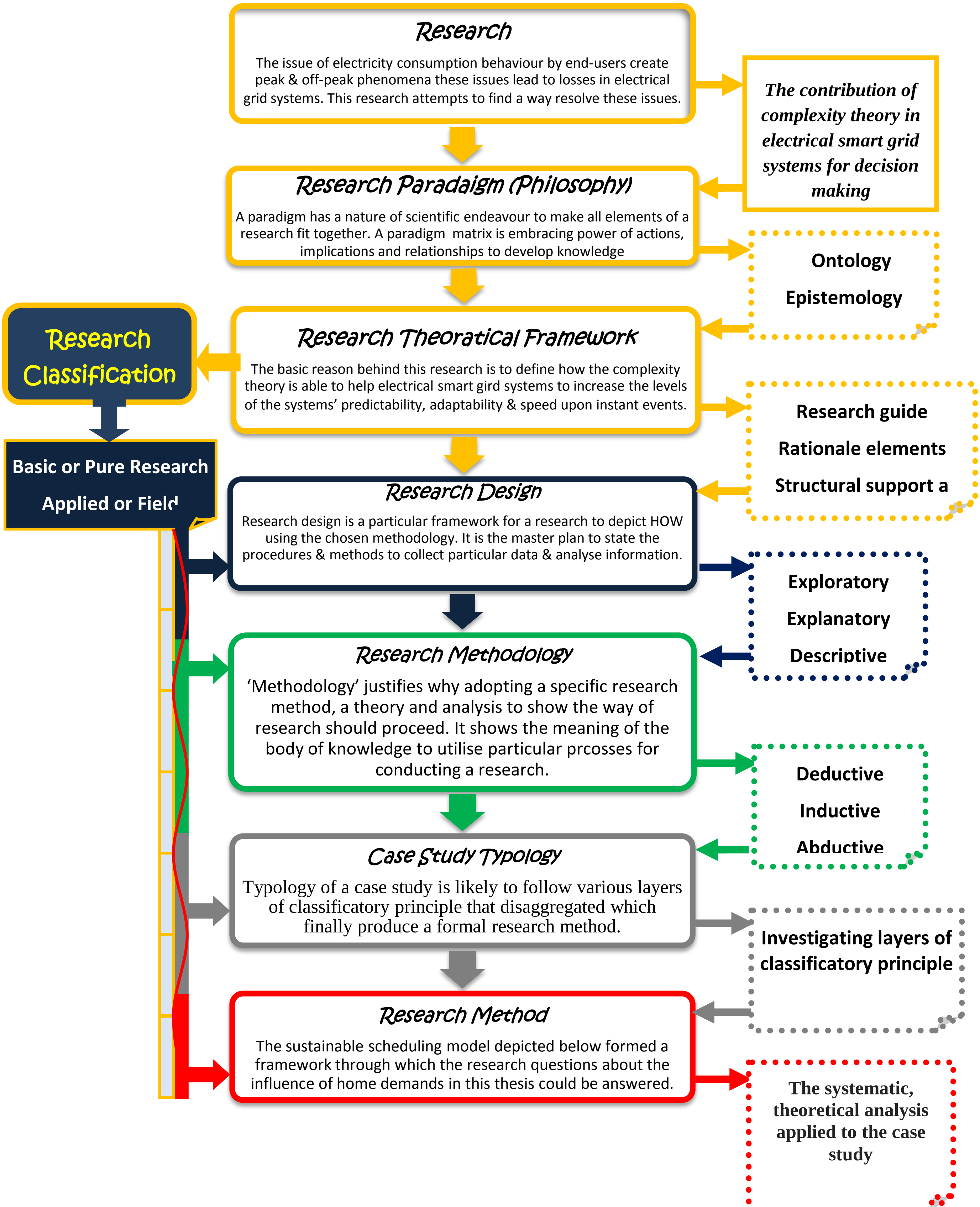
In addition, this research investigates the essential characteristics of the chaos paradox in a complex environment to better recognise their ascending degrees. Furthermore, it aims to discover the relationship between the implementation of complexity theory and the chaos paradox, within a complex system. In a similar way, this research sets out to investigate the role of complexity theory in successfully recognising tiny initiated events (TIEs) earlier. This chapter on methodology depicts the particular methods employed along the research – sampling procedure, stochastic and deterministic techniques of data analysis and analytical used Software. The research onion figure above shows the research approaches adopted in this chapter.

2.5 Research Classification

A taxonomy basis on research types classify any research which comes under one of the following concepts (Verma & Mallick, 1999):

a) By field of academic discipline; b) By research method;

b) By purpose; d) By the kind of process used for data collection



The issue of electricity consumption behaviour by end-users create peak & off-peak phenomena these issues lead to losses in electrical grid systems. This research attempts to find a way resolve these issues.

A paradigm has a nature of scientific endeavour to make all elements of a research fit together. A paradigm matrix is embracing power of actions, implications and relationships to develop knowledge

The basic reason behind this research is to define how the complexity theory is able to help electrical smart gird systems to increase the levels of the systems' predictability, adaptability & speed upon instant events.

Research design is a particular framework for a research to depict HOW using the chosen methodology. It is the master plan to state the procedures & methods to collect particular data & analyse information.

'Methodology' justifies why adopting a specific research method, a theory and analysis to show the way of research should proceed. It shows the meaning of the body of knowledge to utilise particular prcosses for conducting a research.

Typology of a case study is likely to follow various layers of classificatory principle that disaggregated which finally produce a formal research method.

The sustainable scheduling model depicted below formed a framework through which the research questions about the influence of home demands in this thesis could be answered.

Figure 2.6: Overview of the Research Method Chapter

A taxonomy of a particular type of research is essential to highlight some critical differences between research when designed to deal with practical issues or research when orient towards developing a particular theory. Research classification can be concluded within the following four types: 1) Basic or pure research; 2) Evaluation research;

3) Applied or Field Research; 4) Action Research.

The challenge in the above classification is that in a particular mutual and exclusive way the researchers breach the lines between these approaches. It is problematic to avoid these overlaps and avert research not being interwoven among the research classes above. However, the research can be classified to fall mostly under one of these research approaches and in the meanwhile, accepting overlap with other approaches to enhance the research findings and processes. Investigating the above approaches will clarify which class my research primarily follows.

“Basic or Pure Research” is typically oriented to develop particular theories by detecting new principles or identifying broad generalisations. The initiative and pattern of this research type are independently drawn from the science of physics with assurance of a structured accuracy of the analysis. The primary goal of ‘Basic’ or ‘Pure’ research is to define new facts assumed as major and essential in the sense that the new finding will extend the boundaries of a specific area belonging to existing knowledge.

Practical problems are not understood as the first interest in this type of Research. It is typically executed in laboratories or implemented within neatly controlled situations with respect to both factors of precision and control at the cost of reality. Most learning theories from ‘Pure’ research were achieved from the involvement of animals such that the findings in some cases cannot be applied to human problems. This approach is not appropriate to my research. I intend to deal with (human) end-users’ behaviours to provide a solution for the issue that is created by them and known as peak and off-peak phenomena (M, Thorpe, R & Lowe, A 1994); (Verma & Mallick, 1999).

‘Evaluation’ research attributes to systematic procedures are usually adopted over a period of time from a set of events or a particular program to gather and process data. The goal behind this is that to review and find the wished degree needed to produce the desired result. ‘Evaluation’ research highly relies on the scientific neutrality and symbols of measurements, but in the meanwhile barely relies on the influence of behavioural science perspective. (Verma & Mallick, 1999). The goal of the proposed sustainable model is to propose a solution to resolve the complexity problem of peak and off-peak electrical loads that occur due to the demand for residential homes in the network area of households (HANs). Therefore, this approach is not appropriate for the purpose of finishing my research for my PhD. However, it becomes appropriate as a complementary approach to my PhD thesis when the proposed model is valid for the further design and testing stage.

‘Applied’ or ‘Field’ research aims to improve a process by applying a new solution for day-to-day problems and to examine theoretical constructs in actual situations. The features of ‘Applied’ or ‘Field’ research methods are similar to the features of ‘Pure or Basic’ research in connection with the target of the population, and the sampling technique. ‘Applied’ or ‘Field’ and ‘Pure’ or ‘Basic’ research are both utilised through experimental techniques, which may make it difficult to distinguish between them. The only difference in ‘Applied’ research is designing, developing and using a piece of knowledge for the purpose of being applied in an actual situation (Verma & Mallick, 1999). This approach is appropriate to my research study, which it is aiming to explore the most suitable theoretical solution in the light of complexity theory and then explore its practical application and measure its validity and feasibility.

‘Action’ research concerns the immediate implementation to investigate a particular problem, in a specific setting, instead of developing theories. ‘Action’ research is mainly gleaned from social work studies, social education studies and social psychology studies. It can be found that ‘Action’ and ‘Applied’ research is similar unless the sample of ‘Applied’ research for a large number of cases and the result, may be generalised. However, this ‘Action’ research was only for a very small sample and the finding cannot be generalised. Thus, the purpose of the ‘Action’ research is in implementing a change in a very particular situation (Verma & Mallick, 1999). The purpose of my research study is to provide a solution to mitigate the peak and off-peak demand phenomena of electricity which occurs as a result of the end-users’ consumption behaviours. The investigation of ‘Action’ Research is not appropriate to my research study (Miles & Huberman 1994); (Swann, J 2003). The following table justifies the selection of the above research classification:

Table 2.7: Research Classification

Item no.	'Basic' or 'Pure' Research	'Evaluation' Research	'Applied' or 'Field' Research	'Action' Research	My PhD Research	
1	Yes					Developing theory to detect new principles
2	Yes				Yes	Developing solutions from theories to deliver broad generalisations
3	Yes					Initiatives & Patterns particularly Drawn from science of physics
4	Yes					Achieving analysis accuracy & usually done in laboratories
5	Yes					Theoretical problems are the first interest
6	Yes				Yes	New findings extend the boundaries of an existing knowledge
7	Yes					Precision and control are essential in relation to the nature of reality
8		Yes				Data processed in a systematic way
9		Yes				The result of data only achieved from set of events or particular programming
10		Yes			Yes	Relies on the scientific neutrality and symbols of measurements
11		Yes				Relies on the influence of behavioural science perspective
12			Yes		Yes	Practical problems are the first interest
13			Yes		Yes	Improve a process for a new solution upon day-to-day problems
14			Yes		Yes	Utilises through experimental techniques
15			Yes		Yes	Conducting a knowledge for applying in an actual situation
16			Yes		Yes	Suit for a large number of cases
17			Yes		Yes	The result can be generalised
18				Yes		Immediate application to investigate a particular problem in a specific setting
19				Yes		Implementing a change upon a very particular situation
20				Yes		Suit for a small number of cases
21				Yes		The result cannot be generalised
22				Yes		Developing theories to apply a solution for a problem

The above conclusion in Table 2.7 shows clearly that the research in undertake is mostly related to 'Applied' or 'Field' Research". This finding is concurrent with the goal that I attempt to achieve from the literature of complexity theory, that is, to link end-users' behaviours into three complexity aspects: tiny initiated events (TIEs), emergence, and self-organisation. The complex theoretical construct will be used to apply to the issues that emerge from the practical electricity consumption of residential end-users.

In my research, I attempted to apply a new understanding of the complexity theory to provide a solution for the problem of peak and off-peak demand phenomena. Please note that my research is partially related to 'Basic' or 'Pure' research when assuming that the sample is directly used for human experiments rather than animal experiments. 'Evaluation' research can also be used at some later stages when the reliability of the research finding is confirmed and when there is no need for further investigation about the problem and it only remains to build a smart device or smart function which relies on the scientific neutrality and symbols of measurement.

2.6 Research Design

A research design is a particular framework for an adopted research to depict how to use the chosen methodology in the research. It is assumed as the master plan to state the procedures and methods for a particular data collection and for analysing the needed information (Zikmund 2000).

Research design is either descriptive, to show "what is going on", explanatory to investigate "why is it going on?", exploratory, to focus on gaining insights and familiarity, or confirmatory to find out if the theory is supported by the facts (see Figure 2.7). Researchers have to use the most appropriate research design to find answers toward the assumed research questions (Kothari, CR 2004).

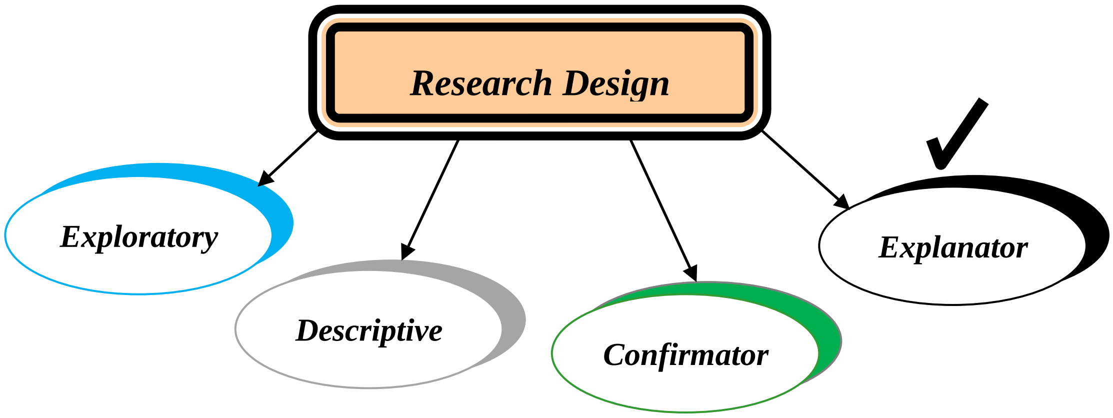


Figure 2.7: Categories of Research Design

Grasping the philosophical issues behind the research design is a crucial procedure. This clarifies which insights suit what kind of evidence, thus identifying what data needs to be collected, including the answers to the research questions. The knowledge based on the research design philosophy is important as it clarifies which research designs are more suitable and which are not good choices consequent with the nature of the research. Knowledge of the research design is a helpful tool for developing a clear picture and assisting in creating a conditional arrangement for data collection and analysis and that in many cases, may not be within the researcher's experience (Zikmund 2000, p. 59).

An important part of this research study is descriptive in order to classify elements of characteristics related to the chaos paradox in complex systems. The usefulness of descriptive research, is that it is possible to explain why and how something is happening. Therefore, we are able to decide on the sampling design and choose the data gathering methods and time horizon. Furthermore, the research design leads to the ability to choose the data analysis method as well as the unit of analysis. Thus, the research design for this study will be built in such a way that it is coherent with the research goals.

More specifically, the purpose of this study strongly emphasises a causal relationship for a particular situation when isolating factors causing a problem. The unit of analysis is the half-hourly consumption of electricity by end-users and is measured by KiloWatt Hour (KWh). Within a context of electrical smart grid systems, this research enquiry is an empirical investigation of end-users' behaviour while consuming electricity in order to investigate the issues of peak and off-peak phenomena that concern suppliers and retailers of electricity (see Figure 2.8). Therefore, the purpose of this research is "explanatory", to test and understand causal relations of electricity consumption at a residential household area. An explanatory approach is used because it is the most common approach to complex management and adequate for very complex situations that make use of experimental when survey approaches are not adequate.

The research design should be conducted in a manner that aims to combine relevance to the research purpose with agility in the procedure. In this sense, research design contributes to the logical structure that seeks to avoid building incorrect causal inferences from collected data. Thus, developing a research design is significantly connected to some rational decisions (Library of Professional Coaching 2014, p. 1). It is essential to have a clear research design that is consistent with a general plan as this shows how the researcher will go about answering the research questions. The following flow chart proposes a general plan consisting of two stages of analysis, 'stochastic' and 'deterministic.' For more details please refer to page 85; table 2.15: (Sustainable Model Characteristics).

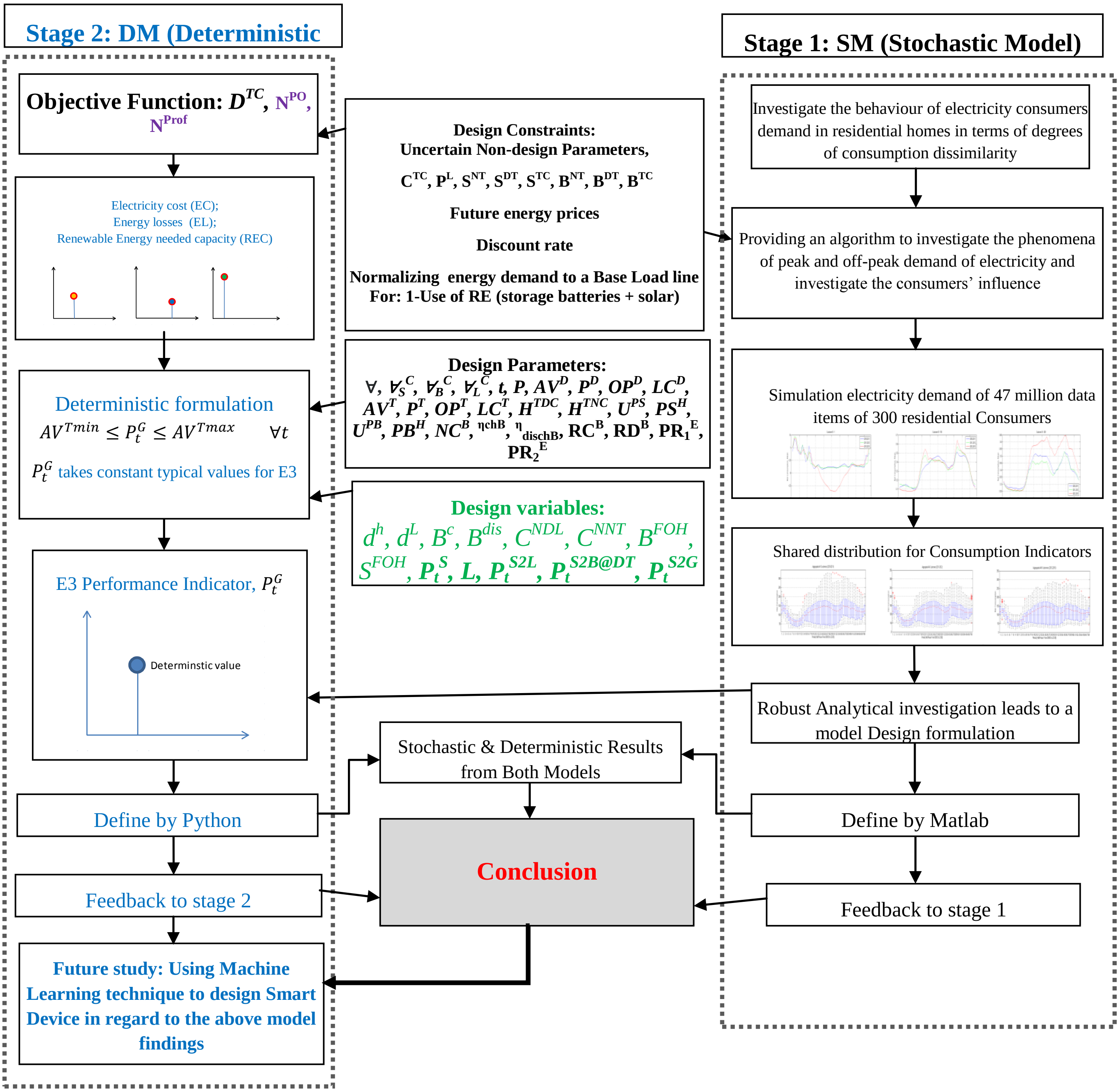


Figure 2.8: Flow chart of the analysis plan

2.7 Research Methodology

Research methodology contributes to high intellectual human activity in order to examine a nature and matter and focuses particularly on the manner in which research data is being collected, analysed and interpreted. The research methodology's underlying theory and analysis in regards to how the research does - or should – proceed is influenced by the research discipline. The philosophical level in research methodology is linked to more general aspects, for instance, the nature of knowledge, the proof of knowledge, mind, truth, matter, reality, and reasons (Zikmund 2000, p. 234).

Four areas that need to be considered when deciding on a particular research methodology are:

- The philosophical paradigm and the objective of the established research.
- The nature of the phenomenon of interest.
- The character and level of both the research questions and practical considerations in relation to the research environment.
- The adequate resources needed to conduct the research.

It is of paramount importance to distinguish between the meaning of ‘methodology’ and ‘methods’. Research ‘methods’ and ‘methodology’ have a relationship similar to the words derma and dermatology, or psyche and psychology. For example, ‘psyche’ means the internal mind, and ‘Psychology’ refers to the discipline that studies, searches and supports the inner mind. Likewise, ‘methodology’ is the justification for adopting a specific research method. Hence, ‘methods’ attributes to the nominated research tools either a quantitative, qualitative or combined method. Therefore, ‘methodology’ explicates the meaning of the body of knowledge, or the discipline, that makes practical and efficient use of specific ‘methods’ to utilise particular processes or techniques for conducting research. To carry out a research objective, ontology, that is, “the nature of reality” and epistemology, “the relation with this reality” are crucial to making the structured approach suit an appropriate methodology which mostly underlies positivist, interpretative or constructionist paradigms.

This research is designed to collect desired literature about the complexity theory, the chaos paradox and the nature of tiny initiated events (TIEs) to measure whether or not the complexity approach fits the assumed hypotheses. This research will conduct a cross-sectional study (one-shot) meaning that the collected data will be confined to a particular past course of consumption events of residential houses. In doing this, it is planned that a retrospective picture of all data will be collected for three hundred consumers, once only, over a period of three years in the state of New South Wales in Australia. The received data consists of 45,000,000 million data items to be used in the proposed analysis.

Table 2.8: Research Methodology (Picard, M & Velautham, L 2014)

Paradigm	Ontology	Epistemology	Methodology
Positivist	Reality is table, it follows laws	The researcher is objective, a detached observer	The practical methods are experimental and quantitative ✓
Interpretative	Reality is subjective and individual “the thing in “ itself”	The researcher is empathetic, Acknowledges, but attempts to “bracket” their own experience	The methodology is interactional, interpretative and qualitative
Constructionist	Reality is socially Constructed and reflected In “discourse”	The researcher is suspicious, focuses on political issues and explains how he/she constructs versions	The methodology focuses on deconstruction; tools such as textual analysis and discourse analysis are employed

As depicted in Table 2.8, my research will follow the positivist research philosophy. Neville (2007, p. 6) interpreted the positivism research philosophy as “positivistic approaches are founded on a belief that the study of human behaviour should be conducted in the same way as studies are conducted in the natural sciences” (Neville 2007, p. 6) & (Collis & Hussey 2003, p. 52). The positivism philosophy is also in agreement with the distance approach based on social world distribution. This approach evaluates a phenomenon through a variety of objective methodologies.

These methodologies lead to the collection of codified trusted data with the collection process preventing the exposure of participants’ privacy as this procedure generalises the collected data with respect to the criteria using such demographics as education level, gender and age. In addition, the application of the positivism philosophy advocates testing the hypotheses by using statistical analysis, random sampling and measuring the data’s precision.

From this point, I assume that the historical data approach in my research is a more efficient approach than survey or interview approaches., The historical data approach is more helpful for the topic under study, as it that needs a large sample size which is difficult to collect from surveys or interviews. It would also be expensive to set up an interview centre to conduct one-on-one interviews with participants. Moreover, the interview approach is time-consuming and tedious for participants. The aims and instructions of my research require using an intelligent logger meter to accurately record the electricity consumption for all participants. However, this approach could not be made through survey or interview as the data is massive (47 million data items) and would need a high level of precision by using smart meter recorders, which cannot be managed manually like interviews or questionnaires.

In this research, I will use the research design that is most expedient in finding answers to the research questions. The ontological premise in this research method is an expressed reality that can be described by a quantitative method. This method is significantly aimed at determining the nature of reality (Picard & Velautham 2014, p. 5). From this perspective, the collected data will be included with the answers to the research questions. This will provide a level of objective realism to describe the appearance of things as they are in observable surface phenomena, and to fulfil my desire to achieve what is possible in this research journey, in order to eventually move to a larger data base? Based on the current sample used in the analysis, one unifying aspect that will follow is that the sample selected will lead to inferences about the whole population.

2.8 Case Study Typology

Figure 2.9 illustrates the typology of a case study is likely to follow various layers of classificatory principle that, when disaggregated, will finally produce a formal research method. The case study typology is drawn from two essential features and these are the subject addressed throughout the case study itself. The object which that regarding the theory and the analytical frame through which the subject is viewed and which the subject is elaborated and analysed. At or to the further side of this distinction, the case study in this research is exhibited as classifiable by its approaches adopted and its principal purposes. The distinction of this research case study is that its interpretation is both complexity theory-centred and an illustrative study of the issue of peak and off-peak demand caused by end-users' behaviour in electrical smart grid systems in Australia. Yin's model describes X axis as the number of cases and Y axis as the units within each case. This research belongs to Type 4 of a multiple case design which has basic relevance for:

- Providing a larger picture of complex phenomena;
- Comparing different cases of end-users' behaviours;
- Testing the replication;
- Avoiding extraneous variation defined in this research known as peak & off-peak demand.

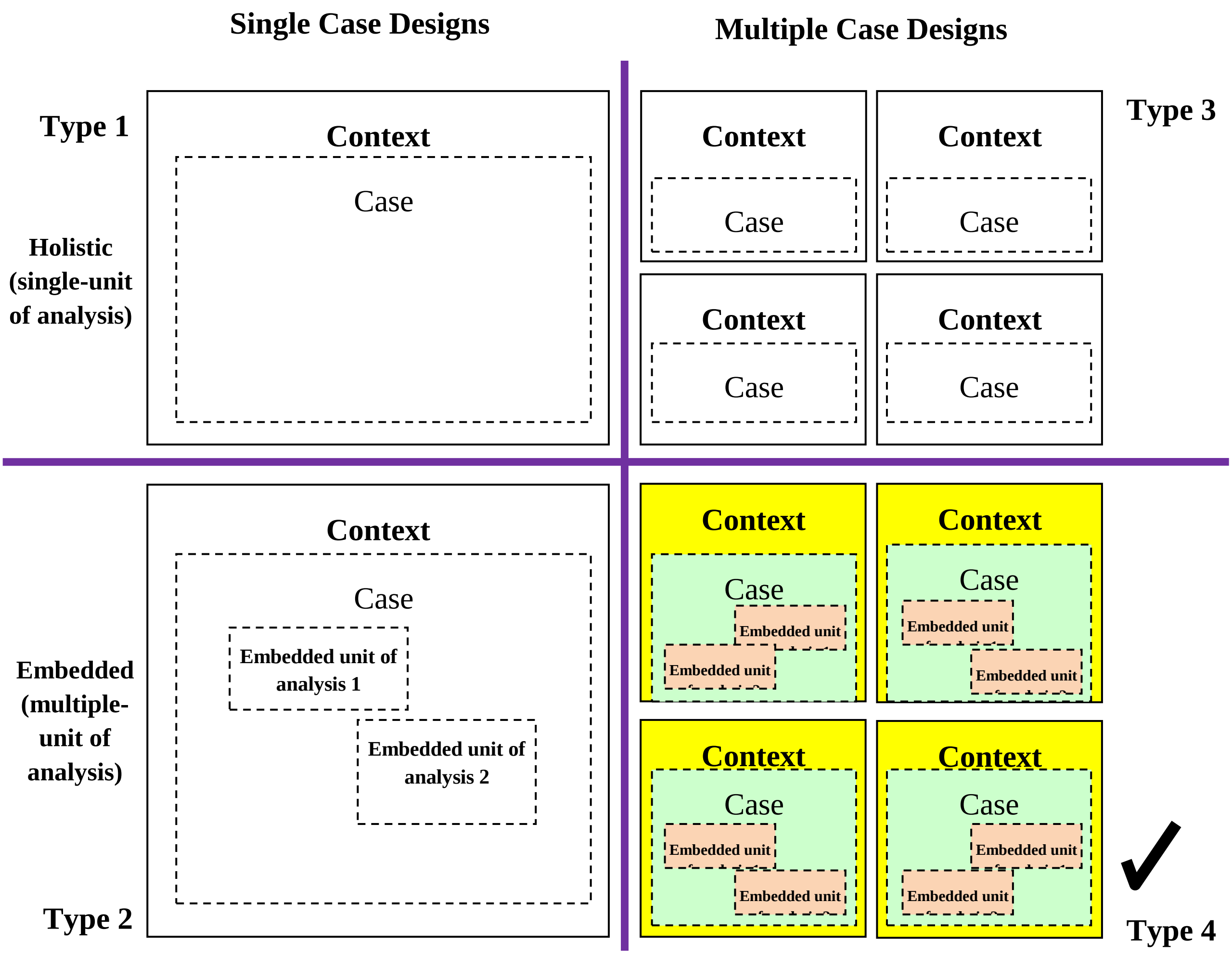


Figure 2.9: Yin Model of Case Study Typology (Milliot, E 2014)

This research discusses an embedded complex case study where the analysis focuses on various sub-units (Homes/end-users) of particular phenomena of peak and off-peak demand. This is essential to put into perspective the holistic illusion, to strengthen the internal validity and to confront conflicting interpretations.

- Internal validity: To verify the causal relationships between variables and achieved results.
- Confront rival interpretations: During the daily demand of electricity, end-users' behaviour could be understood as opportunistic or as a test to assess their commitment `to what the grid is dealing with’.

2.8.1 Case Study for Building Theory

Linked with Yin (1984) Topology, the matrix below in Table 2.9 classifies my research in regards to the strength needed for causal explanation and the emphasis level on research contextualisation. My research has a weak emphasis on contextualisation and a strong emphasis on causal explanation, on which the case study research depends for a non-limited number of cases. This was the goal when I used 47,304,000 million units of data collated from 300 residential consumers in New South Wales (NSW) for analysis.

Table 2.9: Multiple case studies of Residential houses (Welch C., Piekkari R., Plakoyiannaki E., Paavilainen-Mäntymäk E. 2011)

Explanation **Understanding**	***Weak Emphasis on Causal Explanation***	***Strong Emphasis on Casual Explanation***
Weak Emphasis on Contextualization	Inductive theory-building **Multiple Cases (4-10)**	[✓ Natural experiment **Single or Multiple Cases (no limit)**]
Strong Emphasis on Contextualization	Interpretive Sense-making **Single or Multiple Cases (4-10)**	Contextualized Explanation **Single Cases or Very Few Cases**

2.8.2 Case Study Methods for Research Purpose

As stated in the ‘Research Design’ section, the purpose of this study strongly emphasises a causal relationship for a particular situation when the isolation of factors, which causes problems, is addressed. The unit of analysis is the half-hourly consumption of electricity by end-users and measured by KiloWatt Hour (KWh). Within a context of electrical smart grid systems, this research enquiry empirically investigates end-users’ behaviour while consuming electricity to, in turn investigate the issues of peak and off-peak phenomena that concern suppliers and retailers of electricity.

Therefore, the purpose of this research is “explanatory”, to test and understand causal relations of electricity consumptions in a residential household area. Using an explanatory approach is the most common approach to complex management and adequate to very complex situations in which the use of experimental or survey approaches will not be adequate. My research has a weak emphasis on contextualisation and a strong emphasis on causal explanation which should be categorised as explanatory studies (see Table 2.10).

Table 2.10: Methods of Theorising from Case Studies (Milliot 2014)

Explanation **Understanding**	***Weak Emphasis on Causal Explanation***	***Strong Emphasis on Casual Explanation***
Weak Emphasis on Contextualization	Inductive theory-building **Exploratory Confirmatory**	[✓ Natural experiment **Explanatory Confirmatory**]
Strong Emphasis on Contextualization	Interpretive Sense-making **Exploratory Descriptive**	Contextualized Explanation **Explanatory Descriptive**

2.8.3 Case Study Methods for Reasoning

Referring to Table 2.11, there are three methods of reasoning using existing knowledge to deliver explanations, make predictions and draw conclusions. These methods are:

- "Deductive" is a reasoning process which starts from the general rule and proceeds to the specific application.
- "Inductive" is another reasoning process that begins with specific observations and proceeds to form a generalised conclusion that is possible, but not certain, in light of collected evidence.
- "Abductive" is the third reasoning process that starts with an incomplete set of observations and arrives at a most probable explanation for a decision making that does its best based on the information at hand.

By using the same labels in the above matrix, I classify my research as deductive research.

Table 2.11: Inductive, Deductive & Abductive Approaches (Milliot, E 2014)

Explanation **Understanding**	***Weak Emphasis on Causal Explanation***	***Strong Emphasis on Casual Explanation***
Weak Emphasis on Contextualization	Inductive theory-building **Induction (or abduction)**	[✓ Natural experiment **Deduction**]
Strong Emphasis on Contextualization	Interpretive Sense-making **Induction (or Deduction or Abduction)**	Contextualized Explanation **Induction, Deduction or Abduction**

The adopted deductive research method is the process in which researchers formulate their theories in terms of the need to investigate a certain phenomenon within a positivist paradigm (Khalid, Hilman & Kumar 2012). This phenomenon has been reviewed before which is convenient to my research on complexity theory. The deductive research method is connected to previous observations by other researchers on the chaos paradox and complexity theory and is extended to future aspects that it is possible to forecast from the literature review. In doing this, measurable aspects will be identified and empirically tested with respect to the developed hypotheses.

As the research will be designed to analyse whether or not the data supports the considered hypotheses, a deductive approach is required as it aims to determine the hypotheses' validity. In this approach, time series data of electricity consumption by residential end-users aim to define a particular investigation related to the finding of complexity theory. The approach used in this research will consist of 15,000,000 million data items that seek to determine the influence of the designed variables on the population of residential houses in New South Wales (NSW) in Australia. In addition, these data collected are based on the hypotheses that are firmly connected to both dependent and independent variables within the boundaries of the cause and effect relationship. In doing this, the research will utilise mathematical data analysis methods by using Python and MATLAB software.

2.8.4 Epistemological Ontology of the Case Study

Table 2.12 below depicts that there are four types of epistemological ontology: "Neopositivism" is a knowledge that is certainly "positive" and is without a doubt that it has total security from error. The information is then based on natural phenomena that have their own properties and relations and are interpreted via reason and logic. It is not appropriate to my research goal. "Post-neo positivism" is an amendment to the concept of positivism through using critiques to reform logical positivism with no rejection of the scientific method. In other words, post-neopositivism is a reintroduction to the fundamental assumptions of positivism. This approach is appropriate to my research goal.

"Constructivism" is a theory belongs to the ways in which people acquire knowledge and then learn which is constructed from their experience. This approach is not appropriate to my research goal "Critical realism" is an approach realised from the vision of an adequate realist philosophy of social, of science, and of explanatory critique. This approach is not appropriate to my research goal.

Table 2.12: Epistemological Ontology Approaches (Yin 2014)

Explanation **Understanding**	*Weak Emphasis on Causal Explanation*	*Strong Emphasis on Casual Explanation*
Weak Emphasis on Contextualization	Inductive theory-building **Positivism or neopositivism**	Natural experiment **Post-neopositivism** ✓
Strong Emphasis on Contextualization	Interpretive Sense-making **Constructivism or interpretivism**	Contextualized Explanation **Critical realism**

2.8.5 Explanation of epistemological projects

“Praxeology” is the study concerning human actions and aspects that are able to grasp human a priori and the logical implications of preference and conceptual analysis (see Table 2.13). “Nomothetic” concerns the study of what we share with others, that is to say in establishing generalisations or laws. “Idiographic” is an approach that has a meaning of “own” or “private” and wants to discover what makes each of us unique.

Table 2.13: Epistemological Projects Approaches (Yin 2014)

Explanation **Understanding**	*Weak Emphasis on Causal Explanation*	*Strong Emphasis on Casual Explanation*
Weak Emphasis on Contextualization	Inductive theory-building **Nomothetic Project**	Natural experiment **Praxeological Project** ✓
Strong Emphasis on Contextualization	Interpretive Sense-making **Idiographic Project**	Contextualized Explanation **Praxeological Project**

2.8.6 The Research Profile of Nominated Case Study

Several measures were undertaken in this section to define the most suitable ‘case study typology’ and can be summarised in the following Table 2.14:

Table 2.14: Research Profile of Nominated Case Study (Yin 2014)

Explanation **Understanding**	*Strong Emphasis on Casual Explanation*
Weak Emphasis on Contextualization	**Natural experiment** ▪ **Multiple cases** ▪ **Explanatory and/or confirmatory Deduction** ▪ **Praxeological Project** ▪ **Post-neopositivism** ▪ **Qualitative & Quantitative**

2.8.7 Conclusion of Case Study Typology

As stated above and restated in Figure 2.10, in research design, things must be taken into consideration in regard to the context of the adopted case study to cover the circumstances that form the setting for an event, which in terms of the research problem, can be fully understood and assessed (Yin 2014). The context for this research, as is also discussed in chapter one, belongs to electrical smart grid systems in Australia and the case study belongs to residential houses in New South Wales (NSW). This study will investigate the particular influence of residential houses on electricity demand regarding peak and off-peak phenomena.

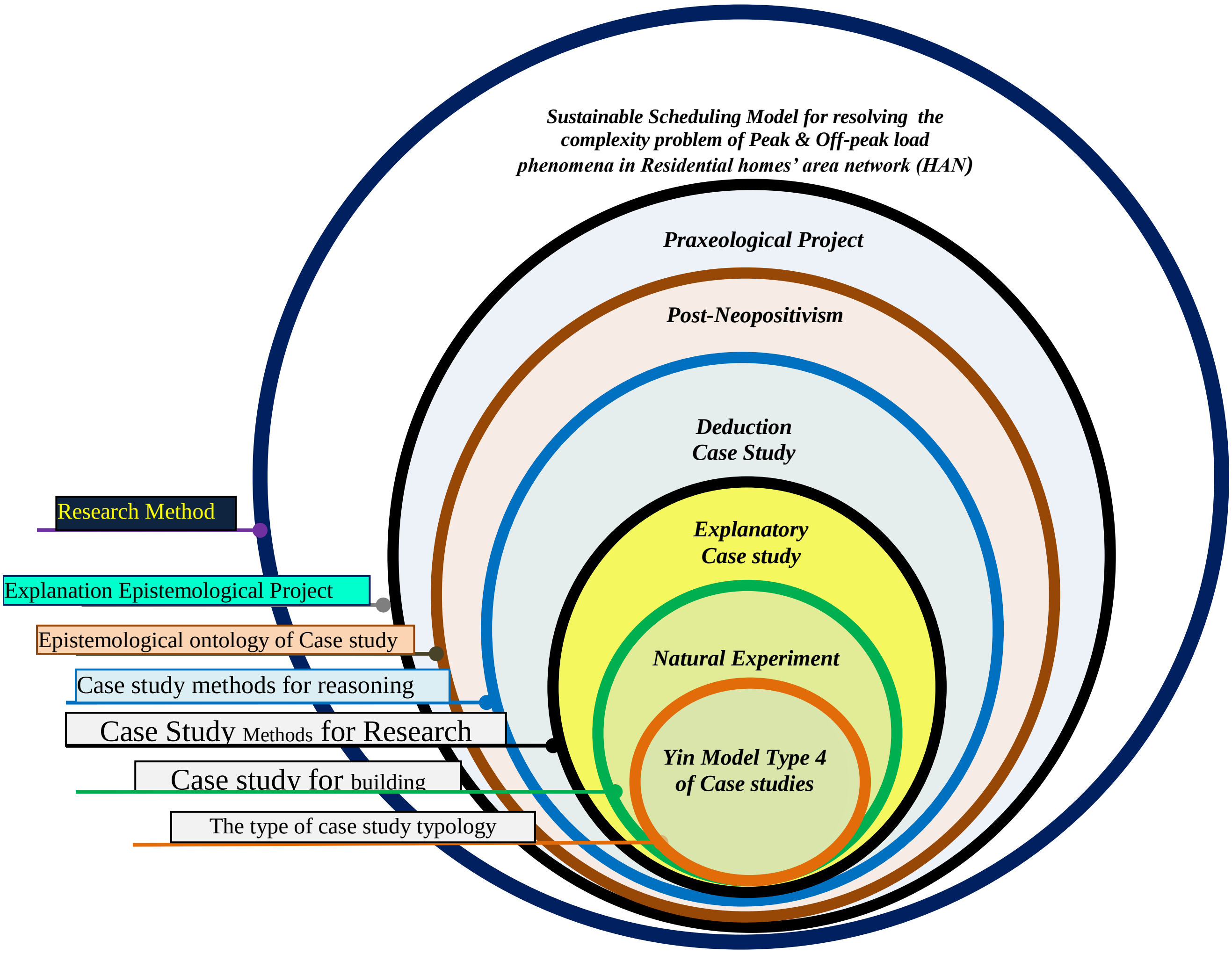


Figure 2.10: Classificatory Principle of Case Study Typology to derive Research Method (Milliot, E 2014)

2.9 Research Method

The sustainable scheduling model depicted above forms a framework through which the research questions about the influence of home demands in this thesis could be answered. This chapter describes the methods used for analysis. It also reports time series data collected from residential households, and the way they are used to optimise non-technical information into useful technical information.

This thesis explores the extent of human behaviour as a non - linear dynamic behaviour in a complex system, by using the case study of an electrical smart grid system. This study uses the complexity philosophy and focuses on the spontaneous emergence of human actions to understand the consequences of events' scalability and the clustering dynamic of unequal consumption of electricity among end-users.

2.9.1 The Model for Proposed Solution

Model Title: *Sustainable Scheduling Model for Resolving the Complexity Problem of peak & Off-peak Loads in Residential Homes in Household Area Network (HAN)*

Table 2.15: Sustainable Model Characteristics

S.N.	Parameter	Variable	Constraints	Objective Function	Abbreviations	Meaning
*1	✓				∀	All values of SC, Bc & every value of CC will satisfy ∀SC ∀BC ∀LC, DC(SC, BC, DC)
2	✓				∀SC	A universal quantification of a predicate logic for solar capacity needed at home
3	✓				∀BC	A universal quantification of a predicate logic for battery capacity needed at home
4	✓				∀LC	A universal quantification of a predicate logic for load capacity at home
5	✓				td	Index of day time
	✓				tn	Index of night time
6	✓				P	Index of power
7	✓				AVD	Average Daily optimum consumption (24 hours)
8	✓				PD	Peak Daily consumption (24 hours)
9	✓				OPD	Off-Peak Daily consumption
10	✓				LCD	Low Daily consumption (24 hours)
11	✓				AVT	Average Half hourly consumption (optimum)
	✓				AVT-max	Maximum Average Half hourly consumption
	✓				AVT-min	Minimum Average Half hourly consumption
12	✓				PT	Peak Half hourly consumption
13	✓				OPT	Off-Peak Half hourly consumption
14	✓				LCT	Half hourly 'Low Consumption'
*15	✓				GC	General consumption at homes from the grid (from the historical data)
*16	✓				CL	Controlled Consumption load at homes

						from the grid (from the historical data)
*17	✓				GG	Solar power installed at homes (from the historical data)
18			✓		CTC	Total timely consumption of electricity (from the historical data)
19			✓		PL	Power demand load
20				✓	DTC	Desired timely consumption (Average)
21		✓			dh	Highest demand load for each consumer
22		✓			dL	Lowest demand load for each consumer
23		✓			Bc	Battery total Charging capacity
24		✓			Bdis	Battery total discharging capacity
25	✓				HTDC	Home Total Day Consumption
26	✓				HTNC	Home Total Night Consumption
27		✓			CNDL	Power capacity available at home, but not needed in the period of Day Light
28		✓			CNNT	Power capacity available at home, but not needed in the period of Night Time
29		✓			BFOH	Battery capacity used from homes to serve other homes achieve Averages
30		✓			SFOH	Solar capacity used from homes to serve other homes achieve Averages
31			✓		SNT	Solar Total Power capacity needed at Night Time for each home
32			✓		SDT	Solar Total Power capacity needed at Day Time for each home
33			✓		STC	Solar Total maximum Solar capacity needed for a whole day for each home
34			✓		BNT	Battery maximum required capacity during night time based on worst night scenario
35			✓		BDT	Battery maximum required capacity during day light time based on worst day scenario
36			✓		BTC	Battery total capacity required at home
37	✓				UPS	Unit Price of Solar
	✓				PSH	Cost of Solar at home
38	✓				UPB	Unit Price of Battery
	✓				PBH	Cost of battery at home
39		✓			PtG	Timely power needed from grid at home
40		✓			L	Load = other homes demand that need to support to achieve average demand.
41		✓			PtS2L	Timely power needed from solar to load
42		✓			PtS2B@DT	Timely power needed from solar to battery at day time
43		✓			PtS2G	Timely power needed from solar to grid
44	✓				NCB	Maximum number of cycling charge and discharge for battery
45	✓				ηchB	Efficiency of charging the battery
46	✓				ηdischB	Efficiency of discharging the battery
47	✓				RCB	Rate of Battery charge
48	✓				RDB	Rate of Battery discharge
		✓			$\boldsymbol{SOC_t^B}$	State of charge battery at time t
		✓			$\boldsymbol{SOD_t^B}$	State of discharge battery at time t
49	✓				PR1E	Cost Index of Electricity losses during peak consumption times
50	✓				PR2E	Cost Index of Electricity losses during off-peak consumption times
51				✓	NPO	Net payoff
52				✓	NProf	Net Profit

Notice: all the above variables are matrices (300 houses so a 1*300 matrices)

2.9.2 Objective function

The fundamental purpose of this model proposal is to control and normalise the power that is consumed by residential homes and to create benefit by having a smooth load profile at average consumption levels. For this purpose, it is considered that there is a supplier (Government and retailer) who wants to invest in solar panels and battery units to install them in 300 houses in a residential house area network. This investment will facilitate coverage of homes' electricity demands from solar, battery, and main grids, as well.

The proposed objective is to minimise energy losses at peak and off-peak times which then minimise the total electricity cost and increase the benefit, that is, the total revenue minus the cost. The average of consuming electricity is the desirable optimal level of consumption in between peak and off-peak consumption levels. The scale of energy losses is financially provided according to the timely demand of electricity either above or below the average consumption levels (minimum and maximum average levels). Thus, the capacity cost of a battery and solar at different homes counts against the losses of energy in order to calculate the feasibility of renewable energy investment in homes for the purpose of reducing the effect of peak and off-peak demand and then, reduce the energy loss and increase the profit.

Additionally, power that is stored and generated by a battery and solar will feed into the power grid according to timely consumption of the houses. In other words, solar and storage batteries are the defence line of homes for timely1 response and to make those homes within the average demand levels (optimum consumption levels). The proposed model is designed to normalise the load's profile down to an individual basis and for each home, at the separate base to make it within the desired range (average consumption range). The desirable ranges are pre-defined according to power grids' point of view. Subsequently, beyond running the designed model, we will estimate precisely the capacity needed for battery charges/discharges, and the solar needs required for each home.

The power output from these two components of renewable energy will always be fed into the grid system for optimisation purposes to make each house demand act within the desired range (average consumption levels). Solar power covers part of the consumption demand above the average levels. Solar panels will also will feed into storage batteries in day time when there is no opportunity for charging these batteries at night times' high peak consumption dominant at night, concurrent with less chance to charge these batteries from the grid power when the demand is above the average levels. Storage batteries are mainly active at night when no solar is available. Storage batteries have essential roles to make the home demand system agile.

Therefore, the objective function for the Sustainable-Scheduling Model and the constraints are defined as follows:

$$\boldsymbol{Min}\left\{\sum_{\boldsymbol{t\epsilon T}}\left[\boldsymbol{Cost_t^{loss,off-p}} + \boldsymbol{Cost_t^{loss,p}}\right] + IniCost^S + IniCost^B\right\}$$

- **OPT**: Off-Peak Half hourly consumption
- **PT**: Peak Half hourly consumption
- **PRE1**: Coefficient of Electricity losses (cost) during peak consumption times
- **PRE2**: Coefficient of Electricity losses (cost) during Off-peak consumption times
- $\mathbf{AV^{T}}$: Average Half hourly consumption
- $\mathbf{AV^{T\text{-}min}}$: Minimum Average Half hourly consumption
- $\mathbf{AV^{T\text{-}max}}$: Maximum Average Half hourly consumption
- C^{TC}: Total timely consumption of electricity

Binary variable: =1 when C^{TC} *goes below* $\mathbf{AV^{T\text{-}min}}$

Binary variable: =2 when C^{TC} *goes above* $\mathbf{AV^{T\text{-}max}}$

$$\boldsymbol{Min}\left\{\sum_{\boldsymbol{t\epsilon T}}\left[\boldsymbol{Cost_t^{PT*PR1E}} + \boldsymbol{Cost_t^{OPT*PR2E}}\right] - [\boldsymbol{Cost^{PSH}} + \boldsymbol{Cost^{PBH}}]\right\}$$

$$\boldsymbol{Cost_t^{OPT*PR2E}} = (\boldsymbol{PR2E} * (|\boldsymbol{OPT} - \boldsymbol{AV^{T-min}}|))$$

$$\boldsymbol{Cost_t^{PT*PR1E}} = (\boldsymbol{PR1E} * (|\boldsymbol{PT} - \boldsymbol{AV^{T-max}}|))$$

$$AV^{T-min} +> 1$$

$$AV^{T-max} < 2$$

The assumption is made that the optimal consumption of electricity within average levels is determined in between minimum and maximum averages levels. Thus, when the consumption is within average levels then no energy losses occur. Any demand value above the Maximum average is at Peak demand, and any consumption value below the minimum determined average is at off-peak demand. When the demand for electricity is above maximum average or below minimum average, then the proposed energy losses occur. The cost of losses increases with the increase of peak and off-peak consumption values. Controlling the demand load is possible with the assistance of solar and storage batteries. When the demand of one or a number of homes at off-peak status, then the power of the grid will feed the storage batteries at homes up to minimum average value. Solar and storage batteries will only send the power to the grid system to balance the homes according to the concept above. Many scenarios occur every second while consuming electricity in a single home and in the two examples below in Figures 2.11 & 2.12, one of them is supported with solar and storage battery and shows home consumption able act within average levels.

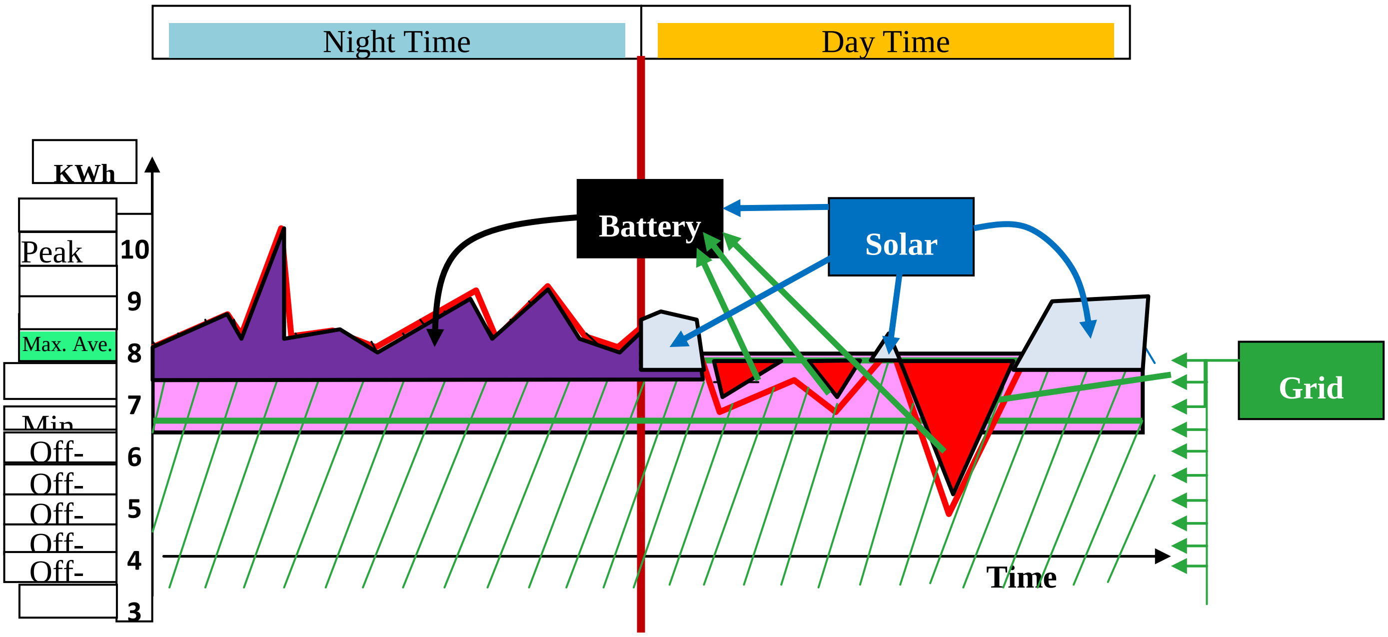


Figure 2.11: Demand of Electricity Example One

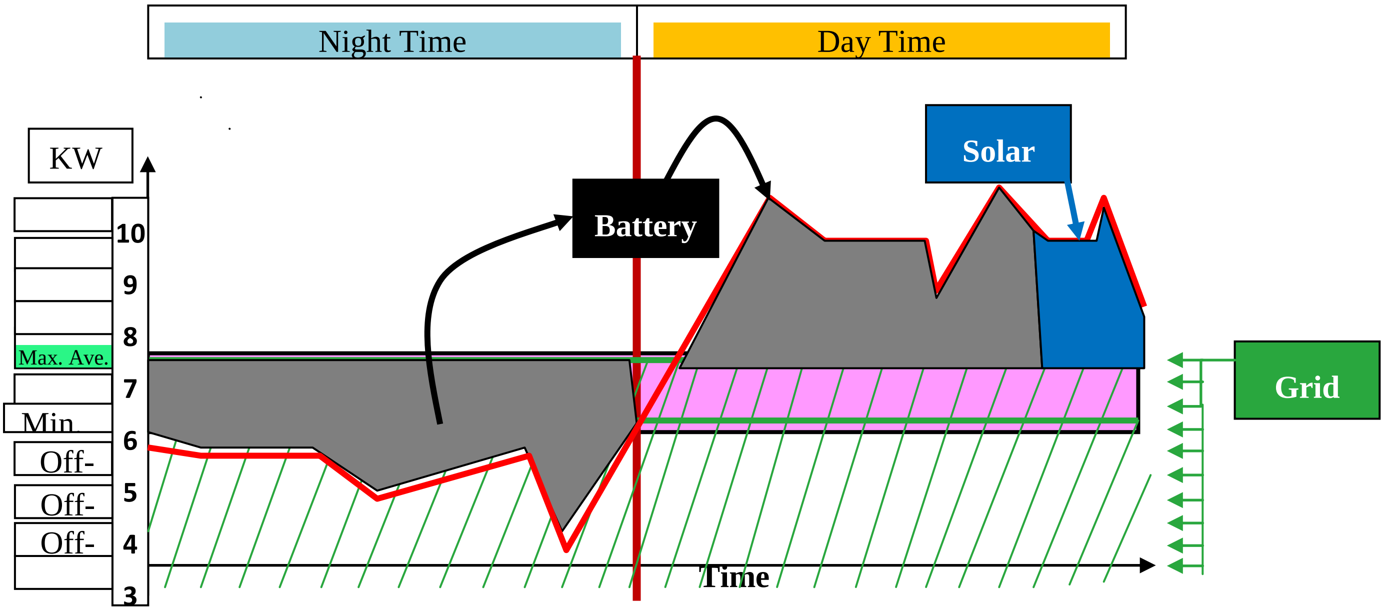


Figure 2.12: Demand of Electricity Example Two

Thus, based of the above explanations, in order to calculate the required solar panel and battery capacity for each house, I considered a worst-case scenario. Since I have the data for three years for every half an hour, we considered the peak load and the difference of this peak amount from the average ideal load. The maximum amount in the following table means the maximum between all days in each of the three years, or in other words, the maximum is from the 365*3 data.

For scenario one, when we have peak in night time:

- SNT: Solar Total Power capacity needed at Night Time for each home
- SDT: Solar Total Power capacity needed at Day Time for each home
- C^{TC}: Total timely consumption of electricity (from the historical data)
- S^{NT}: Solar Total Power capacity needed at Night Time for each home
- S^{DT}: Solar Total Power capacity needed at Day Time for each home
- S^{TC}: Solar Total capacity needed for a whole day for each home
- d^{h}: Highest demand load for each consumer
- d^{L}: Lowest demand load for each consumer
- P^{L}: Power demand load
- D^{TC}: Desired timely consumption (Average)= from $AV^{T\text{-}max}$ to $AV^{T\text{-}min}$
- $AV^{T\text{-}max}$: Maximum Average Half hourly consumption
- $AV^{T\text{-}min}$: Minimum Average Half hourly consumption
- $AV^{T\text{-}base}$: Average Half hourly consumption (optimum)

- H^{TNC}: Home Total Night Consumption
- H^{TDC}: Home Total Day Consumption
- P^{D}: Peak Daily consumption (24 hours)
- t_d : Index of day time
- t_n : Index of night time

When $P^{L} - H^{TNC} > AV^{T\text{-}max}$

2.9.2.1 Solar Power capacity needed for Night Time (SNT)

$$\boldsymbol{S^{NT} = max\left(\sum_{tn} dh_{t_n} * t - \sum_{tn} AV^{Tmax} * t\right)}$$

When $P^{L} - H^{TDC} > AV^{T\text{-}max}$

Then Solar Power capacity needed at Night Time (S^{DT})

$$S^{DT} = max\left(\sum_{td} dh_{t_d} * t - \sum_{td} AV^{Tmax} * t\right)$$

2.9.2.2 Solar Total capacity needed for a whole day for each home

$$\mathbf{S^{TC} = S^{DT} + S^{NT}}$$

$$S^{TC} = max\left(\sum_{tn} dh_{t_n} * t - \sum_{tn} AV^{Tmax} * t\right) + max\left(\sum_{td} dh_{t_d} * t - \sum_{td} AV^{Tmax} * t\right)$$

2.9.2.3 Battery total capacity needed at homes

B^{NT}: Battery maximum required capacity during night time based on worst night scenario

B^{DT}: Battery maximum required capacity during day light time based on worst day scenario

B^{TC}: Battery total capacity required at home

B^{ch}: Battery total Charging capacity

B^{dis}: Battery total discharging capacity

$$B^{ch} = max\left(\sum_{tn} dh_{t_n} * t - \sum_{tn} AV^{Tmin} * t\right)$$

$$B^{dis} = max\left(\sum_{tn} AV^{Tmax} * t - \sum_{tn} dh_{t_n} * t\right)$$

If the capacity needed of Bch > Bdis then there is no need for solar capacity for the purpose of serving the battery in day time to cover the lack of capacity at night time.

if the capacity needed of Bch < Bdis then solar capacity needed at day light for the purpose of filling the battery by needed capacity to cover the lack of power at night time.

When $P^{L} - H^{TNC} > AV^{T\text{-}max}$
Then Solar Power capacity needed for Night Time (S^{NT})

$$\boldsymbol{S^{NT} = max\left(\sum_{tn} dh_{t_n} * t - \sum_{tn} AV^{Tmax} * t\right)}$$

$$B^{DT} = S^{NT}$$

The whole amount of power produced from solar panels in every time slot is sent to the grid or is used for battery charge. The capacity of solar needed can be defined exactly in regards to the weather prediction that can be easily achieved from the historical data we have.

P_t^{S2G}: Timely power needed from solar to grid

$P_t^{S2B@DT}$: Timely power needed from solar to battery at day time

P_t^{S2L}: Timely power needed from solar to load

P_t^{G}: Timely power needed from grid at home $AV^{T\text{-}max}$

$$P_t^{S2B@\boldsymbol{DT}} + P_t^{S2G} = P_t^{S2L} \qquad \forall t$$

2.9.2.4 Load and Grid power constraints

$$P_t^{G} = AV_t \; + P_t^{G2B} - P_t^{S2G} - P_t^{B2G} \qquad \forall t$$

$$AV^{Tmin} \leq P_t^{G} \leq AV^{Tmax} \qquad \forall t$$

2.9.2.5 Storage Unit Constraints

The batteries are charged by solar (PV) units at day times to support a home at night time or power is bought from the grid during off-peaks. For each house, there is one storage battery unit and its maximum capacity will be calculated referring to either the highest capacity needed for charging or discharging at night time.

RCB : Rate of Battery charge

RDB : Rate of Battery discharge

SOC_t^B: *State of charge battery at time t*

SOD_t^B: $State\ of\ discharge\ battery\ at\ time\ t$

NCB: Maximum number of cycling charge and discharge for battery

Bch: Battery total Charging capacity

Bdis: Battery total discharging capacity

$$SOC_t^B = SOC_{t-1}^B + B_t^{ch}\eta^{ch.B}\left(\frac{P_t^{S2B} + P_t^{G2B}}{B^{TC}}\right) - B_t^{dis}\eta^{dis.B}\left(\frac{P_t^{B2G}}{B^{TC}}\right) \quad \forall t$$

$$SOC^{B,min} \leq SOC_t^B \leq SOC^{B,max} \quad \forall t$$

$$0 \leq (SOC_t^B - SOC_{t-1}^B) \leq \eta^{ch.B} RC^B \quad \forall t$$

$$0 \leq (SOD_t^B - SOD_{t-1}^B) \leq \eta^{dis.B} RD^B \quad \forall t$$

$$SOC_t^B = SOC_t^{B0} \qquad \forall t = 1$$

$$\sum_{t \in T} (B_t^{ch} + B_t^{dis}) \leq NC^B$$

$$B_t^{ch} + B_t^{dis} \leq 1 \quad \forall t$$

Note: The equations of solar and storage batteries formulated during the regular meeting with researchers "Dr, Markus Wagner', 'Dr, Sergey Polyakovsky, and 'Maryam Hasani Shoreh' in the electrical engineering and Computer Science School at the University of Adelaide from February 2016 to February 2017.

Table 2.16: Date Collected and used for Calculation

	Total annual consumption in NSW recorded 9,500 KWh per year. In this Max. consumption 10,000 KWh			Average Annual Growth of Traditional & Renewable Power Generation (Department of Industry and Science 2016) The losses only counted for fossil fuel generating sources (Gas 20.8% + Coal 63%) (Australian Energy Update 2016)			It is calculated according to Long Run Marginal Cost of load (LRMC) in NSW which the peak assumed $89.95/mwH & SHOULDER/AVERAGE $47.25/mwH (Mark Cully, 2016, p. 17)	
	KWh	KWh	Per cents	Cent/KWh	Cent/KWh	Cent/KWh	Cent/KWh	KWh per half an hour
							Losses = (E*0.104+F*0.104+G*0.63)	consumption = B/365/48 (kWh every 1/2 hr
Status	KWh Generated	Consumption Demand	Generation Capacity	OCGT	CCGT	Coal	Total NSW Cost of electricity estimated before selling to retailers	Assumed electricity consumption per capita
	0	Zero	0%	10.40%	10.40%	63%	Average of Generation (OCGT 10.4%, CCGT 10.4% & Coal 63%)	0.00
High Generation Losses	500	Low consumption	5%	20			16.76	0.03
High Generation Losses	1000	Low consumption	10%	14	14.5	19.5	10.89	0.06
High Generation Losses	1500	Low consumption	15%	10.8	10.5	13.5	6.36	0.09
High Generation Losses	2000	Low consumption	20%	9.2	8.5	11	4.41	0.11
High Generation Losses	2500	Low consumption	25%	8.5	7.5	9.2	3.10	0.14
Low Generation Losses	3000	Off-peak consumption	30%	7.7	6.6	8	2.17	0.17
Low Generation Losses	3500	Off-peak consumption	35%	7.5	6.2	7	1.48	0.20
Low Generation Losses	4000	Off-peak consumption	40%	7.3	5.9	6.3	0.99	0.23
Low Generation Losses	4500	Off-peak consumption	45%	7	5.6	5.9	0.67	0.26
Low Generation Losses	5000	Off-peak consumption	50%	6.7	5.4	5.4	0.30	0.29
Desired Consumption	5500	Average consumption	55%	6.5	5.1	5	The desirable consumption assumed nil losses	0.31
Desired Consumption	6000	Average consumption	60%	6.4	5	4.8	The desirable consumption assumed nil losses	0.34
(Optimum Average)	6500	Average consumption	65%	6.2	4.8	4.5	The desirable consumption assumed nil losses	0.37
Desired Consumption	7000	Shoulder consumption	70%	6.1	4.5	4.3	The desirable consumption assumed nil losses	0.40
Desired Consumption	7500	Shoulder consumption	75%	6	4.3	4.1	The desirable consumption assumed nil losses	0.43
Transmission & Distribution Losses	8000	Peak consumption	80%	6	4.2	4	6.51	0.46
Transmission & Distribution Losses	8500	Peak consumption	85%	6	4.1	3.9	7.64	0.49
Transmission & Distribution Losses	9000	Peak consumption	90%	6	4.1	3.9	8.27	0.51
Transmission & Distribution Losses	9500	Peak consumption	95%	6	4	3.7	8.96	0.54
Transmission & Distribution Losses	10000	Peak consumption	100%	5.9	4	3.4	8.96	0.57

2.10 Reliability and Validity

Tharenou, Donohue, and Cooper (2007, p. 150) refer to the reliability of a study as when the study's measures are free from random measured errors or the latter have less than perfect reliability. Perfect measures are not usually achieved in a study and not under circumstances where the scores are too low. Thus, it is a matter of compatibility between the procedure or the instrument that is used to generate scores and the tested sample. It is essential to ensure whether the sample has (or to see if it has not) attained the required fit for a proposed tested model.

In this research, it is essential to ensure that the analytical instrument used is consistent with the topic under study (Tharenou, et al. 2007, p. 154). Firstly, to ensure that reliability is being achieved, it is important to check the data collected. In this research, the data collected will be geared towards the influence of complexity theory in electrical complex systems to raise these systems' adaptability levels (see Table 2.16). The relevance of the secondary data collected will be checked with the supervisors and will eventually lead to the nominated tools of analysis.

Furthermore, it is essential to ensure that all data collected are valid in terms of measuring what they are supposed to measure. As mentioned above, the reliability of the research is implied through the nature of collected data, but the validity is the degree of confidence that can be inferred from the meaning attached to these data collected. Thus, no study is valid unless it reaches the level of reliability. However, reliability does not mean the study is valid once the research accidentally does not measure what it is expected to be measuring.

Accordingly, the collected data, must be in harmony and coherent with the research objectives. This ensures that the research study will probably be conducted with minimal measurement errors. This approach is in agreement with high confidentiality in data collection and data handling. Overall, all the above factors signify the chance that reliability and validity will be attained in this research study.

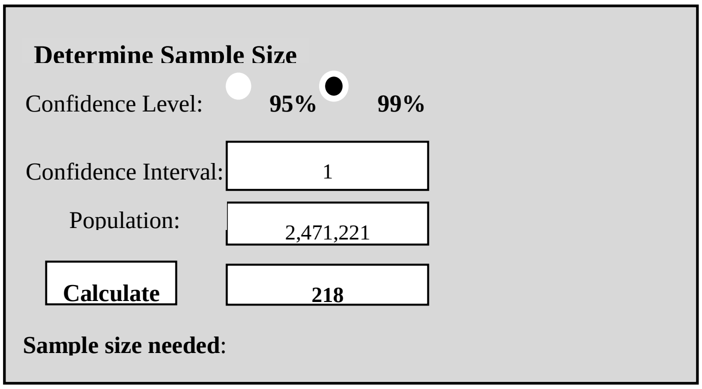
2.11 Sample Size and Population

Data will be collected from residential houses that received electricity from Ausgrid's electricity provider under the Australian Energy Market Operator (AEMO) in the state of New South Wales (see Table 2.17). The sample size in Table 2.18 has been generated by using the formula provided from the web site of "Creative Research Systems" with a 99% confidence level and 1% confidence interval. This means that the above 216 residential houses will be considered in the research analysis.

Table 2.17: Households Number & Size in NSW (Australian Bureau of Statistics 2017)

New South Wales – Households (Enumerated)	2011			2006			Change
Number of persons usually resident	Number	%	Australia %	Number	%	Australia %	2006 to 2011
1 person	599,095	24.2	24.3	562,625	24.2	24.4	+36,470
2 persons	814,694	33.0	34.0	772,246	33.2	34.1	+42,448
3 persons	397,064	16.1	16.0	371,679	16.0	15.8	+25,384
4 persons	392,981	15.9	15.7	371,491	16.0	15.7	+21,490
5 persons	177,102	7.2	6.7	169,301	7.3	6.9	+7,801
6 or more persons	90,286	3.7	3.3	80,875	3.5	3.1	+9,411
Total classifiable households	2,471,221	100.0	100.0	2,328,217	100.0	100.0	+143,004

Table 2.18: Sample Size of Residential Houses



Determine Sample Size

Confidence Level: ○ **95%** ● **99%**

Confidence Interval: 1

Population: 2,471,221

Sample size needed: **218**

- **Confidence Level:** It shows how often the true percentage of the population lies within the confidence interval. A 99% confidence level means that it is 99% certain.
- **Confidence Interval:** It is the margin error that in our case estimated one which if only 90% from the sample being used then we can be sure that the analysis of the total sample (100%) will involve between 89% (90-1) and 91% (90+1) would have used to provide an answer.
- **Population:** The number of people/houses in the area of New South Wales that we

are studying.

- **Sample Size:** It is the needed sample that truly reflects the population – therefore, the larger the sample size is, the more the right answer will be certain.

2.12 Research Timeline

A cross-sectional study has been employed and observations, regarding peak and off-peak phenomena have been made for the selected sample of residential homes in New South Wales (NSW) - Australia. The stochastic and deterministic analyses have been done at one time for the gathered historical data to obtain findings and conclusions for the task under investigation which is being conducted. A set of significant findings related to the research issues were utilised in the manner of conducting a case study as a one-time study. As shown in Figure 2.13 that the cross-sectional study has been used in the way that is suitable to be employed in studies which use the case study strategy studying a sizeable amount of the population to gain insights into the research problem (Babbie 2008). It is an adequate approach upon finishing a quantitative study as in this research case.

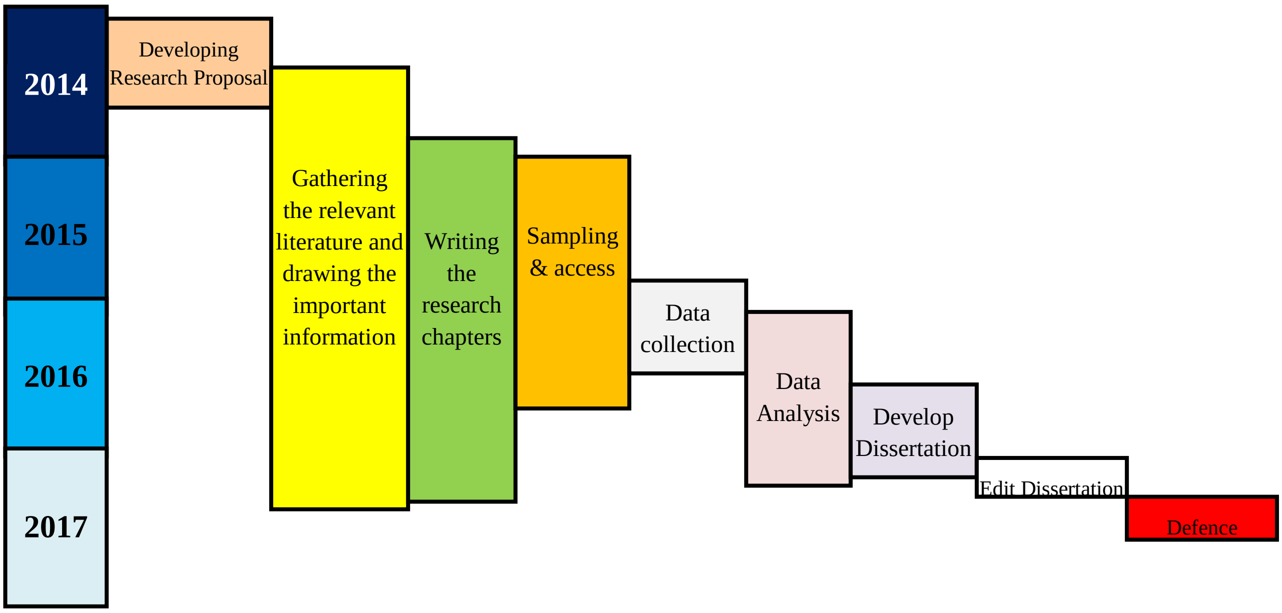


Figure 2.13: Research Timeline

2.13 Conclusion

This chapter provided a description of research purpose, classification, paradigm, methodology, design, case study typology, and methods to meet the particular aims and objectives of the research study. A cross-sectional study of electricity consumption of residential homes was adopted, as discussed earlier. A quantitative data approach has been retrieved from the research participants on behalf of the Australian Energy Market Operator (AEMO) and the Ausgrid electricity retailer. This chapter also derived a justification for why particular methods have been selected. Data collection was achieved for three years from 300 consumers, at 48 interval times per day over three years. This retrospective picture of data went through multiple stages before being used for analysis to make sure that it was free from flaws and any other forms of insufficiencies.

The data was subjected into two analytical stages – ‘stochastic’ & ‘deterministic’. Other factors partially discussed in this chapter included measurement scales, peak and off-peak losses, differentiations, justification of desirable and undesirable demands at residential homes. Reliability and validity, as means of achieving an added robustness to the research method and data analysis. Chapter (3, 4, 5 & 6) will discuss the research issue, and all other parameters, constrains and variables mentioned in this chapter. Chapters (7 & 8) will exhibit the stochastic and deterministic results of this research study.

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Chapter 3

Electricity Market in Australia & New South Wales (NSW)

Acronyms

ACCC: Australian Competition and Consumer Commission

AER: Australian Energy Regulator

AEMC: Australian Energy Market Commission

AEMO: Australian Energy Market Operator

AES: Australian Energy Statistics

ARENA: Australian Renewable Energy Agency

ASIC: Australian Security & Investments Commissions

BREE: Bureau of Resources and Energy Economics

COAG: Council of Australian Government

CPI: Customer Price Index

CSIRO: Commonwealth Scientific and Industrial Research Organisation

ENA: Energy Networks Associations

ESI: Electricity Supply Industry

GDP: Gross Domestic Product

GWh: Giga Watt Hour = 1000,000 Kilo Watt Hour (KWh)

IPART: Independent Pricing And Regulatory Tribunal

LRET: large-scale renewable energy target

LNG: Liquefied Natural Gas

MWh: megawatt hour

NEM: National Electricity Market

NEMMCO: National Electricity Market Management Company Limited

NSW: New South Wales

OTC: Over The Counter

PJ: Peta-Joul (equal 10^{12} Kilo Joul)

PV: Photovoltaic

SFE: Sydney Futures Exchange

SCER: Standard Council of Energy & Resources

TW: Tera Watt

TWh: terawatt hours

WEM: Wholesale Electricity Market

Lessons Learned from Chapter One & Two

Chapter one (Introduction) is contextual to the beginning of the study of energy losses within the Australian electricity smart grid systems. It examines the barriers of optimising energy losses that occurred due to peak and off-peak phenomena; as it was and still influence the technical, economical, societal, environmental and market operational aspects. This is contrasted with the impact of the individual residential houses and clustering effect of human behaviours while consuming electricity in a complex grid system in Australia. While chapter 2 (Research Method) provided a strategic planning methodology for this class of complex problems which adopted in this research. The method chapter defined a design for a multi method approach to manage the complexity of the problem in tandem with the nature of the case that represents within dense and severe changes in the situational complexity.

Chapter Outline

End-users will play a crucial role in upcoming smart grids that aim to link end-users and energy consumption in more efficient and better balanced electrical grid systems. However, although various perspectives have provided diverse insights into this area, further work is needed to provide a consistent and integrated view on how to proceed. The aim is to make end-users behaviours concurrent with smart grid projects and to promote smart energy behaviour which is currently lacking. Therefore, a literature review in this chapter was conducted to establish a clear view of the following:

- The state-of-the-art non-linear dynamic engagement of end-users' behaviour in smart grid projects, from both a theoretical and an empirical perspective.
- This chapter summarises the key findings concerning the reported enablers and the barriers for engaging end-users in smart energy behaviour.
- This chapter three also provides recommendations or "success factors" for end-user engagement and recognises the many key challenges remaining for future research and development.

3.1 Background & Literature Review

This chapter illustrates the background details of the Australian electricity market in regards to its electricity pricing volatility. This is followed by a description of economic growth in the electricity sector over past decades. The electricity market in NSW is specifically examined focusing on how much the electricity power plants have spent to generate energy from supply stations down to end-users' houses in NSW territory. This chapter will discuss how the end-users' consumption behaviours influence the level of investment by electricity suppliers and retailers, and how that affects the cost of electricity supply and demand (Energy Network Association 2014).

The government of Australia invests in diverse electricity infrastructure projects, the supply, transmission, or distribution of electricity to satisfy the end-users' demands. The influence of Peak and Off-Peak demands created by end-users' consumption behaviour is addressed in this chapter, following an examination of how the existing electricity pricing structure in New South Wales concerning the flow of electricity from end to end, is debated. The combination of socio-technical factors that decisively lead the electricity demand losses are presented and interpreted. Following that, the chapter sheds light on the origins of the problem and the possible solutions discussed for the Australian electricity market.

3.2 How do Electricity Supplied to Customers

Figure 3.1 shown the electricity supply industry (ESI) consists of four main divisions: the generation, transmission, distribution, and retailers. This separation applies despite the market structure under which the ESI manages. (Sayers, C & Shields, D, 2001). Electricity is produced from naturally occurring primary energy sources, using fuels such as oil, gas and coal. Other potential energy advantages are taken from geothermal steam and water sources. Electricity is transferred from the generation plants along conductors of interconnected power line systems of high voltage to the nearby point of final demand (Sayers, C & Shields, D, 2001). Step down transformers reduce the transmission voltage before delivering the electricity to end-users over a distribution network (Sayers, C & Shields, D, 2001). Retailers or electricity providers' companies make a contract with end-users to sell electricity according to agreed tariffs and in regard to the metered consumption.

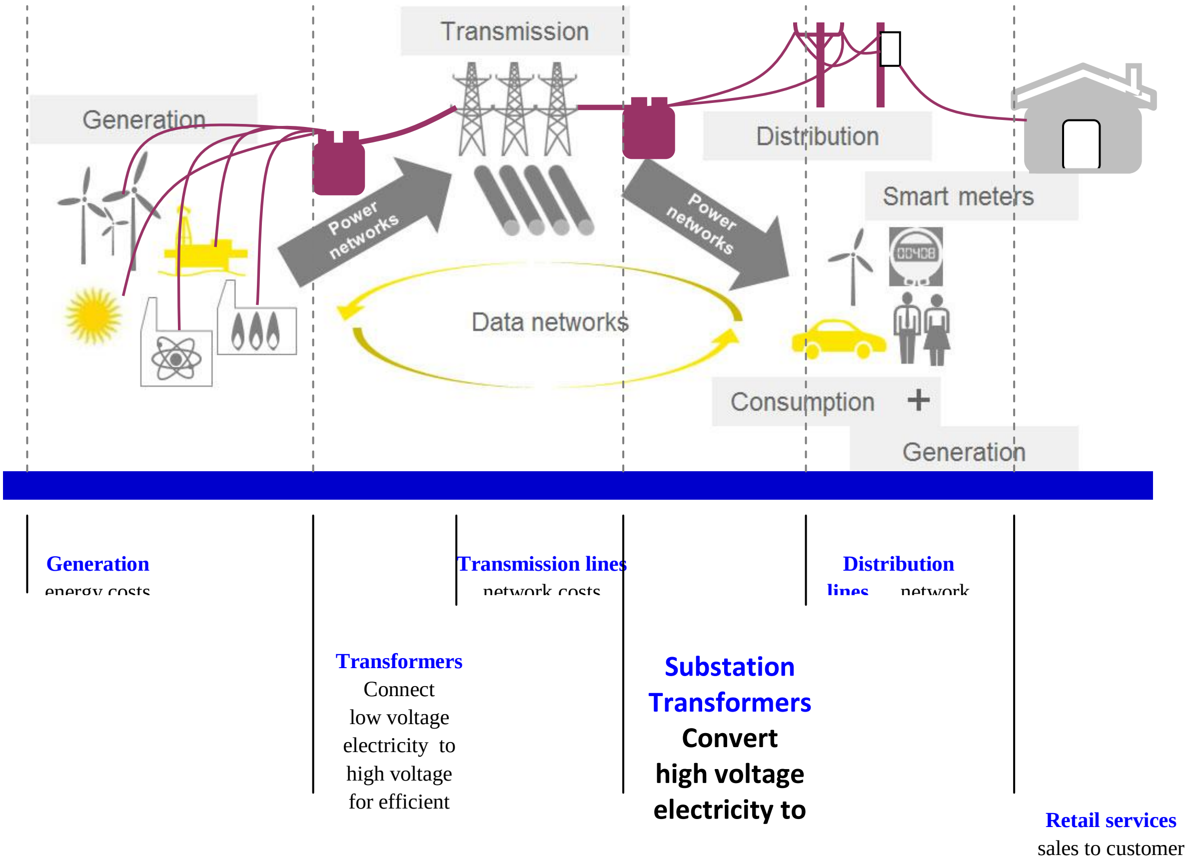


Figure 3.1 The Main Divisions of Electrical Supply System up to End-Users (Ernst & Young 2016)

The electricity delivered by networks is mostly traded through electricity markets, mainly on behalf of two wholesale electricity markets operated in Australia (Australian Energy Market Operator 2010). The first market is the National Electricity Market (NEM) administered by Australian Energy Market Operator (AEMO) and operates in NSW, Queensland, the ACT, South Australia, Victoria, and Tasmania. The second operatoring market is the Western Australian Wholesale Electricity Market (WEM) administrated by IMO (Independent Market Operators) and operates the South West Interconnected System. Both markets target the supply of energy from generation stations to customers in the least-costly and most efficient manner (Opportunities in Electricity Networks 2013).

The drivers for each augmentation to transmission and distribution networks that shown in Figure 3.2 take into account the criteria of security, quality, reliability and safety standards. The weighted average loss of electricity through transmission and distribution networks combined is estimated at 5,800 GWh (20.8 PJ) and equal to 6.7% of total inputs. Some studies found some 15% of losses in transmission lines are due to transformers, with conductors making up the remaining 85%. The Australian weighted average loss for distribution networks and out of total input is approximately 5.4% (2008-09 to 2010-11), and equivalent to 9,300 GWh p.a. which equals l 33.6 PJ. Losses for individual networks in distribution areas that are operated by different retailers range from 3.7% to 9.1% (Energy Efficiency Opportunities in Electricity Networks 2013).

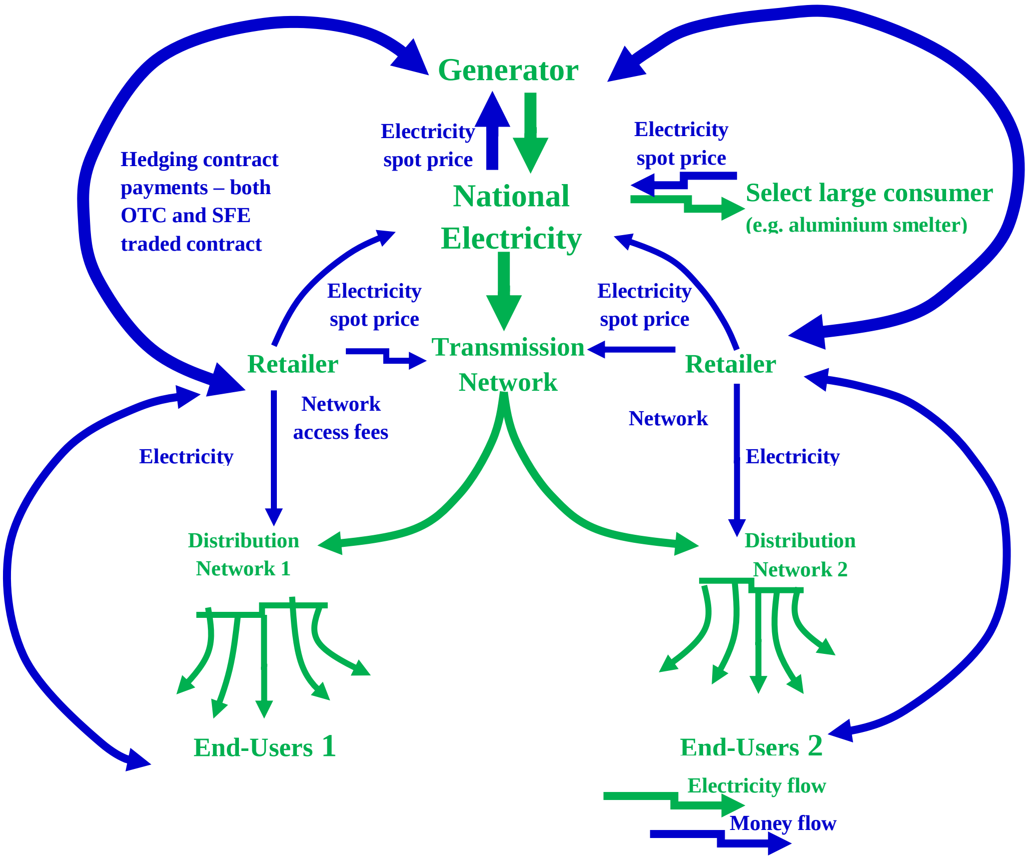


Figure 3.2: Electricity Market from Generators to End-Users (Nicholas Tan 2011, p. 3)

3.3 Electricity Market in Australia

The Australian Gross Domestic Product (GDP) was worth 1.34 Trillion US dollars (1340 billion) in 2015, and the population in Australia, 23,781,169 million in the same year (The World Bank, 2016). The GDP outcome for Australia that shown in Figure 3.3 illustrates 2.16 per cent of the world economy. The average of GDP in Australia recorded at 386.58 USD billion between 1960 and 2015. The highest GDP was 1563.90 USD billion in 2013, and the lowest was 18.60 USD billion in 1960. In the year 2013-2014, Australia witnessed 75 per cent of the verity of fuels used to produce energy, particularly for three leading industries: electricity, transport and manufacturing. The power of electricity is generated by the conversion of the received primary energy achieved from burning petroleum fuels. The electricity industry in Australia consumes 1,6669 petajoules (4630277.78 GWh), and shares 28.2 per cent of the total burnt fuel to produce needed the national power needs for electricity.

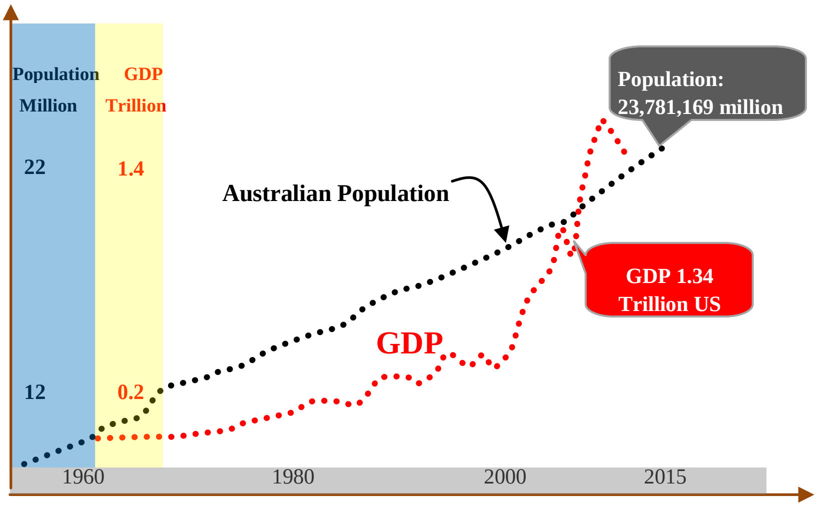


Figure 3. 3: Gross Domestic Product (GDP) & Australia Population 1960 to 2015 (The World Bank 2016)

In the last decade, Australia has experienced a decrease in the average growth of supply of electricity, down by - 0.4 per cent. In 2014-2015, the average annual growth of electricity supply was increased 5.5 per cent (Mark Cully, 2016). The energy productivity in Australian industries (i.e. electricity, transport & manufacturing) rose by 28 per cent over the past 15 years, followed by 1 per cent in 2014-2015 to approximately 5,920 Petajoules. This growth in using energy is consequent with the growth of using solar and wind. Currently, wind power accounts for one-third of renewable energy generation in Australia (It is not equal to the third of national electricity generation).

The ore concern over total final energy consumption is massive and related to a number of sectors who are responsible for managing this consumption in a responsible way. The electricity sector is at the top of these industries. Therefore, it is important to have long-term, alternative plans to oversee and control this vital industry of electricity. The macroeconomic indicator in Figure 3.4 depicted the ‘Customer Price Index’ (CPI), monitors the price inflation for the service or good faced by end-users. As per the CPI, figure the inflation of the average amount paid by each household is increasing over time for the same capacity of electricity used. Other trends of Gas and Automotive fuels are added for comparison purposes only.

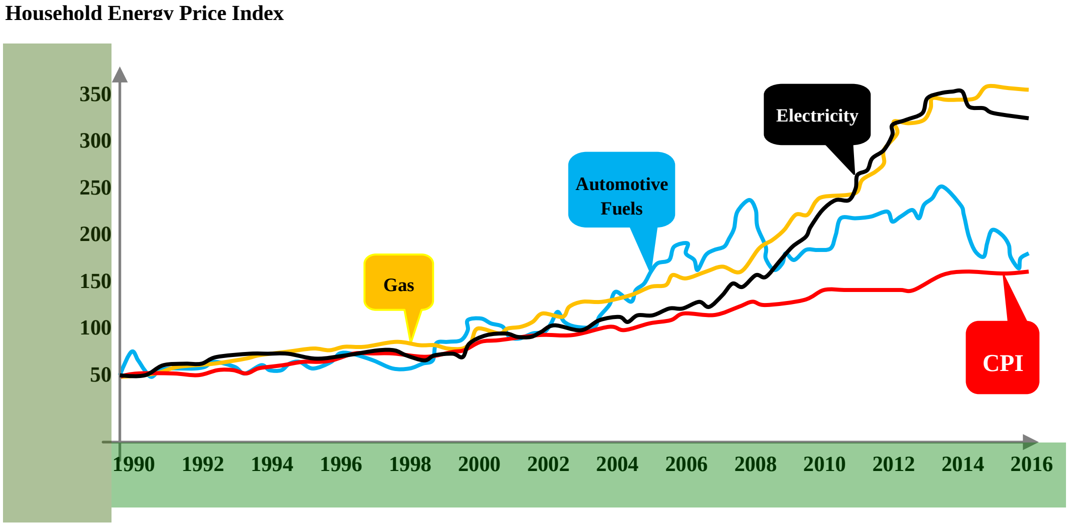


Figure 3.4: Household Customers' Electricity Price Index (Australian Government Fact Sheet 4 2016)

Conflicting claims about the rising demand for electricity over a period of time appear to have been driven by two factors: first - many sectors have been increasing their practices towards energy efficiency; secondly, there is a strongly negative reaction from residential consumers to higher electricity prices delivered to them by electricity retailers. The Australian government is aware of the fact that Australia's energy markets are undergoing significant transformations. The Bureau of Resources and Energy Economics (BREE) report in 2014 called for a new plan to change the patterns of demand and supply. This call was intended to devise a new way to achieve accurate, accessible data on energy, to make it readily and comprehensively useable.

At last, there is an expectation from the main players that change in the Australian electricity market will be through changing patterns of demand and supply that are expected to rely on technological changes. Changing patterns of demand and supply of electricity are also having an impact outside Australia, as shown by developments in international markets for a better future. Thus, it is crucial to devise alternative long-term national plans for energy sources and distribution, drawing on the use of renewable energy at the household level so that end users are able to monitor and control this vital sector of electricity.

3.4 Electricity Network in Australia

The electricity networks of Australia comprise over 860,000 km of distribution networks and over 50,000 km of transmission lines (Energeia in Consultation 2013). These networks are managed and operated by 23 businesses. These networks delivere over 252 terawatt hours (TWh) of total electricity generated to approximately 20 million customers (Energeia In Consultation 2013). The Figure 3.5 shows the financial performance of Australian electricity businesses in NSW to all of distribution, transmission and generation parties (PSM, A.T.W, 2015, p. 8). Reporting accurate and timely financial information on performance of electricity enhances transparency and confidence in such a public sector for decision making. In addition to this, a clear understanding of the financial expenses is essential in order be able to analyse, design and reform policies (Electricity Generation Costs 2012, p. 2).

Revenue

Distributors
$6.8 billion

TransGrid
$887 million

Generators
$464 million

Profit/(loss) after tax

Distributors
$930 million

TransGrid
$203 million

Generators
$(743) million

Return on Assets

Distributors
8 Per Cent

TransGrid
7 Per Cent

Assets

Distributors
$31.5 billion

TransGrid
$6.6 billion

Generators
$325 million

Debt

Distributors
$17.8 billion

TransGrid
$2.9 billion

Equity (Net Assets)

Distributors
$8.7 billion

TransGrid
$2.1 billion

Generators
$14 million

Figure 3.5: The Financial performance of Australian Electricity Businesses in NSW (PSM, A. T. W, 2015, p. 8)

3.5 Resources of Power Generation in Australia

Coal is the primary fuel used for electricity in Australia, a source that has declined when compared with past decades (see asterisk '*' in 2.2), but which is currently returning to higher use, and continuing into the future. In 2014-2015, the use of black coal fired generation rose by 2 per cent, and brown coal rose 11 per cent. Other sources joining coal to generate electricity are natural gas comprising 21 per cent, and renewable energy generation accounting for 14 per cent of total generation in Australia. The use of 'Natural gas' and renewable generation fell in 2014-2015 by 4 & 7 per cent respectively. A significant factor causing an increase in energy productivity (gross domestic product/energy consumption) is attributed to the growth in energy use for electricity generation (see Figure 3.6). Thus, there is a meaningful future increase in electricity generation based on the demand for electricity and mostly, a rise in the generation mix of lower efficiency coal rather than renewables.

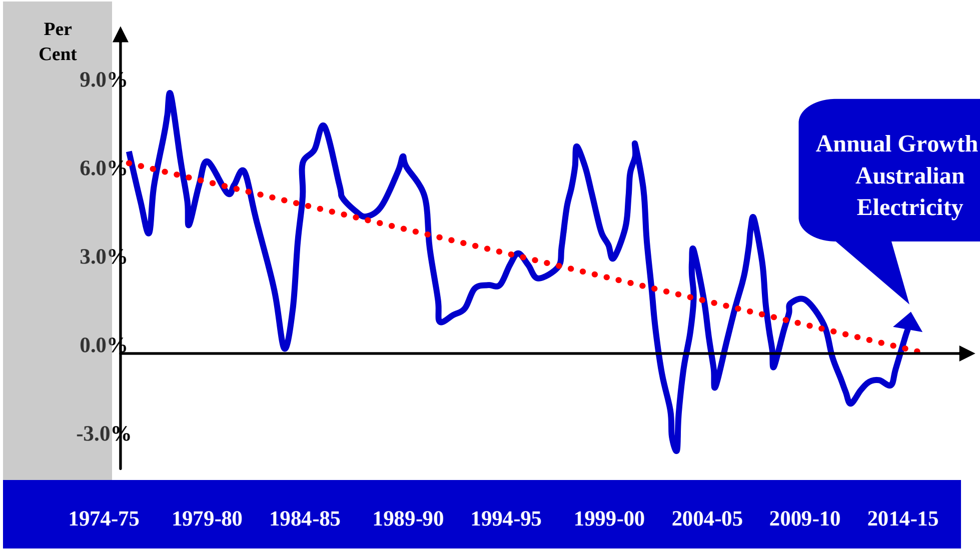


Figure 3.6: Annual Growth of Australian Electricity Generation (Department of Industry Innovation & Science 2016)

While coal remained the primary fuel source to generate electricity in 2014-15 it has also more recently fallen to 63 per cent, which is well below its fuel mix share of above 80 per cent at the beginning of the century (Department of Industry Innovation & Science 2016). The actual levels of coal-fired generation are similar to other levels recorded in 1997-98. Overall, in 2014-15, coal-fired generation increased in South Australia, Queensland, and Victoria, with black coal rising by 2 per cent and brown coal by 11 per cent. This growth followed five consecutive years of decline in brown coal-fired generation and seven years in black coal-fired generation. The higher prices of gas and decreased hydro generation due to lack of water availability, reflect the switch back to coal. This likewise coincides with the removal of the carbon price (Department of Industry and Science 2016).

Natural gas-fired generation accounts for 21 per cent of total electricity generation in Australia. In 2014-15, natural gas-fired generation fell by 4 per cent in all states due to the closure of a number of gas power plants, such as the '*Tamar Valley*' in Tasmania. Only in Queensland did the use of natural gas to generate electricity increase by 18 per cent.

This rise is largely attributed to increasing residential and commercial demand, particularly for heating during winter, and due to the start-up of LNG projects. The share of oil-fired generation in Australia to generate electricity rose to 3 per cent in 2014-15, mainly in Western Australia where this increase may have been due to growing demand for power in remote mining regions (Department of Industry and Science 2016).

Table 3.1 shows renewable energy makes up approximately 14 per cent of the total Australia's electricity generation. The lower water levels in hydro dams led to a decline in hydro generation of 27 per cent in 2014-15, causing a decrease in renewable generation of 7 per cent. For renewable energy in 2014-15, Hydro continues to be the largest contributor,with a share of 39 per cent, although this share at its lowest lowest since the drought of the mid-2000s. Wind has become the second highest renewable behind hydro with its 33 per cent contribution of renewable electricity and 5 per cent of total electricity generated in Australia, which it increased to 12 per cent by 2014-15 (Department of Industry and Science 2016). Solar generation has been notably growing in scale in 2014-15, to 23 per cent, but only accounted for 2 per cent of total electricity generation in Australia. Additionally, this capacity of solar is only limited to large scale solar installations, such as in NSW 'the Royalla Solar Farm'. However, the installation of rooftop solar PV is still assumed to be the most reliable source for total solar generation in Australia (Department of Industry and Science 2016).

Table 3.1: Average Annual Growth of Traditional & Renewable Power Generation (Department of Industry & Science 2016)

	2014–15			Average annual growth	
	GWh	Share (per cent)		2014–15 (per cent)	10 years (per cent)
Fossil fuels	217,871	86.3		3.1	0.4
Black coal	107,639	42.7		1.8	-2.1
Brown coal	50,970	20.2		10.6	-0.8
Gas	52,463	20.8		-3.6	9.7
Oil	6,799	2.7		35.6	9.3
Renewables	34,488	13.7		-6.9	5.3
Hydro	13,445	5.3		-27.0	-1.9
Wind	11,467	4.5		11.8	23.5
Bioenergy	3,608	1.4		11.4	-1.0
Solar PV	5,968	2.4		22.9	59.3
Geothermal	1	0.0		27.3	2.7
Total	252,359	100.0		1.6	0.9

As described in Table 3.1, a high proportion of irregular output comes from wind generation and used for thermal generators. This adds to the advantage of an increase in the overall capacity of the energy generation mix. It would also add a higher degree of the intermittency for stakeholders in the the overall electricity supply (AEMC 2015, p. 8). Increasing intermittency of generation causes increased volatility to wholesale electricity spot prices. This influence has been observed in South Australia recently (AEMC 2015). Following the increased spot prices volatility, it would also increase the level of risk which mostly retailers and consumers will carry. One means by which the volatility of spot prices can be managed is by purchasing higher cost hedge contracts. These costs effect consumers through higher retail prices, which are passed on by electricity retailers to them (AEMC 2015); (AEMC 2016).

In this sense, a large-scale renewable energy target (LRET) increases complex integrations that influence the costs of wholesale electricity (AEMC 2015, p. 8); (AEMC 2016, p. 7). Increased consumption puts upward pressure on costs. LRET encourages renewable energy investment to suppress wholesale costs, but over time this could well cause generator retirements. Intermittent forms of renewable generation will lead to higher spot market volatility which will increase costs and the risks to retailers. These impacts cause upward pressure on wholesale electricity costs as summarised in Table 3.2.

Table 3.2: Theoretical Effect of LRET & Generator Retirements on Wholesale of Electricity Market (AEMC 2015); (AEMC 2016)

	Influence on wholesale Electricity costs	Influence on retail Electricity prices	Effect on wholesale spot price volatility
Introduce more Renewable Generation	Decrease	Increase	Increase
Thermal generation Retirements	Increase	Increase	Increase

3.6 Generation Investments in Australia

The investment in new generation plants in the Australian electricity market has mostly disappeared, other than in solar and wind plants. Large-scale solar generation has been focused at macro levels, other than in micro levels where end-users demand to participate. However, at macro levels large-scale solar generation has been slow to develop in Australia, to some extent as a result of its incurred cost per megawatt hour (MWh) generated proportionally to the costs of other equivalent technologies. The Australian Renewable Energy Agency (ARENA) and its partner, the Clean Energy Finance Corporation, announced their plan in September 2015 to fund $350 million to build ten additional large-scale solar plants by 2017. Additionally, 270 MW of wind capacity has been added to the national grid in 2014-15, an additional investment in commercial wind generation of 8 per cent (State of the Energy Market 2015).

Declining electricity demand since 2008 has given rise to significant gas and coal powered generation plants being temporary or permanently removed from the market (see Figure 3.7). Overall, the number of withdrawals exceeded the entry of new generation from the period 2011-12 to 2014-15 (State of the Energy Market 2015). The plants announced for withdrawal in the coming next seven years comprise the following plants:

- Gas fired power plant - *Smithfield (NSW)*
- Coal-fired power plant - *Liddell (NSW)*
- Gas fired power plant – Torrens Island (South Australia)
- Coal-fired power plant – Northern (South Australia)
- Coal-fired power plant – Playford (South Australia)
- Gas fired power plant – *Tamar Valley (Tasmania)*
- Gas fired power plant – *Daandine (Queensland)*
- Gas fired power plant – Mount Stuart (Queensland)

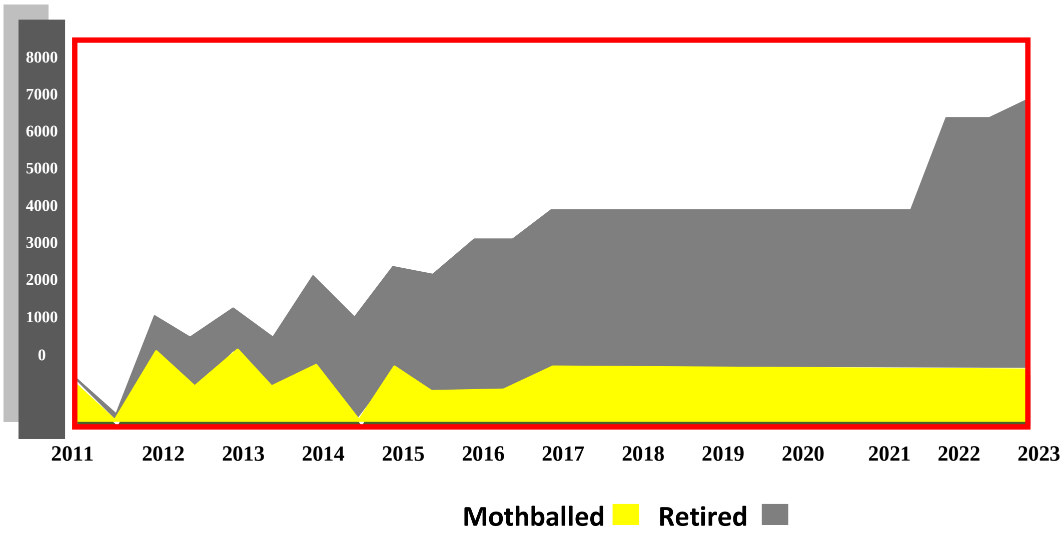


Figure 3.7: Generation Capacity Removed/Expected to be removed from the Market (2011 – 2023) (State of the Energy Market 2015)

At the same time, other renewable generation facilities, including rooftop solar PV, have been generated by industries such as manufacturing and mining and off-grid generation. The peak recorded for generation of electricity was 254 terawatt hours in 2010-11. Generation of electricity in Australia rose by 2 per cent in 2014–15, following three years of decline (from 2011-12 to 2013-14). This reflects a possible increase the electricity demand in the National Electricity Market (NEM) and continued growth in off-grid use (Mark Cully, 2016, p. 17). However, Australia's dependence on 'coal' is relatively high in accounting for 63 per cent of total electricity generation.

This amount has declined when compared with the beginning of the century; the coal share was above 80 per cent. Coal was, and still is, a major player in producing electricity (see Figure 3.8). Hydro is one of the main renewable energy sources that generates electricity and has been significantly influenced by water shortage (see Figure 3.8). It is recorded as the most depleted source of renewable energy, due to droughts in 2000 and 2014-2015. The droughts reduced hydro down to 27% (Cully, M, 2016).

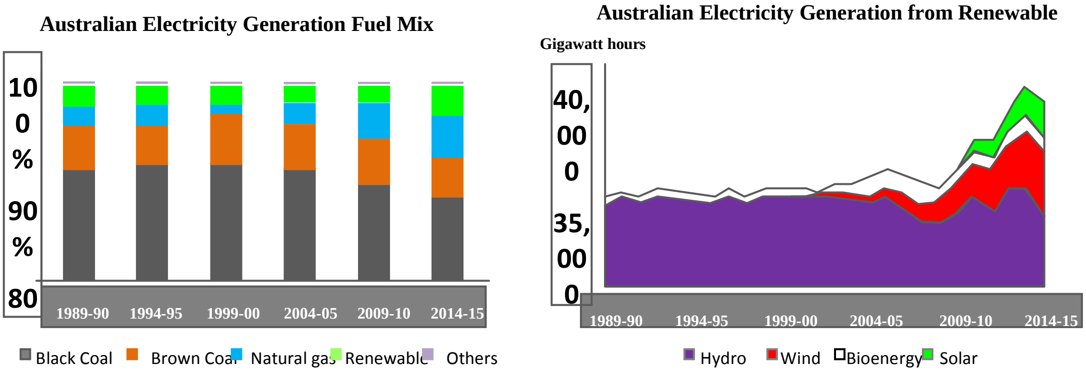


Figure 3.8: Australian Electricity Generation: Fuel-mix & Renewable (Cull, M. 2016)

3.7 Transmission and Distribution

The electricity transmission networks transport bulk generated energy from large generators over long distances to major load centres at the capacity of very high voltages from 132 to 500 KV. Territories in Australia are interconnected via regional networks to enable the economic sharing of generation. Transmission and distribution networks have functional boundaries defined as within and outside the jurisdictions of both National Electricity Market (NEM) and not NEM (Energeia In Consultation 2013, p. 20) (see Figure 3.9). The National Electricity Market (NEM) has different regulations in Northern and Western Australia where vertically integrated business networks undertake the function of distribution and transmission (Energeia In Consultation 2013, p. 20). Typically, the range for sub-transmission is for both high voltages (HV) 132 KV and for low voltages (LV) 415/230 V. Electricity distribution and electricity transmission are differently regulated by the jurisdictions of National Electricity Market (NEM).

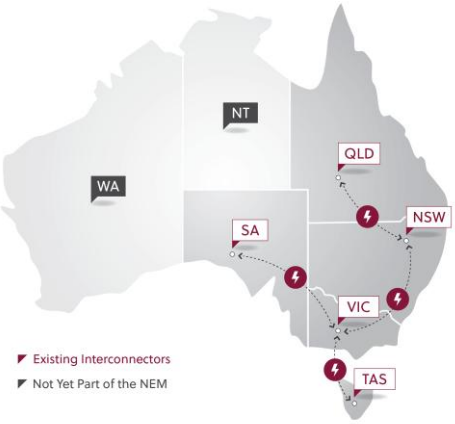


Figure 3. 9: National Electricity Market & Rules (Electra Net 2016)

The drivers for transmission and distribution networks take into account the criteria of security, quality, reliability and safety standards. The weighted average loss of electricity through the combined transmission and distribution networks is estimated at 5,800 GWh (20.8 PJ) and equal to 6.7% of total inputs. Case studies found losses of 15% in transmission lines due to transformers, and conductors making up the remaining of 85%. The Australian weighted average loss for distribution networks out of the total input is approximately 5.4% (2008-09 to 2010-11), and equivalent to 9,300 GWh p.a. and that equals 33.6 PJ. Losses for individual networks in distribution areas that are operated by different retailers range from 3.7% to 9.1% (Energy Efficiency Opportunities in Electricity Networks 2013).

Electricity distribution networks function to deliver energy from bulk supply conductors from the transmission network, and from minor generators within the distribution network, to end-users in the industrial, commercial, or residential spectrum. Australia’s electricity network businesses, as clarified in Table 3.3, and all transmission assets in the region of the National Electricity Market (NEM), are treated equally in market settlements. The network ownership boundary is not aligned with the transmission boundary. As an example, in NSW; Ausgrid is a distribution network service provider (DNSP) whose usage of electricity depends on the distance involved, linked to both generator and customer demand.

Table 3.3: Electricity Network Business in Australia (Energeia in Consultation 2013)

Transmission	Distribution	Jurisdiction/region
Powerlink	ENERGEX ERGON energy	Queensland
APA Direct Link interconnector		
TransGrid	Ausgrid Endeavour Energy Essential Energy ActewAGL	NSW
		ACT
SP AusNet	CitiPower Jemena Powercor SP AusNet United Energy	Victoria
APA Murraylink interconnector		South Australia
ElectraNet	SA Power Networks	
Basslink interconnector (a)		Tasmania
Transend	Aurora	
Power and Water Corporation		Northern Territory
Horizon Power		
Western Power		Western Australia
Basslink is a market interconnector, which trades between NEM regions. All other network businesses have regulated revenue or prices.		

3.8 Network Losses of Energy

Losses of electricity interconnections between the transmission networks carrying bidirectional flows are apportioned between the adjacent regions. Australian regions incur losses of electricity in these interconnections (see Figure 3.10). Demand loads and generators for transmission and distribution are unequal, which makes the output of the transmission networks uneven as the bulk supplies to the distribution networks are connected to it (Energeia in Consultation 2013). The average loss occurring in distribution and transmission networks are respectively 5.4% and 2.7%, as combined average losses that are estimated make the total losses in Australian electricity networks 6.7% of the total inputs. The energy losses in grid systems are still under investigation because energy losses are a result of unfixed and differently integrated factors that make it hard to consider the losses in a fixed manner. (Energeia In Consultation 2013, p. 23).

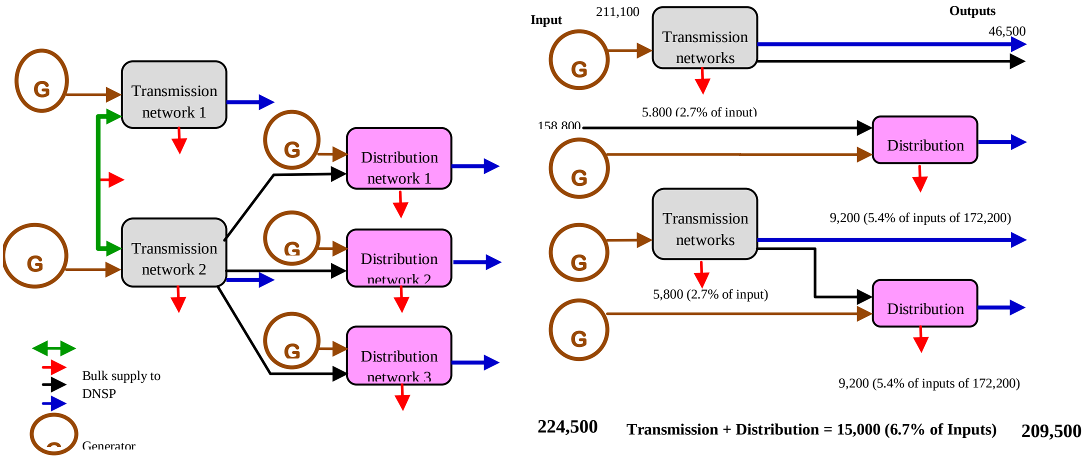


Figure 3.10: Total Percentage in Australian Electricity Network (Energeia In Consultation 2013)

A research project, the Regulation Impact Statement [RIS], had been established to define efficient ways for network expansion. This project highlights that there is a lack of reliable and publicly available information on losses and trends occurring through transmission and distribution networks. In addition, network businesses and specialised agencies are not tasked with consistently and systematically gathering and reporting losses in information off the grid. This lack of transparency could be addressed as an addition to the reporting requirements through the electricity regulatory frameworks (Energeia In Consultation 2013, p. 22). Overall, electricity losses can be only collected from a limited number of reports, such as:

- Regulatory Report of Distribution Network Service Provider (DNSP).
- Energy Supply Association of Australia (ESAA) - annual reports.
- Network Management Plans.
- Australia Energy Regulatory (AER) reports (State Of The Energy Market).

A meaningful attempt has been made by the Commonwealth to foster greater understanding and support measuring the implementation of distribution and transmission networks. In a frequent refrain, programmes such as ‘Energy Efficiency Opportunities’ (EEO) is assumed to achieve ‘Cost Effective Energy Efficiency’. This program, divides energy usage into two segments: energy used through business operations (Type 1) and energy used through transmission and distribution (Type 2) (Grid Australia 2012, p. 1). In 2012, the Australian Energy Market Commission released a report indicating that no benefits had been delivered from type 2 energy loss saving projects. Moreover, recent analysis saw no additional achievement in meeting the Commonwealth’s policy objectives. It seems that no energy efficiency improvements are expected to be achieved. By increasing the electricity costs for consumers there is an additional administrative burden on electricity businesses.

Although the ‘Grid Australia’ report predicts Australia’s most efficient electricity grid yet. Notwithstanding the shortcomings highlighted above, the Pursuit Types 1 & 2 for losses reduction (energy used via transmission & distribution) are still valid. Both EEO (Energy Efficiency Opportunities) and NEM (National Electricity Market) are taking account of the current regulatory obligation of the National Electricity Market (NEM) (Grid Australia 2012, p. 4). NEM primarily focused on efficiency which creates a conflict between the objectives that have no risks supported by the programmes of Energy Efficiency Opportunities (EEO) (Grid Australia 2012, p. 4).

Realistically, the electricity base load requirements will be mainly provided by technologies based on fossil fuels until at least 2020 (ATSE 2009, p. 9). Objectives are still targeted in accordance with the improvement options of Type 1 & 2 to reduce the losses from either electricity transmission and distribution or from business operation by electricity providers. As regards ‘Climate Works’, the improvement of each single percentage point (1%) in the grid performance is assumed to cost $1.2 Billion (Grid Australia 2012, p. 4). Further, Grid Australia found that a decrease in energy losses from 8 per cent to 6.5 per cent needs to improve 20 per cent of energy transfer from generators to end-users (transmission & distribution systems). So, how much would that probably cost? (Grid Australia 2012, p. 4).

The key message is understandable that there are is constant need for improvements in energy efficiency by adding sustainability measures such as renewable energy. However, merely adding renewable energy would not be sufficient to outweigh the desire of the Australian community for increased prosperity and hence more energy (the Australian Academy of Technological Sciences and Engineering (ATSE) 2009). The view taken here is that Australian stakeholders would continue to see advances in their economic prosperity as their wished for demand is consistent with advances in their personal wellbeing and prosperity. These advances in many cases oblige more energy, in addition to increased efforts toward sustainability by way of efficiency, is acquired in power generation and consumption (ATSE 2009, p. 8).

The problem of energy losses is deemed to be too burdensome, either to the electricity grid or stakeholders. This did not occur overnight and will not be solved tomorrow. Thus, strong efforts should continue to support the views expressed on the value a nd size of network losses by focusing equally on macro and micro levels in the grid. Diverse studies such as mentioned above have brought to light some alarming results reveal that fewer efforts at micro levels where end-users reside. Intervening for solutions at micro-levels may need to take direct action. Seeking to bring unprecedented possibilities for delivering efficient solutions may need focused action against the causative of energy losses that originated from end users‘ demands.

3.9 Electricity Generation vis-a-vis Electricity Demand

Electricity has the nature of a complexity flow in which it is not possible to configure a particular flow to specific supply points. The flow of electricity is defined in the laws of Physics whereby it pursues along the path of least resistance. Thus, the operation of electricity systems in different areas can be both affected by and affect the nature of the operation in these various service areas. The commodity of electricity cannot be stored. For this reason, production and demand of electricity must be synchronised to match instantaneous changes to create the needed balance in real time. Unequal to other industries, electricity net demand is not influenced by inventories held at points along the way of the supply chain (see Figure 3.11). Electricity transaction costs will be continuously monitored with the prices. Further, in most cases, the electricity cost is considered after end-users have consumed it and received a bill for the consumption period. Most end-users pay a bill which mirrors the average cost over a period, often over a quarter or a year. With this, there is a conflict against the demand management options for short term use in relation to cost-reflective prices.

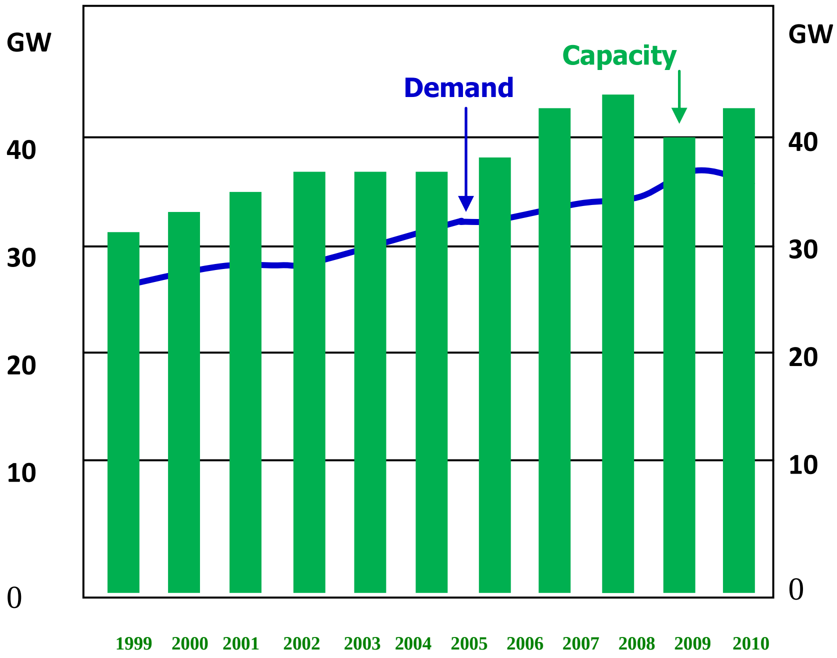


Figure 3.11: Electricity Demand Influence Electricity Generation Capacity (Australian Energy Regulator 2010)

Electricity can be identified as an equally uniform commodity that is ultimately difficult and hardly adjustable to brand differentiation or product. Electricity cannot be dealt with as a good in itself but as an input to produce other services and goods that are consumed as a final product. The characteristics of electricity can be distinguished when we use many of the conveniences in our current era such as personal computers, artificial respirators and house appliances (Sayers, C & Shields, D, 2001). Therefore, the demand is sensitive for what is derived and is not as price sensitive (Sayers, C & Shields, D, 2001).

The demand for electricity varies every day and in many cases, fluctuates randomly in a way that provokes attention for its unpredictable forecast and demand pattern (Sayers, C & Shields, D, 2001). The power of electricity can be delivered at different frequencies, voltages and reliability levels. However, the source of producing electricity is unimportant to its form. End-users have no idea how to distinguish electricity from which physical source produces it. Rather, a number of consumers are willing to pay higher prices for electricity produced in environmentally preferred plants such as solar and wind (Sayers, C & Shields, D, 2001).

The value of use electricity varies regarding daily consumption time which is not necessarily revealed in the cost which appears on the bill. ‘Controlled Load’ tariffs are typically charged for loads like air conditioning systems, which do not reflect the associated costs of supply.

The demand for electricity is defined as an artificial inelastic demand which is not responding to price as it might. End-users‘ costs reflect market prices at any given time and then these users adjust their consumption accordingly. The nature of electricity as a commodity needed in a frame of near continuous consumption which is a non-storable good, with sufficient capacity to ‘quick start’, crucially needs to be held in reserve to cover demand peaks. This capacity is problematic because it is very expensive to operate, creating in average costs increasing non-linearly with generation capacity. In many cases, the average costs of electricity rise rapidly to satisfy various demands. The variety of demands might also lead to extreme price volatility at the wholesale level when an auctioning system determines the prices.

The Australian Government released policy decisions in 2008 based on the assumption that a target of 60 per of carbon emissions could be reduced by 2050 and strategy terms were set for reaching that goal (ATSE 2009, p. 9).

These are:

- A regulated expansion to a Renewable Energy Target (RET);
- Increase the investment in carbon capture and storage demonstration;
- Action on energy efficiency.
- Enforce trading scheme of market-based emissions to serve the goal of 'emissions drives down'.
- Enforce a mandated national target for the use of renewable forms of electricity.
- Coal continues to be the primary source of energy while enhancing carbon reduction and capture technology (ATSE 2009, p. 8).

3.10 The Influence of Consumers on Electricity Costs & Prices

Refer to Figure 3.12, the main entity in charge of governing electricity consumers’ demand-supply relationships in Australia is known as the ‘Australian Energy Regulator’ (AER). This independent body has the authority to play the role of electricity regulator in the ‘National Energy Market’ (NEM) which was originated by the ‘Australian Competition and Consumer Commission (ACCC) that came into force in 2010 via the ‘Competition and Consumer Act 2010’. An associated requirement with this regulation is ‘Australian Energy Market Commission’ (AEMC) which is responsible for energy market rule settings. AEMC is available under ‘Standard Council of Energy & Resources’ (SCER) that is controlled by and answers directly to the peak intergovernmental forum in Australia known as the ‘Council of

Australian Government' (COAG). The figure below illustrates the existing top-down structure and relationships of COAG, SCER, AEMC, AEMO & AER toward suppliers, retailers and consumers of electricity (Parliament Of Australia 2012).

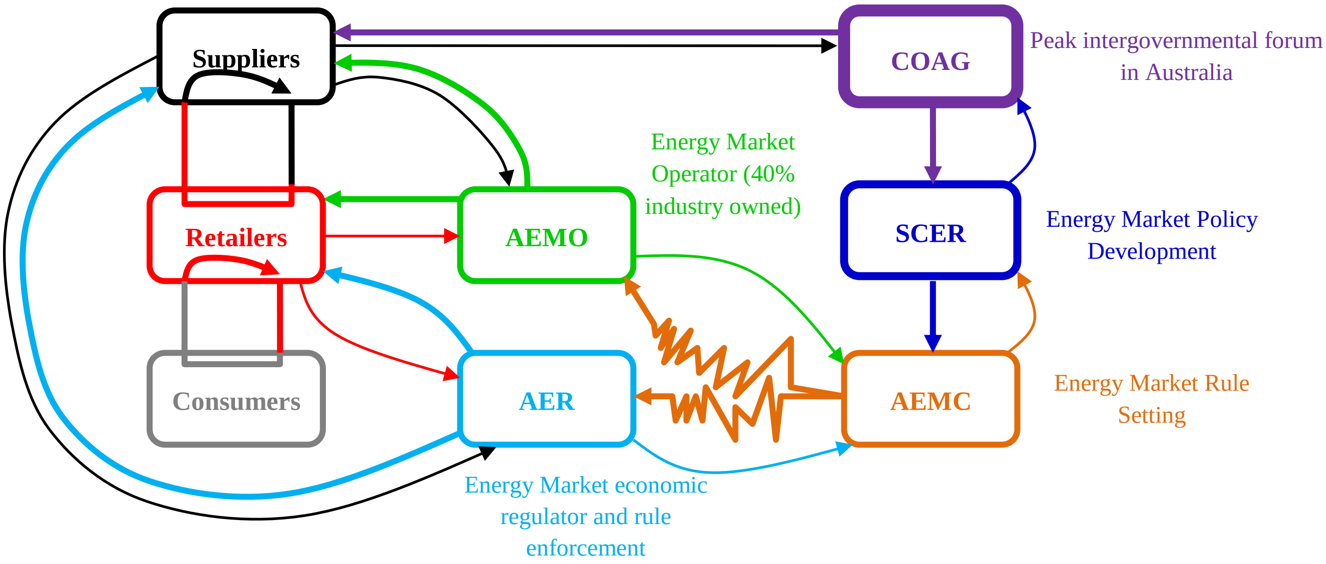


Figure 3.12: The Existing Structure Demand-Supply Relationship in Australia (Parliament of Australia 2012)

3.11 Energy Losses Factors & Electricity Market Rules

The key factors that influence the cost and price of electricity and lead to energy losses are at the heart of this thesis and have been discussed throughout the thesis and particularly discussed and divided into five chapters:

- Non-linear dynamic behaviour of consumers and the concept of "change for the better" (Chapter 1);
- The influence of end-users' consumption behaviour upon the level of investment by electricity suppliers and retailers (Chapter 2);
- Complexity-Shaped View of What Cause What (Chapter 3);
- Pareto approach to linking the energy consumption of residential users between micro and macro levels in a grid system (Chapter 4);
- Time Series Data Voices of Innovation to explore the dynamics of electricity consumers (Chapter 5).

3.12 Regulatory Power & Policy Instruments

Australian political preferences and institutional frameworks have devolved enormous regulatory power to independent regulatory agencies nominated based on criteria of high quality, as presented in Figure 3.13 below. Australia has also been supporting its use of regulation by contract with no dependency on outsourcing of regulatory functions to other parties (Martyn Taylor, M 2015).

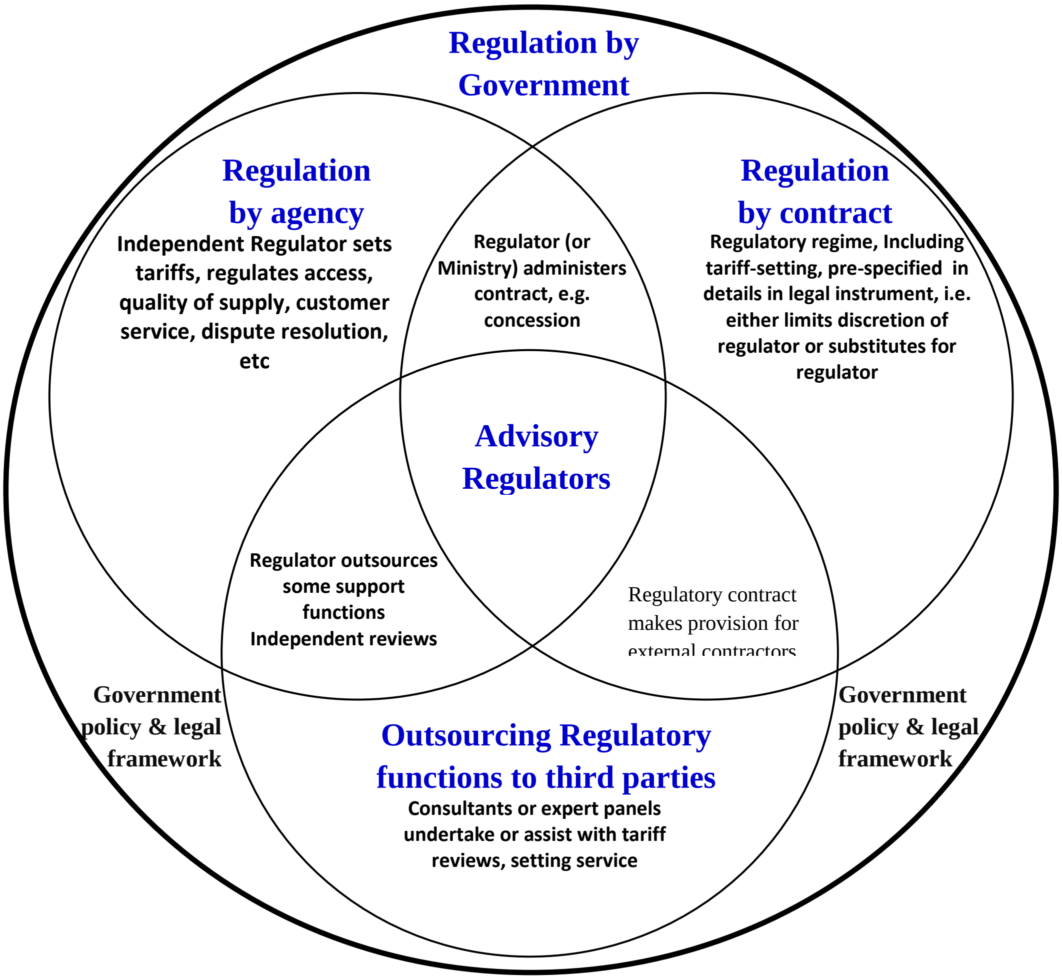
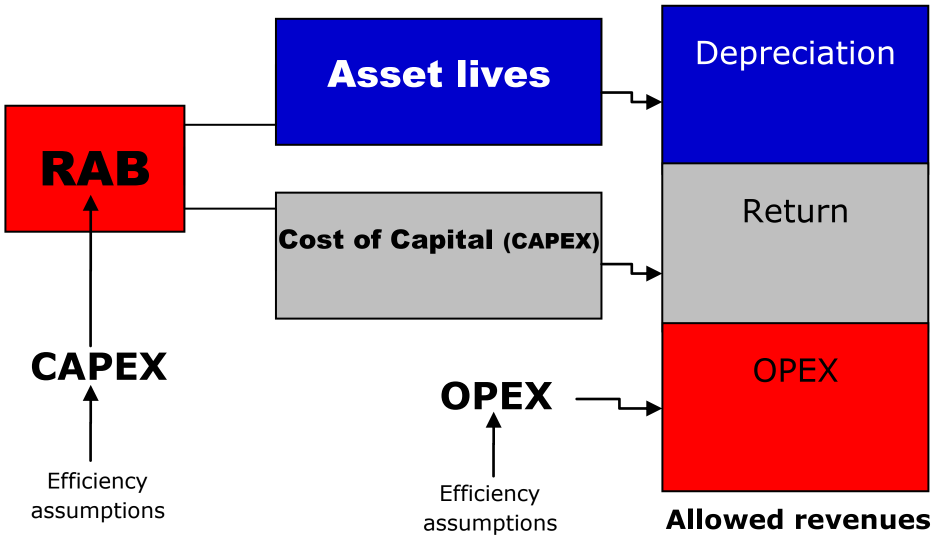


Figure 3.13: The Range of Policies (Martyn Taylor, M 2015)

The concentricity of ‘Regulators’ Models’ in regards to how to provide revenues in advance for a pre-specified period to recover the expected efficiency costs incurred while delivering the regulated goods of “electricity”. As such, the expected revenues must be in line with the structured nature of any competitive market. Economic regulation takes various forms, each of which has implications for how the costs of a regulated firm influence the allowed revenues out of prices it charges to customers. The rationale for electricity cost-price regulation is rooted in treating ‘market failures’.



Note: RAB, regulatory asset base. CAPEX, capital expenditure. OPEX, operating expenditure

Figure 3.14: Physical Network Assets (RAB): Tracking/Comparing Actual & Forecast Prices of Electricity (Regulatory Asset Base 2016); (Plumb, M & Davis, K 2010); (Regulated Assets Trends 2011); (AEMC 2012)

The Australian Energy Regulator (AER) monitoring the market activities is up to date with market conditions and meets compliance issues (Australian Energy Regulator 2016). AER is the Australian Energy Regulator responsible for monitoring activity and behaviour in the National Electricity Market (NEM). The AER is also responsible for defining the significant variations between actual and forecast price of electricity. Moreover, the AER traces the movements of the contract markets, together with the analysis of rebidding behaviour and spot market outcomes (Australian Energy Regulator, 2016). The AER plays the role of setting the network charges components of retail electricity prices. The estimation must cover the amount of revenue wished for to cover a network provider's costs over a five year regulatory control period in addition to operation and maintenance (O & M), tax liabilities, asset depreciation costs, and return on capital.

Selling electricity has a "lumpy nature" of investments. It means, each particular year has different annual allowed revenues (AAR) represented by the sum of the right side building blocks in Figure 3.14 (Depreciation, Return & OPEX). Operating expenditure (OPEX) is sometimes included in the cost of capital (CAPEX) as 'pay-as-you-go' items that are efficiently undertaken OPEX in a particular year (see Figure 3.14 & 3.15). The cumulative historical investment collected for a firm can be exhibited through the net cash recovered from regulatory depreciation which in many cases required a 'coiling' via the Regulatory Asset Base (RAB) to assume the right calculating model for CAPEX and returns on capital.

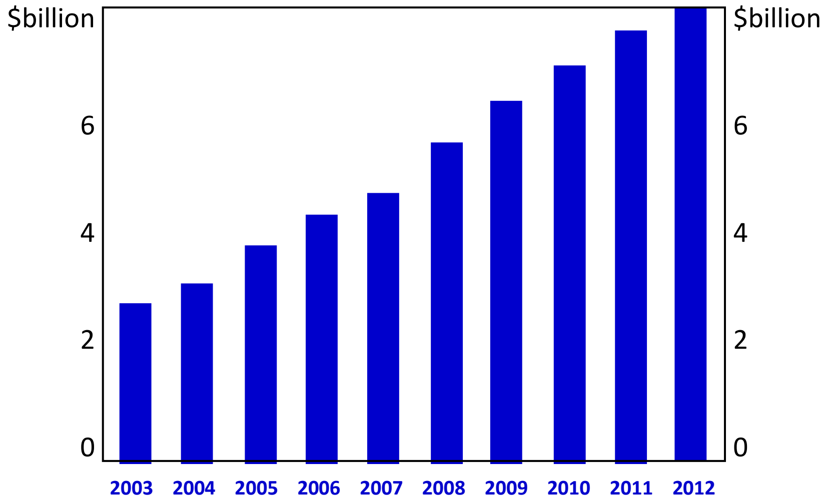


Figure 3.15: CAPEX (Capital of Expenditure for Electricity Network) (Australian Energy Regulator 2010)

The revenue in regards to return on capital is the largest component of the revenue that includes the internal funds to finance the network investment. For example, funds, such as, borrowing costs and "regulatory depreciation" through which firms recover the cost incurred through capital expenditure over the lifecycle of an asset. The Return on Capital (ROC) is calculated according to the value of physical network assets named "Regulatory Asset Base" (RAB) times the weighted average cost of capital (WACC). It is highly expected that (RAB) will grow? based on the increase in the amount of net capital expenditure (Regulatory Asset Base 2016). Thus, increase in the capital expenditure is concurrent with a higher return on capital and a larger value for the depreciation term in which these circumstances increase revenue requirements. Therefore, the regulatory control period takes into account a smoothening of the annual revenue requirements by forecasting the demand for electricity to determine the annual increase in network charges that end-users' face (Michael Plumb & Kathryn Davis 2010).

Over the asset life that equals the asset economics' life, the cost is divided across the life cycle of the asset instead of paid immediately in full "Depreciation of CAPEX over time". Employed assets need to be regulated efficiently to deliver the expected return on equity which is commensurate along with the risk of their stake in the firm. Achieving this goal requires assuming the weighted average cost of capital (WACC) and multiplying it by the value of the Regulatory Asset Base (RAB). This means passing-on any overcharge incurred due to the increasing CAPEX or OPEX, either for electricity suppliers or retailers which will affect how this cost is reflected to raise additionally allowed revenue. Electricity as a type of product to be generated and sold by vendors/suppliers and purchased by retailers, has been cartelised (five minutes bidding every five minutes and wholesale every 30 minutes).

It is irrefutable that the Regulatory Asset Base (RAB) delivers the features of cost-plus regulating that are achieved from the retrospective records of cost accounting values. Regulatory regimes have different asset records, different planned values subsequent to asset values and different accounting practices. These features need different mechanisms for adjustments, disallowances and time lags, and also the practising of particularly highlighted rules that require different re-evaluation to assets under construction and ongoing assets book entry. Therefore, there is not an ideal link between the 'Regulatory Asset Base' (RAB) and the centralised asset values (electricity generation, transmission, & distribution).

In many cases the stock market valuation for a firm is not related to its historical CAPEX, making no explicit relation between pre & post-RAB prices, and implies that the prices and allowed revenues referred to factual situations. This would reveal a limited 'pass-on' in regards to any increase in CAPEX based on the cartel (Oxera Agenda 2015). Overall, understanding this link cannot accurately occur when regulatory regimes provide detailed knowledge over the whole regulatory asset lives. Rather, the condition of understanding the link is highly tied to the demand of electricity that end-users emerge.

The above discussion can be concluded with the following points:

- The overcharge of CAPEX items during the entire life of the affected assets is a fact of 'pass-on' which leads to significant implications.
- Cartels influence electricity products during asset lives of typically 25-45 years.
- RAB (the value of network asset) has a large proportion for any overcharge occurring since the 40-year depreciation profile in the year 2000 has 63% of the value but remaining in the RAB by 2015.

Recent regulatory determinations reveal a sharp increase in network charges mainly occurring due to the following (Plumb, M & Davis, K 2010):

- Need to enhance higher regulatory standards for reliability of supply.
- Network expansion leads to higher capital expenditure.
- Higher input costs are concurrent with the need to replace ageing assets.
- Higher revenue expected in regulatory control periods caused by higher borrowing

costs that are producing a greater weighted average cost of capital (WACC).

3.13 The Volatility of Electricity Prices

As previously mentioned, the supply of electricity in Australia has a massive economic benefit. It is recorded that the annual turnover was $21.6 billion during the financial year 1997-1998, and total asset worth estimated at $74.8 billion, and 35,000 people employed in this sector (ABS 1999). The generating capacity recorded for the Australian electricity industry was approximately 40,000 MW (ABARE, 2000). Total electricity consumption registered in 1997-1998 was approximately 161,762 GWh (ESAA, 2000), and over 180,000 GWh was produced in the same year. There are some 8.5 million customers, of whom 85 per cent are residential customers, who are responsible for the consumption of 30 per cent of the total consumed electricity. The average residential consumption per customer is approximately 2500 KWh per year referring to 1997-1998 (ABS 1999). However, currently, the average is booming up to 6500 KWh. A household fuel and power expenditure survey in 1998-1999 shows that 72 per cent of this value is consumed for electricity (ABS 2000a).

The annual averages, which are usually quoted for the wholesale electricity market, were masked by the feature of volatility in prices. Refer to the figure below and notice that Victoria's average daily prices on many occasions went above $2300 per megawatt hour at certain times in peak hours (see Figure 3.16). Trades of spot prices during peak time intervals climbed to the NEM price cap of $12,500 per megawatt hour in mid-2010. Extreme price movements are one of the challenges facing wholesale electricity providers, and for this reason, the wholesale providers use instruments of the financial market to hedge against unexpected extreme trends.

Electricity prices in throughout the 1990s were curbed against a prices inflation feature. Recent years have seen a notable increase in electricity prices in Australia following pressure to increase the feature of 'consumer price inflation'. The range of factors influencing increased electricity prices are apparently soaring to move upon cost-based pricing concepts, and these are as follows: (Plumb, M & Davis, K 2010):

Increase investment to expand and replace ageing infrastructure leads to increase in input costs.

The direct impact of utility prices incurred at peak times added to aggregate inflation.

Firms lodge higher input costs leading to inflation in electricity prices ‘good’ and for other services.

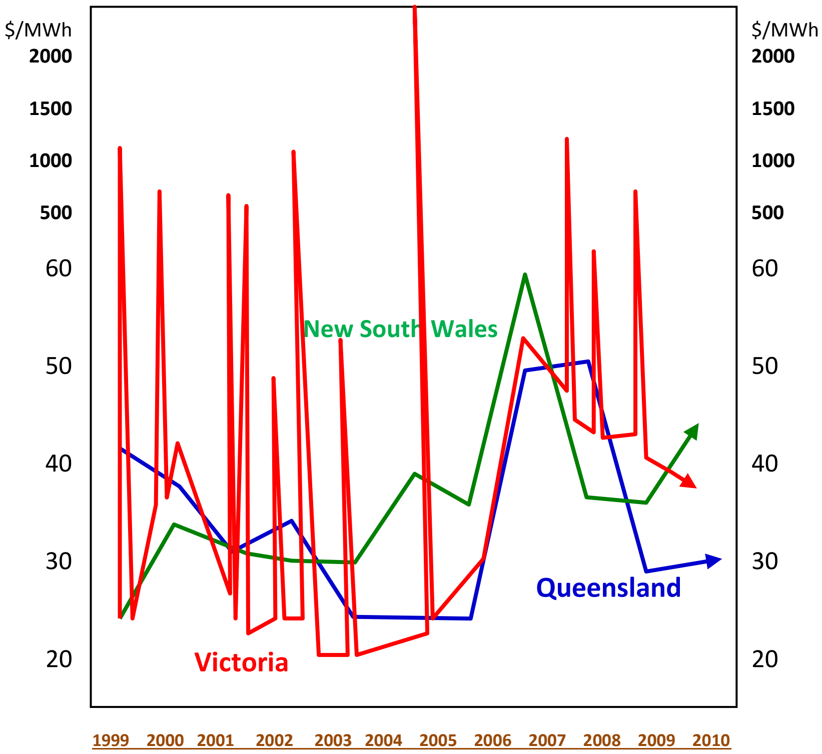


Figure 3.16: The Pricing Snapshot of the Whole Sale of Electricity: 1999-2010 (Australian Energy Market Operator 2010)

3.14 The Generators Dispatch Cycle

The electricity delivered by networks is mostly traded through electricity markets, mainly on behalf of two wholesale electricity markets in operation in Australia. The first market is the National Electricity Market (NEM), administered by AEMO and operating in NSW, Queensland, the ACT, South Australia, Victoria, and Tasmanian (Energeia in Consultation 2013). The second operator market is the Western Australian Wholesale Electricity Market (WEM) administrated by IMO (Independent Market Operators) and operating in the South West Interconnected System. The target of both the markets has as their objective the supply of energy from generation stations to customers in the least-costly and most efficient way: Energy Efficiency (Energeia in Consultation 2013).

Ascending prices are stacked to bids for producing electricity received by AEMO for orders defined to each dispatch period. Therefore, generators are then progressively scheduled into the needed production to cover epidemic demand. This procedure starts with the least costly generation option. Therefore, the cost of generating power is increasing and decreasing in response to the demand for electricity which is affected by consumer behaviour. From the example below, we can realise how the losses occur.

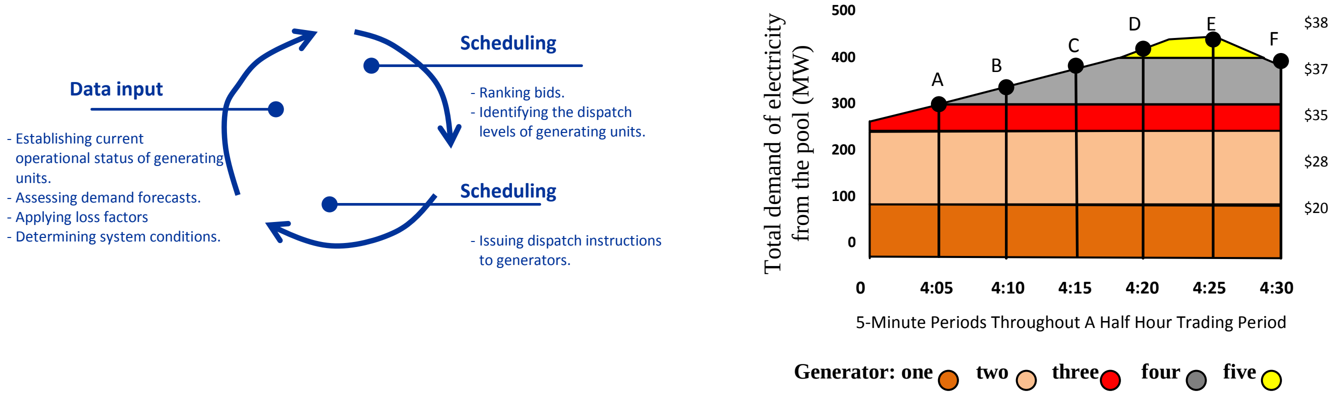


Figure 3. 17: Setting the Spot Price (AEMO 2010, p. 11)

- a) Referring to the example above, in the Fgure 3.17 at the right side, the power supply at 4:05 pm needs to operate generators one and two at full capacity, and generator three is less than fully dispatched. The dispatch price is $35 per MWh.
- b) At 4:10 pm, there is an increase in the demand and all of generators one, two and three are fully dispatched, but generator four is partly dispatched. The dispatch price is $37 MWh.
- c) At 4:15 pm the demand has continued to increase up to 30 MW to make all of the generators one, two, three & four continue producing power with a dispatch price at $37 MWh.
- d) At 4:20 pm the demand has increased further to the pint that requires a slight power from generator five. The price increases to $38 per MWh.
- e) At 4:25 pm, generators from one to four are fully dispatched, but generator five is partly dispatched. The price still $38 per MWh.
- f) At 4:30 pm, demand starts falling, which makes the most expensive generator, number five, no longer required and generator number four is partly needed. The price drops to $37 per MWh.
- g) According to the process above, the spot price for the trading period (half an hour) is achieved as the average of the six dispatch rates $(35+37+37+38+38+37) / 6 = $37per MWh. $37 is the price all generators receive per MWh for the mentioned half hour

period. Additionally, the price market customers are paying for electricity they have consumed from the pool through the above period.

Referring to the discussion above, it is evident that there is a financial risk for the participants in the National Electricity Market (NEM). This risk is associated with the significant degree of spot price volatility every trading period (half an hour) which needs to be managed. Currently, there is a typical financial contract to lock the electricity pricing in at a firm price at a given time in the future (Australian Energy Market Operator 2010). These contracts are known as 'hedge contracts', as illustrated in Figure 3.18, and the purpose of these contracts is to serve to reduce the financial exposure and provide spot market stability.

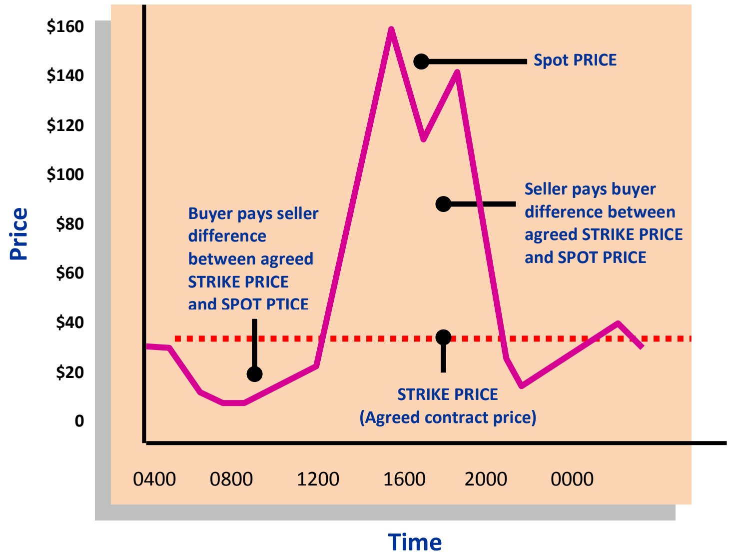


Figure 3.18: Hedge Contracts in National Electricity Market (NEM) (AEMO 2010, p. 20)

The alternative to the 'hedge contracts' in the National Electricity Market (NEM) is a typical agreement between customers and generators to reduce the risk of spot prices. Hedge contracts may be arranged under long term or short term contracts and are not regulated according to rules, but to help operate the market and AEMO's administration independently. Unfortunately, the outcome of these contracts only gives more time rather than balancing between supply and demand of electricity. These contracts arrange the price of electricity traded through the pool, known as the 'Agreed price' or 'Strike price' (Australian Energy Market Operator 2010). The advantage of these contracts is that they reduce the risk of potential volatility of the spot price, but cannot avoid its influence. The recipe of 'Strike Price' operates when generators pay customers the gap when the spot price is above the strike price. Consequently, customers (retailers) will pay generators the difference in between strike price and spot price when the spot price is found to be below the strike price (Australian Energy Market Operator 2010, p. 20). Overall, as appear from the above discussion the risk of spot price still exists which is the result of a problem caused by demand fluctuation.

3.15 Electricity in New South Wales

Residential, commercial and industrial end-users rely on electricity for various purposes include cooking, cooling, heating, machinery operation and transportation. The growth of the economy indicates that increasing use of electricity is conditioned with an increase of efficiency. In a logical manner, a demand for electricity increases alongside the number of households to increase (Energy Network Association 2014). New South Wales Government Officials and 'Independent Pricing & Regulatory Tribunal' provided the average consumption level of residential consumers in NSW as illustrated in Table 3.4:

Table 3.4: Influence of Consumption Levels on Average Electricity Price (AEMC 2014, p. 79)

Annual Consumption Level	**2013/14 Average market Offer (cents per KWh)**	**2013/14 Annual household bill**
Low (2,500 KWh)	36.12	$903
New South Wales-specific average (6,500 KWh)	28.76	$1,869
High (9,500 KWh)	27.77	$2,638

New South Wales is a partner of the National Electricity Market (NEM) which spans to Australia's eastern and south-eastern coasts to comprise four interconnected states. Hundreds of electricity suppliers are registered to deliver a capacity of electricity equal to $11.4 billion as recorded in 2012-13. Constraints in electricity supply occurred between 2006 and 2008 reflecting a drought and reduced water sources. The prices of electricity nearly doubled in 2013. Prior to the New South Wales first round sale in 2008 there were seven state owned corporations to utilise electricity production and distribution. In 2012 the new Government sold all of the remaining state assets of electricity generation.

The current electricity market in NSW is illustrated in Figure 3.19 below in the context of the state's privatisation (Shaun McGushin & Adam Seeto 2012, p. 1). Information on purchasing power of the state-owned electricity generators would be understood in terms of what price, from whom and how much, but this information is not publicity available. The NSW government has a continuous strategy to divest its interest through sales in electricity businesses through long-term leasing arrangements (PSM, A.T.W, 2015, p. 4).

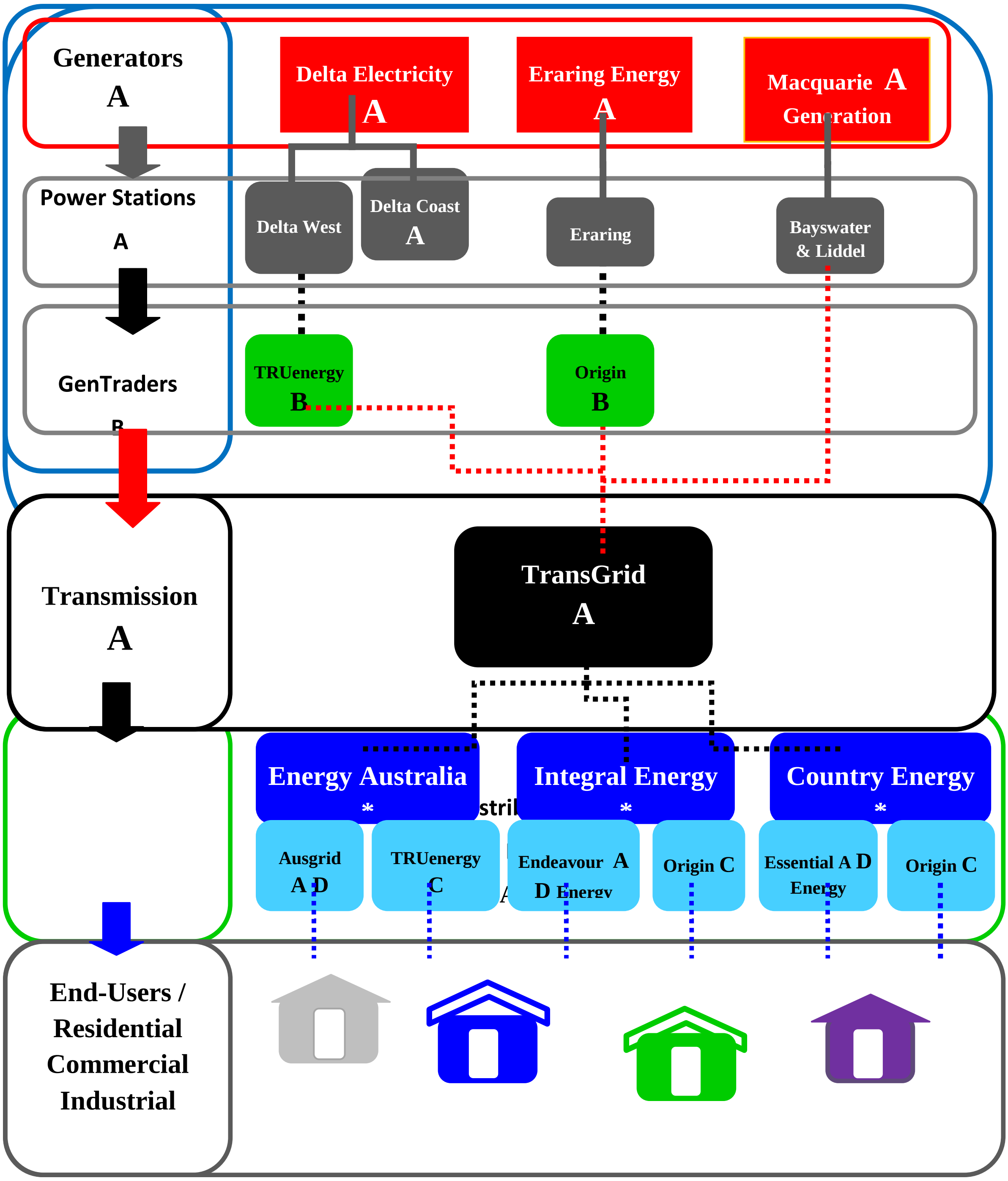


Figure 3.19: Electricity Market in NSW (Shaun McGushin & Adam Seeto 2012)

A- Government owned

1- Delta Electricity's generators

- Munmorah (coal) has been commissioned in 1968 as little to no profitable life remaining (McGushin, S & Seeto, A 2012).
- Under the agreement of GenTrader, TRUenergy may elect to terminate earlier on 2029.

2- Eraring Energy's generators

- Eraring (coal) power station has been commissioned in 1982 (Eraring bundle subject to GenTrader agreement) and has been assessed as it has a useful remaining life of around 20 years until 2032(McGushin, S & Seeto, A 2012).
- Shoalhaven (hydro), as well as, (Bendeela & Kangaroo Valley) were both have been commissioned in 1977 (Eraring bundle subject to GenTrader agreement) and had been assessing as it has a useful life of around 26 years and up to 2038 (McGushin, S & Seeto, A 2012).

3- Macquarie Generation

- Macquarie Generation has a contract of 900MW with Tomago Aluminium until 2021
- Liddell (coal) power station has been commissioned in 1971 and has been assessed as it is has a useful life until 2022(McGushin, S & Seeto, A 2012).
- Bayswater (coal) power station has been commissioned in 1985 and has found as it has a useful life until 2035 (McGushin, S & Seeto, A 2012).

B- Owns 100 per cent of generated electricity output

- Wallerawang (coal) has been commissioned in 1976 which has a useful life until 2008 (Delta West bundle subject to GenTrader)
- Under the GenTrader agreement, TRUenergy expected to terminate in 2018 or earlier on 2029.
- Mount Piper (Coal) has been commissioned in 1992 (Delta West bundle subject to GenTrader) and assessed as it has a useful life until 2043 (McGushin, S & Seeto, A 2012).
- Vales Point (coal) has been commissioned in 1978 and assessed as it has a useful life until 2029.
- Colongra (gas) has been commissioned in 2009 and evaluated as it has a useful life until 2039.

C- Purchased the retail operations and brand names of the former Government-owned retailers

D- Electricity transmission and distribution network (poles and wires)

- The Government retains its ownership of the network and transmission infrastructure.
- Transmission and distribution networks worth from \$29.2 to \$34.5 billion.
- Selling the asset of Macquarie Generation, Delta Electricity and Eraring Energy does not mean the sale of network businesses, such as poles and wire.
- The Government retained transmission operators and generators (Ausgrid, Essential Energy, Transgrid & Endeavour Energy).
- Retention values of the wires and poles assets were calculated and considered in future bids.
- The Government retail electricity businesses which were valued to a five year plan by reference to the forecast growth rate of an estimated cash flow of five years.
- The average regulated electricity prices increase due to rising network costs of using distribution and transmission facilities to transport electricity to end-users premises and increasing the green scheme of mitigating the growth in carbon emissions (see Table 3.5).

Table 3.5: Selling the Assets of Generation (McGushin, S & Seeto, A 2012)

Vendor	Purchaser	Gross proceeds \$ million (excluding GST)
Country Energy	Origin Energy	1,300
EnergyAustralia	TRUenergy	1,486
Integral Energy	Origin Energy	1,000
Total		3,786

*Brand names sold to purchasers

3.16 Types of Electricity Tariffs

The tariff structures of Australia's electricity distribution network are increasingly inefficient, outdated and unfair. Current tariff structures do not either reflect the drivers of network costs or various customer uses of the network (Energy Networks Associations 2016, p. 39). The unavoidable reality is that the load profile diversity of consumers will continue to grow as the use of solar panels, energy efficiency and air conditioning increases (ENA 2016, p. 39). The value must drive the focus in energy growth from the angle of distributor energy resources (DER) and energy storage they create, instead of transferring costs among stakeholders (users). It would need to reform electricity network tariffs to reflect better the cost of providing network services that are at least partly constrained by the previously mentioned hidden cost transfers among network stakeholders that are in place today.

Tariff reform is important because in the future it is expected to be harder to use cost reflecting pricing to efficiently enable greater stakeholders alternative and integrated new technologies. This is because, in the future, the size of existing cross-subsidies will be“ entrenched and growing more deeply into the market. Helping customers to optimise their own energy production and consumption is a critical step to deliver societal benefits which need an integrated national approach to achieving better long-term customer outcomes (ENA 2016, p. 39). In the basic form, interval smart meters facilitate a greater range of implementing tariff options for ‘Distributor Network Service Providers’ (DNSP) (Energeia in Consultation 2013). They are also used to gather information on the consumer’s consumption patterns for improvements in network management. Efforts deployed from data of interval meters to deliver more cost reflective tariffs for household customers via these tariffs:

- Time Of Using Tariffs (TOU) **-** Capacity & demand based tariffs.

The use of non-utility based communications tariffs during peak or load baseline times. The use of tariff options is effective in ‘flattening’ the load curve and reducing the peak demand to reduce losses at peak times. The role of tariffs bound to demand loads grows. Tariffs attempt to provide greater utilisation of the network capacity towards reducing the effects of increasing losses. These effects are. illustrated in the figure below, in which the route of residential peak demand during the day has been changed. The highest 5% of the demand has been trimmed and shifted from peak times to other off-peak times (Energeia In Consultation 2013, p. 70).

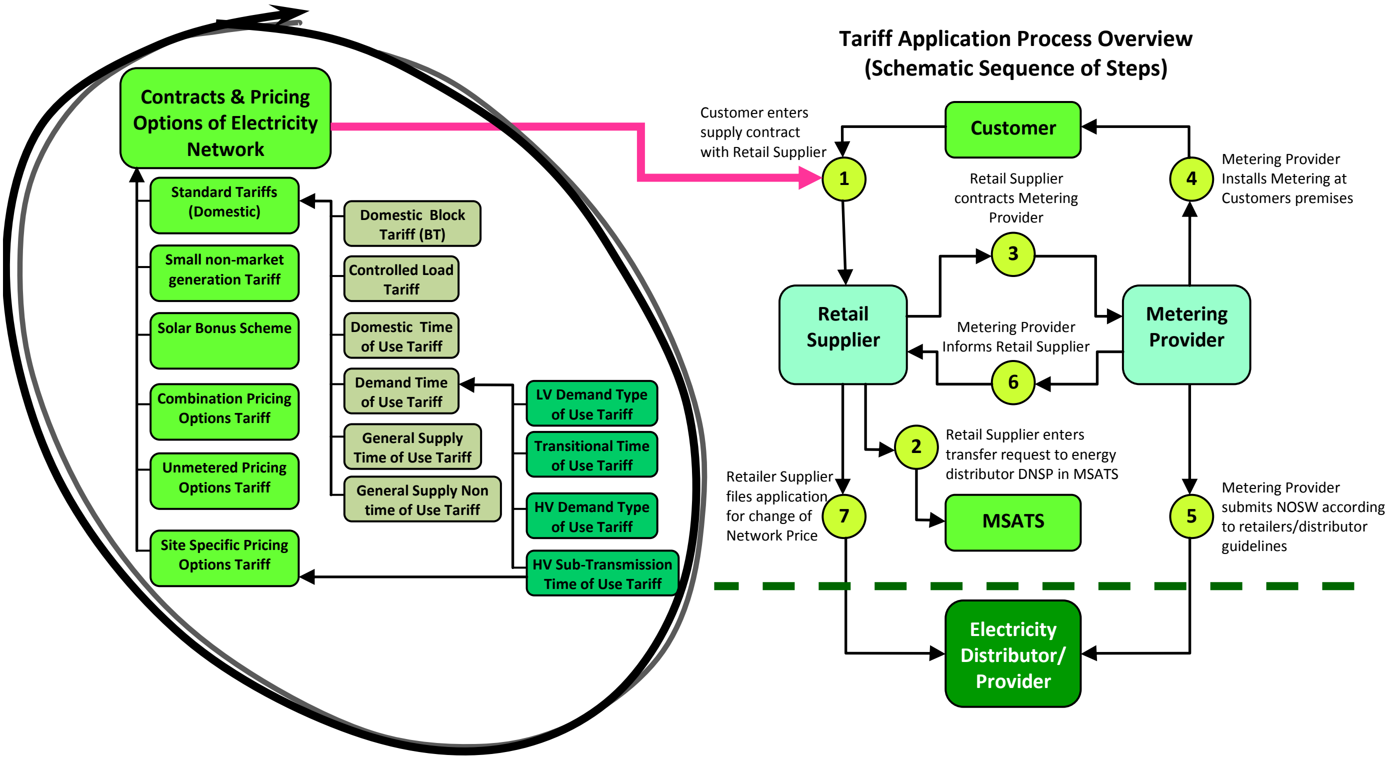


Figure 3.20: Electricity Tariff Options (Network Tariffs 2015)

There is a variety of pricing option in the Electricity network as illustrated in Figure 3.20 which categorised as follows: (Network Tariffs 2015):

1- Standard

a) Domestic Block Tariff (BT) – N70

The domestic Block Tariff (BT) consists of two pricing components; Network Access Charge (NAC) and block tariff energy consumption charges (Network Tariffs 2015, p. 2). It applies to customers‘ connection services that are supplied to a connection point categorised as less than 160MWh per financial year of total electricity consumption (Australian average houses 5-6MWh per financial year). This service specialised for customers using low voltage (LV) being nominally 230/400 V (residential & commercial premises, churches, mosques, temples, worships, caravan sites, hospitals, kindergartens, & schools).

b) Controlled Load Tariff

The controlled load tariff also consists of two pricing components, Network Access Charges (NAC) and block tariff energy consumption charges. It also applies to customers using less than 160MWh per financial year of total electricity consumption (Network Tariffs 2015). This service is specialised for customers using nominally low voltage (LV) between 230/400 V. There are two controlled loads: Controlled Load 1 supplied to approved specified appliances that should not be in use in between 7:00 am and 10:00 pm.; Controlled Load 2 is available for appliances using electricity for limited periods not exceeding a total of 17 hours in a period of 24 hours (Network Tariffs 2015, p. 3). Although both controlled & uncontrolled load consumptions are synchronously read, they are separately metered by using the same type of meters.

c) Domestic Time of Use Tariff

The purpose of the domestic Time of Use (ToU) Tariff is the same as set out in the description of BT tariff. However, ToU tariff applies to connection points at the premises of domestic customers where a meter capable of recording interval meter consumption data is fitted (Network Tariffs 2015, p. 3).

d) Demand Time of Use

The Demand Time of Use Tariff has four types: ‘Low Voltage Demand Type of Use’ which is used in premises using electricity for any purpose other than domestic use and which has installed a time of use meter from which both demand data and interval meter energy is obtained (Network Tariffs 2015). The second type comes under this tariff known as ‘Transitional Time of Use (ToU)’ for customers who use greater than 160MWh and less than a maximum demand of 40GWh. With this type there must also must be installed a time of use meter from which both demand data and interval meter energy is obtained. The third sub-tariff type named ‘High Voltage Demand Time of Use (ToU)’ which applies to customer connection services at a voltage level defined as high voltage (HV) (11-122 KV). With this type there must also be installed a time of use meter from which both demand data and interval meter energy is obtained. The fourth is named ‘Sub-transmission Time of Use Demand’, and the supplied voltage levels will be higher and defined as Sub-transmission (ST) (33, 66 & 132 KV) (Network Tariffs 2015, p. 4). With this type also must be installed a time of use meter from which both demand data and interval meter energy is obtained.

e) General Supply Time of Use

The General Supply (ToU) consists of two pricing components; Network Access Charge

(NAC) and block tariff energy consumption charges. It applies to customers' connection services that were supplied to the connection point categorised as less than 160MWh per financial year of total electricity consumption (Australian average houses 5-6MWh per financial year). This service is specialised for customers using low voltage (LV) being nominally 230/400 V (residential & commercial premises, churches, mosques, temples, worships, caravan sites, children houses, health centres, hospitals, kindergartens & schools). It applies only for those who installed 'a time of use meter' (Network Tariffs 2015, p. 4). There are two types of tariffs related to 'General Supply Time of Use'. The first type of interval meter is able to obtain consumption data for a single 'peak, 'shoulder' and 'off-peak' for the electricity use for any purpose other than domestic use. The second type of interval meter is designed to record the consumption data at 30 minutes intervals (Network Tariffs 2015).

f) General Supply Non-Time of Use

The General Supply Non (ToU) consists of two pricing components; Network Access Charge (NAC) and block tariff energy consumption charges. It applies to customers' connection services that are supplied to a connection point categorised as less than 160MWh per financial year of total electricity consumption (Australian average houses 5-6MWh per financial year). This service is specialised for customers using low voltage (LV) being nominally 230/400 V (residential & commercial premises, churches, mosques, temples, worships, caravan sites, children houses, health centres, hospitals, kindergartens & schools). It applies to customers characterised as those who use electricity for any purpose other than domestic use (Network Tariffs 2015, p. 4).

2- Small Non-Market Generation

It is a pricing option for non-market micro-generation installations at private premises. These generators added to connection points in distribution systems which are formulated on the basis of the equivalent Standard Pricing Options by energy providers (Network Tariffs 2015, p. 8).

3- Solar Bonus Scheme

The New South Wales (NSW) Government established a Solar Bonus Scheme (SBS) to allow customers to collect credits under a feed-in tariff procedure. Under a SBS; installs renewable energy (solar and wind turbine) at eligible houses can be organised to deliver electricity to the network (Network Tariffs 2015, p. 7).

4- Combination Pricing Options Tariff

This option is a mix of standard pricing options applicable where a combination meter of a controlled load and regular domestic are installed (Network Tariffs 2015).

5- Unmetered Pricing Options Tariff

These options are appropriate for unmetered connection points. Examples are a single energy consumption charge only for ‘the unmetered Street lighting supply tariff’, ‘Traffic control signal lighting’, ‘Night Watch’ (Network Tariffs 2015).

6- Site Specific Pricing Option Tariff

This tariff option is only for High Voltage or Sub –transmission Demand Time of Use (ToU). It is also conditioned for electricity consumption equal to or greater than 100GWh during 36 months. It is also applied when consumed electricity reaches to equal or greater than 40GWh per year in each of the two financial consequent years. Further, this option suits consumers who have a monthly peak demand equal to or larger than 10MW for 24 months out of 36 months (Network Tariffs 2015, p. 9).

The eventual influence of tariffs is mainly designed to modify the load shape that aims to reach the network capacity. As seen practically, Tariffs led to increasing the load on the peak day from 68% to 71% and the losses have also risen by 10%. However, the economic justification through the introduction of the interval meters, is in using tariffs cost reflectively, to improve the use of network utilisation and reduce network demand. The side effect of this development of using meters and tariff options increased use the capacity of the grid networks, as well as, increased the network losses (Energeia In Consultation 2013, p. 70). Tariffs, tasked with improving the capacity of network usage and decreasing the peak demand effect, have not yet helped to flatten the demand load and to decrease the peak effect, as shown in Figure 3.21 (Energeia In Consultation 2013, p. 70).

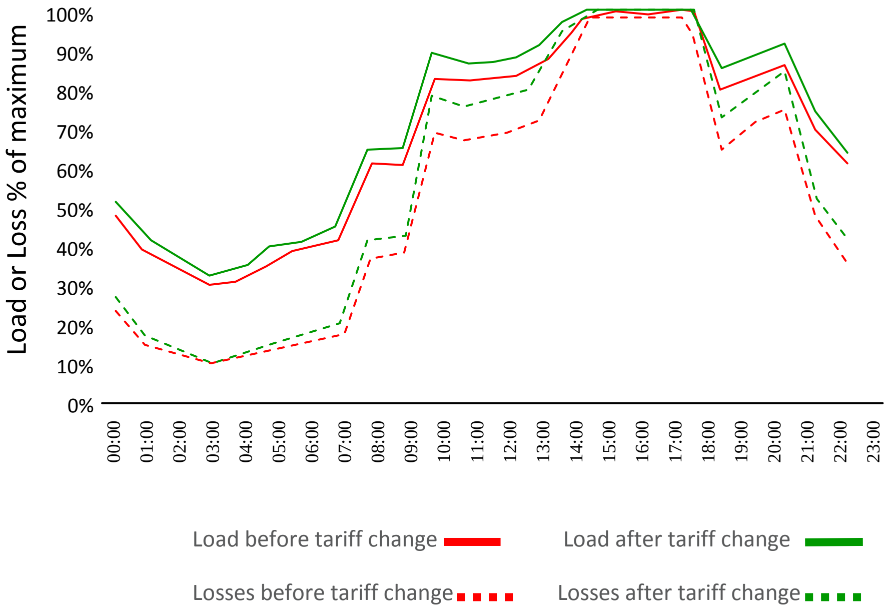


Figure 3.21: Improving Netwrok Utilisation (Energeia In Consultation 2013, p. 71)

3.17 Electricity Retailers

Energy retailers represented in Figure 3.22 have the sensitive duty to bundle electricity with network services for sale to different segments of industrial, commercial and residential energy consumers. Therefore, electricity retailers are the main customers in the Australian national electricity market. Network charges are the main drivers to increase or decrease electricity bills. Falling network costs reflect the improved environmental investment environment arising from healthy decisions taken by AER ‘Australian Energy Regulatory’ which usually follow decisions taken in previous periodical rounds. Declining grid consumption has been recorded at an annual average rate of 1.7 per cent during the five years till 30 June 2014 (State Of The Energy Market 2015). However, this consequence did not happen because of operational decisions, but for two other reasons:

- The consequences of terminations and closures of two aluminium smelters caused a dropping demand for energy requirements for vehicle manufacturing and steel making.
- The following influential factors caused energy decline in use by residential consumers when they adopted energy efficient measures (i.e., efficient air conditioning and refrigeration systems, solar water heating, rooftop solar photovoltaic

(PV), for which governmental incentives and subsidies provide support, so alterating consumer behaviour (State of the Energy Market 2015).

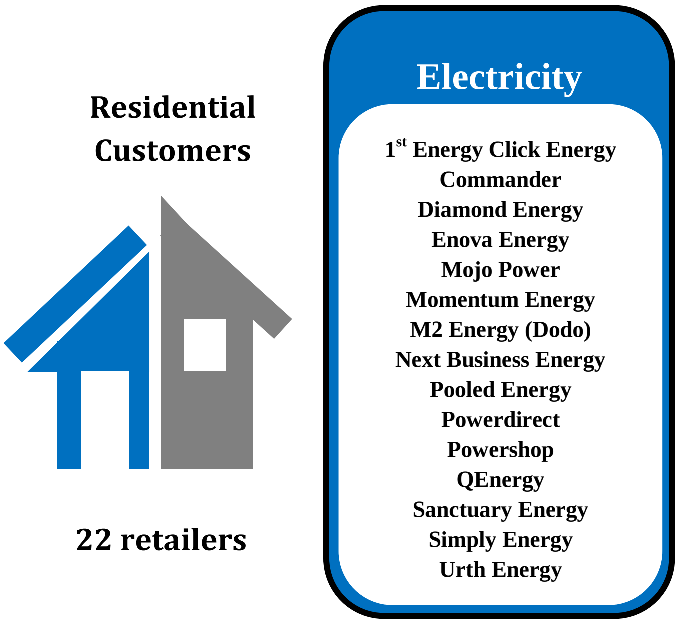


Figure 3.22: Energy Retailers Contesting in NSW as at 30 June 2016 (Boxall AO, P, Catherine Jones, C & Willett, E 2016)

The electricity demand is the annual electricity charge for a typical residential consumer living in NSW, Queensland, the ACT and South Australia. This brings about moderated network costs, lowers financial cost pressures in those jurisdictions; having an opposing effect upon costs of green schemes and expenses in a competitive market. Taking rural customers as an example, we witnessed the largest reduction in NSW retail bills reaching 17 per cent (Australian Energy Update 2016) (State of the Energy Market 2015).

In reverse, the forecast of the Australian Energy Market Operator (AEMO) in June 2015 predicted an annual increase of 1.2 per cent in electricity consumption from the NEM grid until 30 June 2018. This forecast consequence is accounted for the following reasons:

- Ascendant energy requirements of the project of liquefied natural gas (LNG) in Queensland. This project needs to gather and transport coal seam gas from coal plants to the LNG plants.
- The forecast of commercial and residential demand expected to increase marginally, because of population growth, as well as due to easing in retail electricity charges.
- There are some indicators of consumers becoming less responsive to “bill shock”.

- Most of the 2014 jurisdictions underpin the easing of retail electricity prices which show that the majority of consumers are less active in managing their daily energy consumption (State Of The Energy Market 2015).

All end-users of energy in Southern and Eastern Australia are free to select their electricity retailers via a regulated standard contract price (Australian Energy Update 2015, p. 18). The contracts are designed to cover three sets of costs, with the first set associated with network cost comprising both transmitting and distributing from power plants to end-users. The second set relates to buying electricity from the wholesale market while the third cost set refers to the retail costs covering marketing, billing and margin. The weight of retailers' prices varied and averaged 10 per cent, counted network and wholesale costs at 90 per cent of the total retail billing prices. The increase in regulated retail of electricity was mainly driven by network costs (Oxera Agenda 2015). Power generators, transmitters and distributors are all connected to the National Electricity Market (NEM).

Firms are measuring their businesses based on their ability to recover an incremental input into costs by increasing their own prices. This process is recognised in some countries under the name 'pass-on'. Companies operating in a highly competitive market will share a highly likely risk since that increase is due to small margin expected in the highly competitive market. Thus, costs increase in a highly competitive adjacent market with a little option but to pass it on to end-users (Oxera 2016). At the same time, increased prices lead to a cost shock that will sometimes lead to a loss. Whatever the reason that influences increased electricity prices, it is never appreciated at the other end of the spectrum where the demand of end-users' originated. Moreover, the obstacles surrounding 'pass-on' in the Australian electricity market encompass regulated settings that have been discussed as narrowly despite the fact that they have become, and are progressively expected to be, a crucial aspect in peak demand cases in response to the tacit patterns emerge from different houses(Oxera Agenda 2015). This is in light of the controllers‘ identification of a number of cartels in the supply of inputs to regulated firms. The goal is to make electricity transmission and distribution companies add more controllable flow in their networks.

Revenues are set at one end of the spectrum where the demand for electricity emerges and particularly when end-users act. The rate of return (ROR) recovers the costs of running the regulated business at the other end of the spectrum, where the pure price cap regulation that is rarely adjusted for short-term changes in costs. In such a model, electricity prices are de-linked from short-term cost movements, and the term of ‘pass-on’, are either so extremely high or unexpectedly zero or low, that they are cyclically affected by the duration of the price control period. There is a gap in incentive regulations between the two spectrum ends (suppliers and end-users) in the electricity supply chain.

3.18 Conclusion

A brief background to the electricity market in Australia is presented in this chapter to assist in understanding the current Macro-level situation of the electricity supply chain. Along with the electricity supply features, the activities in electricity industry are highly dependent on diverse residential consumers and the methodologies of their relations to the electricity market in terms of the way they are integrated. From this, it is believed that Australia does need a soundly based national energy policy, that a portfolio approach is required relating to the options to be selected from the sources of non-renewable and renewable energy (ATSE 2009, p. 10). This is because electricity networks provide the means by which the power of electricity is transported from generators to end-use customers. Therefore, it is not surprising that the influence of electricity end-users is a key driver in the electricity industry today. In order to avoid issues of energy misuse or losses, improving the involvement of end-users and particularly residential consumers, is a fundamental part of electricity networks, that would help to control costs of energy market analysis.

Such a fact implies a key message of ‘electricity demands evaluations’ that we should not deny while we think to reform the current policies for making investment decisions and raising electricity demand awareness. The exercise of evaluating and identifying the influence of end-users in itself draws attention to the fact that both renewable and traditional energy sources have influences that easily create economic inefficiencies (ATSE 2009, p. 11). Therefore, setting priorities for preserving energy and the environment, are particularly concerning in the evaluation of consumers’ demands. This is essential for cost-benefit analysis in order to define where the best returns can be secured when reforming new policies (ASTE 2009, P, 12).

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Chapter 4

Relevant Complexity Concepts

Acronyms

DNSP: Distribution Network Service Provider

DSM: Demand Side Management

PLs: Power Laws

GP: Genetic Programming

MOO: Multi Objective Optimisation

NEM: National Electricity Market

NSW: New South Wales

OP: Off-Peak

P: Peak

R/F: Ranking/Frequency

TIEs: Tiny Initiated Events

TNSP: Transmission Network Service Provider

Lessons Learned from Chapters One, Two & Three

This chapter illustrates the background details of the Australian electricity market in regards to its electricity pricing volatility. This is followed by a description of the economic growth of the electricity sector over past decades. The electricity market in NSW is the focus for describing the costs incurred by electricity power plants in generating energy from supply stations down to end-users' houses. This chapter examines how the end-users' consumption behaviour influences the level of investment by electricity suppliers and retailers, and how, in turn, that affects the cost of electricity demand (Energy Network Association 2014).

Chapter outline

Without any claim of being complete, this chapter is a literature review giving a brief account of my concerns and particular findings in the field of complexity science.

- In this chapter a literature review establishes 'Complexity Theory' to define an optimum way of consumers' integration in improving grid performance and reducing energy losses and costs?
- A number of theories are reviewed, such as emergence theory, Tiny Initiated Events (TIEs), determinism, organisation, self-organisation, fractal, chaos and system of systems. Reviewing these theories will demonstrate the influence of consumers' behaviour which is causing energy losses.
- Home sustainability, is also briefly mentioned in this chapter, to pave the way for further discussion in the following chapter four. The literature of "Home sustainability" mainly investigates the influence of consumers on the grid performance.
- It then moves on to following chapter five by using complexity understanding and approaches from both chapters three and four. This is done to review the phenomena of electricity demand and to investigate the influence of peak and off-peak phenomena, and why generation costs increase at particular demand times.

4.1 Introduction

The literature reviewed through these three chapters, which concerns some of the most essential topics in this study are: complexity theory, related approaches to complexity, and the losses caused by consumers in the electricity industry of Australia. Recent empirical and theoretical studies that concern the ‘Demand Side Management’ (DSM) of electricity are reviewed, always with a goal to understanding how energy losses in the electric smart grid system may be reduced and performance improved. The electricity pricing context is reviewed in relation to energy losses in Australia and specifically in New South Wales (NSW). Gaps in the literature relating to this research are revealed. The overview is exhibited as a simple diagram in Figure 4.1 below.

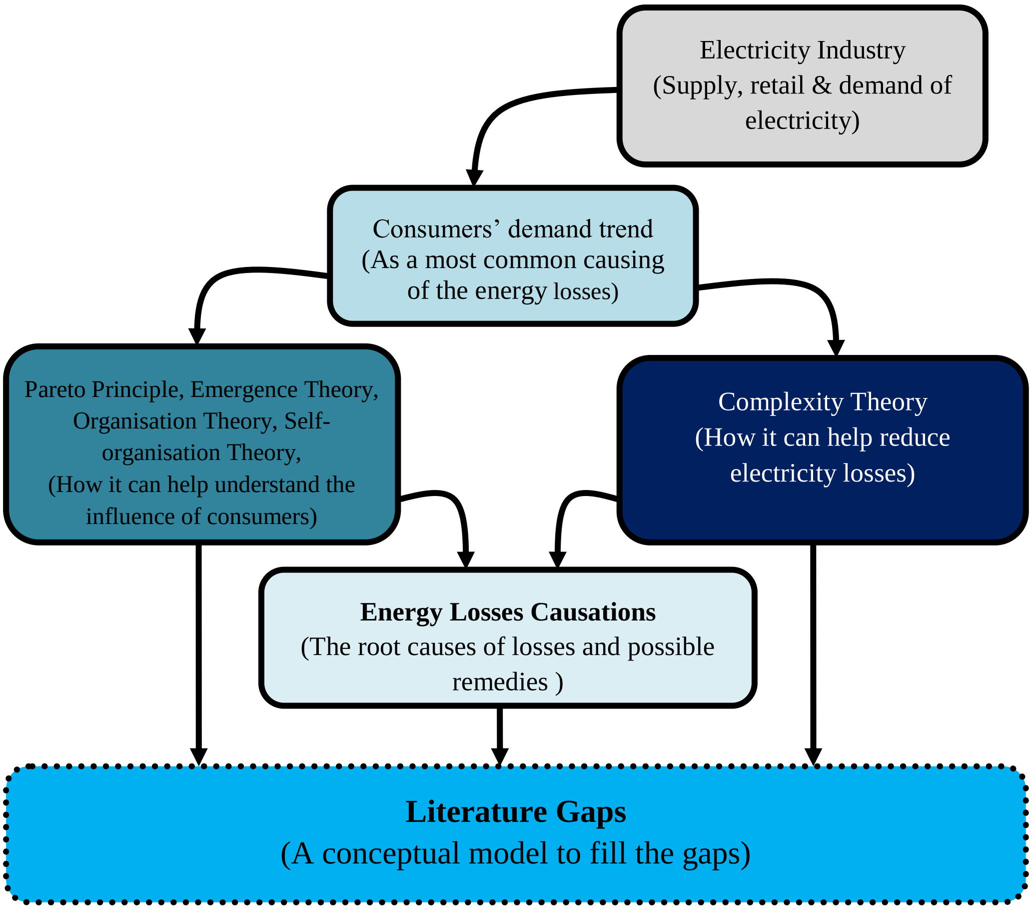

Figure 4.1: An overview of the Literature Review Process

4.2 Complexity Theory

The science of complexity is a multi-disciplinary endeavour comprised of multiple sets of theoretical constructs giving rise to better understanding when applied to a complex system made up of a vast number of elements. These elements usually interact in webs to introduce chains of interactions, and a leastwise number of these elements are non-linear (Goldspinr C, Kayb R. 2003). The concept of non-linearity means an output of a sub-system or a system varying in a manner that is indirectly proportional to its input. Thence, sometimes only a few components exhibit non-linearity in a highly connected system. However, the sufficient condition which helps to emerge non-linearity occurs when increasing the level of interconnectivity between dissimilar entities. This is typically similar to what is happening in between different houses in a grid system. Systems rich in non-linearity are able to demonstrate a wider range of behaviours. Here, the insight of complexity theory contributes to increasing our capacity to distinguish the micro-conditions of non-linear behaviours (Goldspinr C, Kayb R. 2003).

In Complex Natural Systems, agents are not to be tempted to change their behaviours based on a notion of 'self'. Further, the macro behaviour of a complex system is a result of micro interactions influenced by local conditions. This is something not presented in natural systems but achievable in social systems: that micro levels might be observed through macro consequences and aligned through feedback loops (Goldspinr C, Kayb R. 2003). Therefore, a non-linear system may exhibit a stable pattern of behaviour within local operational boundaries disconnected from any external directive agents. Such a phenomenon expresses itself in self-organisation process which are common in complex systems (Goldspinr C, Kayb R. 2003).

4.3 Managing Complexity

Currently, while growth has been substantial in electrical smart grid systems, it is essential to find new solutions that look through many strong and weak complex forces. These forces are unavoidably divided due to the tendencies of diversity that are being significantly increased while concurrent with the increase in electricity consumption (Harvey, 2005). As a fact, a perfect grid system of electricity does not exist. Worse, many, if not most stakeholders in the electricity sector are the end-users and they are connected indirectly to each other and intensively, in significant ways. Electricity retailers compete and pursue activities, and learn to provide the service needed for end-users; finally the behaviour of end users‘ consumption whose influence retailers and the government equally (Axtell 2008). The philosophies of complexity theories are more suitable to systems, which suffer a high level of uncertainty.

Complex studies first originated from the scientific study of open systems. The perspective of complexity science does not build to compete and achieve what the “right” system looks like!

Despite this, complex systems deliver more freedom based approaches for making sense of events, exploring and analysing the problem into multiple views, to find potential solutions. Recently, the systems engineering and soft system methods delivered more attention towards the human dimension. It seems that this intention occur within a context in which the value based perception shows the position and role of end-users of electricity during the systems being conceived and used.

The usefulness of complexity theory makes sense of the behaviours of people, who are defined by the qualitative aspect, while doing their daily activities. These behaviours will influence other systems in a quantitative manner, for instance, when you are sleeping, you will not consume electricity or when you take a shower, you will consume water which is a quantity. Therefore, understanding the complex activities of people by reviewing complex theory will help to create a simple process (quantitative).

Complexity studies will be used to enhance the performance of smart grids of electricity. Mainly, this is used to deliver a proportion and commonality of the interactions between policies and the measurable characteristics of technologies, and practices of end-users.

Complexity principles enable new approaches to theorise and develop distributed control and self-organising with less dense of specifications. Therefore, the complexity philosophy provides tools which are quite different from the traditional ones. For instance, traditional tools deal with centralised directives to preserve a system’s consistency which do not suit the interdependence contexts of complex systems. Complex approaches aim to utilise relationships between individuals in the system as the fundamental unit of analysis (Suchman, 2006) (Gambino, 2008; Nash, 2008). (Miller et al.,1998; Dershin, 1999; Anderson et al., 2000; Ashmos et al., 2000; Barger, 2003; Begun et al., 2003; Iedema et al., 2005) (Begun et al., 2003; Anderson et al., 2005; Stroebel et al., 2005; Chaffee and McNeill, 2007; Forbes-Thompson et al.,2007) (Buscell, 2006); (Baskin et al., 2000), (Letiche, 2008) (Cusano, 2008). Therefore, the complex nature frame attributes to create a coherence approach far from consistency meaning. The reason is that because of the complex systems’ inherent nonlinearity behaviour pattern, interactions, emergence and self-organising patterns of meaning in humans. Thus, it seems that complex theory delivers a self-organising approach to refocus and use energies in the electrical grid system and to raise the level of system integration and collaboration. Thus, the purpose of complexity science makes sense of observed patterns of nonlinearity, self-organisation and emergence, and constrain the reductionism approach.

Complexity theory endorses self-transformation, the science of evolutionary change, and adaptation. Ideas in managing fields of complexity science have notably increased to enhance systems thinking and to erode other existed paradigms. Management intervention in complex systems helps to deliver ideas and to design complementary systems for regulation and control purpose (Shukla, M. 2013); (Merali, Y, Papadopoulos, T, Nadkarni, T 2012); (Whitfield J. 2005); (Mikulecky, D.C. 1996); (Ayres, R.U. 1997). Earlier parts of the twentieth century a design paradigm for management and problem-solving appeared. Further design paradigms through Complexity science need to attach to ideas of 'emergence', 'self-organisation', 'co-evolution' and 'adaptation' to explain and find new ways to deal with the unintended consequences of people's actions (Vanderstraeten R. 2005); (Bailey K 1997); (Raine, A, Foster, J, Potts, J 2006); (Merali Y 2000); (Toussaint, O, Schneider, E.D 1997); (McKelvey B. 2004). Other aspects such as dissipative and auto-genesis systems introduce influential forces able to deliver evolution of ideas based on managing and organisation perspectives (Reynolds, C.W. 1987); (Checkland P. 2011); (Schneider, E.D 1994); (Bausch, K.C. 2015); (Child, J, Ihrig, M, Merali, Y).

Searching for the electrical grid systems represents the dynamics of socio-technical activities that always aim to reach economic success. The complexity approach arises from the idea of extending the limitations of existing models of System Dynamics of feedback loops. The structure of any dynamic models is tracking the system's reality, but are sometimes very misleading when the model experiences substantial limitations that are neither stated nor understood. Complexity sciences are varied and deliver different contributions of emergent science. Maximising the challenge against the unpredictable emergence of complex enquiry, are emerging insights from the knowledge of complexity. Complexity embraces various contexts to produce more specificities, more similarities, or more complementarities. Models other than complex models rely strongly on a frequent set of feedback mechanisms and the causal effect which will sustain as a constant norm during the lifetime of the model. On the contrary, complexity theory gives a type of interpretation based upon the predictive power of System Dynamics and utilises more ways for designing interventions than those that, to date, are limited.

4.4 Tiny Initiated Events (TIEs) & Extreme Events

Andriani P. & McKelvey B. (2011, p. 93) borrowed the definition of TIEs from Holland as 'small, inexpensive inputs or 'lever point phenomena'. Using electrical appliances at homes can be described as the origin of TIEs, but it is not exclusive to only what happens in houses, where it can arise in other forms and as other aspects of different elements of the electrical system. For this reason, the behaviour of Electrical Smart Grid Systems is being changed instantaneously. However, the biggest concern of TIEs occurs around the Paretian tails where low linkages are available to connect smart grid components of which end-users are a part. Tails are the source of both positive and negative tiny initiated events (TIEs). The issue emerges when TIEs spiral up within a time to higher levels of negative scalability. In this aspect, the question borrowed from Andriani, P. & McKelvey B., (2011, p. 96) asks, "what should (I) do to stop negative TIEs scale up to cause an extreme event?".

TIEs occur at different levels of a grid system. Within a single house, end-users consume electricity when using different appliances and other electrical gears which are responsible to emerging TIEs, and their influence on the whole grid performance. These TIEs are strong based on it's a collective influence. Other type of TIEs may be assumed in between the houses, and this type has a lack of linkages and connectivity. Houses demand leads to a great mix of TIEs in a timely manner emerged towards retailers. The total consumption of end-users' flows through different retailers, who are greatly influenced by these emergences, in relation to bidding prices and subsequently, the whole sale of electricity. Lack of linkages between different houses opposes the flow of TIEs between them. Average consumption of electricity aims to avoid peak and off-peak phenomena. Houses could be linked together when they are serving that particular goal. Creating such new positive TIEs would create a positive effects on the whole grid and also oppose the effect of other negative TIEs.

There is doubt that the Paretian Approach helps to launch a different understanding about TIEs, scalability and scale free theories. This understanding may provide new tools to govern the transformation of TIEs into extreme consequences. The benefit of this action, is clear when it takes place at stages of initiate events to scale up into a favourable structure, in turn, stopping the reasons for destructive outcomes. TIEs have inputted the nature of smallness and also defined the levers that lead to the phase of transformation and emerging effect finally arising from either positive or adverse impact. Table 4.1 below proposes some causations of Tiny Initiated Events as conceptualised in Electrical Smart Grid Systems.

Table 4.1: Tiny Initiated Events (TIEs) in an Electrical Smart Grid System uses which generate power by solar & wind, support by batteries (Combined by the Author)

Early clues	Evidence of Scalability	Evidence of Management Failure for a smart grid
Large Renewable energy cuts in households	Suppliers increase the tariff of electricity due to increase peaks and losses in the electrical supply system	Wrong consideration of end-users as consumers in electrical smart grid systems, which, in fact, they are co-producers
Householders unfamiliar with assigned electricity	Sometimes the electrical system being gridlocked due to environmental reasons	There are no means of the grid system organise and detect householders' integration
Not enough connectivity between suppliers and consumers	Traditional households means no further action might be taken to avoid and help to solve the grid problem	Consumers mentality is the victim and not the culprit
High Electricity prices concurrent with electricity peaks demand	A failure in the electricity supply line could cause a general problem to all householders	So far electricity providers and suppliers neither assume householders as co-producers nor believed that they would find many if they did to avoid grid system's deficiencies and failures
Renewable energy individually maintained according to each consumer view.	No other options available for Electrical grid systems against exacerbating load demand either to peak or to off-peak	Demand Side Management is taking responsibility for Monitoring, controlling and automating the electricity demand side to incubate the demand behaviour. A disproportionate behaviour with End-users behaviour with highly subjective end-users.
Householders demand could not be adequately managed	Once is happen it then will be repeated instantaneously at all levels of the electrical systems' hierarchy	Electrical smart grid systems although not traditional anymore but still prefer to centralise and formalise the supply of electricity and customers treated as then are out of it
Electrical providers lagging; not leading the demand of electricity and that make it hard to predict the capacity needed of electricity	Enlarging the gap between demand and supply of electricity	Customers keep mentioning cost raising with the abandonment of workarounds, and electricity demand keeping the pressure on the supply side

Coupled with tiny initiated events (TIEs), the role of complexity theory from a managerial perspective, is about explaining the origin of the tiny initiated events and interpreting the tipping off point from a static to a dynamic condition, and finding a way to manage the events, particularly in extremely diverse technical and business structures. Each end-user is able to exhibit extreme diversity structure, although their frameworks may have similar intentions. In the same way, individual end-users also have the norms of limited variance. Positive examples of extremes are Microsoft and Google, while other examples of unlikely events with negative extremes are Pioneer disasters and Challenger. Amazon, on the other hand, is individually thriving at a micro-niche level, by selling millions of books estimated to equal 17 million family-owned stores.

Societies, organisations, and consumers such as electrical smart grid systems, need better ways to respond to sudden TIEs which emerge from multiple end-users with timely demands. These Tiny Initiated Events which therefore emerge due to the natural daily needs of humans, are interconnected into one grid system and the timely demand outcomes are interdependent with end-users' timely behaviour (Helbing, D 2013). Therefore, it is essential to investigate the nature of the relationships between energy losses during peak and off-peak times, and the impacts of social networks on the grid performance outcomes. This step is important to realise the most tailored organisational effectiveness in stable and adversarial situations during the operation process of the grid.

When Tiny Initiated Events (TIEs) which are created in homes, it is important that we understand the formation and adaptation of emerging non-hierarchical and hierarchical self-organising structures that are the most suitable (see Figure 4.2). This will help to characterise the needed types of adaptation processes, which will be learnt from analysing the historical data that we have. The objective of such a process is to enable, support and equip the ad-hoc networks based demands of electricity distribution systems to affect community and other stakeholders to function effectively on a daily basis (Helbing, D 2013).

Figure 4.2: Parts fit in many ways alike Electricity End-users

4.5 End-Users, TIEs, & Electrical Smart Grid Systems

End-Users in Smart Grid Systems are an actual social world, and they consist of particular entities that are conceptualised as a fixed centrality. Residential populations of electrical consumers are an example of integrated units similar to dynamic rational variables to originate measurable outcomes. In complex systems, such as electrical grid systems; sub-systems interact as interdependent systems through levers that are caused by tiny initiated events (TIEs). Complex systems, such as electrical grid systems, behave to make emergents and to move through connectivity. Numerically, simulations and modelling approaches introduce advanced success which is only achievable when first, adapting adequate theories for qualitative interpretation, then proceeding to quantitative findings. Unifying both of these inputs towards electrical grid issues would help dramatically to formulate scientists' thinking about how society works.

Andriani, P. & McKelvey B., (2011, p. 105) attributed the meaning of high-reliability entities to the meaning of 'Tiny Initiated Events' (TIEs). They defined TIEs as butterfly events and explained the management issues as about transforming butterfly events into butterfly levers and avoiding the negative ones to enable positive butterfly events. The positive or negative scalability dynamics that originally started from TIEs and then enter a scaling up process until it reaches a positive or a negative outcome. The butterfly effect, as stated in chaos theory, is an event with sensitive dependence on the initial conditions derived from a small change. The latter change emerges in one state of a deterministic nonlinear system and leads to substantial differences. Thus, the levers are TIEs that have either negative or positive scalability dynamic.

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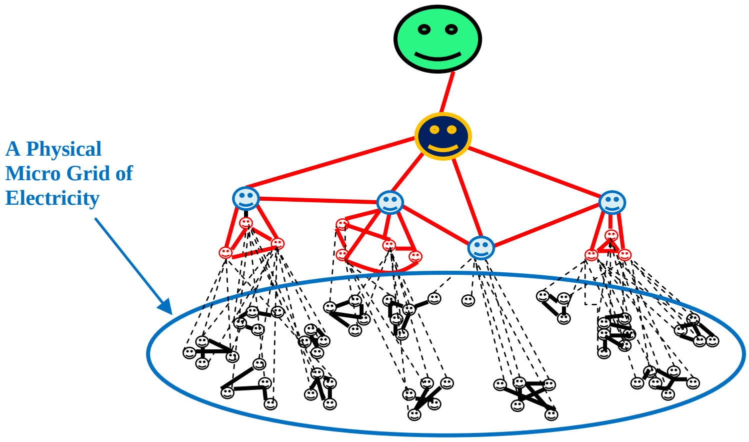

Residential Home/s (a distribution network position) ☺
Scale crossing Electricity Retailers (Network of electricity spot price & whole sale position) ☺
Transmission Network of Electricity ☺
National Electricity Market Operator (NEM) ☺
Generators (Government) ☺
Strong Social TIEs (within a single house) ☺
Weak Social TIEs (in between houses) ———
Strong Social TIEs (between houses and retailers) - - - -
Strong Social TIEs (between retailers, transmission/bidding/whole sale price & NEM) ———

Figure 4. 3: The Hierarchical of Tiny Initiated Events (TIEs) in Electrical Smart Grid Systems

Gaining leverages is a crucial step in Electrical Smart Grid Systems because TIEs emigrate through scaling processes to extreme outcomes. Andriani, P. & McKelvey B., (2011, p. 93) stated that Holland (2002, p. 29) named TIEs ‘inexpensive’ ‘small’ ‘lever point phenomena’ or ‘inputs’. It is still unclear and needs further work on how to define a way to transform butterfly events into butterfly leverages in order to manage the negative spiralling scalability that sooner or later will reach its extreme outcomes. Focusing on the system failures or deficiencies is about defining early clues in Electrical smart grid systems. This is further provision of focus is needed to interpret the circumstances of scalability that stretch the gap ‘so big’ between supply and demand of electricity.

C. P., Stephens, E. R & Smith, D. B. (2015, p. 1) have introduced “A Novel Energy Trading System” to manage the load within a small community of end-users. The research finding shows that end-users introduce their bids, based on the next day forecast of the electricity demand in the grid. The authors described that what end-users will create emerges in the day-ahead; thus, all end-users will be a part of in a decentralised process. End-users may assume the benefit differently, concurrent with their differences which are likely to increase the system unbalance load. Therefore, in micro-grid levels, many actors/participants are individually responsible for acting directly; either negatively or positively. The amalgamations of these disproportionate individual behaviours result in extreme outcomes that should be dealt with and guided through promptly; the emergence of unfavourable behaviours badly affects the system’s outcome. Therefore, it is appropriate to investigate the performance of end-users at extremes of tails that lately will be shown in the Paretian Approach because these users of electricity are the creators of TIEs.

Realistically, there is a connection between the supply chain of electricity from the generation to the demand side, but there is a lack of connectivity from demand to supply side. Andriani, P. & McKelvey B., (2011, p. 109) defined complex systems as a collective system of interdependencies. An electrical smart grid system is one example of those systems. The property of interdependencies is that appears among the systems’ components and the end-users are a major part of it. It is clear that both C. P., Stephens, E. R & Smith, D. B. (2015, p. 2) and Andriani P. & McKelvey B. (2011, p. 95) indirectly agreed about a higher number of low occurrence frequencies located at micro levels in any system, including grid systems, as illustrated in Figure 4.3 & Figure 4.4. These high number, low occurrence frequencies are responsible for causing unfavourable outcomes such as peak and off-peak phenomena.

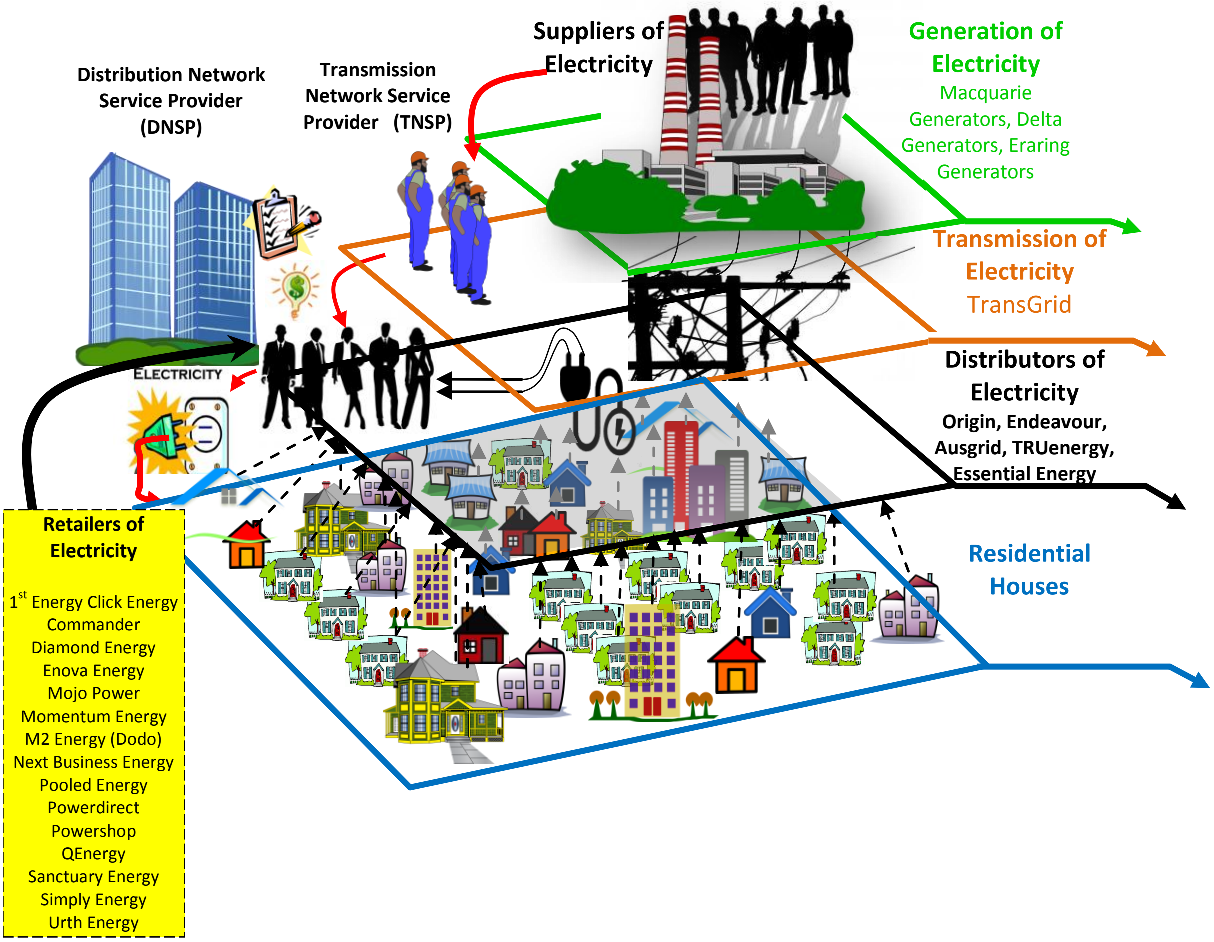

Figure 4.4: Social & Technical Networks of Electricity (Google 2017)

Tiny Initiated Events (TIEs) an accumulation of using different appliances at homes - - - -►
Timely Emergence of Residential Demand Massively influence on Bidding prices & Whole Sale of Electricity

4.6 Consumers' Emergence Demand of Electricity

Consumer emergence demand for electricity, as shown in Figure 4.4, is an uncertain risk factor for adverse post-consumption outcomes. Grid systems that perform to cover higher volumes of average demands have better outcomes than other low-volume grid providers. In this issue of uncertainty, I found that through data analysis; the unstable demand of some consumers has caused a reduction in the grid stability and increased either probability of instability or failure when they consume electricity at levels experiencing peak or off-peak trends (Wolters Kluwer, 2017). In an accompanying Editorial View, many researchers discuss this phenomenon as a significant step toward elucidating the best solution options for a demand for electricity which requires controlling and normalising from peak/off-peak demands to average demands.

Many of these researchers have explored the issue of the non-linear demand of electricity; it is the question that this research is exploring. So much has already been attempted to control these unstable demands, thus far, with no acceptable results. Thus, the lucid question is: “What next?”. I was searching so hard, as a result of my searching, I could not find the simple something everyone knew all along but could not entirely explain. It is so much harder for a grid system to balance differences in-between utilities – the utility which is theirs (Supply of electricity and retailers) and other utilities of the subjective demands (electricity consumers). That is why so many fail to succeed with grid systems. It is also hard to make one unified sense of people’s demand for electricity, why they consume in that way, why not shift their demand to other times, and how various demands seems controllable at particular times (Marshall, C 2004).

More popular in current research is to focus on anything that violates their expectations because they have an innate need to figure out whether the incident emergent’s a threat or a positive development. The more disruptive a development is, the more interesting it becomes. Attention now paid to complexity theory and its applications to human systems opens new paths to possible futures, and a range of evolutionary routs that may occur. Additionally, it also alerts us to the fact that unpredictable occurrences, can and will happen (Allen, P 2016). Instead of merely moving from the concept of answers based on a mechanistic view of the world, we may now also move to answers based on a complexity view. Sometimes it is found that there may not be answers? For this reason, there is a strategic need to adopt an opportunistic and exploratory attitude where we ought to continually need to reflect on what we thought might occur and what is realistically happening. Some researchers and others say that there is no point in modelling complex systems. However, reality sometimes breaks away from any predicted trajectory, which means that, as an alternative to building models to predict the future, we may need to model with a view to detecting creativity and emergence within a system, during the time that our current interpretive framework fails.

4.7 The Philosophy of Emergence

Serious attempts have been made to touch base with what emergence might develop into, inspired by prevailing science. The reason for this is because complex systems are encompassed and held by evolutionary emergences of forms and structures (Allen, P 2016); (Raven, J., 2014). The goal is not to defend the truth of emergence, so much as to elucidate its motivation and structure. Therefore, it is crucial, in the first place, to understand what the philosophy of emergence, "emergentism" may offer. We can begin with that task and then turn to the emergence forms in subsequent sections to see the common characteristics among several emergentist theories.

Emergence is a promising study realised from studies of complexity and nonlinear systems, and it is concerned with reshaping the way of thinking about system change and development (Galatzer-Levy, RM 2002). It is also recognised as the track in which new, unexpected, and qualitatively distinct configurations are being unexpectedly released in a complex system. In particular, emergence appears differently in humans (Thomas, R, & Mark, N. 2013). This fact is put forward as a basis of argument by many researchers and scholars such as Durkheim (1997); Carneiro (1998); Burt (1992); Cook & Emerson (1978) & Bowles et al. (2010).

The trade-off between any system forces , including electrical grid systems, gives rise to the function of emergence. The issues posed by the 'emergence phenomenon', since the social forces in networks play a dominant role, elaborate and perpetuate themselves in determining behaviour. A clear example is the emergence of negative societal forces which appear to have the future of humankind and the planet in its grip (Raven, J., 2014). Groups can, to a lesser or greater extent, utilise their different behaviours (or neglect and then destroy) either to a culture of intelligence or to dependency and conflict. Thus, is there a basis for the emergence of particular human functions? Emergence in its nature, is defined as the coordinated effect of individual components that lead to/establish an objective, not within the capacity of a single element (Rajapakse, I & Smale, S. 2016).

4.8 Emergence in A Complex System

Emergence improves the stability of complex systems through the tension arising between the stability necessary to sustain identity and the adaptation process needed for change. In the case of end user behaviour in smart grid systems, cross level relationships can be used to understand the variation of intervening behaviours and attempt to align this tension in a productive balance (Leana and Barry, 2000). Yet so far, most applications of emergence and system change are descriptive, and few have created explanatory metaphors to derive factors influence self-organising criticality. Emergence can be visualised in a socio-technical construction framework along with control and adaptive factors. Therefore, the effort must be made toward electrical smart grid systems in how guiding emergence grants greater adaptability. The random interaction of end-users' behaviours does not suggest answers yet. Subsequently, a need arises to assess the various constructional processes that are possible.

An emergence of patterns can also be assumed as a defending line in a system elucidated from interrelationships of some functions against fluctuations (Prigogine, I, 1947, 1978, 1997) & (Monod, J, 1970); (Goldstein, J, 2001, 2002, 2004, 2006). Some authors have realised the development of extreme events and emergence in social systems (Sornette, D, 2000); (Kauffman, S.A. 2003); (Mandelbrot, B.B. & Hudson, R.L, 2004); (Jacobs, J, 1969); (Mokyr, J, 1998). To inspire and develop practical innovations, the theory of complexity, not only historically, reflects human systems as nonlinear dynamic systems, but contribute to providing new ideas of the adaptive capacity of individuals. Chiles et al. (2004) argued that we need to "understand emergence as involving a 'self-organising logic' composed of a set of 'hodge Podge configurations' neither 'planned', controlled,' nor 'created' through 'human design' (Peter Allen, Steve Maguire & Bill McKelvey 2011).

From a complex perspective, emergent lies in between so-called order and so-called chaos (Jamshidi, M 2009). Any order is the origin of the first critical value when it first appears and then defuses toward the edge of chaos. The melting zone is another definition of the 'edge of chaos', and both describe it as the state where heterogeneous events are interacting in the phase that is named second critical value. Simultaneously, first and second critical values exhibit the same state of electricity consumption by end-users; at households. First, significant value emerges at the start when a consumer separately uses different appliances. The second critical value arises when electricity consumption for using these different appliances interacts and exhibits the instantaneous consumption present in a non-linear dynamic shape.

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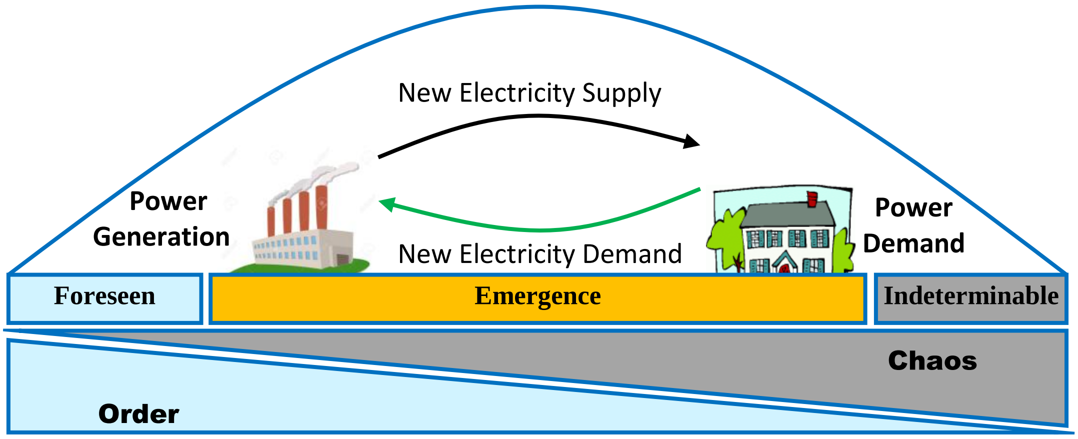


Figure 4.5: Emergence, Order & Chaos

Thus, emergence may possibly occur along the grid system, starting from generation, passing through transmission and then into distribution areas. However, emergence becomes hard to manage and predict on the demand side where end-users locate, as presented in Figure 4.5. The following typical examples of emergence in a grid system happens every second when end-users consume electricity at different capacities:

- End-users' consumption of electricity varies frequently as with all individual consumers daily, and hence it is difficult to predict the accurate daily demand of consumers at certain times of the day.
- The inherent mismatch between the power generation and the load timely created by end-users leads to significant energy wastage which reduces safety, increases pollution and diminishes energy security.
- End-users cause Peak demands (P) of electricity which create a dramatic increase in fuel use that increases gas emission and losses of energy and affects the environment.
- End-users cause Off-Peak demands (OP) of electricity which create a dramatic increase in fuel use, that increases with low generation power and which then increases gas emission and losses of energy, and also affects the environment.
- The emergence of end-user demand leads to insecurity of electricity supply.
- Insecurity of electricity supply is unable to keep up with ever-increasing demand.
- Insecurity of electricity supply is unable to keep up with the fight against climate change.
- Insecurity of electricity supply is unable to keep up with the global trend toward massive urbanisation.

Therefore, the adaptive capability of the grid system should be at its maximum at the extremes or at the ‘edge of chaos’ where end-users demands attack the grid system when introducing their unconscious consumption behaviour for electricity. In this light, at least ten features of the philosophy of emergence are reviewed in this chapter; under which we may think of these as constraint or concepts of varying strength, which are occasionally overlap.

4.9 Emergent Self-Organization

An argument arises about emergent phenomena in complex systems. Cohen, J & Stewart, I. (1994) defined the emergent phenomena that ‘Existence Theorem for Emergence’ which proposed that emergent phenomena could not be expressed except in intractably long deductive chains emanating from their lower level or antecedent conditions’. The micro-diversity of end users‘ consumption is assumed as the fundamental perception of emergents. To create self-organising and self-regulating assets in the grid system. Emergence is a system complexity and no one is able to precisely tell when and where it will happen. All that can usually be done is to provide needed management when it appears in the system. “This, however, turns out to be less a question of how to anticipate the downstream processes of emergent self-organisation than of how to predict the upstream scalability dynamics that drive these” (Andriani, P & McKelvey, B. 2009).

Organising capability is realised on the adaptive tension of emergence and connectivity with positive feedback to preserve the scaling up process of TIEs and to deliver desired outcomes (Schumpeter, J, 1934); (Andriani, P & McKelvey, B. 2009). The function of self-organisation can be described as the emergent collective behaviour when any dynamic linkages provide a self-organisation mechanism for the purpose of interaction with a society of rational agents (P. T. Welch, F. R. M. Barnes and F. A. C. Polack 2006). Homes as we all know, have dissimilar electricity consumption and to reach self-organisation mechanisms, these homes must be strongly similar in growing mechanism. This condition may be reached when the agents in a system seek self-interested goals. Residential homes have recursive demand that would allow us to provide recursive organisation and build complex adaptive systems at various levels of the grid system (Namatame, Akira ; Sasaki, Takanori 1998).

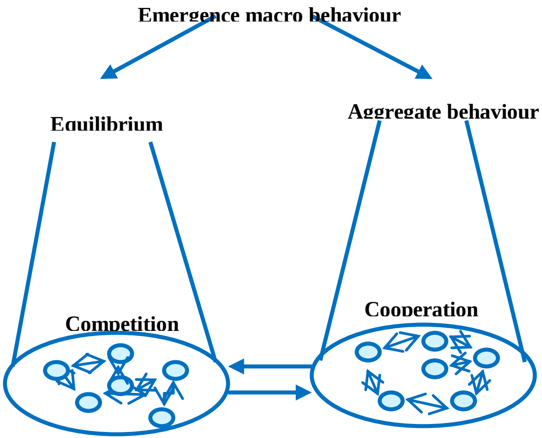


Figure 4.6: Emergent Properties in a Society of Rational Actors/End-Users (Namatame, A; Sasaki, T 1998)

The finest graining of non linear dynamic behaviour in an electrical grid system can be revealed exactly at the time end-users are using their appliances and consuming electricity. More importantly, it seems that the behaviour of end-users is creating very important information, which leads to design a future state. The complexity theory view on the perspective of coherence, path and speed of those emergents sees that processes are influenced in nonlinear ways. The influence is likened to the concept of a container holding agents together although they are different, all transfer information and material and create patterns and motivations for exchange and change, as illustrated in Figure 4.6 above (Eoyang, G, 2001). Agents in complex systems produce intrinsic emergences that oppose the end-users' emergence as a result of their behaviours. Solutions against emergence come from analysing a retrospective picture and then building prospectively informing action that influences system change. Adapting turbulent change is ambitious, and the challenge suggests the capacity of adapting the right action at the right speed to preserve the system's stability, which is not yet clear.

4.10 Emergence is a naturalistic phenomenon

Emergence is created only due to natural factors that lead to a causal role in the different phenomena of mind and life, as presented in Figure 4.7 (Richardson, R.C. & Stephan, A. 2007). The fundamental point requires an understanding of naturalism that is something featured with no unnatural entities or supernatural powers. Thus, the structure of emergentism could have a philosophical component, but its falsity or truth is not that of a philosophical thesis. Residential households subliminally emerge their timely demands for consumption that be countered by also subliminally emerging (in the case of undesirable homes' emergence), but this time the new emergence should intentionally be from house components that promote the concept of a bearable selfhood to achieve a particular goal (Forche, C. 1999).

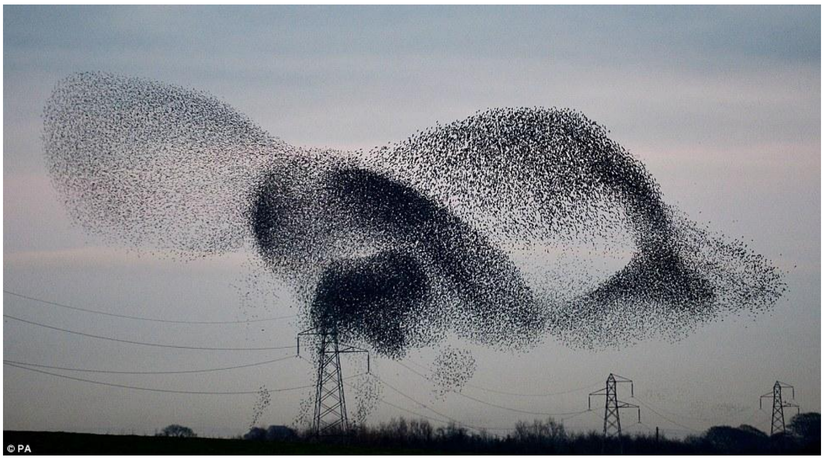


Figure 4.7: Emergence of flock of birds (Google 2017)

4.11 The novelty of emergent properties

Novelty is assumed decisive to emergence. Two substances of chemical combination deliver, as is well known, a third substance with properties varying from either of the two substances (Biggiero, L, Angelini, P.P, Basevi, M, Carbonara, N, Mastrogiorgio, A, Pessa, E, Sevi, E & Valente, M 2016). This leads to the statement that the emergence of a new quality from a level of existence denotes that the same level has a particular collection or constellation of the motions related to that level. Thus, although some emergent properties are only defined as novel, and nothing but, the emergent properties of any object are probably unique in that they are not symbolised by any of the objects' proper components (see Figure 4.8).

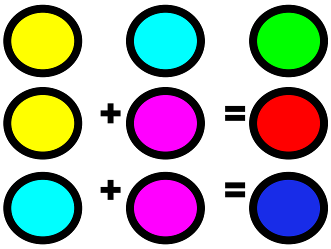


Figure 4.8: Complexity has different Features from a Composition of a System

Once a particular property (Z) is the result of some elements of a system, or, if no part of a system possesses that particular property (Z), then (Z) is emergent, collective, systemic or a structure of a type of novelty that is not adequate for emergence. A property is described as novel once all proper parts have determinates of the same determinable. Whereas some of the proper components have conscious features, not all of them do. Thus, with novelty, consciousness is not restrained from being emergent. The obstacle now, however, is that since novelty is essential for emergence, then there is no longer an interesting sense in which emergent properties are novel. The consciousness of electrical grid systems and be alive are novel, but so, overly, are a broad diversity of running electrical grid properties (Francescotti, R.M. Erkenntnis 2007).

Advocating emergentism through appeal to novelty is a ubiquitous task because in many cases it cannot be conceptualised as an evolutionary task. The perspective of novelty need not be a temporal claim, though certainly there are evolutionary novelties. Thus, what is at issue with the concept of 'emergence' is a temporal novelty (Richardson, R.C. & Stephan, A. 2007). For this reason, it often comes across as saying that the properties of emergent cannot be derived from or explained by the more fundamental properties. Emergence in a way may not have been addressed or noted as a relationship that speaks directly to the transition from systems thinking to complexity thinking (Polany, M., 2007). With this perception, there is something more to say about the 'novelty' when it is spelled out with enough clarity, when more complex entities exist. Thus, more complexity (electrical grid system) reveals very different features from those assumed to be a composition of a system (i.e. single residential consumers of electricity).

4.12 Emergence Enabling Systematic Properties

The Electricity demand of consumers involves the systematic properties of a grid system (i.e. generators, transmission infrastructure, distribution networks, monitoring systems, suppliers and retailers); these properties are irreducible and typically novel. It is, of course, not a matter of perfectly systematic properties, but somehow, and in some cases, part of it are unconnected with the properties of constituents, for example,. private retailers changing their business activities, varying usage of some generators due to weather conditions, developing infrastructure in some areas rather than others. Emergence in such a case will violate the requirement of naturalism. Rather, it is, however, only the features of complex systems that are typically believed to be emergent (Feller, J., Parhankangas, A., Smeds, R., Jaatinen, M. 2013) & (Richardson, R.C. & Stephan, A. 2007). Therefore, systematic properties such as a grid asset might be novel, but could hardly be convinced that all systematic properties are not emergent.

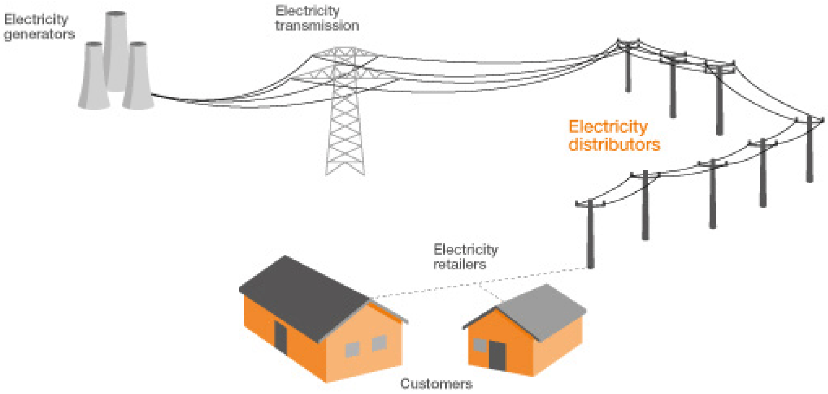


Figure 4.9: Supply Chain of Electricity (Google 2017)

4.13 Are Complex Systems Hierarchically Organised

It may be conceptualised that nature is hierarchically ordered as represented in Figure 4.9, with some characteristics of one single level, and not of any other adjacent levels. This conceptualism may be a somewhat controversial commitment, but the thought in part is that, properties that physics attaches to its fundamental entities are not, in fact, the only properties there are. It is possible that higher level entities possess many of the properties connected to more 'basic' entities, such as physical entities, which, , as do their constituents, have locations in space-time, but some higher level properties are not a part of those constituents, as illustrated in Figure 4.10 (Richardson, R.C. & Stephan, A. 2007); (Polany, M. 2007). A logical implication of a hierarchical structure seems that only a process not manifest at a lower level can cause a higher level to be born and come into existence, a process which thus qualifies as an emergence (Polany, M. 2007). Therefore, it would be obvious that admitting a hierarchical structure to the natural order, such as consumers when consuming electricity, does not entail anything approaching emergence.

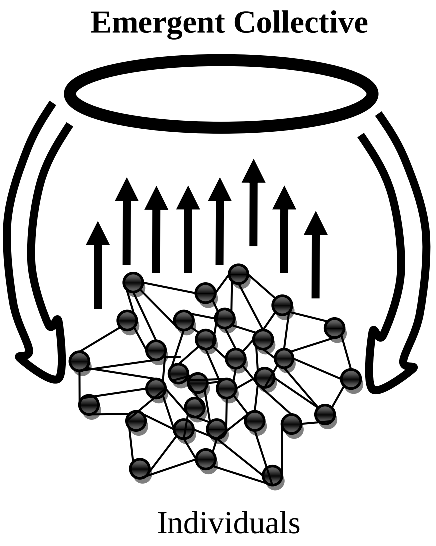


Figure 4.10: Hierarchical Structure of Complex Systems (Polany, M. 2007)

4.14 Emergence is a synchronic determination

This is conceptualised under the term "Supervenience" , that is, the ontological relation to depicting cases where the lower properties of a system are responsible for determining the upper-level properties of a system (see Figure 4.11) (Richardson, R.C. & Stephan, A. 2007). Advocating emergence, the behaviours and properties of a complex system depend on their constituents/parts, and how to be organised, and on nothing else. Needless to say, the significant challenge is 'organisation' (Richardson, R.C. & Stephan, A. 2007).

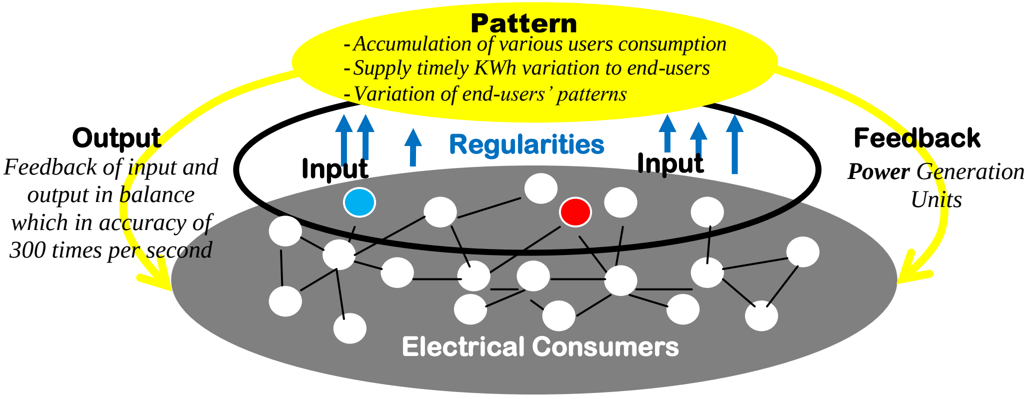


Figure 4.11: Electrical Smart Grid Complex Systems (Richardson, R.C. & Stephan, A. 2007)

4.15 Properties of Emergence are Irreducible

As the consequence of synchronic determination explained above, the question is whether or not systematic properties are fixed by the properties of constituent parts. This condition is met when the organisation, the constituents and the behaviour of a system are invariant (Richardson, R.C. & Stephan, A. 2007). In many cases, the influence of higher level entities (i.e. electrical suppliers, and electrical retailers) brings relatively inconsiderable results to the properties of components which then lead to the fact that the self-organising characteristic are insufficient. Thus, involving the ‘synchronic determination’ of higher level properties cannot be defined as an “emergent” because these properties ‘of higher levels’ (power plants, environmental involvements, Governmental regulations, rules and decisions) do not appear to be an outcome of lower properties’ components.

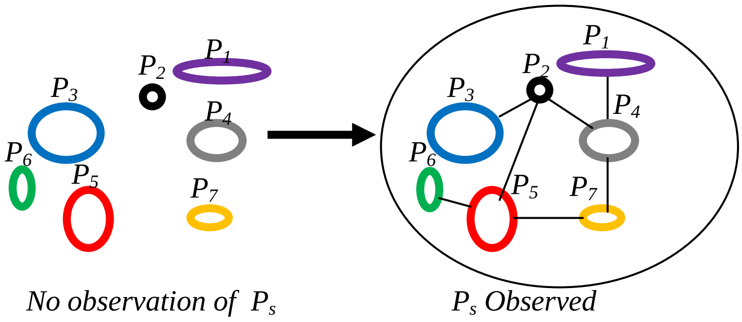
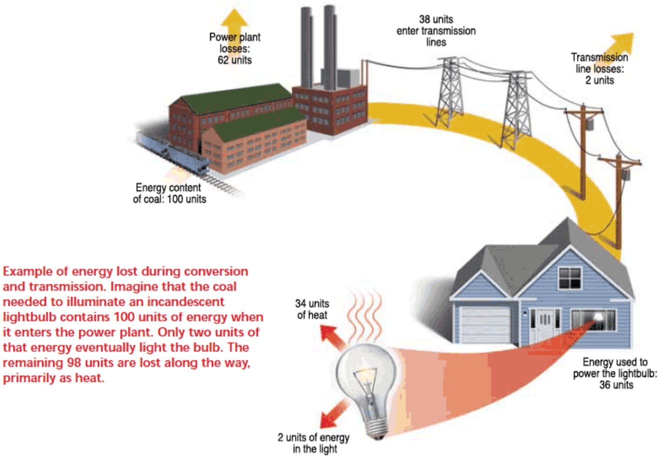


Figure 4.12: Properties of Emergence are Irreducible (Richardson, R.C. & Stephen, A 2007)

Giving sense to ‘emergence’, the feature of systems’ self-organising is not a consequence of the properties of the constituents. It looks to be for this reason a matter of ‘configurational’ properties (an arrangement of elements in a particular combination, form, or figure) that are fundamental to emergence (Richardson, R.C. & Stephan, A. 2007). Perhaps, defining configurational property as ‘required’ should be without a default value since the impact of the application appears to function, that is, different consumers have different consumption trends then they need different configuration, as shown in Figure 4.13. Overall, ‘Emergent’s’ are committed to the ‘irreducibility of properties or systemic behaviour. Thus, the message that originates out of this is that complexity drives from the recognition of an irreducible element of uncertainty in societal systems and an actual limit to knowledge about the future (Allen, P 2016).

4.16 Systemic Emergent Behaviour & the Principle of Non-Deducibility

What may not be deducible is not reducible, and suited for irreducibility. For now, it may suffice to assume that a systematic property would be irreducible from a macro picture view of a system in which this view or property of a system is unable and not sufficiently analysable in terms of what is suited/needed for a system‘s constituent properties (Richardson, R.C. & Stephan, A. 2007). The simple answer is because the behaviours of a system components are primarily differing when revised in isolation. The electricity used to operate appliances in homes cannot be pulled out from people’s consumption base (see Figure 4.14). Common sense considers these natural demands as commonly opposed to a reduction in the energy losses in the grid, as well as, the fact that it is also opposed to the financial budget for using electricity that people have at their disposal.



Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent lightbulb contains 100 units of energy when it enters the power plant. Only two units of that energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.

Figure 4.13: Systemic Emergent & The Principle of Non-Deducibility (Google 2017)

4.17 The Principle of Emergent Properties are Unpredictable

The non-deducibility principle is a more emergent demanding condition than those previously mentioned. It does not matter if we could predict the evolution of emergent properties before the fact occurs (Richardson, R.C. & Stephan, A. 2007). Referring to the composition and organisation of a complex system property would be a predictable matter, and able to predict further properties other than that the system will exhibit. However, this fact never shows that we are able to predict the properties of any complex systems from first principles (Richardson, R.C. & Stephan, A. 2007). Thus, systemic properties are possibly dependent on constituent properties, but the important question is whether the configurational properties, and organisational properties are straightforward consequences of the system constituent properties. Certainly, organisational and configurational properties are predictable in a harmless and neutral sense when the problem of a complex system are well-reviewed by taking into consideration the above perspectives.

4.18 Emergent Properties in terms of Upward & Downward Causation

An emergent property is not ‘epiphenomenal’ that has a secondary effect that are not causal affect a process. The criteria of emergent properties has novel causal power as well as causal power. The novelty exists in the sense that it is distinct from the causal powers of the objects’ components when taken in isolation from the whole (Francescotti, R.M. Erkenntnis 2007). This involves the emergent property has a novel effect in being discrete from the influence of the systems’ components when taken in isolation from the whole. Overall, the concept of an emergent property appears to imply something stronger than diachronic downward causation (Macro – Micro view). However, upward determination (Micro-Macro view) fits perfectly to be compatible with the emergent property and causes the greatest influence on the properties that its parts simultaneously will be the same at some later time (Francescotti, R.M. Erkenntnis 2007).

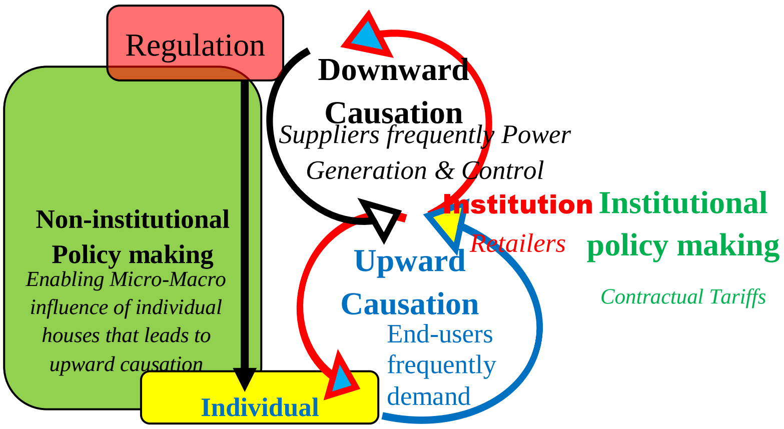


Figure 4.14: Emergent Properties Based on Upward & Downward Causations (Glückler, J, & Lenz, R 2016)

The state in Figure 4.15 above is the most controversial among all of the above conditions. A system with emergent properties will apply an influence on the behaviour of the constituents (Blee, K. 2013). Here, the emergent commitment will conflict with the naturalism requirements (Richardson, R.C. & Stephan, A. 2007). If higher levels of system self-organisation matter to the behaviour of components/constituents, then whatever be offered from higher to lower levels will be wrong or incomplete; at least to some of these constituents in lower levels. Insofar as emergent theory fails to prove the downward causation (top-down approach), the upward causation (bottom up approach) is still valid. However, I will assume that these are two broad classes of emergent cases that conversely claim to exhibit emergence (Richardson, R.C. & Stephan, A. 2007).

4.19 Rationality Appeal

Rationality is crucial to emergence, and causal relations might be assumed particularly important when cannot be clarified only from the elements, compositions and environmental relationships (Blee, K. 2013). However, they can be clarified in terms of the causal interactions among the actors/elements. Thus, it fails to highlight the relationship over the rationality; it does lead us nearer to understanding what we have to do with relational properties of the objects' components. Here, there are ?expectations that some special types of rationality are crucial to emergence. Referring to the idea that the whole is something greater than the sum of its parts, then what specific type of rationality might that be in the case study of electrical grid systems, the residential consumers of electricity (lower level) have different properties. These lower levels aim to secure their supervenience (lower levels determine the upper properties in a system) and will surely include relations that the parts (consumers) unconsciously bear to one another, and also certainly, the parts (consumers/ houses) bear to the whole (Grid System), and vice versa (Francescotti, R.M. Erkenntnis 2007).

4.20 In Few Words: Full view Upon Emergence

The purported unpredictability phenomena are influenced by the characteristic of emergent phenomena which are the result of a randomness combination into a new construction (Allen, P & McGlade, J 1987). From the above discussion it is found that to construct a full view of emergence then four essential, fundamentals are required: Building small-scale blocks which represent individual consumers/end-users of electricity; Secondly, utilise constructional operations to satisfy each scale block of each end-user in the electrical grid system; Thirdly, tasks of constraining and containing need to be provided down to tiny blocks; Fourthly, confront the anonymous aspect of end-user behaviour in the grid system by taking into consideration the provision of a simultaneous transcendence process where continuously suits the variability of micro-systems (Goldstein, J 2006); (Ehresmann, A.C. & Vanbremeersch, J, 2007).

4.21 Self-Organisation

Self-organisation is not a newly discovered phenomenon, but almost as much of a "buzz word“ nowadays as complexity (Corning P. 1995); (Mancuso, Peggy; Liu, Fuqin; Restrepo, Elizabeth; Hamilton, Patricia; Grigolini, Paolo & Zou, Lin 2016). Self-organisation is defined as the process in the search for evaluating the largest probability of a macro-state (Lozneanu, Erzilia ; Sanduloviciu, Mircea 2006); (Engelen, Guy 1988); (Arena P, Caponetto R, Fortuna L, Rizzo A, La Rosa M 2000); (Yukalov V, Sornette D. 2014). Assuming residential houses as a self-organising adaptive system that gives rise to dynamic patterns to amplify an event until it becomes a mass order to make a significant effect on the grid system, either positive or negative.

In the description of the above case by Andriani, P. & McKelvey B., (2011, p. 108) it is seen as something that science can study and on which it could build a new model on the ways in which to try to anticipate it. Despite the fact that the current science still lacks the capability to precisely predict events, from TIEs to higher scalable levels, but is able to build interdependencies, these may be achievable in electrical smart grid systems. The intuition of both authors mentioned above, relies on a Paretian point of view as being considered more realistic to represent the case of the social dynamic, of which end-users in electrical smart grid systems are an example.

Complex, adaptive systems are challenging to control because their feedback mechanisms make it difficult to predict the effects of perturbations (see Figure 4.16). A system falls into a critical state not only via external influences affecting its stability. It is known that some endogenous processes can automatically drive the system towards a critical state, where an avalanche or cascading effects of arbitrary size appear.

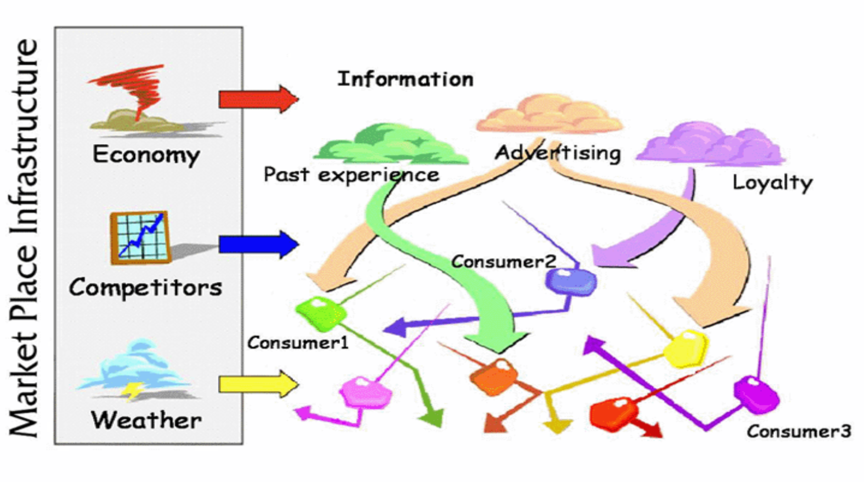


Figure 4.15: Some Characteristics of a Complex Adaptive System (CAS)

Self-Organisation systems apply the principle of forming a new structure through a Nonequilibrium phase transition and can be defined as the evolution of a system into an organised form, in the absence of external pressures (Arena P, Caponetto R, Fortuna L, Rizzo A, La Rosa M 2000); (Corning P. 1995); (Prokopenko M 2009); (M. Viroli, J. Beal, F. Damiani & D. Pianini 2015). Because of its distributed character, this organisation tends to be robust, and resisting perturbations. The self-organising dynamics of a system is typically non-linear, because of circular or feedback relations between the components. Non-linear systems, such as the consumption behaviours of end-users, have in general several stable states, and complex philosophy tends to increase these numbers of stable states at an increasing input of energy pushes the system further to optimum levels (Engelen, Guy 1988); (Dixit, S 2004). Amplifying and adapting along with a changing environment, the system needs to use a variety of stable states that are gleaned from complexity philosophy that are big enough to react to all disturbances, but it are limited so as to avoid its evolution be uncontrollably chaotic.

Practically, the basic mechanism underlying self-organisation is understood as the noise-driven variation which explores various spontaneous behaviours in the system's state space until the local system enters a new attractor. This micro-local action bans further variation outside the attractor, and thus restricts the freedom of the system's further variation outside the attractor, and in turn, limits the freedom of the macro system's components to behave interdependently (Macarthur, B. D.; Anderson, J. W. 2014). This is equivalent to the concept of either an increase in coherence, or a decrease of statistical entropy, that defines self-organisation. 'Self-organisation' is also interpreted as the process of decision making carried out by a complex system (Arena P, Caponetto R, Fortuna L, Rizzo A, La Rosa M 2000); (Yukalov V, Sornette D 2014); (Lozneanu, Erzilia; Sanduloviciu, Mircea 2006).

Another definition of self-organisation, offered by Prokopenko M (2009) is that self-organisation of residential homes captures three main aspects relevant to artificial life. These characteristics assume that the system has many interacting consumptions of electricity in homes. Such a system dynamically advances from a less organised state to a more organised state, for some time, during the exchange of energy and information with the environment and the grid (Prokopenko M 2009). This assumed an organisation at micro levels is manifested via macro coordination, and the macro behaviour of the system is a result of the interactions of proposed self-organised homes. Therefore, the achieved macro pattern is not imposed on the system by an external ordering influence (M. Viroli, J. Beal, F. Damiani & D. Pianini 2015). The reason that the assumed houses whose behaviours and properties are defined prior as self-organisation, have only local information of their own, and do not have the knowledge of the Macro-state of the system.

In light of this, the self-organisation process involves micro organisation transfer to Macro levels (Arena P, Caponetto R, Fortuna L, Rizzo A, La Rosa M 2000); (Prokopenko M 2009); (Lozneanu, Erzilia; Sanduloviciu, Mircea 2006). Conclusively, self-organisation is a circular process for a specific system, which acts when certain causes occur in that system and needed 'self-organisation' causality which occurs in different homes, forming micro levels and are tangled hierarchies with macro levels exhibiting 'strange loops'. These loops importantly create circular causality between micro and macro levels which lead to stable behaviour.

The different studies the research have reviewed have uncovered some key signatures that distinguish self-organising systems from the more traditional systems studies. Some of these traits, such as the absence of centralised control, are shared by all self-organising systems, and can, therefore, be viewed as part of what defines them. Other traits, such as continual adaptation to a changing environment, will only be exhibited by the more complex systems, distinguishing, for example, an ecosystem. Societal and economic forces can shift the grid system to near a critical point that in many cases need long-term displacement into self-organising means (Dobson I, Carreras B, Lynch V, Newman D 2007); (Georgiev, Georgi Yordanov 2012).

4.22 Power Laws & Pareto Approach

Electricity demand requires great effort to reduce the influence of consumer behaviour, which refers to the long demand experience and this solution will not well-adopted by consumers. Thus, historical data on consumers and the purchasing history of electricity are needed to review the best scenarios to achieve the needed outcomes (Jella Pfeiffer, J & Scholz, M 2013). Multi-objective optimisation (MOO) may be defined as Pareto optimisation, is an area of multiple criteria decision making, involving more than one objective function to be optimised. Pareto aims to trade-off between more than one conflicting objective, for example, minimising losses of energy while maximising performance of the grid. The Pareto approach may help to maintain a more relaxed demand side management of homes' systems and provide higher grid performance. Another key aspect to remember is that Pareto approaches are proposed to solve multi-objective scheduling problems (Chiuh-Cheng, C, &

Wei-Shung, C 2010); (Qiang Meng, Hooi Ling Khoo, 2010); (Xundi Diao, Heng Li Saixing Zeng, Vivian WY Tam, Hongling Guo 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

Andriani, P. & McKelvey B., (2011, p. 95) arguing that the reality is not centred in the average of the results, and it sounds as being centred in the extremes that practically contradict. In this sense, Andriani, P. & McKelvey B., (2011, p. 95) assume that more valuable solutions might be achieved when they connect with the real problems related to ‘Power-Law Science’, which leads to a similar meaning as that of Pareto-based science. Andriani, P. & McKelvey B., (2011, p. 95) ended their comparison with a question: “How does the study of PL science contribute to practitioner-relevant academic research and the practice of management?”. This question tries to establish a new path and to build an approach that sheds light on the scalability process and on extreme events that are induced by Tiny Initiating Events (TIEs).

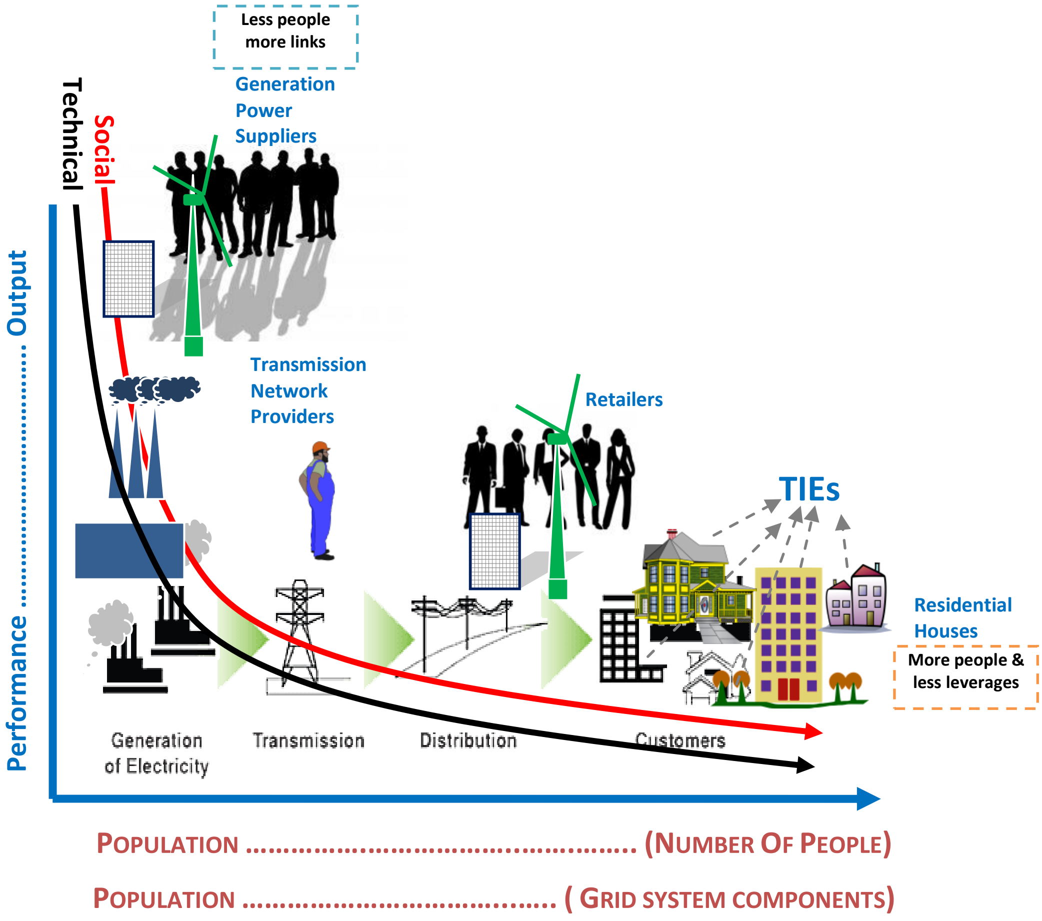


Figure 4.16: Paretian Distribution of Electrical Smart Grid Systems

The ubiquity of Power Law activities still exists around the industrial world. Pareto-driven ideas are still valid to build new models and frameworks to make sense of the emergence of Power Laws or what is known as scale-free theory. Conceptualising new models assists in recognising the living frequently Paretian changes in thinking and in providing solutions based on the practices in our Paretian world, as illustrated in Figure 4.16.

People with technologies gave rise to a more complex world which behaves according to scale-free dynamics and indicates the existence of power laws (PLs). The Power Law is built to bind two quantities and to define their functional relationship when a relative change first happens to one of them. Accordingly, the relative proportional change in one of those related quantities leads to change in the other. Following this, one of the two initial sizes of quantities will take the initiative to make its independent change, and then the change maker of quantity will power the other one.

Inhomogeneous behaviours have ubiquitous PLs in many aspects, such as music, coastlines, populations and other similar entities' that they collectively affect to characterise, for example, hurricanes and earthquakes. Power Law phenomena are explicit in rank/frequency (R/F) relationships and appear to occur when the system's tension and exists and its connectivity is dynamic. Power Law might be defined as a natural attractor start from normal to perform PL distribution. In the Power Law, they are two extremes capturing the distributions that make the whole system between them. The two extremes in a system seem to be the whole entity in any system which forms the ends/extremes are the source of the natural attractors in a limited variance phenomenon. It is right to say that Power Laws are forming a natural attractor for independent phenomena which relies on scale invariance or scale fractal.

Decentralising the nature of end users' demands in an electric smart grid system is a complex behaviour and more related to the Paretian approach. We focus on visualising the perceived internal and external locus of causality in electrical grid systems and define whether controllable or uncontrollable end-users provide the solutions to electricity issues and failure. The proposed vision by authors widens the distance between the nature of any reality and a Gaussian Approach since it always counts for averages results. As regard to Pierpaolo Andriani & Bill Mckelvey (2011, p. 90), the Gaussian and the Paretian strategists are not the same in their view of the probability of human events. The initiative of interdependencies exhibits signs more related to Paretian dynamics and power laws (PLs) (Andriani P. & McKelvey B., 2011, p. 94); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

4.23 End-Users Demand & Supply chain management of electricity

In an electrical smart grid system the demand of end-users are proposed as autonomous agents which must meet with approaches of multi-issue negotiations. However, empirical evidence assumes that autonomous agents, often what end-users in grid systems are, also often fail to formulate possible joint gains and finish up with inefficient system. Therefore, different strategies must be implemented to mediate these different indirect relationships of end-users of electricity to support them in reaching an efficient outcome that is desired from a macro perspective (Minyi Li, Quoc Bao Vo & Ryszard Kowalczyk, 2014); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

Supply chain management of electricity as visualised below in figure (19) is viewed as a timely integrating power generation, transmission and distribution in a number of substantial deterministic processes, to resolve an uncertain demand from end-users (K, J. J, D, G. S, G. A, Soumya, B & Partha, D. 2011). The nature of electrical smart grid systems enforced to take instantaneous activities of consumers into consideration and at the same time, as shown in Figure 4.17. Therefore increased demand agility is required to remain optimal against energy losses and to respond to timely changing behaviours of end-users. In this sense, end-users/homes demand and exhibit one of the most essential phenomena to be traced and controlled by governmental policies and standards.

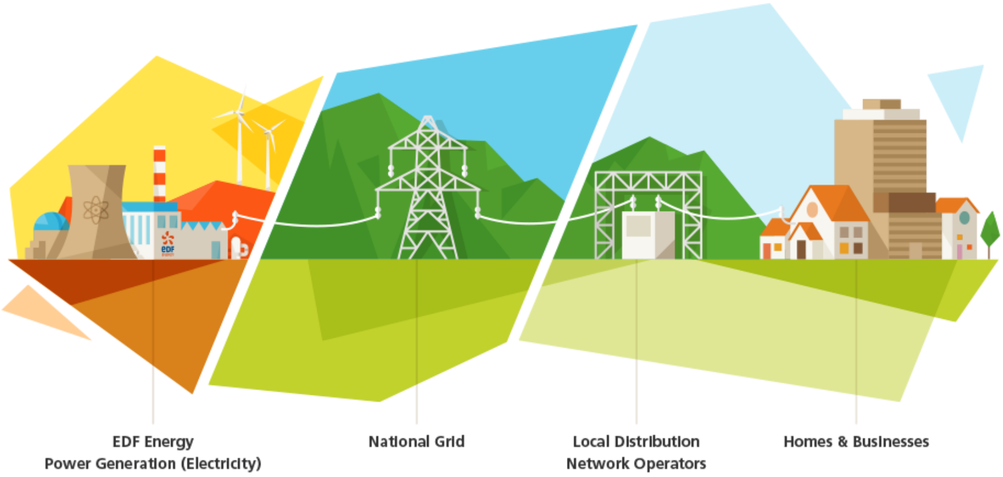


Figure 4. 17**: Supply Chain of Electricity (EDF Energy 2017)**

Intuitively, population based analysis reflects facts upon a natural human environment to support solutions that learn to decompose the overall task between these multiple individuals or a group of electricity end-users. It is most important to define the proposed framework in which evolving the end-users of electricity must not be arranged so as to set up specific processes that aim to secure help from pre-specified sources. For example, if one has a bakery and another has an ice-cream factory, then we cannot install fire detectors with the same specifications in both because one factory‘s normal temperature may mean ‘a fire’ occurs in the other place. However, a good procedure is to fight a fire relative to the nature of the place without applying the same rules to multiple locations , which is unlikely to result in success or in cooperating individuals (McIntyre, AR, & Heywood, MI 2011). To reach such a goal, each end-user/home evolves a mapping to a distribution of outcomes that, follow clustering. To do so, establishes the parameterisation of Gaussian separate homes functions (McIntyre, AR, & Heywood, MI 2011). This presents an opportunity to present each consumer demand task and example of the worst circumstances, where the overall task is to control the difference classifications of end-users through the controlled learning domain (McIntyre, AR, & Heywood, MI 2011).

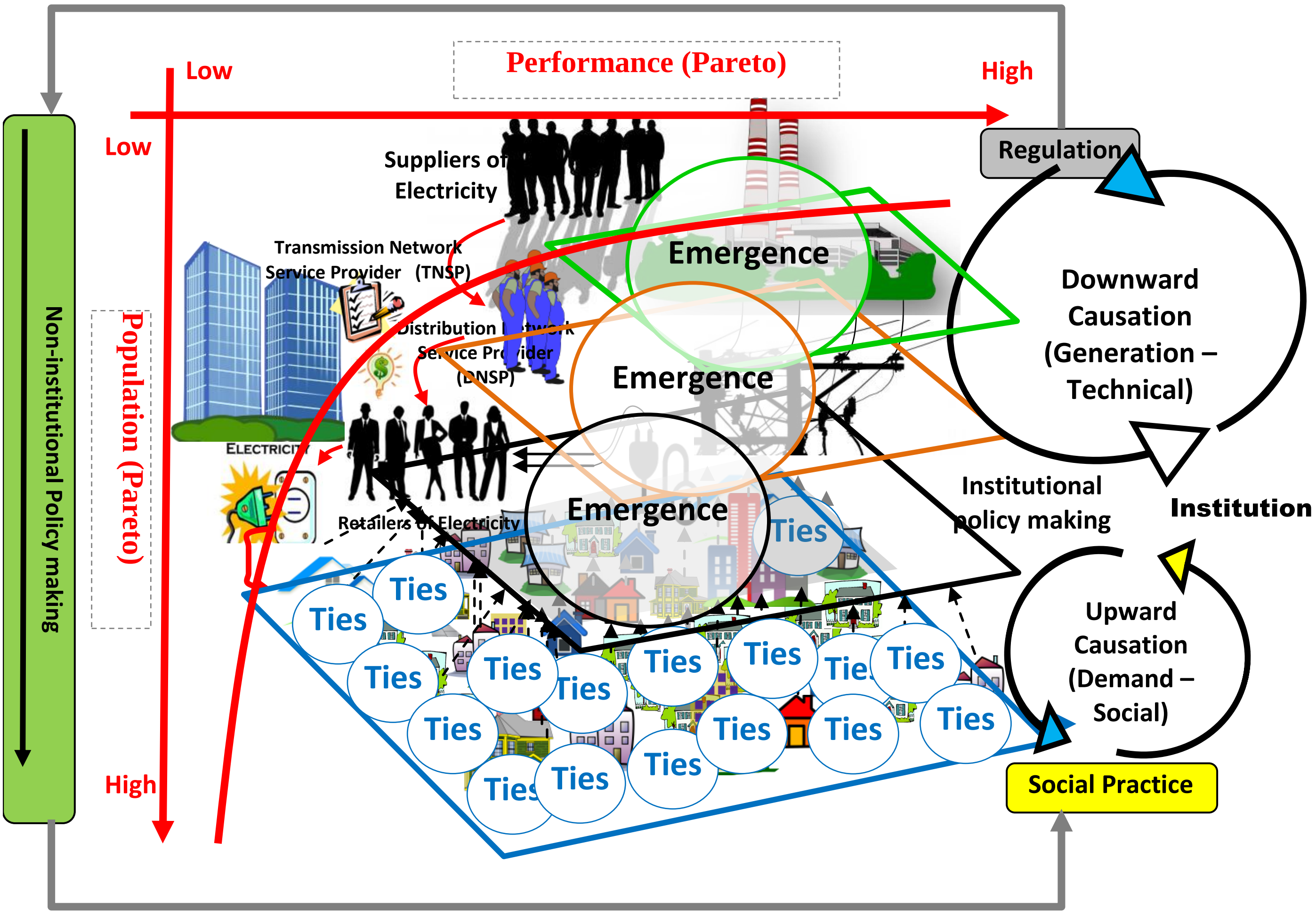
General underlying motivations for pursuing the concept of a problem decomposition might contain scalability to more difficult domains, and help individuals/end-users/single houses with a lower level of complexity than could be apparent under a macro single classifier per class model (i.e. a region, a city, a state, a country) (McIntyre, AR, & Heywood, MI 2011). An ensemble of different end-users has a great influence on the macro level of any system, therefore it must be ensured so that each one of these users provides a learner who responds to his/her differences and to the particularly uniqueness of that case (McIntyre, AR, & Heywood, MI 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

From a contrary point of view, work on teaming or at a macro levels assumes that all the individuals are a single population in which each individual then consists of a fixed category, the same for each consumer/end-user (McIntyre, AR, & Heywood, MI 2011). Thus, each individual explicitly contributes to the macro demand of electricity, and then a linear combination of a group of people‘s responses is generally expected. A particular problem can be specified when each end-user/home contributing to a particular distribution area is naturally uncorrelated (McIntyre, AR, & Heywood, MI 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011). The reason for this is that the fitness of individual home/end-user seems to follow the weak learner methodology in which all models contribute to create the macro demand for electricity Thus, the principle of ‘divide and beat’ through grouping is supported, but we should not deny that each home is established out of a single complex interaction prior to developments between multiple individuals (McIntyre, AR, & Heywood, MI 2011). Overall, ensemble cases of consumption usually exhibit a similar constraint, but definitely need different management approaches to manage their individual behaviours (McIntyre, AR, & Heywood, MI 2011).

Unfortunately, as the dimensionality of the demand management problem increases, so does the size of the Pareto set. It then becomes prohibitively time consuming to study every single Pareto compound in more detail (Kurt L, Stefaan C & Veronique V. S. 2013). Most of previous studies have therefore tried to reduce the number of candidates even further, with only a few of them offering a quantitative ordering solution (Kurt L, Stefaan C & Veronique V. S. 2013). This study, on the contrary, proposes a quantitatively founded procedure that attempts the ranking of the Pareto compounds, subsequently defining the most optimal compromises with respect to the appropriate design requirements (Kurt L, Stefaan C & Veronique V. S. 2013).

A Pareto ranking view that illustrated in Figure 4.18 is assumed with an existing explicit archiving structure of end-users demand data set to create a diverse collection of non-dominated solutions as the result. These proposed collections of non-dominated solutions can only be achieved from single homes at micro levels of electricity, which is difficult to achieve at macro levels (McIntyre, AR, & Heywood, MI 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011). In this sense, specific algorithms are nominated in terms of the approach taken to their ranking categorisation, maintenance of diversity, and attempt to avoid and prevent solution losses (McIntyre, AR, & Heywood, MI 2011). These objectives are usually conflicting since maximum demand coverage must be covered, while maximum optimum connectivity is desired while minimising the electrical network energy cost (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

When all of these elements are considered, it seems reasonable to propose that, rather than looking for a holistic solution representing the entirety of consumers, it is better to consider end-users and their houses which are free to present unique demand subsets within the overall control task. The Pareto competitive coevolution framework and other discussed approaches (please see figure [20] below) support this mechanism for scaling to potentially large, unequal and unbalanced demands of end-users' houses (McIntyre, AR, & Heywood, MI 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011). Solutions aim to provide a good balance between electrical smart grid performance and end-users'/houses' models of complexity, particularly as the number of consumers increase.



TIEs: Tiny Initiated Events (TIEs) express on the timely use of home electricity appliances Emergence: TIEs leads to Timely Emergence of Residential Demand which massively influence on the bidding prices & the whole Sale of Electricity.

Figure 4.18: Social & Technical Networks of Electricity

4.24 Conclusion

Behaviour categorisation exhibits a widely studied domain, either from the perspective of genetic programming (GP) or machine learning in particular (McIntyre, AR, & Heywood, MI 2011). However, complexity approaches such as those mentioned in this chapter, describe end-users‘ demands as a multi criterion problem which mostly includes both qualitative and quantitative factors. Therefore, in order to select the best solution, it is important to think of the best way to make a trade-off between some intangible and tangible factors, some of which may conflict (K, J. J, D, G. S, G. A, Soumya, B & Partha, D. 2011).

Referring to the discussion in this chapter, controlling the demand side of electricity is occurring while facing a great challenge of consumer demand which exhibits diversity and dissimilarity. This issue is both troublesome and essential to attaining convergence and diversity of solutions (Moslehi, G, Mahnam, M 2011). For large-sized problems, the selection of the best local guide for each end-user of the population from a data set has a great impact on delivering the diversity and convergence of solutions since we know that they are dissimilar consumers (Moslehi, G, Mahnam, M 2011); (Shafaq B. C, Victor C. H, Ratan K. G & Kenneth O. S 2011).

There is an evidence that end-users of electricity, emerge load constraints in electrical smart grid systems. These phenomena of emergence are probably non-linked constraints which may then split the optimal solution into pieces which significantly complicate the solution task (Ebrahimi, J & Abadeh, M. S. 2012). When the unsupervised nature of people‘s behaviours/clustering exist, then it is difficult to evaluate the output since multiple interpretations are needed according to people‘s different behaviours. (Ebrahimi, J & Abadeh, M. S. 2012). Many of the research works in this area of study attempt to improve the clustering outcomes of end-users by employing emerged load constraints (Ebrahimi, J & Abadeh, M. S. 2012). However, most of these constraints are inherent properties which are imposed through daily applications of individual consumers. With that, the possible solution in regard to complex theory most generally takes the form of an individual categoriser per house/end-user. Therefore, in this work, I am interested in pursuing a framework that is able to partition the issue of unstable demand into subsets of categorisers when it is advantageous to do so.

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Chapter 5

Factors Influencing the Formation of Electricity Costs and Prices

Acronyms

AER: Australian Electricity Regulatory

AEMC: Australian Energy Market Commission

AEMO: Australian Energy Market Operator

AES: Australian Energy Statistics

ASIC: Australian Security & Investments Commissions

BREE: Bureau of Resources and Energy Economics

CPI: Consumer Price Index

CSIRO: Commonwealth Scientific and Industrial Research Organisation

DITR: The Commonwealth Department of Industry Tourism and Resources

ENA: Energy Networks Associations

ESI: Electricity Supply Industry

GDP: Gross Domestic Product

IPART: Independent Pricing and Regulatory Tribunal

LRET: Large-Scale Renewable Energy Target

NEM: National Electricity Market

NSW: New South Wales

OTC: Over The Counter

PJ: Peta Joul

PV: Photovoltaic

SFE: Sydney Futures Exchange

ASX: Australian Securities Exchange

TW: Tera Watt

Lessons Learned from Chapters One, Two, Three & Four

These chapters depict complexity theory as a multidisciplinary endeavour comprised of multiple sets of theoretical constructs giving rise to better understanding a complex system, such as that existing in a complex grid system that produces energy in NSW, that is significantly impacted by losses to the system, behaviours of end users and the impacts of peak and off-peak phenomena at the household level, as explored in earlier chapters.

Chapter Outline

1) This chapter discusses the factors that influence the formation of costs and prices.
2) This chapter designates appropriate methods to integrate Australian customers based on their different consumption demands for the peak and off-peak of electricity.
3) This chapter pinpoints the influential nature of consumer behaviour in explaining energy losses and given solutions and their significance for policy and regulatory reforms.

5.1 Literature Review

This chapter presents a literature review that discusses the importance of understanding end-users' behaviour in leading to economic incentive regulations which control the regulatory price of electricity. It explores Possible ways in which to influence the extent of 'pass-on'* and to reduce the overcharging of electricity prices. The chapter connects the philosophy of complexity theory with the economic regulation of the electricity industry operating within a monopolistic market structure, and supports end-users who seek lower costs. The literature review considers electricity smart grid systems through the lens of existing theories of complexity. The review also focuses on advancing previous solutions to grid system problems and constraints (Picard, M & Velautham, L 2014).

** Firms are measuring their businesses based on their ability to recover an increment input costs by increase their own prices, this process recognised in some countries under the name of 'pass-on'*

Given the significance of the electricity industry to Australia's economic performance and as an essential service to the residential community, further research is vital on how to remediate the set of societal causes of energy losses. This is made even more critical if, as the electricity industry is increasingly required to move in the direction of more renewable energy sourced, productivity based methodologies (Chris Sayers & Dianne Shields, 2001).

Currently, the electricity industry still incurs losses for multiple societal, economical, technical and environmental reasons, but societal and environmental reasons dominate (see Figure 5.1). This chapter therefore examines in depth the key societal factors underlying losses incurred by the electricity industry, benchmarking a number for further analysis. The chapter begins with an examination of the relationships between electricity consumers and other stakeholders in the electricity grid system. Therefore, the demand for electricity by consumers is considered most important, after which the relationship is defined between energy losses and consumer behaviour.

Before clarifying the nature of any conceptual models in this thesis, it is worthwhile to comprehend the features of models in general, and how to link them to a theory.

Market or Jurisdiction	Number of Customers	Energy delivered (GWh) (% of NEM)	Maximum Demand MW
NEM	8,940,000	184,400 (91%)	31,084
WEM	973,500	17,400 (9%)	3,400
Northern Territory	74,300	1,890 (1%)	330
Total for Australia	9,987,800	203,690 (100%)	34,814

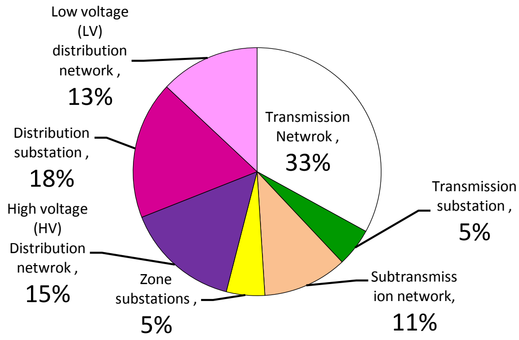


Figure 5.1: Australia-Wide Electricity Per Cents of Total Losses by Transmission & Distribution Subsector, GWh

(Energy Efficiency Opportunities In Electricity Networks 2013)

5.2 Electricity Reliability & Supply Interruption

The house shook once the electricity had gone out as if a powerful wind had gone by or technical issues occurred. Onlookers, consumers, retailers, suppliers and market operators always watch in horror as the blackout took place while technical matters or natural disasters hit the grid. Recently, it has been amazing to see that complex grid systems have advanced so many steps towards sustainability. Previously, the electricity flowed through the traditional grid before the demand side had a chance to use renewable energy to make changes. In this light, attempts at solutions for natural disasters may seem unreachable or hard to manage, but controlling peak demand is extremely difficult, since it is a result of our consumption behaviours.. For this reason, further explanation is needed as to why losses caused by a demand for electricity are very hard to control.

The reliability base on which the the power system components, that is, generation, transmission, & distribution rely, is used to supply electric power to all end-use points. A failure in generation can cover a large geographical area and requires a coordinated response to restore system-wide stability, which may disrupt customer supply (Koc, Yakup, Warnier M, Mieghem, P.V, Kooij, R.E & Brazier, F.M.T 2014, p. 170). A failure in distribution systems frequently causes disruptions on a more localised basis (Chris Sayers & Dianne Shields 2001, p. 133). Generation failure has a bigger effect and leads to electricity supply interruption, which can possibly occur at any time (Sayers, C & Shields, D 2001, p. 134); (Koc, Yakup, Warnier M, Mieghem, P.V, Kooij, R.E & Brazier, F.M.T 2014, p. 170).

Real examples of electricity failures have occurred in Australia, with significant consequences, for example:

- On 23 January 2000, two generating units of 660MW tripped in NSW.
- Bayswater generation unit (660 MW) failed for low boiler airflow.
- Mt Piper generation (660 MW - Delta Electricity) tripped due to DC failure.
- Torrens Island Unit in South Australia & Newport generating unit in Victoria tripped as a consequence of the above failures.
- The loss of generators in SA led to load shedding of small industrial.
- The loss of generators in NSW resulted in load shedding of Tomago Aluminium smelter potline.
- The loss of generators in Victoria led to load shedding of Point Henry Smelter poltine in Victoria.
- Generating units comply with ancillary service agreements with the National Electricity Market Management Company (NEMMCO).
- NEMMCO recover failing systems by sending signals set by reliability panel to maintain the system back into normal operation on behalf of the procedure of Automatic Generation Control (AGC).
- In the 23 January incidents, nine generators were not tripped at the time of the incident.
- Five generators withdrew their AGC ancillary service.
- The result was only 42.5MW out of 250MW were available to recover the failure under NEMMCO ancillary service agreements.

On 28 September 2016, Adelaide and much of the state of South Australia remains in darkness due to a widespread blackout . This outage occurs as a result of a storm damage to electricity transmission infrastructure which resulted in almost the entire state being in the dark and losing its electricity supply for a couple of hours.

5.3 Key Drivers of Electricity Prices Increase

The term “electricity losses“ results when consumers (and retailers) need to buy more electricity from the National Electricity Market (NEM) than is truly consumed by the end-users. Simply, electricity is ‘lost’ as it is transported along transmission and distribution networks and as the result of increased electrical resistance, occurring at peak times. Therefore, the exact benefit would be challenged to control these given electricity losses in such a highly dynamic (electricity) product (frontier economics 2015, p. 10). The losses amounted to approximately 12 billion kilowatt hours (TWh) in energy consumption sector and other 12 billion kilowatt hours (TWh) in transmission lines (World Nuclear Association, 2015).

- Transported (Native) Energy = 50,000 GWHrs* (1 year)
- Total Losses = 1,900 x 2 GWhrs* (1 year), 7.6% of Transported & distributed Energy
- Value of Losses @ $55/MWhr = $210M

Historically, Australia has been distinguished with low electricity prices, until, over the period from 2008 to 2014 electricity prices were increased by over 80 per cent; this massively exceeded inflation. It has been claimed that the biggest driver of these price increases has been the cost of upgrading and maintaining the electricity network to cover end-users' demand, as shown in Figure 5.2 (Australian Government Fact Sheet 4, 2016, p. 1).

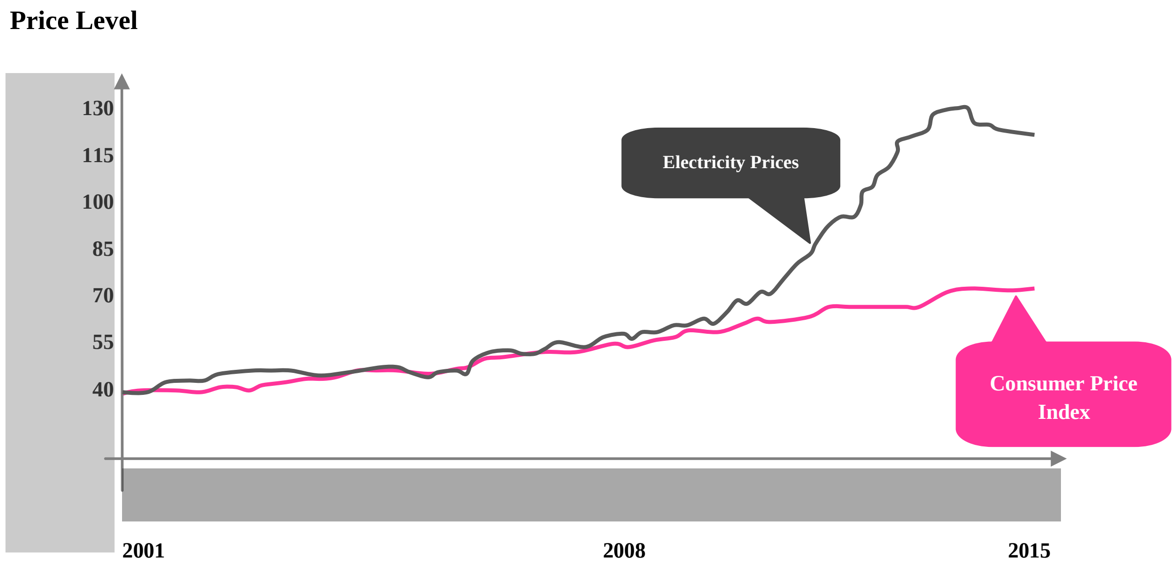


Figure 5.2: Electricity Prices & Consumers' Price Index (2001-2015) (Australia Bureau of Statistics 2016)

The cost faced by electricity retailers is definitely implicit the origin of retail electricity prices and broadly falls into three key features as outlined in Figure 5.3 (Callam Pickering, 2010, p. 1).

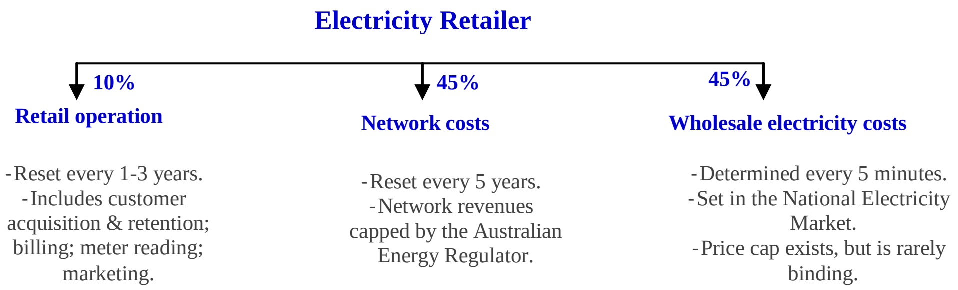


Figure 5.3: The Origin of Retail Electricity Prices (Callam Pickering, 2010, p. 1)

Furthermore, the cost of electricity in Australia and particularly in New South Wales (NSW) is influenced by a number of factors, which always draw attention and concern all stakeholders equally. Either generators or consumers identify these factors as:

- Base load coal technologies;
- Base load gas technologies;
- Lowest capital cost solar;
- Lowest capital cost wind

The consumers of electricity put pressure on the electrical grid system, which leads the operators of this system to create different schemas to deal with the variations in consumers' demands. These phenomena occur instantaneously in all electrical grid systems. Accordingly, the Australian government responded to this issue by creating different electrical tariffs to satisfy different tiers of consumers and achieve the expected financial gain.

The purpose of managing dissimilar behaviours of consumers leads to reducing the costs occurring in power generation stations. These costs from energy losses in the power plants will also lead to reduce other costs in transmission lines from power generation to distribution area where consumers are located. This sort of management will also help to reduce environmental pollution and better managing to solar at homes.

5.4 Future Challenges for the learning curve approach

The price rate of technology does not always diminish steadily with an increase in the number of units produced. Diverse factors may have an effect on the actual slop that may occur to the price of any a learning curve (Brinsmead, T.S, Hayward, J & Graham, P, p. 54, 2014):

- Dramatic improvement occurs in technology structural changes.
- Set of new market forces will arise when price instead of cost data are used to reconstruct the learning curves. Especially when influencing the rate of demand and supply, the prices can easily control, leading to a perceived decrease in the learning rate. This may happen, in the case of changing the way of using renewable energy in residential premises (solar & storage batteries). This happens if the promise of optimal operation is being realised by enabling houses separately to overcome losses incurred of peak operation times (Brinsmead, T.S, Hayward, J & Graham, P, p. 54, 2014).

- Moving beyond the demonstration phase supported by Government policy as well as by research and development (R&D) spending which helps to push new techniques down into the learning curve.
- Component learning by combined demand for electricity at household levels as different rates of learning (Energy Network Association 2014, p. 27). This can result in learning and managing being saturated in one component, which, as a consequence, reduces the losses rate for the grid as a whole.
- The region and the entire country can organise for system learning in regard to local rates that differ from one region to another and from global rates, since uptake of electricity is on a different scale (Brinsmead, T.S, Hayward, J & Graham, P, p. 54, 2014).

5.5 Cost Components of Electricity

Electricity supply has an overall contribution to economic activities which may be examined from the angle that suggests that electricity is consumed as an intermediate input leading to production (Sayers, C & Shields, D, 2001). The term 'intermediate input' implies that a large proportion of the electricity product was consumed to operate its system which reached 19.3 per cent of the total production, as illustrated in Figure 5.4 (Sayers, C & Shields, D, 2001). There are other unavoidable inputs, such as coal, gas and oil account for 32.6 per cent (ABS 2001). Therefore the electricity cost has direct and indirect influence on the market competition by firms.

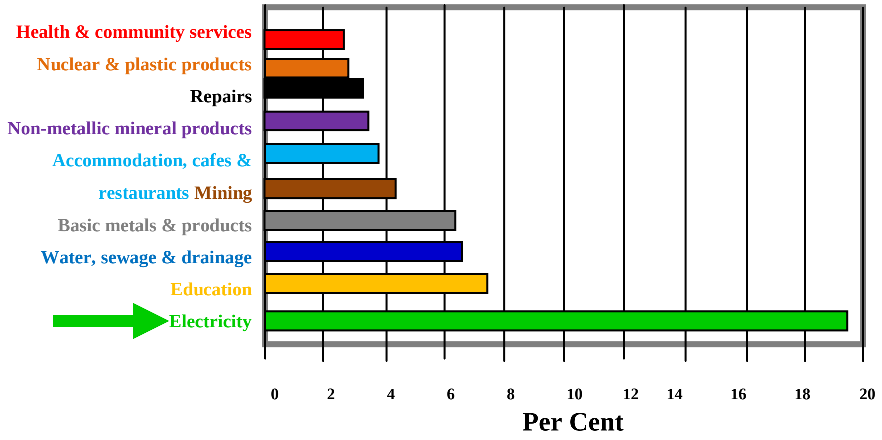


Figure 5.4: Electricity Supply Expenditure as a Proportion of Total Expenditure by Industry (ABS 2001)

The policy of costing consumption of electricity has resulted in segmenting the consumers into three bundles and estimating Indexes of electricity prices. The Electricity Supply Association of Australia (ESAA) is in charge of comparing these prices with Australian electricity suppliers. The expression ‘consumption bundle’ is used here to describe all the defining elements of usage that influence a customer’s overall bill. These categories of consumption bundles may be a residential bundle, a small to medium business bundle and a large business bundle (Sayers, C & Shields, D, 2001). These bundles give information about how prices are varied, in regards to the demand characteristics and based on a different proportion of peak/off-peak consumption (Sayers, C & Shields, D, 2001).

End-users of electricity purchase electricity at negotiated-commercial-in-confidence rates (Sayers, C & Shields, D, 2001). Admittedly, the estimates of contracts are mainly derived from commercially obtainable information on these prices (see Figure 5.5) (Sayers, C & Shields, D, 2001). For this reason, ‘spot market prices’ are justified for future revenue certainty. This is because to infer actual prices must have regard for the premium paid through hedging and entering into long-term contracts (Sayers, C & Shields, D, 2001). This is why end-users‘ consumption characteristics in Australia are defined through multiple consumption bundles which have been costed in cents per Kilowatt-hour. On the other hand, eligible consumers using the price or tariff available over which a particular bundle might receive more than one tariff structure, Receive the lowest cost possible. Thus, typical contract prices will be designed with the purpose of costing the bundles.

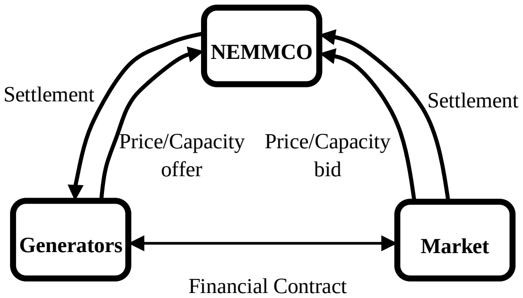


Figure 5.5: National Electricity Market – Settlement of Electricity Prices (Sayers, C & Shields, D, 2001)

NEMMCO: National Electricity Market Management Company Limited

This makes it possible for the, International Energy Agency (IEA) to avoid the problem of modelling consumption demand for different consumers, by using a revenue yield approach to calculating expected average prices. Meanwhile, the market facilitates enough headroom to attract and feed competition (Utility Commission 2010, p. 18). Conversely, there is an issue of non-cost reflective prices which distort the signal to avoid new entrants from entering the market and consumers from managing their demand. Therefore, objections and criticism arising from the price setting model of electricity regulation are valid (Utilities Commission 2010). This is because of either a lack of clear objectives or the existence of conflicting objectives in the price setting schema. It is a chronic symptom of difficulties in determining an efficient and appropriate regulated price associated with the gap in information and knowledge between market participants and regulators. Thus, a more segmented approach for solo houses, which differentiates between them, is likely to appear in this section of my thesis, in an attempt to reform a new tariff and price structure. Thus, it is more likely to occur in this study of my thesis with its more segmented approach for solo houses consideration to differing between them in an attempt to reform a new tariff and price structure.

5.6 Electricity Pricing

The creation of new operation strategies based on the expected costs of renewable energy sources (i.e. storage batteries and solar panels) would be critical to the development of Australia's future energy mix (West, J 2011, p. 13). There is a great deal of criticism in terms of the slow response of policy makers and Australian energy generators in switching to this new energy mix and away from fossil fuels (West, J 2011, p. 13). Such a move must be carefully planned to ensure that the actual cost of a long-term sustainable energy supply avoids being skewed towards less efficient energy schemes (West, J 2011, p. 13).

This chapter identifies the key societal factors leading to losses and their relative significant costs. Further, by describing the pricing factors and estimating their magnitude and relative impact on energy losses with peak and off-peak demands, it is hoped that the research will better support policymakers in taking on board the needed scope of restructuring for the use of renewables in homes. In addition, this research will also contribute to reforming new tariffs to mediate the relationship between all stakeholders to derive an equal advantage from the utilities of electricity.

There are considerable efforts being made to obtain and manage factors that influence the operating costs and the capital of electricity utilities, since no control over them has been demonstrated to date many of them over which have no control yet (Sayers, C & Shields, D, 2001). Electricity is influenced by a large number of factors either inside or outside the electrical industry. To determine the outside effects, it is important to mention factors such as the operating environment, economies in production, government intervention regulations, taxes for economy and environment, and energy losses (Sayers, C & Shields, D, 2001). However, the factors associated with the distribution (demand) and generation (supply) of electricity likely, are the most significant in influencing price differences. The asset of generation and distribution demonstrates approximately 80 per cent of the total cost of the industry (Sayers, C & Shields, D, 2001). Together, these external factors along with the internal factors strongly influence residual price differences.

5.7 Levelised Cost of Electricity

A projection of the levelised cost of electricity (LCOE) has been adopted for the years 2020 and 2030, with and without a carbon price (Thomas S. Brinsmead, Jenny Hayward and Paul Graham 2014, P. 22). An Australian Energy Technology Assessment (AETA) undertook this task under the Bureau of Resources and Energy Economics (BREE) in 2012 - 2013. The projection has involved forty electricity generation technologies in Australia. It takes into account operations and maintenance (O&M) costs for solar and wind to overview a comprehensive assessment of the current costs and its operating predictions out to the year 2050 (Brinsmead, T.S, Hayward, J & Graham, P 2014). The levelised cost of electricity (LCOE) has been calculated in relation to Commonwealth Science and Industrial Research Organisation (CSIRO 2011) estimates in \$/MWh as:

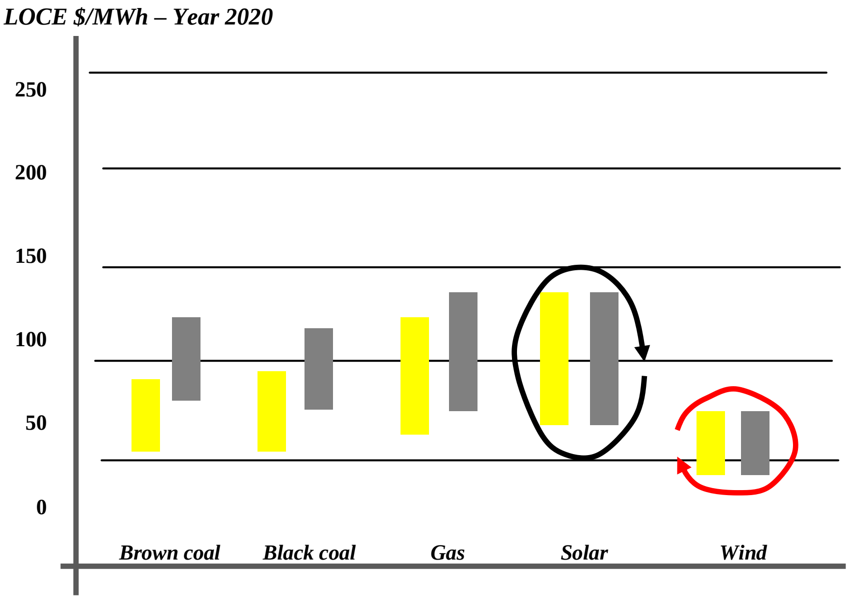
$$\text{LCOE} = \text{KC} + \text{O\&M}_{\text{fix}} + \text{O\&M}_{\text{var}} + \text{FC} + \text{SC} + \text{PC}$$

KC: Capital cost
$O\&M_{fix}$: The fixed cost of operation and maintenance
$O\&M_{var}$: The variable cost of operation and maintenance
FC: Fuel cost
SC: CO2 storage cost
PC: Permit cost when carbon price applies
r: Discount rate
IDC: Interest during construction
eff: The fuel conversion efficiency
emiss: The fuel factor
carbprice: The carbon price

$$\text{KC} = \text{KC (\$/KW)} \times \frac{r(1+r)^L}{(1+r)^{L-1}} \times \frac{1000}{cap \times 8760} + IDC$$

$$\text{O\&M}_{\text{fix}} = \text{O\&M}_{\text{fix}}\ (\$/\text{MW}_{\text{yr}}) \times \frac{r(1+r)^{L}}{(1+r)^{L-1}} \times \frac{1}{cap \times 8760}$$

FC = FC ($/GJ) × 3.6 ÷ eff
PC = emiss ÷ eff ÷ 1000 × 3.6 × carbprice



WITH ■ AND WITHOUT 🟨 CARBON PRICE: LEVELISED COST OF ELECTRICITY (LCOE) For The Year 2020

Figure 5.6: Levelised Cost of Electricity with & without Carbon Price to the year 2020

The figure 5.6 describes the levelised cost of electricity (LCOE) for the year 2020, with and without the carbon price. Clearly, wind technology is provided at the lowest cost, and with a carbon price, solar and wind are less costly than the fossil fuel technologies.

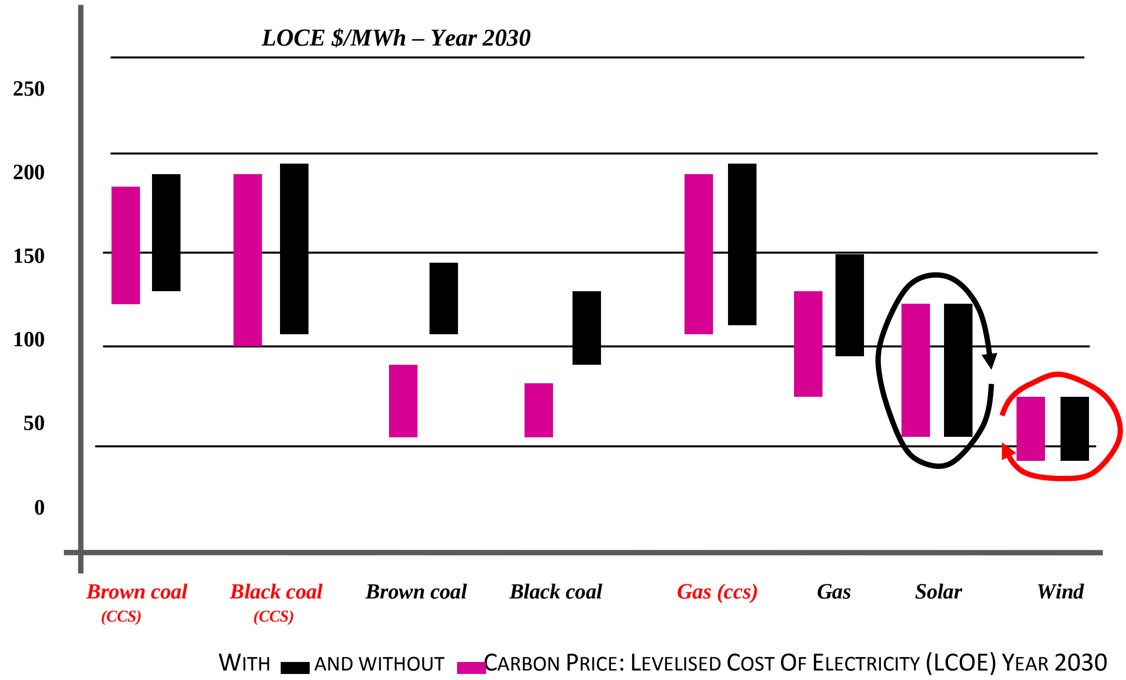


Figure 5.7: Levelised Cost of Electricity with & without Carbon Price to the year 2030

The levelised cost of electricity (LOCE) for the year 2030 (Figure 5.7) has dramatic cost differences between black and brown coal technologies in which the cost appear to more than double under a carbon price. The findings of the scenarios assumed in this analysis for both years (2020 & 2030) (Brinsmead, T.S, Hayward, J & Graham, P, p. 40, 2014) conclude that:

- Wind technology is typically the lowest cost option.
- Carbon prices make a dramatic cost difference for black and brown coal.
- The Carbon Capture & Storage technology (CCS) is the highest cost (LCOE) both with and without a carbon price and is therefore not subject to permits.
- Black & brown coal technologies have similar LOCE to solar.
- Respectively wind, then solar are lower cost technologies than fossil fuel technologies.
- There is a neglected change in wind costs between the years 2020 and 2030.
- Solar costs drop by 15 per cent $/MWh as the reduction occurrs in capital costs over that period.
- There is a little change to the non-CCS fossil fuel (LOCEs) between 2020 & 2030 when assuming no carbon price (Brinsmead, T.S, Hayward, J & Graham, P, 2014).

5.8 How the electricity price is set in NSW?

Figure 5.8 shown the price of electricity varies across different states in Australia, which have different plans which were created unequally. This is attributed to many reasons: weather conditions and temperatures, population and generation, transmission and distribution resources (Australian Government Fact Sheet 4, 2016). The electricity bill in any territory in Australia is an outcome of differently incurred prices that have been disbursed by generation, transmission and distribution of the grid (AER, 2012). Pricing of power varies across Australia and also varies between different suppliers within in the same state, particularly in NSW (Rebuilding NSW 2014, p. 14). There is also data for a notable breakdown of the components for how the power prices have risen over time in different states and how often people switch between retailers. (AER, 2012); (AER, 2016); (IPART, 2012).

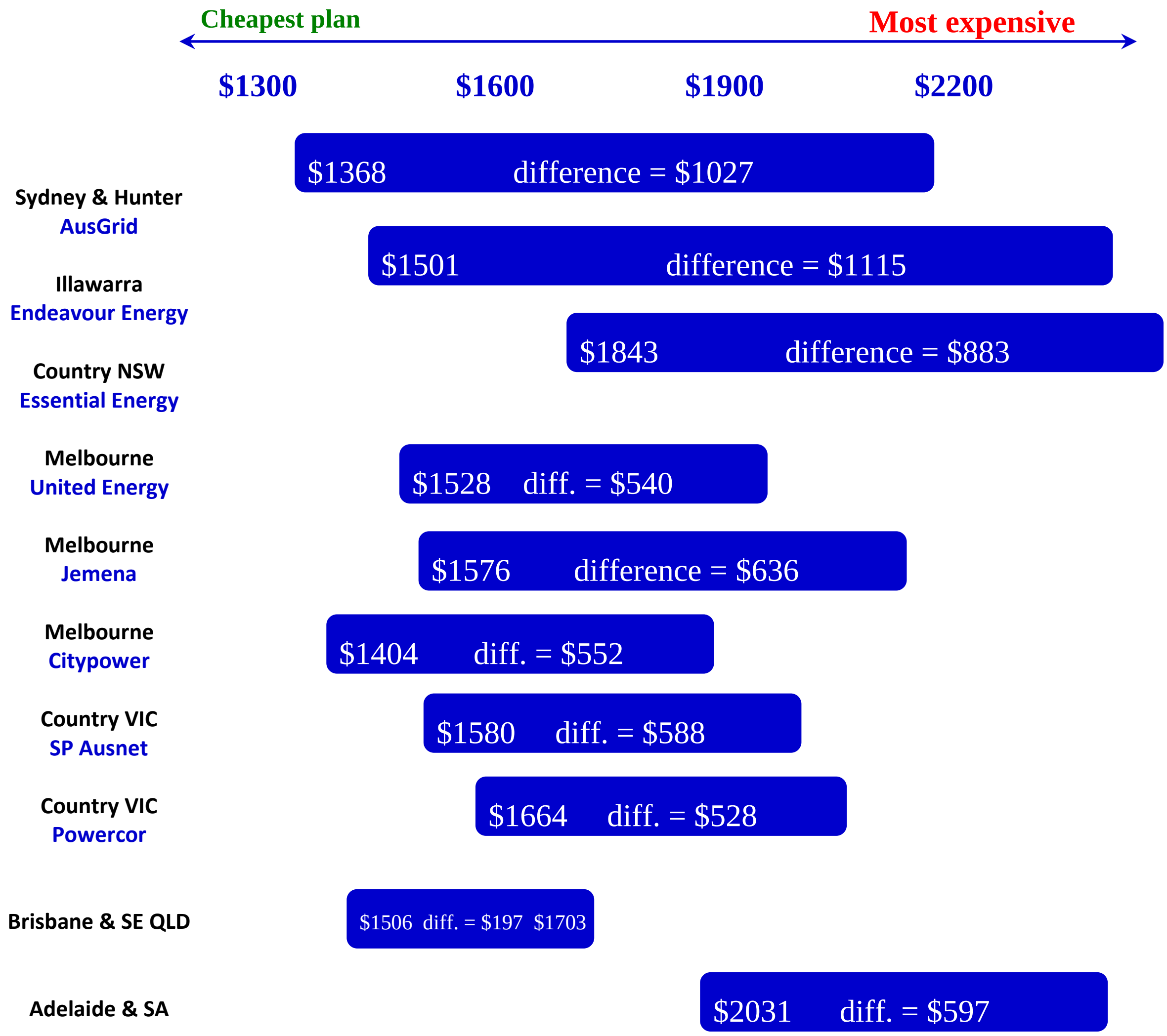


Figure 5.8: Suppliers' Pricing of Electricity in Australia in the same States (IPART 2012)

Figure 5.9 also shows an example of a bill of electricity which arises as a result of different cost per cents and that due to the follow reasons:

- 7 per cent for green costs;
- 8 per cent of carbon cost;
- 10 per cent of the retail cost;
- 25 per cent of energy cost and;
- 50 per cent of network cost (AER, 2012).

Network cost is the cost of delivering electricity from generation sources to end-users via a system of transmission and distribution network (Rebuilding NSW 2014, p. 15). Thus, the pricing of electricity heavily depends on and influenced by the distance between the end-users locations and the power generators' plants.

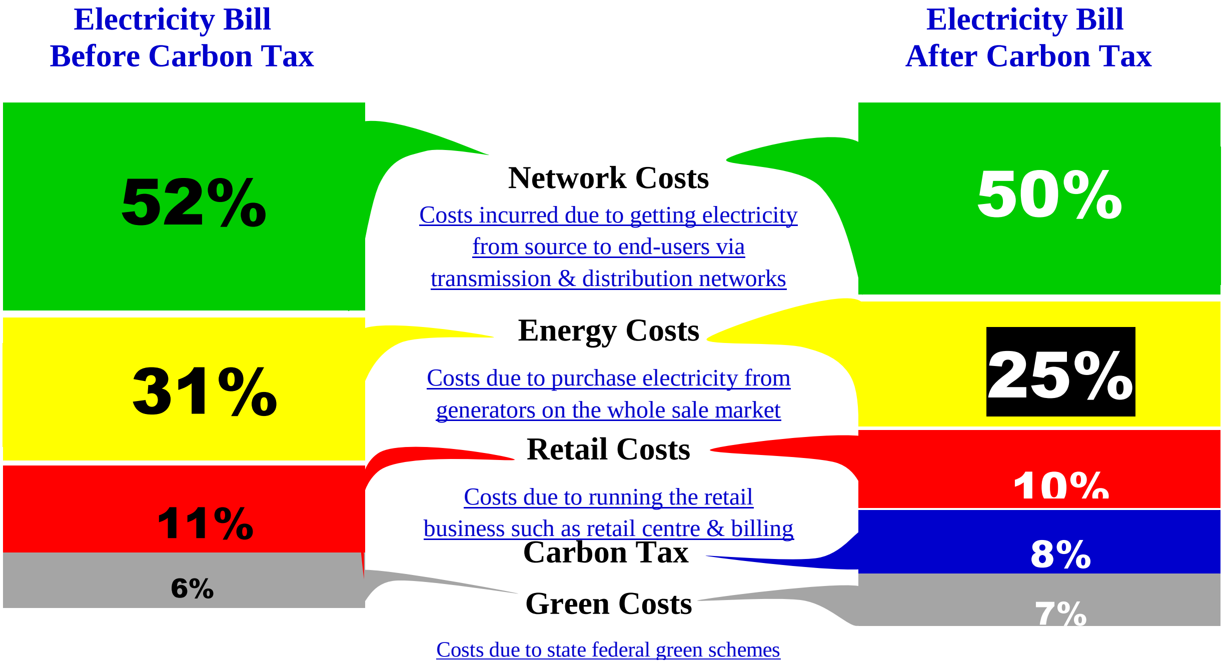


Figure 5.9: The Origin Costs of Electricity Bills (Rebuilding NSW 2014)

5.9 Tariffs Reform & Prices of Electricity

Supply, transmission, and distribution networks support tariff reforms as essential to ensuring maximised benefits of future investments in distributed areas in integrated electricity grids (Energy Network Association 2014, p. 27). Electricity's different prices are a function of a range of factors. In a competitive, wholesale electricity market, the spot/pool price of electricity reflects the timely balancing of supply and demand (see Chapter 2).

The power path of electricity from generation station to end-users, is usually devised by a number of players involved to make both occur: the flow of power and a payable fund. The diagram below in Figure 5.10 is a simplified illustration explaining the electricity flow from generators to end-users and in reverse, the money flow from end-users to retailers and generators. Electricity is produced by generators that is then purchased by retailers of electricity from the National Electricity Market (NEM). Retailers purchase the electricity from transmission network selling points and then sell it to end-users via distribution points. Electricity is sent through a long-distance transmission network by transfer via poles and lines of transmission to other lines of distribution network directly to end-users.

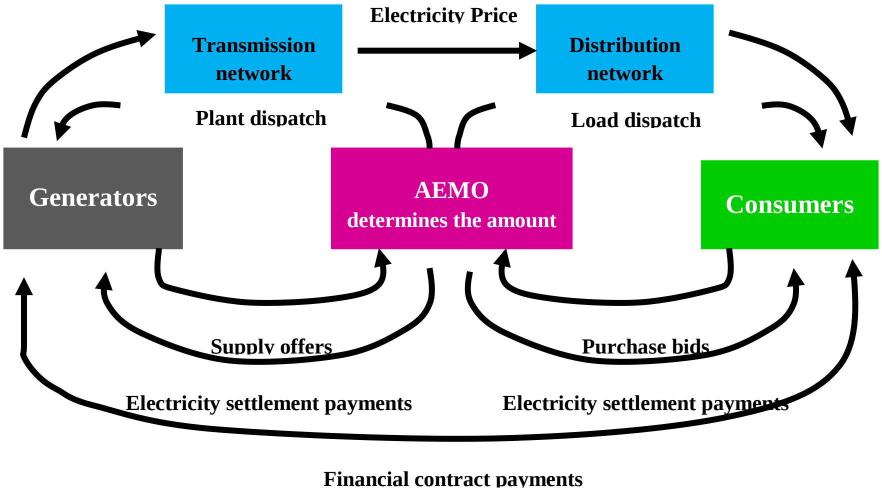


Figure 5.10: Electricity Financial Process from Generators to End-Users

Leaving customers on outdated network tariffs will massively increase the community costs, over the coming twenty years, in both the distributed generation and storage capacity and the electricity grid. More significantly, this will also flow through into higher electricity bills because customers will be charged network tariff due to their use of network capacity at peak and off-peak demands. However, customers are consuming unequally. In turn, there will continue to be cross subsidies paid to consumers with peakier/off-peakier loads by all other consumers under peakier and over off-peakier loads (Energy Network Association 2014, p. 27).

Cost-reflective tariffs should opt into a new regulatory framework based on individual consumers, in order to achieve tariff reform which relies on their individual scales. There is an urgent need for tariff reform, and governments are also required to deliver action plans to network businesses, market participants and retailers to unify their efforts in the interests of customers have their own direct interests as well who directly linked to their interest as well (Energy Network Association 2014, p. 27). However, the spot prices do not account for any forward price agreements, such as hedge contracts for retailers or ‘time of use’ (ToU) contracts for residential consumers, as illustrated in Table 5.1 (see chapter 2). Viewed in isolation, the wholesale prices of electricity to retailers, and also the final retail prices of electricity to end-users may give a misleading picture of the wholesale value of electricity.

Table 5.1: Time of Use Tariff (ToU) (Intelligent Energy System 2004)

Time Period	Day of Week	Time of Day
Peak	Monday to Friday	7am to 9am 5pm to 8pm
Shoulder	Monday to Friday	9am to 5pm 8pm to 10pm
Off-Peak	Monday to Friday	10pm to midnight Midnight to 7am
	Saturday, Sunday & Public Holidays	All

The Commonwealth Department of Industry Tourism and Resources (DITR) has developed an indicative index to deliver the wholesale of electricity value (d-cyphaTrade 2016). This index is known as ‘the Wholesale Electricity Price Index (WEPI) and is used in New South Wales (NSW), Queensland, South Australia (SA) and Victoria (VIC). It is also published daily on the ‘d-cyphaTrade website (www.d-cyphatrade.com.au) to exhibit the “day before“ value. WEPI takes certain key elements into account to provide an adequate measure of the wholesale value of electricity in the Australian NEM regions (d-cyphaTrade 2016). The limitation of the WEPI calculation is that it is composed of a combination of contract and spot electricity prices to find a better way to embrace demand volume of electricity disregarding demand shape (d-cyphaTrade 2016). Moreover, WEPI only calculates the working days, as Saturday, Sunday and public holidays. There is no trading of electricity ‘Futures Contracts’.

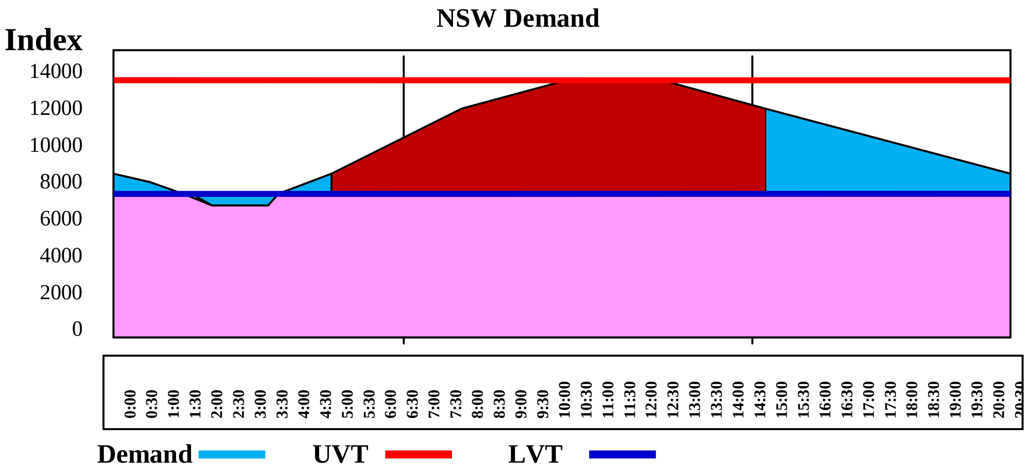


Figure 5.11: Whole Sale Electricity Price Index (WEPI) based on the History of Highest Peak & Lowest Off-Peak Demands (d-cypha Trade 2016)

The assumption of the WEPI methodology exhibits 90 per cent of the highest ever demand in NSW known as the 'Upper Volume Threshold (UVT)' 'peak demand', indicated in Figure 5.11 by the red line and covered through 'Hedge Contracts' (d-cyphaTrade 2016). The majority of the load up to a certain level of demand, comes under Base-load contracts (Pink shaded area) which are the equivalent to the average of the previous day's 'off-peak demand' and are referred to as the 'Lower Volume Threshold' (LVT). Thus, any additional demand emerging above the estimated peaks, will lead to further hedge contracting.

The above figure shows that any demand over the LVT is covered by peak contracts (brown shaded area), and any demand above the UVT (red line) or above the LVT (Blue line) is assumed as uncontracted cover and is directly priced against the real spot interval price (blue shaded area). These rational expectations that stakeholders in the electricity market consider in order to manage their exposure, thoroughly depends on the outcomes of the spot prices of the previous market outcomes. Overall, the expectations of the future demand market are based on the past market data (d-cyphaTrade 2016, p. 2).

Therefore, mathematically the 'Wholesale Electricity Pricing Index' (WEPI) calculates the time-weighted average of the effective off-peak and peak wholesale electricity prices as follows:

$$\boldsymbol{WEPI = \left[P_{peak} + \frac{30}{48}\right] + \left[\,P_{offpeak} + \frac{18}{48}\right]}$$

P_{peak} : The effective wholesale price during peak times through the weekdays from 7am to 10pm excluding public holidays.

$P_{off\text{-}peak}$: The effective wholesale price during off-peak times through the weekdays in all hours outside the peak times.

$$\boldsymbol{P_{peak}} = \frac{\sum([\boldsymbol{D_a} \times \boldsymbol{S}] + [\boldsymbol{D_b} \times \boldsymbol{F_{peak}}] + [\boldsymbol{D_c} \times \boldsymbol{F_{base}}])}{\sum \boldsymbol{D}}$$

$$\boldsymbol{P_{off-peak}} = \frac{\sum([\boldsymbol{D_c} \times \boldsymbol{S}] + [\boldsymbol{D_d} \times \boldsymbol{F_{base}}])}{\sum \boldsymbol{D}}$$

D: The regional demand at each trading interval peak period.

Da: Uncontracted volume when the demand in excess of the upper volume threshold (UVT).

Db: The peak contract volume when the demand in excess of the lower volume threshold volume (LVT) but less than (UVT). (if D ≤ L then Dd = D, otherwise Dd = L).

Dc: The base load contract volume when demand below the lower volume threshold (LVT) (if D > L then Dc = D – L, otherwise Dc = 0).

Fpeak: The price of the future peak load contracts of electricity averaged over the first four listed quarters.

Fbase: The price of the future base load contracts of electricity averaged over the first four listed quarters.

L: The lower volume threshold (LVT).

U: The upper volume threshold (UVT)

S: The sport price of electricity

From the equations above, it can be seen that the peak and off-peak demands are considered for the trading interval (every 30 minutes) (see Chapter 2). In such a scenario it is possible that a new record demand is reached intraday, and a new upper volume threshold (UVT) will emerge and should therefore be used in ongoing calculations starting from the day of change.

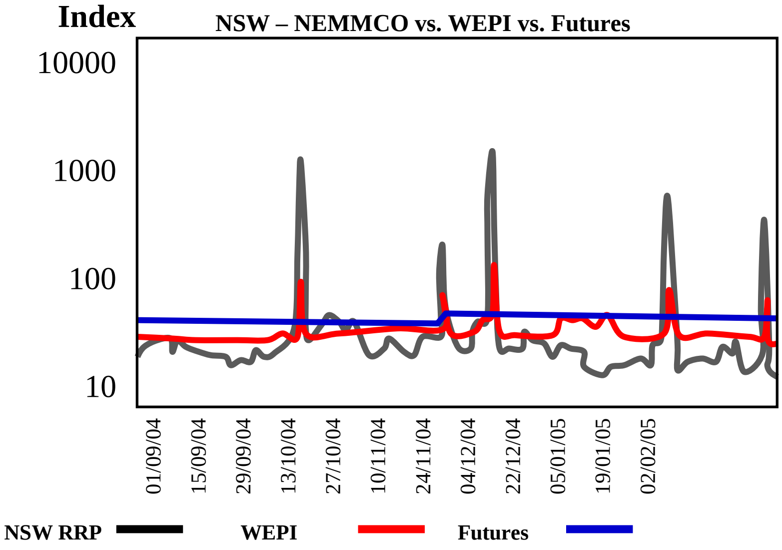


Figure 5. 12: Whole Sale Electricity Price Index (WEPI) Vs. Recommended Retail Price (RRP) Vs. Future Expected Average Price (d-cyphaTrade 2016)

The chart plotted in Figure 5.12 states the performance of the WEPI against RRP (Recommended Retail Price) and the future expected prices of electricity. The WEPI movement based on the combination of spot electricity prices and contract prices, contracts prices in proportion to uncontracted and contracted quantities (d-cyphaTrade 2016). As displayed in the chart above, the RRP has the higher level of volatility, and WEPI, to some extent, reduces this degree of volatility, but the worst result of the WEPI is that it raises the wholesale prices of electricity. As we see, the WEPI has little effect on contract prices, which probably adds a limited stability to the wholesale prices(d-cyphaTrade 2016, p. 4). Given these uncertainties, this way of controlling and managing the electricity prices is still not able to provide any rigorous indication of the potential future prices of electricity.

5.10 The Influence of Peak/Off-Peak demands on Electricity Prices in NSW

'Peak Demand' exhibits the maximum volume of electricity demanded at any one point in time measured in kilowatt (kW) or megawatt (MW) (AEMC 2014, p. 13). There is a relationship between peak demand and the reliability standards of network prices. The forecast level for electricity peak demand is the primary driver of the need to upgrade distribution and transmission networks. It is quite hard for ageing assets to cover higher input and meet higher reliability standards (George Gardner 2010). Further, undertaking network expansions incurs costs associated with the capital expenditure that is finally is paid for by consumers through their retail bills (AEMC 2014, p. 24). Such investments in network infrastructure varies from one region to another, depending on local load patterns that are usually dissimilar between jurisdictions and within each jurisdiction (AEMC 2014, p. 24). Therefore, an increase in the energy demand calls for an enduring need to expand the network capacity of electricity. This is a major reason for rising network charges, an increase in electricity prices, and increase in the wholesale cost.

The latest statistics indicate a rise in the number of households consequent with increased use of electricity and increased size of appliances (i.e. television, air conditioners and fridge). This new demand has placed greater pressure on the electricity network, especially at high use times when people get home each day and need to do basic things such as eating, watching TV, using lighting, air conditioners, computers, washing machines and dryers. At the same time, as services, products and businesses are still serving us during these times which are also placing greater demands on our network at specific points in time (Australian Government Fact Sheet 4, 2016, p. 2). This leads to a large rise in demand for electricity across the network for limited hours every day. The network of electricity must be able to service these peak demand hours when it is at greatest risk of blackouts by a loss of all power, or brownouts due to power surging and fluctuation in homes, which may cause problems with home appliances. Therefore, customers' bills will include network costs during peak times when the electricity networks are most busy (Australian Government Fact Sheet 4, 2016, p. 2).

The study of "Independent Pricing and Regulatory Tribunal" in NSW (IPART) assigns an Intelligent Energy Systems (IES) to address the 'Long Run Marginal Cost' (LRMC) of electricity in New South Wales (Intelligent Energy System 2004). IES recommended a range of costs including a peak, shoulder and off-peak, as well as an LRMC and value for each electricity retailer depending on the nature of each individual load profile (Intelligent Energy System 2004). This raises a question as to whether the LRMC allowance would be more effective to compute a single value and then apply it to all retailers based on a 'typical' load profile or should it be retailer specific (based on their different load profile)? Once a single benchmark value is recommended, then the next question is raised: what should a typical load profile appear to be and what are the relationships with demand management issues, and what are the implications of this considered load for retailers' incentives?

The study of the 'Independent Pricing & Regulatory Tribunal' (IPART) in fact pointed out to the cost versus capacity factor characteristics (Intelligent Energy System 2004). The plots cross over points in the figure below represent the characteristics of the generators used in NSW. From the chart below, one generating technology becomes more economical than the next in regard to the capacity factor. Thus, it is possible to realise the optimal capacity factors and to predict the new entry costs for each generator type. The findings of the above study developed 'a linear program approach' (LPA) to achieve an optimal operation of the combination of different generation plants in NSW territory (IES 2004). The expected advantages of the LPA are that it would address an optimal load profile by minimising the operating cost, transparency, and predicting shadow prices (e.g. the marginal cost of supply electricity in regard to an increment of a load during a particular hour) (Intelligent Energy System 2004).

At a glance into the linear programming approach (LPA), it would seem that this finding addresses for retailers the cost of load profiles at peak, shoulder and off-peak time. This arises from the revenue 'neutral' marginal costs and the increment load in the respective time. The average finding of the LRMC was quite different from one retailer to another due to the different load shapes for each of them (see Figure 5.13). Retailers with loads representing more peaks will incur a larger weighting of high-cost generation (OCGT) in comparison with others that have a flatter load and, in turn, a higher overall LMRC (Intelligent Energy System 2004).

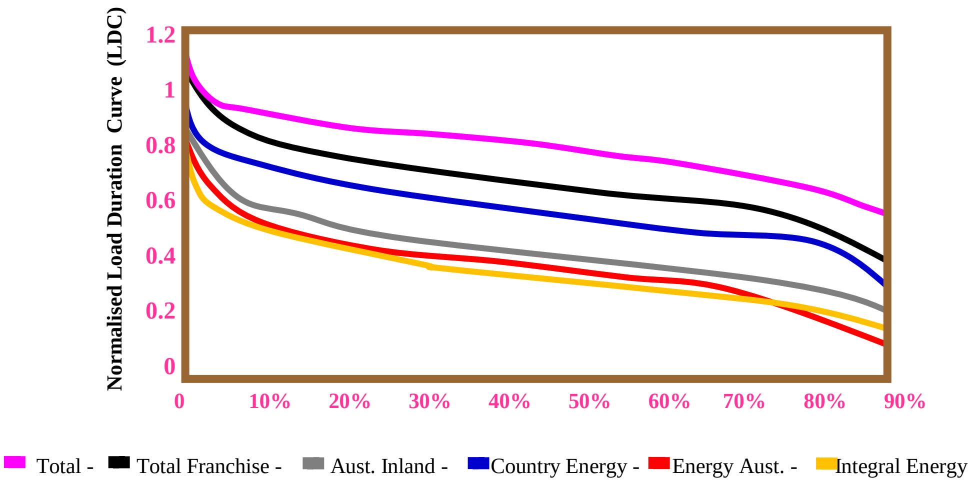


Figure 5. 13: Normalised Load Shapes for Long Run Marginal Cost (LRMC) (Intelligent Energy System 2004)

Therefore, and from the above findings, the Long Run Marginal Cost (LRMC) which defined for peak, shoulder and off-peak times, the results are as shown in the table below. Retailers apply these timely definitions on consumers, disregard their diversity and timely real consumption of electricity (Intelligent Energy System 2004). There is evidence of different consumers having different consumption behaviours and a different load profile during weekdays.

There are different load profiles for a mix of generators to supply the electricity in NSW to retailers, then to consumers. These generators use fossil fuel to generate power at different costs. Table 5.2 represent three types of generators are mainly employed in NSW, and these are ‘Open cycle gas turbines’ (OCGT), Combined cycle gas turbines (CCGT), and Black coal thermal power stations. These types of generators significantly influence the cost of electricity. Each generator model has a fixed capital cost, fuel cost, variable operating and maintenance (O & M) costs, and financial structures (discount rate) (Intelligent Energy System (IES) 2004).

Table 5.2: Load Capacity Factor For Coal & Gas Generators Vs. Cost $/MWH (Intelligent Energy System (IES) 2004)

Optimal Capacity Factor for Generators Associated with Entry Cost $/MWh			
Load Capacity Factor (CF)	**100%**	**55%**	**14%**
Thermal Coal	***$36.2 MWh***	*Higher than $55.9 MWh*	*Higher than $109.0 MWh*
CCGT	*Higher than $36.2 MWh*	***$55.9MWh***	*Higher than $109.0 MWh*
OCGT	*Higher than $36.2 MWh*	*Higher than $55.9 MWh*	***$109.0MWh***

The Figure 5.14 below also shows the cost versus capacity factor from zero to 100%. It is very clear that the operation of any type of these previously mentioned generators at partial load increasingly incurs losses due to increasing the specific fuel consumption to generate the same capacity of electricity.

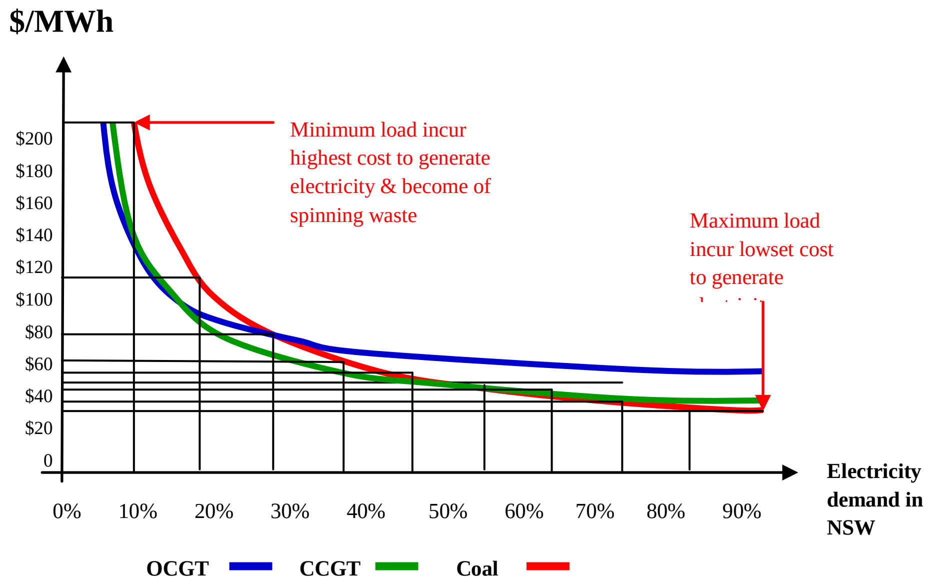


Figure 5.14: Coal & Gas Generator's Performance & the Cost of $/MWh Energy System (IES) 2004)

5.11 Retail Price Regulation & Immediate Impact of Deregulation

Retailers sometimes do businesses with more than one transmission and distribution network and are sometimes involved in trading between states. The profit margin for most of the retailers is in the range of 3-10%. For a retailer, the price of electricity is different in different states due to the fact that they have different operating, billing and meter reading costs; they have different network costs, and they also have different wholesale electricity costs, as illustrated in Figure 5.15. It has also been noted that electricity prices are going to increase in the next two years. This is explained as due to an imposed mining tax, carbon tax and delayed investments in electricity resources and infrastructure. The reason behind this is that every Kilowatt hour (KWh) of electricity generated from coal-fired power stations in NSW creates 1.06 Kg of carbon pollution known as greenhouse gas or Co2. The Council of Greenhouse gas emissions determined the Co2 emitted due to the electricity used and use of other goods, for example, gas and fuel supplied to buildings and vehicles, and facilities, but the remaining majority is derived from electricity plants (Randwick City Council 2009, p. 31).

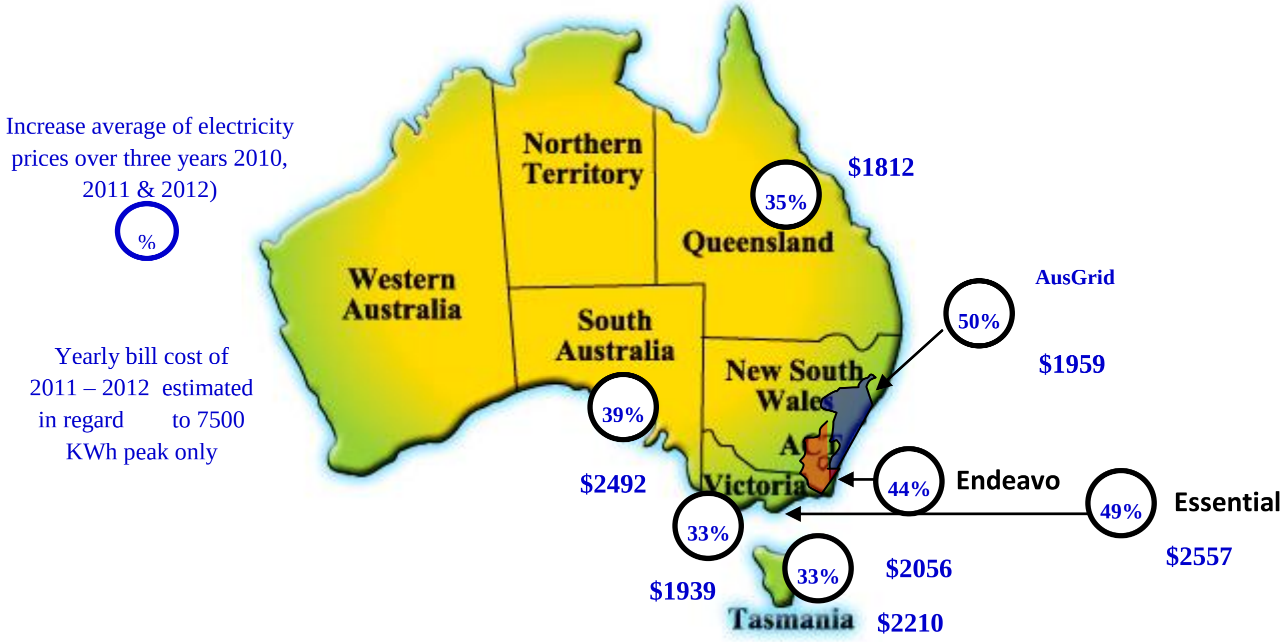


Figure 5.15: Yearly Bill of the Cost of Electricity in Australian States (AER, 2012); (AER, 2016)

The Australian Government assumes that the setting of electricity contracts is one of the important ways to reduce the effect of losses incurred from generating electricity. Australian Electricity Future Contracts (SFE), founded in 2002, is contracts specialise in electricity sold and bought in regard to ‘Base Load’ and ‘Peak Period’ in the National Electricity Market (NEM) in South Australia, NSW, Victoria and Queensland. The contracts use the unit of 1 Megawatt of electrical energy per hour and are available from 1 quarter to 15 quarters, or 3 years out (ASX, 2016), whereas “Over The Counter” (OCT) contracts are private and traded directly between two parties with no intermediaries involved or going through an exchange.

This perception leads to the certainty that any types of contracts will be welcomed if they can be customised and negotiated to fit within the accepted risk and return needed by stakeholders (Australian Security & Investments Commissions 2016).

Some large energy intensive companies, “Retailers” purchase electricity directly from generators through hedging contract payments (for example, the OTC and SFE) (ASX 2016). These large enterprises purchase electricity from the National Electricity Market (NEM) at the spot price which these settlements determined via the Australian Energy Market Operator (AEMO). Note that all money transactions are undertaken at the spot price. On the contrary, traded derivative instruments (SFE) and “Over The Counter” (OTC) are significantly used in order to enhance the hedge against the spot market price. End-users are responsible for paying the access fees according to use of the infrastructure of the electricity network. Similarly, retailers purchase the electricity from the NEM and also pay access fees for using the infrastructure of the network of the electricity.

Table 5.3: NSW Cost of Load during Peak, Shoulder & Off-Peak Times (Intelligent Energy System (IES) 2004)

Long Run Marginal Costs (LRMC) ($/MWh) for Peak, Shoulder & Off-Peak times			
Electricity Generation	**Peak**	**Shoulder**	**Off-Peak**
Total NSW Cost of Load	*$89.59 MWh*	*$47.25MWh*	*$22.66MWh*
Total NSW Franchise Price of Load for Retailers	*$123.77 MWh*	*$33.99 MWh*	*$30.92 MWh*

The jurisdictional government provides the jurisdiction‘s consumption levels which are measured by ‘cent per KWh’. The representative consumption levels for different consumers differentiate between high and low consumption levels. This plays a role when consumers deal with market offers that have various levels of variable and fixed charges. It means that consumers who are consuming less electricity (lower than 2,500 kWh per year). will receive a market offer with the highest price, and when their consumption is at highest levels ‘9,500 KWh’, the market offer will be introduced at the lowest price. This particular case of high consumption and low consumption levels creates a larger discrepancy in the sense of $/KWh values. Time of use contracts (see above Figure 5.1 & below Table 5.4) presents the opposite facts, that the consumption at peak times incurs higher payment values than the consumption at off-peak times, which conflict with the market offer received by consumers, based on their previous consumption history (AEMC 2014, p. 97).

Table 5.4: Annual Consumption of Electricity Vs. Average Market Offer $C/KWh (AEMC 2014, p. 79)

Annual Consumption Level	2013/14 Average market Offer (cents per KWh)	2013/14 Annual household bill
Low (2,500 KWh)	36.12	$903
New South Wales-specific average (6,500 KWh)	28.76	$1,869
High (9,500 KWh)	27.77	$2,638

By using geometric proportional calculus the relation between the LRMC and average market has a conflict as showed in Figure 5.16:

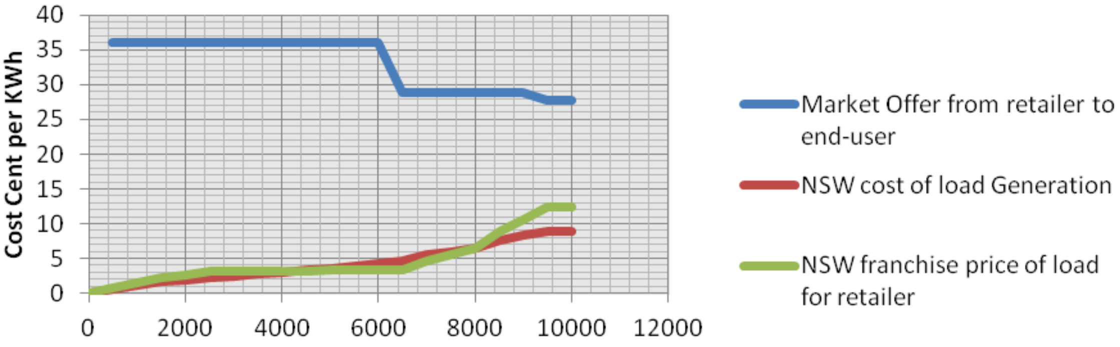


Figure 5.16: Load generated to cover the demand of electricity

5.12 Biodiversity of Electricity Consumers

Consumers such as residential houses must be expected to smooth out the net national product that causes resource depreciation and environmental damage. Ascribing monetary values to external impacts on biodiversity of electricity consumers and their consumption qualities is acknowledged to be a ‘Complex’, imprecise and a subjective exercise. For this reason, there is an issue which still exists, that, there is an intrinsic limitation to deriving agreed values for externalities, particularly when they are related to consumers behaviours, which in itself is a controversial topic. For most electricity generation technologies based on fossil fuels and renewable energy, the main external costs belong to the nature of human lifestyle and health, and climate change (ATSE 2009, p. 13). Therefore, it is legitimate to raise a claim against the degree of uncertainty inherent in valuing externalities (out of control of the grid).

Residential end-users of electricity are significant contributors to demand instability and Australia’s stationary energy greenhouse gas emissions. It is imperative that to review energy consumption by consumers as a basis for the development of climate change response strategies as already being commissioned by the Australian Government, is essential . The second national baseline study (1986-2020) was established for residential energy use. This study has identified that the consumers indicate:

- There is wide variation between end-users‘ behaviour in energy use patterns within households.

- New appliances will lead to new future trends with new potential energy implications.
- Trends in appliance lifetimes are a significant changing factor influencing the stock level and the replacement rate in the houses.

User behaviours can be most understood through accurately ascertained data collected from metering loggers. To develop a better understanding of controlling the range of usage requires underpinning for more focused policy development, over time (Department of the Environment, Water, Heritage and the Arts 2008, p. 9). Therefore, it is a critical exploration, and a vital area of further study that must be undertaken, to measure the contributions of residential peak and off-peak electricity demands in controlling and reducing energy losses in the grid systems (Department of the Environment, Water, Heritage and the Arts 2008, p. 9).

It is generally thought that attitudes to the conservation of electricity are highly affected by pricing. In a previous Australian survey, participants had been asked if the price they paid for electricity should be discounted in proportion to their conservation of electricity use (Table 5.5). The result of the survey indicated a general support for the proposition of penalising heavy energy users by finding a method of differential pricing to encourage all electricity end-users across the entire Australia.

Table 5.5: Incentive for Electricity Conservation For Residential Consumers(Randolph, B & Troy 2007, p. 50)

	Yes	No	Don't Know	Total
Separate Houses Semis	66%	30%	4%	1383
Semis	71%	25%	4%	246
All Flats	66%	28%	6%	528
Flats <4 Storeys	66%	29%	6%	332
Flat >4 Storeys	66%	27%	7%	179
Total	1434	631	4%	2157
%	66%	29%	4%	100%

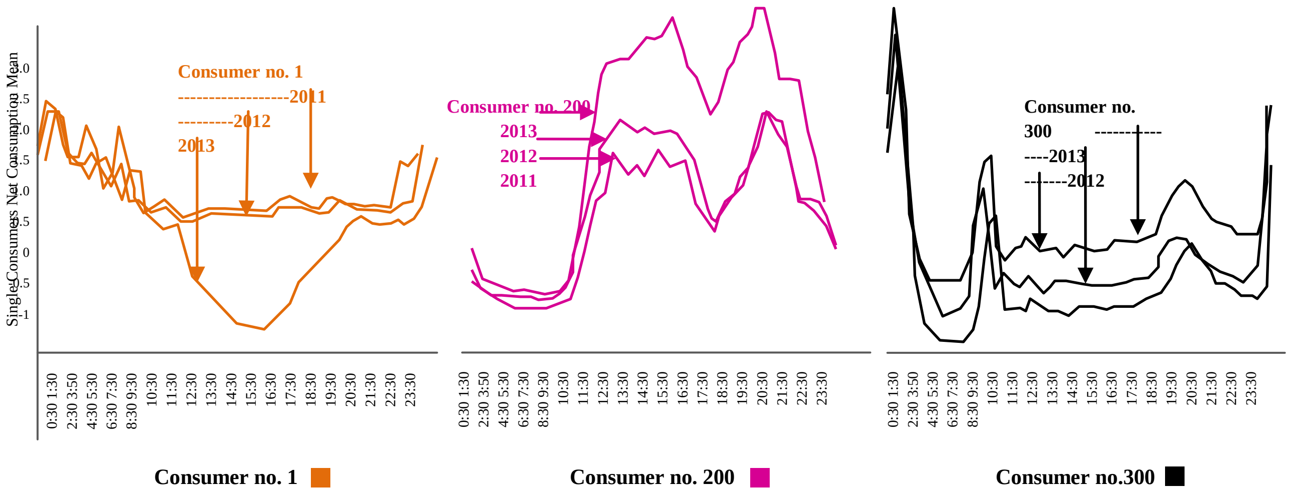
Base: 2179 participants

5.13 Electricity Consumer Behavior

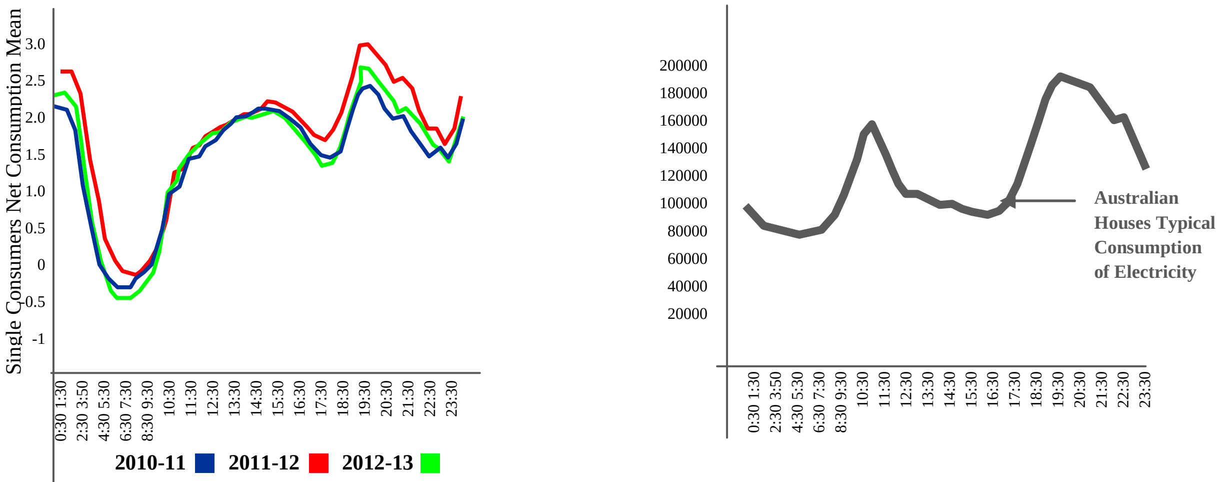
End-users become not purely consumers when they install rooftop solar. Using solar and windmills enhances the opportunities for end-users to be at the centre of electricity generation. The average consumption per end-user (household) in Australia is a major factor that shapes the output density and the resulting variations in Australian electrical economies.

Customer density can be measured per kilometre of a network, which has a large proportion of electricity price differences (Chris Sayers & Dianne Shields, 2001). Therefore, it is observable that there are statistically significant negative correlations between the ranking of output density and the ranking of the utilities by prices, which is also the case for other utilities when the cost of fuel generation results in higher costs (Sayers, C & Shields, D, 2001).

Figure (24) Provides a typical day example of a daily electricity load profile in Australia. The figure shows the Net System Load Profile for all customers (all households) with an annual consumption below 100MWh per annum (ACT Government 2015). Peaks are clear in specific morning and evening times. The analysis graphs of the three samples of individual consumers show the non high level of non-linearity and unique behaviour over three years. As can be noted from net consumption graph, each residential consumer has different consumption characteristics. In addition , the cyclic consuming behaviours for individuals are unique to some extent, with similar repeat trends. Rather, their individual consumption over three years is vibrant and at sometimes similar and at other times is drastically different.

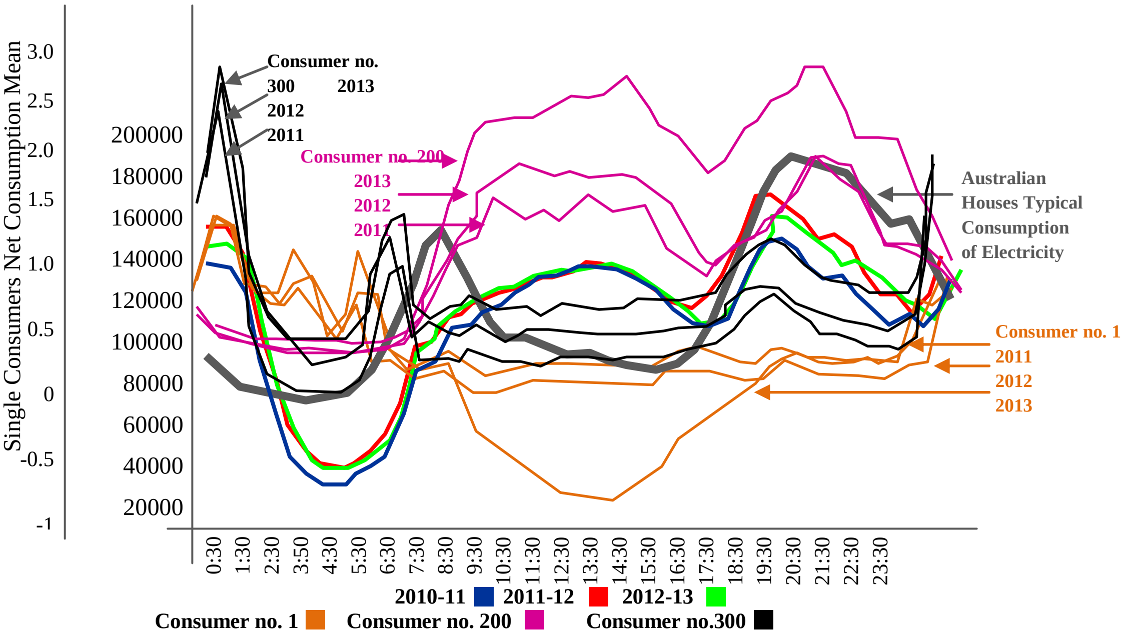


A: Random Sample of Electricity demand for Three Different Houses in NSW



B: Electricity consumption - 300 Houses in NSW

C: Australian Houses Typical electricity Demand



D: Aggregated Electricity consumption for the Figures 22, 23 & 24

Figure 5.17: Aggregated Electricity consumption for the Figures A, B & C

The residential home consume electricity differently and unequally as shown in the above Figure 5.17. Thus, finding new approaches is essential to deal with consumer consumption behaviours whose actions will effect positively on the whole grid system, and improve the concept of competitiveness among electricity retailers. Accordingly, further investigation is explored in this chapter to find a way to improve the role of residential homes in the grid system.

This research study aims to improve the activities of residential houses while consuming electricity as a complement to other previous studies. The aim of my study is to investigate and examine the energy losses in the grid system that are particularly caused by end-users/houses‘ different behaviours and which the grid system is unable to control. Some previous theories and methodologies could be perceived as inappropriate to reveal what are leading to energy losses in the grid system. Energy losses are consequent with peak and off-peak consumptions of electricity which are created by end-users. There remains a gap in investigating these phenomena from the end-users‘ perspective.

5.14 Customer Segmentations & Behaviours

Different types of end-users have different opinions on electricity conservation and management. Some have a habit of saving energy and planning the usage of electricity in regard to the electricity prices during daylight hours (Energy Network Association 2014). However, some are negligent and use electricity without any thought towards conservation (Bill Randolph & Patrick Troy 2007, p. 38). In the survey shown in Figure 5.18 below, respondents were asked about their opinions on energy conservation. Only 1 per cent said it is not important at all, with 82 per cent of the consumers agreeing that it is essential to save electricity, and 14 per cent said it is somewhat important (Randolph, B & Troy 2007).

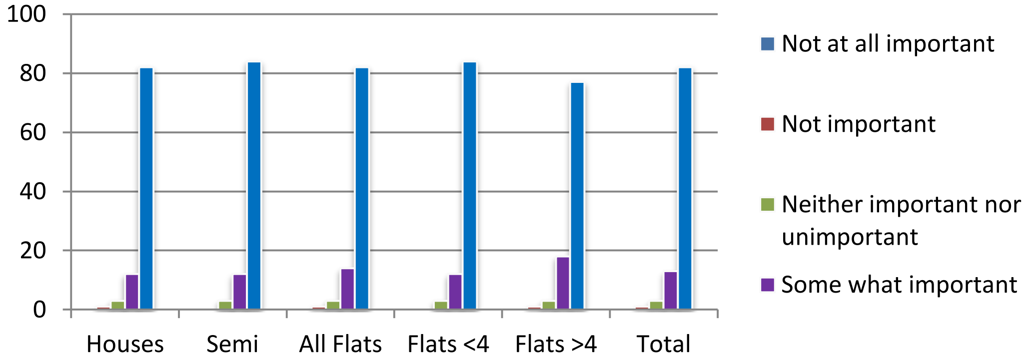
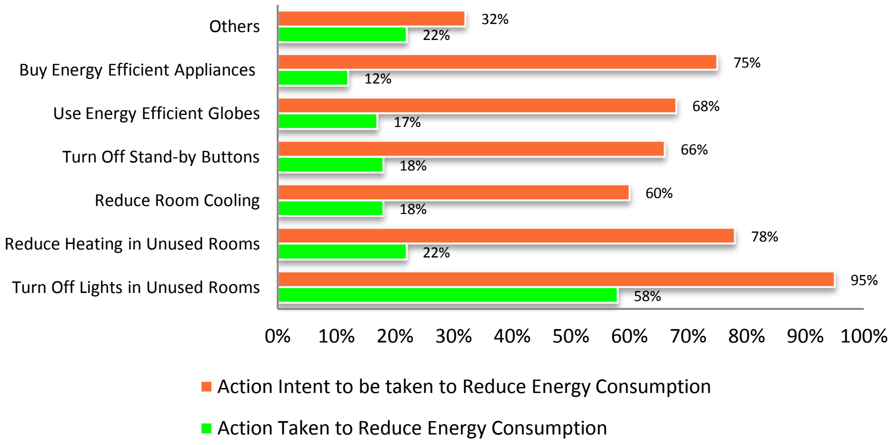


Figure 5.18: Consumers View toward Electricity Conservation (Randolph, B & Troy 2007)

Demand management can be impactful if the consumers' behaviour is accurately analysed during the peak hours to get the maximum output from demand management initiatives. The consumers who are more inclined towards conservation are more likely to adopt practices at their homes to reflect energy saving. For this, the age and socio-economic status of the consumers are considered to be important since those with higher education are more likely to save energy through different measures at home. However, renters were less likely to adopt such practices (Morrison et al., 2013, pp-184).

The nature of demand of different consumers, could take multiple forms, some straightforward (industrial & commercial consumers) and others more subtle (residential consumers) (Energy Network Association 2014, p. 27). Practically, and by referring to the chart below in Figure 5.19, end-users of electricity have a somewhat limited margin for controlling action on their electricity demand unless there are incentives of education and promotion. This suggests strongly that more highly educated people are playing roles showing individual control, by regulating their demand, orchestrating the peak demands and slowing the momentum of peak consumption, that is they are purposefully looking to raise the stakes over consumers diversity understanding.



Base: 2179 participants

Figure 5.19: Consumers Intentions vs. Actions toward Electricity Conservation(Randolph, B & Troy 2007)

People can consume electricity that serves their needs. Each person will have his/her point of view toward the concept of organising their different consumption/demand to serve the goals of the environment and the electrical grids, to reach to the optimum consumption. However, consumers are likely to prioritise serving their needs rather than thinking of optimising the grid. One fact that we all should agree on is that consumers unconsciously consume the capacity of electricity they and they are not fully aware or interested to know about the problem of the grid optimisation.

However, these houses' consumption are not linked to each other; however they all take electricity from the same source and could have a unified influence on that source, either positive or negative. Therefore, involving them to resolve the problem of energy losses energy means involving them separately as standalone premises to serve a unified goal.

The Independent Pricing and Regulatory Tribunal (IPART) has conducted household surveys in regards to electricity consumption during the following fiscal years:

- The year 2006 in Sydney,
- The year 2008 in Hunter, Gosford, and Wyong,
- The year 2010 in the areas of Sydney's metropolis, Blue Mountains, and Illawarra (Sydney)

All of the above surveys affirmed that there is a relationship between electricity use and houses‘ characteristics, in particular and as illustrated in Figure 5.20, the higher consumption of houses concurrent with the following facts:

1) Households that mostly have more occupants;
2) Households defined as free-standing houses rather than flats, dwellings, or semi-detached;
3) Households have higher usage for amenities/appliances and use them more often, for example, second refrigerators, air conditioners, swimming pools, and dishwashers;
4) Households which do not use gas for heating and cooking purposes;
5) Households that mostly have larger blocks of lands and use more sprinkler irrigation for gardens;
6) Households that have a higher average income;
7) Households located in different areas which have different consumption patterns:
    - House size
    - Number of occupants
    - Temperate coastal areas have less need for space cooling and heating than inland areas (Sims, R, Cox, J & Krieger, S 2010).

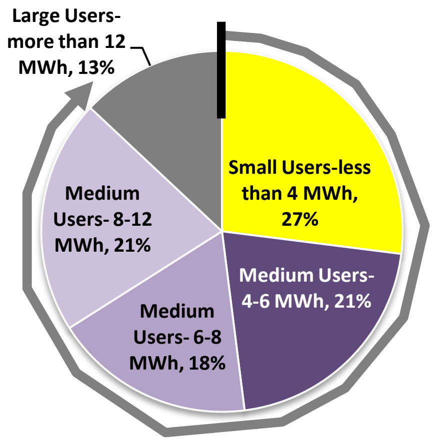


Figure 5.20: Average electricity Consumption by Household size (MWh pa) (Sims, R, Cox, J & Krieger, S 2010); (ACT Government 2015)

Electricity prices in Australia do not, however, appear to be especially when compared with the electricity costs in a number of advanced economies. However, in Australia, in recent years, the electricity prices have been one of the fastest growing sectors of the consumer price index (CPI), as shown in Figures 5.21, 5.22 & 5.23 (Plumb, M & Davis, K 2010, p. 9). Many indicators show a further substantial increase will occur in the prices of electricity in coming years. This notable feature reflects the move towards cost-based pricing unless replacing or expanding infrastructure is able to meet demand which also will lead to rising input costs (Plumb, M & Davis, K 2010, p. 9).

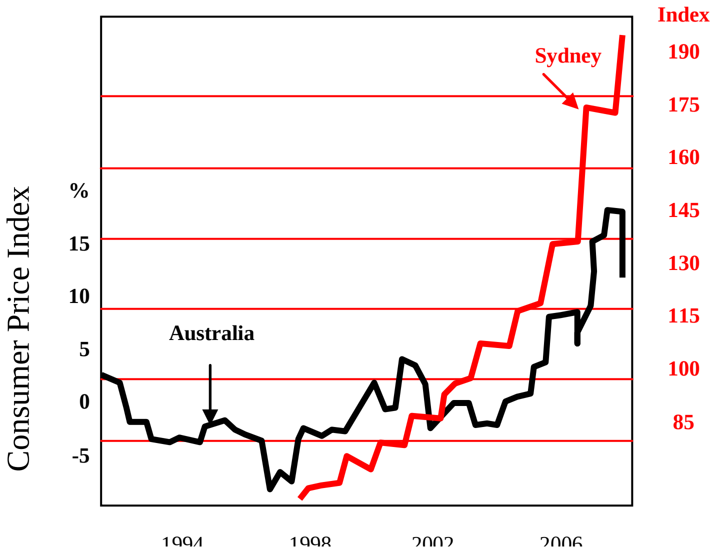


Figure 5.21: Electricity Prices Inflation(Plumb, M & Davis, K 2010)

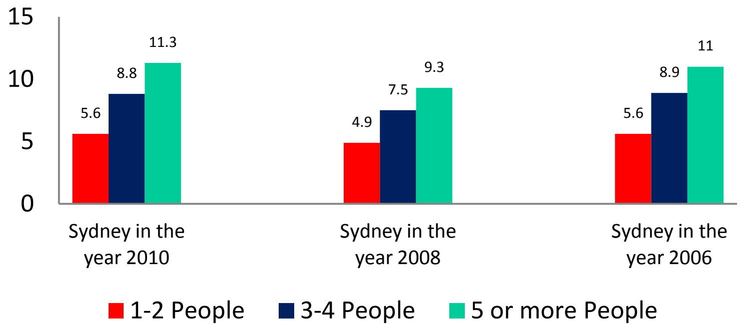


Figure 5.22: Average Household and Per Capita Electricity Consumption by Household Size, Sydney 2010 – (MWh pa) (Sims, R, Cox, J & Krieger, S 2010)

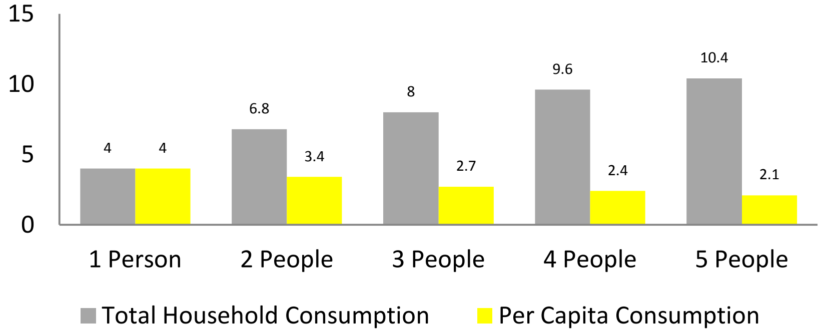


Figure 5.23: The Rate of Household Consumption in Relation to Number of Occupants per House (Sims, R, Cox, J & Krieger, S 2010)

5.15 Awareness of Retailer Choice

To shed some light on electricity market shares in NSW, a comparison has been made in Figure 5.24 to indicate the proportion of residential consumers who selected to be supplied by particular retailers. Approximately ten retail electricity firms were operating in the tested areas during the time the survey was adopted. The relative market share observed across three studies in the years ‘2006, 2008 & 2010’ (IPART) and the survey results, indicated there are dominant distributors of electricity chosen by different consumers (i.e. Energy Australia & Integral Energy) (Sims, R, Cox, J & Krieger, S 2010).

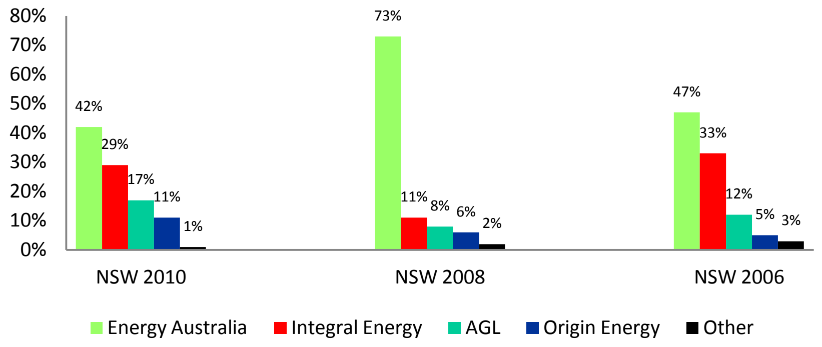


Figure 5.24: Indication of Consumers Choice Toward Particular Retailers (Sims, R, Cox, J & Krieger, S 2010)

5.16 Awareness in Energy Choice

The residential electricity sector stands for only 30% of total global electricity consumption, but the underlying drivers and structures are still poorly understood (Fan, H., Macgill, I.F. & Sproul, A.B 2015). These drivers are complex, many and varied, comprising household demographics, local climate, building stock, household behaviour and type and number of appliances. Therefore, households have considerable variations, so their consumption needs will be different, with potential implications from their different choices. This is because the forecast of the impacts of different possible residential trends is a changeable goal. Utilities, which are still looking to make a better impact upon different residential patterns, until recently, often lacked a good household electricity consumption model (Fan, H., Macgill, I.F. & Sproul, A.B 2015, p. 1).

Residential households were asked to understand more about the level of their awareness of choosing an electricity retailer and how the competition in the electricity market influences their selection (see Figures 5.24 & 5.25) (Sims, R, Cox, J & Krieger, S 2010). Overall, the three surveys (2010, 2008 & 2006), showed that most respondents (90 per cent) in NSW virtually have the same awareness across there three surveys of their choice of their electricity retailer. Rather, the small users' group (4 MWh per year) was slightly less aware than other groups of consumers (Sims, R, Cox, J & Krieger, S 2010, p. 159).

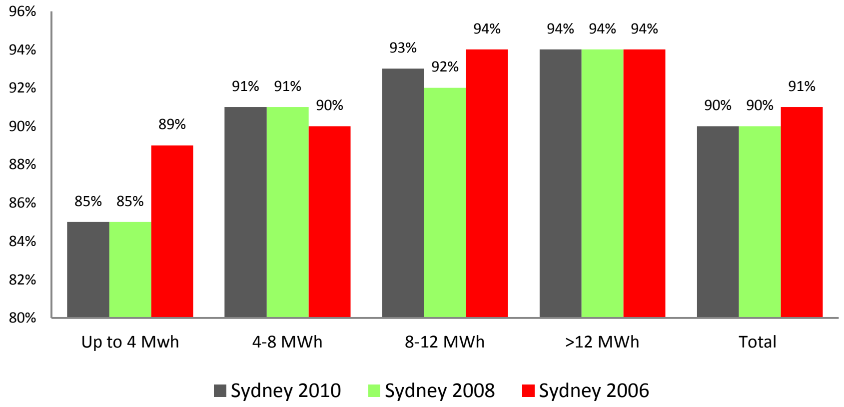


Figure 5.25: **The Influence of Electricity Market Competition on Electricity Company Selection (Sims, R, Cox, J & Krieger, S 2010)**

5.17 Investigating The Barriers of Energy Options

In my view, the most essential feature for any competitive market is low barriers to entry. This is because new retailers have the chance to enter and compete for customers, and incumbent retailers encounter an ongoing threat of competition from new market entrants. The advantages of this ongoing threat and competition provide the most effective protection for residential consumers from the exercise of market power. Particularly, in New South Wales (NSW), the top three barriers to entry into the market and expansion were identified through a survey by electricity retailers as follow:

- Difficulty in accessing reasonably priced hedging products (40 per cent of retailers).
- Imposed compliance costs by National Electricity Market (NEM), state-based and energy efficiency and environmental schemes (38 per cent of retailers).
- Precautionary and credit support arrangements (33 per cent of retailers).

Determination to strengthen relationships between consumers and more energy efficient technical processes has been depleted. To attain such targets, we need to understand and appreciate the mechanisms by which energy behaviours are made more competent. We determinedly believe that only through the all-inclusive reflection of the electricity system in terms of technology, policy, and human interaction can the “heroic effort” required to achieve targets be successful. Within this framework, critical innovation are fundamental; existing technological and strategic methods are not attaining the required change at the required pace. In order to impact change in consumption of the magnitude that is prerequisite, a re-conceptualisation of the path of how electricity is generated and consumed is required (Miller B. 2005).

5.18 Switching Behaviour and Experiences

The societal factor of consumers' behaviours in the electrical grid system is the most complex factor when comparing this behaviour with other electricity system factors, such as technical, political, or economic factors. Regarding the recent projects provided by the government, which that aim to find a way to influence consumer behaviour to reduce use of electricity at peak times, it is found that the attention and the incentive of consumers is mainly to reduce their payable amount in electricity bills and also to add benefit to the wider community.

The response from participants was powerful, but according to individual feedback sent via SMS through the trial , the program did not represent any statistically significant changes in the consumption of electricity (Department of Industry Innovation & Science 2016). The Department of Industry, Innovation and Science (DIIS) recommended that future trial programs for reducing electricity consumption should not focus on the personalised feedback of consumers (Department of Industry Innovation & Science 2016).

Rather, this plays a role in retaining and engaging residential houses in energy efficiency activities. In light of these recent trials, inspiring the consumers' behaviours again, will need to come through an alternative to this less than ideal method. That is because residential consumers are continuously on the cusp of a potentially dynamic change that makes their ways of consumption particularly sensitive to provocations (Department of Industry Innovation & Science 2016). Instead, there is certainly a different unique set of operational circumstances surrounding the upcoming transition of consumers' behaviours.

Exploring the dynamics of consumption is essential for understanding the broader socio-technical transitions in regard to achieving consumer objectives in the electricity sector. This insight is of particular importance when considering systems like electrical Smart Grids. The grid for electricity is a complex adaptive system (CAS) comprising end-users, economic markets, physical networks, and multiple, heterogeneous, and interacting agents (Miller B. 2005). Vital to complexity innovation studies is a close monitoring of social practices and technological artefacts to understand the alternatives to be put it in a better form and how they can be formed by interacting one another. Diverse routes of socio-technical system transition are fundamentally linked to the behavioural and cognitive norms of individuals, communities, businesses, sectors, and governance institutions.

Thus, the transformation to smart grids certainly necessitates a knowledge development and behaviour change amongst such networks and actors groups. The aim of this research draws on the Energy Cultures' framework by using different lenses to understand the real societal world (consumers') interpretations and to incorporate representative models by integrating consumers' behaviours into the model and then, discussing the Grid Model (Miller B. 2005). The expected insight from examined models will enable the examination of how far we can acquire and scale up new strategies from data we have , to implement to similar Socio-Technical Systems with larger size and greater interconnectivity, such as the National Grid.

5.19 Conclusion

End-users lie at the heart of the internal factors that are influencing and hovering around the electricity business performance by making an inconstant demand, affecting cost and, hence, price. The intended outcome of optimising end-users' behaviours is the main reason proposed by this study to improve the electricity network efficiency through fine tuning the Electricity Market Rules and regulating it in regard to consumers‘ diverse behaviours. From the discussion in this chapter we can conclude the following facts:

- Little attention has been devoted to the sole impact of each individual end-users' demand and their level of amenability to management control.
- There has been no previous attempt to use tools from complexity theory such as those discussed in chapter three, to conceive the impact of individual differences in electricity grid system.
- The integration of micro and macro grid levels for future investment must concern consumers separately to understand the full social cost of electricity in planning future capacity.
- Resolutions should be used by taking into account individual differences under the control of management to the peak and off-peak demand for electricity to reduce energy losses.
- The likely significance in general terms of solo end-users must be targeted to reduce energy losses in the grid system.
- The focus on solo end-users to reform a new policy and to develop customer tariff incentives.

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Chapter 6

Sustainability of Residential Homes in Electrical Smart Grid Systems

Acronyms

B^{c}: Battery in Charging status

B^{dis}: Battery in discharging status

B^{FOH} : Battery capacity used from homes to serve other homes achieve Average

CSD: Complex System Dynamic

CSP: Complex System's Process

C^{NDL} : Power capacity available at home, but not needed in the period of Day Light

C^{NNT} : Power capacity available at home, but not needed in the period of Night Time

D^{TC} : Desired Timely Consumption

d^{h} : Highest demand load for each consumer

d^{L} : Lowest demand load for each consumer

L: Load = other homes demand that need to support to achieve average demand

ICT: information communication technology

P_t^{S2L}: Timely power needed from solar to load

$P_t^{S2B@DT}$: Timely power needed from solar to battery at day time

P_t^{S2G} : Timely power needed from solar to grid

P_t^{S}: Timely power needed from solar at home

S^{FOH}: Solar capacity used from homes to serve other homes achieve Averages

SS: System Sustainability

SSD: System Sustainability Dynamic

SSM: Self Sustaining Model

Lessons Learned from Chapters One, Two, Three, Four & Five

Through these chapters, the factors that influence the costs of electricity are examined, based on different consumption demands, for peak and off-peak of electricity. The findings of the literature in this chapter reinforce the nominated methodological application used in chapter two and the conceptual model inspired from complexity theory in chapter 4. These chapters illustrate the remarkable impacts of consumers' behaviour that cause energy losses to the system. These chapters address assumptions about these losses, as attributed to market policy and management literature. These chapters also demonstrate the probability of the proposed conceptual model of 'sustainable residential houses' as a well-advanced solutions towards a complex integrative framework, which is drawn from, and extend, the existing literature. These facts deliver further keys to resolving the energy losses, as addressed by appropriate management of the system's complexity, by integrating sustainable solutions.

Chapter Outline

To investigate a complex system one is required to examine at the inner relations of the system, decomposing it into smaller scales that can be controlled to command non-linear dynamic behaviour (Agostinho, C. & Jardim-Goncalves, R. 2015). This chapter will focus on the sensitivity of the initial conditions that have the nature of randomness and unexpected behaviour, through the lens of complexity theory (Sayama, H. 2015); (Mason, Mark 2009). Based on complexity literature, it will then propose a novel metaphor to assist in building an objective functional model to apply the concept of 'home sustainability' (Agostinho, C. & Jardim-Goncalves, R. 2015); (Miller, B. J. 2005).

6.1 Managing Sustainability of Residential Homes

Managing for sustainability, stems from the physical and biological scientific disciplines (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). An adaptation of these methods should be utilised to apply an ecosystem approach, complementing but not displacing the existing efforts of system optimisation (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Managing for sustainability is possible (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). If so, how? Without good theories, good management can only happen by accident (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Without practice, all theories are suspect (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Are there ways to combine science and management in a way that builds on the strengths of both? Definitely. Thus, it should be a way to combine the managerial perspective and science in a way that builds on the strengths of both to learn more about a sustainable human future.

It is vital that the optimisation of electricity consumption seeks innovative methods at the household level to meet potentially more demanding delivery and performance criteria (Halliday S, Beggs C, Muneer T. 1999). Modern engineering offers the challenge of household area networks to ensure healthy consumption behaviour at acceptable limits using renewable technologies and other passive means (Halliday S, Beggs C, Muneer T. 1999).

My circle of thinking uses the lens of an immediate enabling of household environments to understand and take an action on the non-linear dynamic behaviour of end-users while consuming electricity (Mason, Mark 2009). It is essential, in using this way of thinking to apply the perspectives of complexity theory to the critical mass in the middle of the diverse range of elements, agents and factors that comprise a particular environment (Mason, Mark 2009). The powerful action that can be achieved from complexity theory is the dominant directional course of the phenomena over other competing phenomena (Mason, Mark 2009). The complexity philosophy speaks to the phenomena of Physics as well as to social behaviours; It offers ways to manage the science of collective societal behaviour (Mason, Mark 2009). Therefore, the theory of complexity, as discussed in chapter four offers a set of heuristics that can be aggregated and applied to support the dynamic of networks and to keep stable the overall level of outcomes (Agostinho, C. & Jardim-Goncalves, R. 2015); (Egbert, M. D. & Barandiaran, X. E. 2014); (Knutsen, W. L. 2013).

This discussion focuses on how to enable collaborative learning systems through system infrastructure and policy, and how we are building the capacity of experience and practice

(Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). An important element in the design of sustainable societies consists of the end-users of electricity. In a sustainable society, we must strive to create as much overlap as possible with renewable sources of electricity (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Strategies promoting the process of home sustainability have often been framed by the integration of both ‘hard’ and ‘soft’ systems to provide insights and to make innovative systems that better manage behaviours (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

This establishes links between the household and different mechanisms that can lead to reaching a self-sustaining goal and the emergence of various levels of sustainability (Miller, B. J. 2005). A household network determines conditions under which random household systems are likely to contain subsystems that are autocatalytic by relying on some ambient sources (Mossel, E. & Steel, M. 2005). Such home systems have previously been discussed for their relevance to optimisation models (Mossel, E. & Steel, M. 2005). For this reason, a home sustainability perspective proposes a theoretical framework that is intended to integrate the demand and supply aspects of residential homes for optimisation purposes (Miller, B. J. 2005).

It is crucial to establish sets of feedback loops for the individual household systems relevant to the situation. Non-linear causal models are adequate to describe what goes on in small scale systems (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The aggregation outcomes of single house models can been caused by a series of loops and webs (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

The prevailing action will be sustained according to the system optimisation needed (Mason, Mark 2009). It will continuously exist more amorphously between new emerging power events and those that already exist (Mason, Mark 2009). The term of ‘path dependence’, chosen for ‘sustaining purpose’ is allied to the concept of ‘illuminates lock-in’ to sustain the point where other more sufficient phenomena are competing and resulting in a redirection of that path (Mason, Mark 2009). From the perspective of Physics, a household system will be sustained in certain ways by excluding the weaker agents that are further weakening themselves in an endless and vicious cycle (Mason, Mark 2009).

Some literature claims that complexity theory focuses on supporting the notion of ‘emergence’, ‘system’, ‘adaptive’, ‘dynamic’, and ‘heterogeneous’ elements (Agostinho, C.

& Jardim-Goncalves, R. 2015). Other contributions to complexity theory share a belief that universal principles underly the behaviour of systems, but they are not the same (Agostinho, C. & Jardim-Goncalves, R. 2015). I share this view. The sustaining process remains an essential task to assess the non-linear dynamic behaviour resulting from within the home while consuming reactions and revealing inadequacies while confronted with phenomena that overwhelm the system's integrity (Zumbansen P. 2004). This assessment helps to address the social phenomena and distinctions within a household system which remains fragile or unstable (Zumbansen P. 2004). The questions of how one should exercise control in complex social-technical systems remains a matter of some debate (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The underlying nature of the reality in the consuming behaviour of electricity is always implicit, rather than explicit, for indicator lists (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

The intentional sustaining process aims to construct optimisation, meaning that this is achieved socially by developing a collective vision and shared insights and strategies among households, to sustain a smart grid system of practice (Glazer E. M., Hannafin M. J., Polly D, & Rich P. 2009). A sustaining process can be collaboratively established among end-users of electricity to share instructional values and norms which assist in maintaining the grid optimisation through reform efforts (Glazer E. M., Hannafin M. J., Polly D, & Rich P. 2009). Although renewable energy is expanding gradually in smart grid systems, the generation of electricity is still highly reliant on mechanical systems (Halliday S, Beggs C, Muneer T. 1999). Reversing the trend of traditional energy is all about how to use and create a sustainable built environment (Halliday S, Beggs C, Muneer T. 1999).

The first step to building an objective functional model for self-sustaining involves framing the smart grid system at the household area level and mapping what is possibly involved and the essential relationships used to define the system (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The second step describes the phase of the dynamics of the consumption scenarios that should be developed (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). In the third phase, a compilation structure gained from the previous two stages rehearses how such a situation could possible be unfolded in the future (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

Systems contain patterns of relationships lead which to emergent behaviours (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Systems thinking delivers a window in the electricity world that is gleaned from our understanding of nature and converts this to our relationship to the system (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). It is a way of framing investigations and providing a language to contribute to our understanding (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The intention is to translate the systems thinking into practical actions to simulate what systems approaches are about (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

6.2 Residential Homes & New Economics

Currently, electricity consumers are feeling the strong effects of the expensiveness of coal and diesel fuel; these costs are killing off the demand for those energy sources (Fitchard, K. 2009). Energy costs in Australia per capita are likely to rise as the population increases, just as operational difficulties and the costs of green technologies will drop (Fitchard, K. 2009). Electricity providers will presumably develop their environmental awareness as time goes by and government incentives are likely to be introduced. There will soon come a tipping point where the self-sustaining network at a household level makes for more economic and environmental sense than one that is a grid-powered (Fitchard, K. 2009). The current constraints of resources, however, and the lack of appropriate real-time communication at a household level has brought about several performance challenges (Yavuz, A. A. & Ning, P. 2012).

The demand for electricity has, in recent years, suffered greatly from a range of pressures due to environmental, economic, and regulatory demands (Halliday S, Beggs C, Muneer T. 1999). However, the goal of optimisation between demand and supply of electricity can be achieved through development strategies which are mainly compatible with ecological and economic sustainability (Halliday S, Beggs C, Muneer T. 1999). Sustaining sub-systems create a grid system, which is largely self-sustaining and brings about only slight operational complexity (Halliday S, Beggs C, Muneer T. 1999). Supported philosophy of complexity along The goals to which we should aspire are renewable technologies, supported by frameworks drawn from complexity theory, in order to create truly sustainable household area networks (Halliday S, Beggs C, Muneer T. 1999).

The management of self-sustaining societies and economies has become broadly accepted since the 1980s and exhibited as a backdrop for administration and policy decisions (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). This scenario aligns with current thinking about electricity consumption in our daily lives and current thinking about the future (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). However, in all regions of the planet and at every level (global, regionally, nationally, or individually)governments are having to make urgent and controversial decisions on consuming electricity.

The hard fact is that electricity demands have been based on very little study and research about how to integrate multiple consumption perspectives across spatial and temporal scales (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). What makes it harder is that the decision to make the system self-sustaining relies on the capacity to test, maintain, and create an adaptive capacitive system over time (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Such a procedure requires reconciling social, technical, economic and ecological imperatives (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

Global environmental concerns call for improving standards and increasing concentration on household area networks (Halliday S, Beggs C, Muneer T. 1999). The demand for electricity should contribute to defining a more efficient way of optimisation and appropriate change in the design thinking of demand side management (Halliday S, Beggs C, Muneer T. 1999). It has become increasingly clear that the non-linear dynamic of end-users should be controlled where possible by the capacity and time of use of renewable energy (Halliday S, Beggs C, Muneer T. 1999). This involves an appropriate choice of the renewable energy capacity, solar and batteries, improved timely integration of both to improve gains through better thoughtful specification and control strategies

6.3 Home Sustainability

The household anatomy of electricity is composed of different active systems, and passive elements (Agostinho, C. & Jardim-Goncalves, R. 2015). These include human and other artificial solar, storage batteries, and ICT (information communication technology) components. However, with the appearance of networked systems such as the smart electrical grid, one must accept the fact that humans should no longer have complete control over all the operations (Agostinho, C. & Jardim-Goncalves, R. 2015). This is true also for the consumption of electricity, which requires further mechanisms to maintain needed stability and to remain dynamic in order to follow the demands of such a changing environment (Agostinho, C. & Jardim-Goncalves, R. 2015).

A household electricity network is an ideal candidate in a complex system such as a smart grid system to test out new ideas via decentralised electricity consumption (Fitchard, K.

2009). Massive electricity needs during peak times cannot be met with an array of solar panels, but a single household among a network of tens of thousands could meet them. (Fitchard, K. 2009). The alternative of going off the grid entirely might not be a near-goal possibility, but thinking of households becoming partially self-sustaining could make progress towards this goal. (Fitchard, K. 2009). A household area is a random network that is symmetrically coupled to the electrical grid systems. Assuming that households are excitable elements that are able to become a pacemaker loop, if there are key features in the network of a home able to behave as a sustaining unit, it will be able to move coherently into oscillating states of consuming behaviours (McGraw, P. & Menzinger, M. 2011).

The reason why most suppliers and retailers of electricity in the developing world are moving to sustainable power sources and away from stations of supply generators, is not an overwhelming sense of global responsibility. Certainly, suppliers, retailers and end-users are all in agreement upon environmental concerns. However, suppliers and retailers are more concerned about decreasing generation power losses to secure more benefits, and end-users are concerned about decreasing the amount of payable bills of electricity. By the same token, the promised benefits by activation of self-sustainability approaches at household levels, are mainly to enable, settle and combine both parties to maximise e their benefits equally. The prospects of self-sustainability are the point at which both the trends of suppliers and consumers alike converge, to avoid the integration of spillover benefits and to embrace the integration of utility maximisation.

A network's sustainability depends on the extent to which household's utilities are nurtured and maintained over time (Kapucu, N. & Garayev, V. 2013). Therefore, the sustainability of homes in the grid system is influenced by interdependent relationships of consuming behaviour complexity, as well as how the household is being optimised at the local level (Kapucu, N. & Garayev, V. 2013). If we are serious about developing the household network for sustainability growth, then we will need to move further than the type of claims that have typically set out to influence isolated factors (Mason, Mark 2009). The perception of sustainability incorporates science as we have come to know it and pushes the boundaries of achieved knowledge into realms of societal policy and philosophy (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

Many researchers believe that the key to optimising a grid system is a "macro-micro" relationship (Kosack S. & Tobin J. 2006). Theoretically this belief is valid, although it is still not a perfect fit. At the very least, it needs to introduce other solutions and options from micro-macro perspectives (Kosack S. & Tobin J. 2006). In this research, I add to the work of other researchers to find possible ways from complexity philosophy to catalyse orders, which are required for the emergence of self-sustaining autocatalytic networks (Mossel, E. & Steel, M. 2005). My objective in drawing on complexity philosophy is to develop a suitable home perspective which relies both on continuity and change (Halliday S, Beggs C, Muneer T. 1999). A proposed process that is suitable for the home should indicate which conditions need to be in place to deliver the emergence of sustainability and to make these homes separately able to change (Halliday S, Beggs C, Muneer T. 1999).

Many electricity users are good at exploiting resources but much less adept at consuming only the amount of electricity they need (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Recently, the consumption of electricity has escalated the complexities of demand on societies. This critique, together with an increase in the rate of non-linear dynamic behaviour, implies that a singular cause which comes purely from end-users‘ behaviour (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The need to facilitate the evolution of these challenges has therefore become urgent (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The desired approach requires quick adaption to individual changing circumstances (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Autonomous sustainable systems rely on a collaborative and iterative learning approach to generate continual innovation and respond to rapid environmental changes (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The approach of sustaining management, when considered in the context of complex systems, is itself a complex activity (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The power of complexity lies in the shift from linear to exponential orders of magnitude (Mason, Mark 2009).

6.4 Sustainability Developments & Processes

I trace and track the vocabulary of sustainability to ‘grasp’ when it becomes attached to flexible practice: at the moment when dialogue is shaped through a variety of technologies of empowerment (Schofield, B. 2002). The underlying incentive to adopt a self-sustaining context is not there yet, but it could be one day (Fitchard, K. 2009). So far, there is no straightforward program that will take a system from here to “there” (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Proposed principles of self-sustaining will be drawn from the investigations undertaken through the literature (Urken, A. B., Arthur, B. N. & Schuck, T. M.

2012). Generally, ‘System Independency’ properties should be presented in no particular order and some or all of them overlap when necessary (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

The term sustainability may define the policies and processes that instantaneously deal with the electricity ‘‘spillover" , which goes into the grid from the integration of consumed electricity by end-users (Miller, B. J. 2005). In electrical smart grid systems, the learning of the whole system is synonymous with individual household learning (Peter Y.T.S. & Scott, J 2005). With individual acts, a distinction arises (Peter Y.T.S. & Scott, J 2005). What a macro level in an electrical smart grid system knows is overwhelmingly less than the sum of an individual system that is utilised in households (Peter Y.T.S. & Scott, J 2005).

Sustainable development is also part of the process. It relies on the kind of human capital that is as essential as a sustaining procedure (Kosack S. & Tobin J. 2006). The complexity theory addresses the concept of interdependence and sustaining process at the household area network level (Miller, B. J. 2005). Ralph Stacey stated three parameters that are essential to complex adaptive systems:

1) The rate of information flow through a system
2) The richness of connectivity between elements agents in a system
3) The degree of diversity between and within the schemas of the elements and agents (Mason, Mark 2009).

In order to make a household sustainable, all of the above parameters would need to be utilised (Mason, M. 2009).

When referring to a sustaining process, there is not much freedom to choose a starting point, unless it has been joined from a wider approach on the level of individual households (Zumbansen P. 2004). The view of understanding an identifiable, possibly autonomous order of consuming electricity, attracts the attention of a number of end-users (Zumbansen P. 2004). Different end-users have different norms generated on diverse levels of interaction (Zumbansen P. 2004). Providing self-sustaining grid systems is about making sure the system works interdependently on what it makes and within desirable boundaries (Roman H. 2012). The process of sustainability relies on reactions of collective autocatalytic subsets that have the nature of subtleties arising only on a micro scale level such as a household and absent at a macro scale level such an electrical smart grid system (Steel, M. 2015). Such a finding helps to present several new results to enhance the demand-side management processes in the household area and increasing the chance of the system's optimisation (Steel, M. 2015).

Many researchers have noted the sustainability of networks being possible once there is an inherent organisational value to provide certain levels of needed inter-organisational interaction, disregarding whether different entities are together or not (Kapucu, N. & Garayev, V. 2013). Mismanagement of network complexity leads to a chaotic environment as well as disorderly relationships unless the network actors rely on the network complexity to utilise what is added beneficially (Kapucu, N. & Garayev, V. 2013). Two cases decrease network sustainability, and those are disasters which are not common and emergences which occur every second in electrical smart grid systems and other complex systems(Kapucu, N. & Garayev, V. 2013). The interrelationship of households increases the interaction and the number of actors multiplies, in turn, increasing the chance of greater sustainability and an effective network (Kapucu, N. & Garayev, V. 2013). The most important factors for sustainability are how to provide the right concept for utilising ICT and structural factors (Kapucu, N. & Garayev, V. 2013).

With that in mind, a sustainability view was developed to try to provide a more nuanced look at end-user behaviour while consuming electricity and also to assess whether or not any particular operational structure would help lead to sustainability (Kurpius, D. D., Metzgar, E. T. & Rowley, K. M. 2010). The goal of this approach is to define new potential operations at the household area level and to seek insights into how the complex philosophy may start transitioning to a new enterprise environment (Kurpius, D. D., Metzgar, E. T. & Rowley, K. M. 2010).

6.5 Home Ecosystems

The ecosystems which we call homes, are complex, diverse, and dynamic (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). By using electricity, we have accelerated technological growth by increasing the scale of changes that were already nonlinear and full of surprises (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). As such, there is a concern about the scientific uncertainty surrounding our individual ecosystem's change and the management of our electricity consumption activities. The decision-making process is concurrent with a high degree of uncertainty which is coupled with an urgent need for a sustainability process (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Traditional science, while necessary, is not by itself sufficient for understanding and dealing with the case of complexity behaviour (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The sustaining perspective creates more time for the agents and the context of the ecosystem to make a change (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

Ecosystems of electrical systems have the property of interacting with the demand environment and within relevant moral interests, to survive by enabling itself as an integrated whole with given self-identities (Lockwood, Jeffrey 1996). Much of the existing literature examining the optimisation of a smart grid system focuses more on how to provide facilities tracing the issue of the non-linear dynamic behaviour of consuming electricity. Rather, the complex sustaining process focuses on how those facilities are well-structured and whether they are sustainable for the long-term (Kurpius, D. D., Metzgar, E. T. & Rowley, K. M. 2010). A valid approach to a sustaining human/ grid system is inspired by non-biological principles); (Salomon, G. 1981); (Letters from Readers 1984).

Nature gives examples of sustaining systems, such as ecologies, where interactions among organism components involve information, energy exchanges and matter, and where complexity awards stability (Colombano, S. P. & Shen, W. M. 2006); (Walles, B., Troost, K., Ende, v. d. D., Nieuwhof, S., Smaal, A.C. & Ysebaert, T. 2016); (Powell, J., Maise, G. & Paniagua, J. 2001). Natural ecologies are thus a fountain of inspiration for the diverse types of intelligent systems we need to build. The empowerment development nexus at a household scale, which is discussed in terms of the interrelationships of the scale agents. is probably too weak so far to be self-sustaining (Duflo E. 2012). Sustaining systems need to illustrate not only for components coordination but further for the exchange between energy and matter (human). Therefore, an increasing complexity factor should not come at the cost of reducing the stability of a system.

This mechanism of self-sustaining (SS) activity patterns attributes to the temporal memory of individual agents (McGraw, P. & Menzinger, M. 2011). Reciprocal exchange is an example of self-sustaining and can be found in societal tiers in electrical smart grid systems when more people engage in a reciprocating exchange on the electricity market (Kranton R. E. 1996). Greater population in the grid system found in household area network makes the concept of sustainability harder to trade, the greater the incentives to illustrate reciprocal exchange relationships (Kranton R. E. 1996). The sustaining process of intelligent systems aims to achieve more scientific returns, decrease tracking costs and reduce the chance of unfavourable events (Colombano, S. P. & Shen, W. M. 2006). Robotic concepts, electric vehicles, and electrical power generation are all good examples of attempting to create self-sustaining approaches implemented within a short term for purposes that can be considered relatively immediate (Colombano, S. P. & Shen, W. M. 2006); (Ono K. 2015).

The past science has concentrated on simple cause/effect relationships like Newton's formula, 'force equals the product of mass and acceleration', and shows regularities to detect, replicate, measure, and control behaviours (Agostinho, C. & Jardim-Goncalves, R. 2015). In contrast, the science of complexity theories offers simple causes for complex effects, with complex rules showing how a set of elements interacts and behaves over time within its boundaries (Agostinho, C. & Jardim-Goncalves, R. 2015). Complexity science is not providing a prediction for one sort of outcomes for a particular state. Rather, it would provide learning algorithms which enable the system to be adaptive to its environment over time, which at large population new emergent take a place to emulate a real world phenomenon (Agostinho, C. & Jardim-Goncalves, R. 2015).

In a complex system, the emergence of self-sustaining systems never comes from a single node or an agent which must be delivered from the collective activity patterns of interacting agents (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). Agents in the self-sustaining systems are allowed to change their connections and redistribution strength and robustly split into several clusters, with partial permittivity of the agents to synchronise within each cluster (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). The sustainability processes modelled through threshold elements when the local environment of a household exceeds a particular threshold, leads to cascading activations throughout the whole system (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). For example, the neuronal dynamics is a well-known model which describes the mechanism of sustaining activities in networks (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). Many researchers have realised particular analogies amongst societal and neuronal systems through information processing when gathering from those systems and acting accordingly. An example of this is firing in the case of neurones, and another, consumption in the case of residential electricity users(Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015).

Other studies of mechanic-chemical activation and human neuroscience describe an essential property of a self-sustaining reaction as an adiabatic process, which maintains the stability of the concurrent system with non-repetitive activity patterns that consistently emerge (Steel, M.

2015); (Scorcioni R., Hamilton D. & Ascoli G. 2008); (Butler, B. 2013). It seems that the value of self-sustaining is also defined as far from the equilibrium that generates a balance between energy generation and energy dissipation at no cost (Egbert, M. D. & Barandiaran, X. E. 2014); (Knutsen, W. L. 2013). This assumes that the action of consuming electricity may be represented as ‘molecules’ of information nodes moving through internal network dynamics and facing disruptive interoperability based on the end-users‘ dynamic (Agostinho, C. & Jardim-Goncalves, R. 2015). Finding a well-balanced point of consuming electricity in households for optimum use of electricity, reaches a maximum as a way to go, by using efficient power management circuits (Mahlknecht, S. & Roetzer, M. 2005).

It is also characterised as the process of interaction between the two predominant coherent structures (renewable energy and traditional energy) and their possible additional functionality within domestic demand scale (Sargen N. 2010); (Hwang, Y. 2015); (Teramura, T. & Toh, S. 2016). Further, sustainability is also defined as a ratio reaction of the internal energy of a system (enthalpy) in relation to the capacity of that energy produced to cover its space demand (Takacs, L. 2014).

Importantly, it takes fully exposing individual observers for each household to realise the complex image of societal self-sustaining under the constant control of the regulatory intervention (Zumbansen P. 2004). The observation of the self-sustaining process is a merited expression if only to lay out the ground work adequately toward the contributions, such as the one feed, to add the consciousness through the monitoring and controlling systems in various households (Zumbansen P. 2004). The observer of the self-sustaining system is entirely determined by its approach which would be understood in the most basic way (Zumbansen P. 2004). Through exploring the rationale of underlying systems thinking and its possible applications, it is essential to turn the attention to the principles of self-sustaining gleaned from different disciplines (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Therefore, a sustaining approach is a tool to look at the problem state by using the lens of system thinking (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

6.6 Investigate A Home Complex System

There is a lot redundancy in how unrelated individuals are consuming energy. For an individual household system to sustain itself, a lot of external energy is essential, as there is a very little recycling of energy usually available at household level (Castillo, R. D., Kloos, H., Richardson, M. J., & Waltzer, T. 2015). A household system moving toward a sustainable change may be attributed to involve new properties and behaviours which emerge from the interaction of ample factors in technical areas, policies, economics, and environments (Mason, Mark 2009). To sum up by way of a restatement of what I see as an essential insight of complexity philosophy regarding the sustaining process: It is that new behaviours emerge that are not limited to the elements that constitute a household system. Rather, this comes from the diversity and rich connections among those elements, as shown in Figure 6.1 (Mason, Mark 2009). It can be described in a different way as the successive linear addition of new features to the household multiplying exponentially into the number of connections among the other constituent elements.

The phenomena of initial conditions leading to subsequent outcomes that are shaping in nonlinear dynamic behaviours are hard to predict (Mason, Mark 2009). Inexorably, the initial condition will grow with the richness of uncertainty and cause nonlinear fluctuations in consuming phenomenon (Mason, Mark 2009). Complexity theory and the science of end-users‘ behaviour are relevant, particularly when vast numbers of constituent elements are being connected and interact together, in many different ways (Mason, Mark 2009). Examples of constituent elements in complex systems, are organisations, neurones, molecules, atoms, and human beings (Mason, Mark 2009); (Agostinho, C. & Jardim-Goncalves, R. 2015).

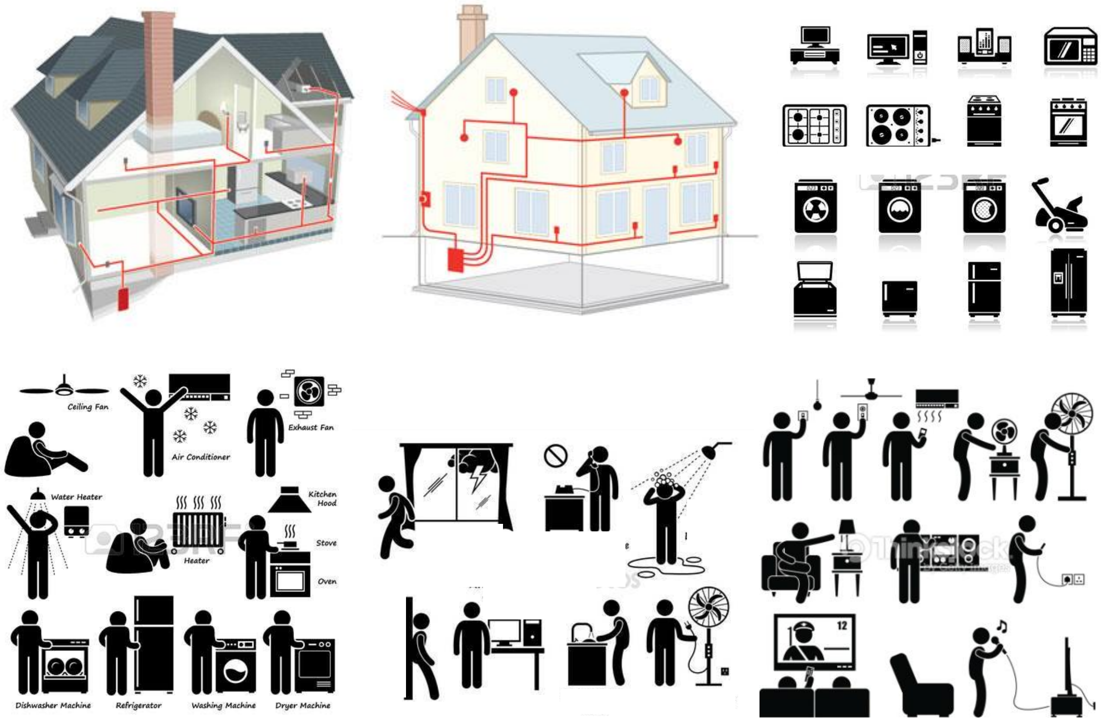

Figure 6. 1: Home Complexity Demand of Electricity (Google 2017)

The definition and assessment of self-sustaining processes (SSP) are dependent upon the context and history of individual households regarding the consumption of electricity (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). The process of self-sustaining should, therefore, involve analysis and exploration of the familiar and historical context of the consumption situations on multiple scales (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012). Amongst the deep diversity of the end-users' activities across a variety of consuming scales, any process to promote self-sustainability should be learnt through incorporating mechanisms for cross-system collaboration and communication (Urken, A. B., Arthur, B. N. & Schuck, T. M. 2012).

The actual domain of a controlling system's interoperability has a need for a new paradigm able to manage the dynamic of the network, and to deliver an optimal adaptation along the lifecycle of a venture, as illustrated in Figure 6.2 (Agostinho, C. & Jardim-Goncalves, R. 2015). For this reason, the theory of complexity gives a set of heuristics that can be aggregated and applied to support the dynamic of networks and keep the overall level of outcomes stable (Agostinho, C. & Jardim-Goncalves, R. 2015). Beyond that, there is always technology suitable to practically implement such approaches (Agostinho, C. & Jardim-Goncalves, R. 2015). Therefore, from the complexity literature, I will propose a novel metaphor to build a model and apply the mechanism for a self-sustaining purpose (Agostinho, C. & Jardim-Goncalves, R. 2015).

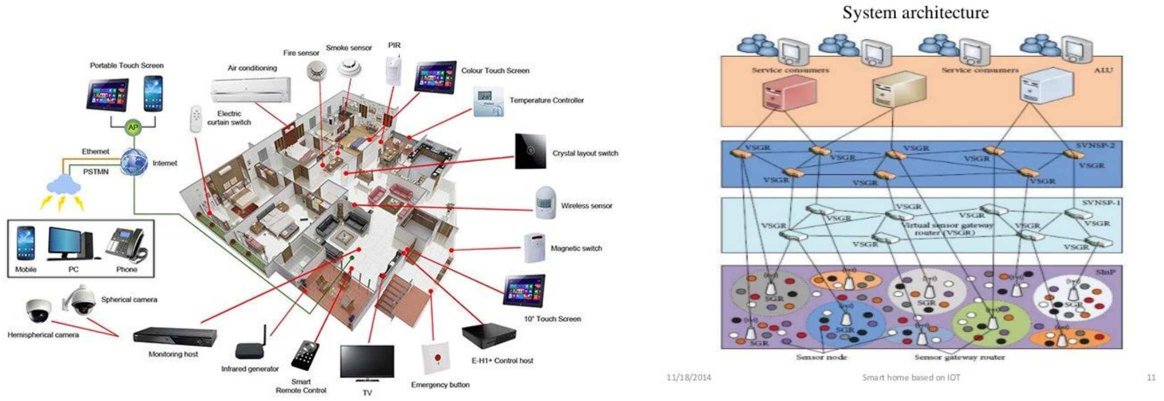

Figure 6.2: Home Electrical monitoring & Controlling Systems (Google 2017)

The household area network could reach a level of sustainability through the perception of inter-organisational relationships, to become involved in a house area network (HAN) by using information-communication technology (ICT) similar to that explained in the above figure (Kapucu, N. & Garayev, V. 2013). Seeking sustainability outcomes, is about preparedness against emergences, response, mitigation and recovery of household area network as a complex network (Kapucu, N. & Garayev, V. 2013). Achieving this depends on a multiagency collaborative approach by using ICT utilisations to facilitate inter-organisational relationships (see Figure 6.3) (Kapucu, N. & Garayev, V. 2013).

Providing a change at the individual household level is a fundamental aspect of modifying the way of governing the electrical smart grid systems (Peter Y.T.S. & Scott, J 2005). The sustainability of individual households in the grid system is more bound up in the commitment of the originators, in an existential way, to ongoing interwoven actions (Fuller, T., Warren, L. & Argyle, P. 2008). The self-sustaining process (SSP) has consistently emerged from non-repetitive activity patterns (Scorcioni, R., Hamilton, D. J. & Ascoli, G. A. 2008). The threshold values of consuming electricity by individuals are narrowly constrained with different stochastic initial conditions (Scorcioni, R., Hamilton, D. J. & Ascoli, G. A. 2008). These values indirectly affect network stability depending on the variability of the output range for each individual (Scorcioni, R., Hamilton, D. J. & Ascoli, G. A. 2008).

The achievement of the networks' sustainability requires investment by suppliers, retailers, and consumers of electricity towards increasing technical capacity and interrelationships (Kapucu, N. & Garayev, V. 2013). The emergences of non-linear behaviours by end-users, while consuming electricity, is a continuous emergency phase that should be consequent with the characterisations of density relationship structures among the system actors (Kapucu, N. & Garayev, V. 2013). Changes at the micro level help to touch base with individuals' cognition and finding most suitable individual frameworks (Peter Y.T.S. & Scott, J 2005). First order change always happens when the demand for electricity appears from individuals, while second order change is the attempt made by individual systems at the household level to serve and translate those actions to the organisational level.

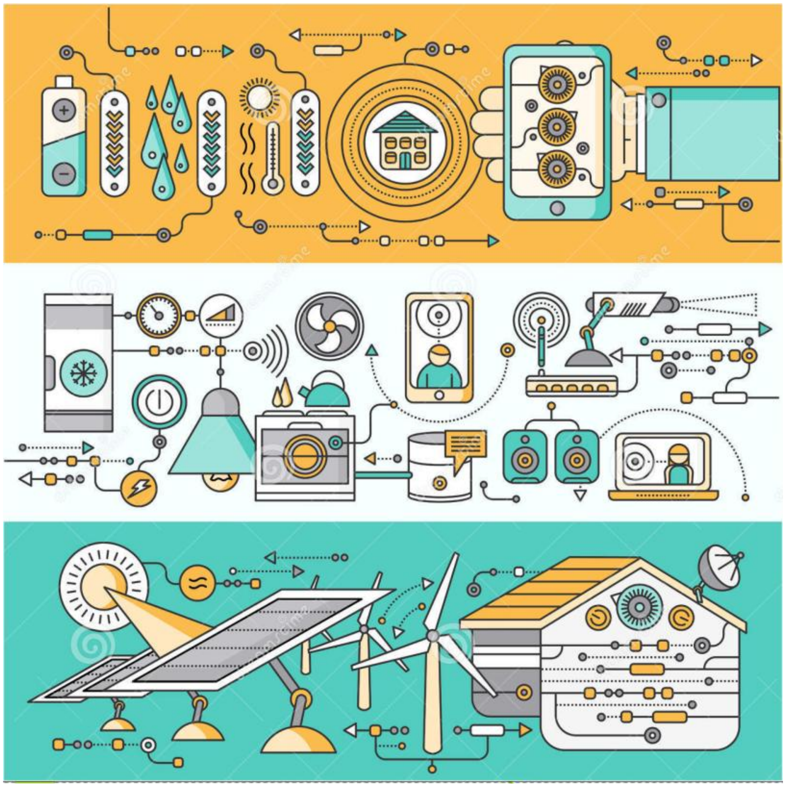

Figure 6.3: Modifying individual households for governing the electrical grid systems (Google 2017)

The relevance of system complexity at micro levels that shows in the figure above crystallises around the dynamics involved in the interfaces between multiple individual house levels and the electrical smart grid context (Peter Y.T.S. & Scott, J 2005). Governing the unconscious of electricity consumption by end-users either revolves around actions that are massive and sudden or incremental and gradual (Peter Y.T.S. & Scott, J 2005). In order for individuals or households to sustain their existence, they should act through flexible responses against uncertain environments (Fuller, T., Warren, L. & Argyle, P. 2008). Self-sustaining, relating to the interface between individual levels of households and their systems to initiate second order change, occurs at that micro level and in macro smart grid contexts (Peter Y.T.S. & Scott, J 2005). Therefore, capturing this concept in a framework means focusing on critical areas of interfaces elaborated through specific procedures and processes (Peter Y.T.S. & Scott, J 2005).

The particular argument is that it is either possible, or not, that the unconsciousness of consuming electricity by multiple end-users be organised and structured by self-sustaining policies (Castillo, R. D., Kloos, H., Richardson, M. J., & Waltzer, T. 2015). This is explored because individuals have different and unique behaviours, even within their individual scales, while they are consuming electricity at the same time (Castillo, R. D., Kloos, H., Richardson, M. J., & Waltzer, T. 2015). Although consumption activities may be different in detail, they are still similar enough to become coupled together to provide mutual reinforcing experience (Castillo, R. D., Kloos, H., Richardson, M. J., & Waltzer, T. 2015). At this precise point of combining multiple end-users, we should seek to spell out what the explanatory mechanism looks like, using our understanding of complexity theory as a guide (Castillo, R. D., Kloos, H., Richardson, M. J., & Waltzer, T. 2015).

6.7 Theoretical Implication of Home Sustaining Model

The complex system dynamic (CSD) is a feedback loop concept based on object-oriented modelling paradigm. This idea of complex modulation was developed in 1958 by Forrester (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). Recent advances in modelling tools for event monitoring should be a support to understanding heterogeneous aspects of a self-sustaining system in order to provide the operative stability (Agostinho, C. & Jardim-Goncalves, R. 2015).

The approach of self-sustaining work on solutions taken from complexity philosophy in order to propose a self-sustaining framework reveals a set of technical solutions which may be implemented (Agostinho, C. & Jardim-Goncalves, R. 2015). In this regard, I have borrowed the ideas of Rehan, R.; Knight, M.A.; Haas, C.T.; Unger, A.J.A (2011) about sustainability and made concurrent changes in order to draw out a household relevance to the practice of self-sustaining governing, as illustrated in Figure 6.4. The model was re-exploited for establishing short term loops (a household system) rather than long term loops (a grid system).

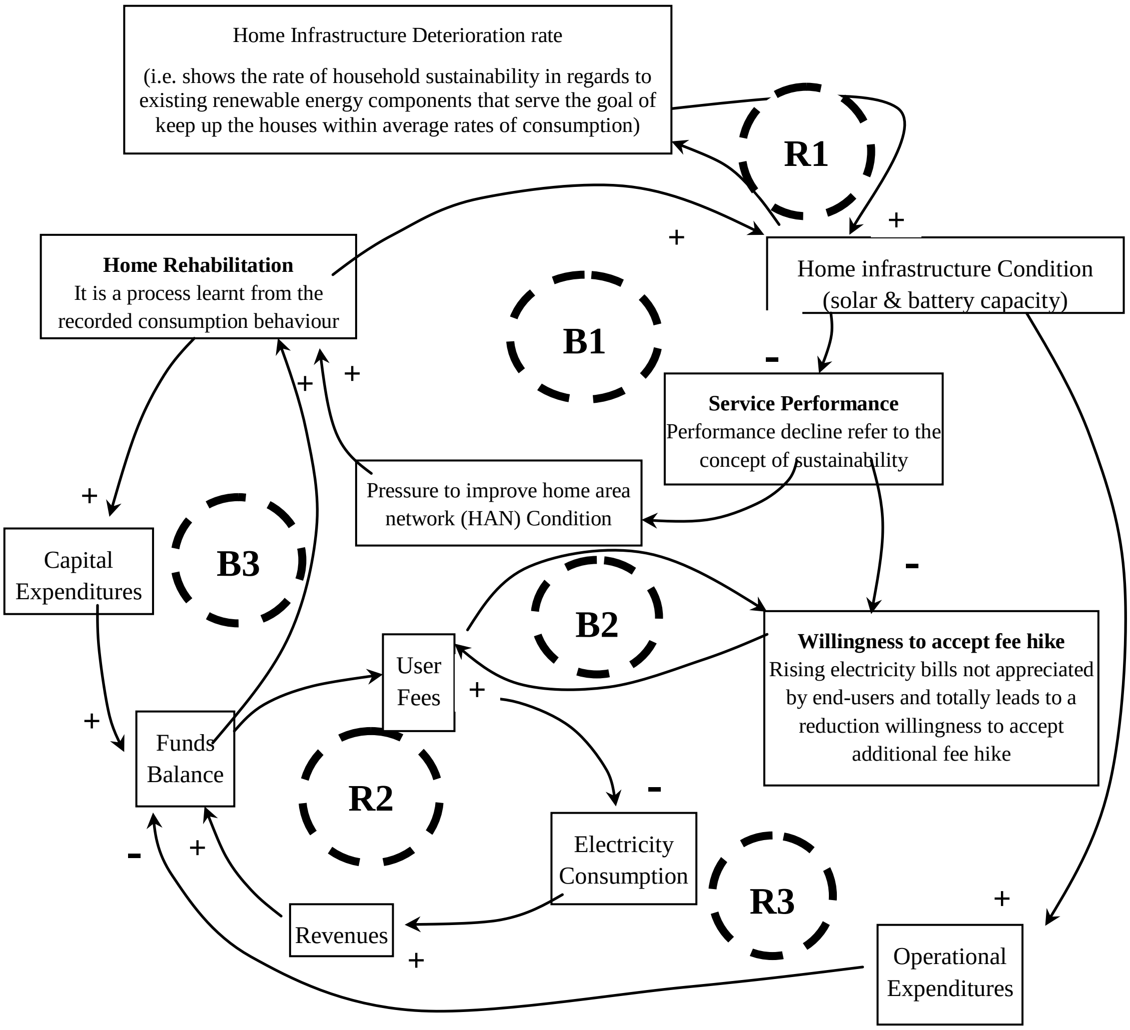

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Figure 6.4: SELF-SUSTAINING MODEL (SSM)
(Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011)

6.7.1 Reinforcing loop Of Household Conditions R1

A feedback loop of household infrastructure deterioration shows the rate of household sustainability in regards to existing renewable energy components, which in turn, determine the condition of the homes individually (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The rate of deterioration describes a particular need of renewable energy resources for a certain household (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The condition of the household is based on renewable energy components deviating up or down from the proposed base load line of consumption (5500-7500 KW.hr/Year). The feedback loop then reports the timely cases of deterioration and collectively decides the possible action needed (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

6.7.2 Balancing Loop Of Household Conditions B1

The rapid accumulation of consumed electricity by residential houses is caused by loop R1 and possibly mitigated by a balancing loop B1 (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). If a specific home condition increases the process of deterioration, then the grid service performance will decline as a result (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). That increase is discomforting to both end-users who must pay extra money in such a case and also suppliers, because the system incurs more energy losses accordingly (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). Such a case will be resolved by improving the conditions of the home by providing a rehabilitation process learned from the recorded behaviour. Thus, increased deterioration behaviour will subsequently translate into improved home infrastructure status (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). This closing loop in a household area functional society, will ultimately drive improvement (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

6.7.3 Reinforcing Loop Of Revenue Generation R2

An electrical utility is financially self-sustaining in the cases of its revenues exceeding or equaling its expenses (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The electrical utility increases user fees when fund balances (revenues minus expenditure) fall to certain threshold value (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The reduction in using electricity at peak times is characterised by time delays that shift the consumption to other occasions which consumers cannot avoid (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). Furthermore, if the customers are aware of such an issue and decide to decrease the volume of electricity consumption, that will lead to reducing the revenues. This, then, will cause a decreasing fund balance (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

The loop of self-reinforcing feedback cannot operate indefinitely since any constraints occurring around the loop could trigger to stop growth. An example referring to the causal loop figure, is that once electricity consumption reaches zero rate due to a household not using electricity for any reason, further mitigation of electricity costs will occurs from that home. In the meanwhile, it will be impossible to measure that particular consumption behaviour from that home in relation to electricity user fee increases or decreases as the whole sale figure of electricity will finally influence the selling pricing of electricity.

6.7.4 Balancing Feedback Loop B2

An electrical utility is financially self-sustaining in the cases of its revenues exceeding or equaling its expenses (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The electrical utility increases user fees when fund balances (revenues minus expenditure) fall to certain threshold value (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The reduction in using electricity at peak times is characterised by time delays that shift the consumption to other occasions which consumers cannot avoid (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). Furthermore, if the customers are aware of such an issue and decide to decrease the volume of electricity consumption, that will lead to reducing the revenues. This, then, will cause a decreasing fund balance (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

The loop of self-reinforcing feedback cannot operate indefinitely since any constraints occurring around the loop could trigger to stop growth. An example referring to the causal loop figure, is that once electricity consumption reaches zero rate due to a household not using electricity for any reason, further mitigates electricity costs will occurs from that home. In the meanwhile, it will be impossible to measure that particular consumption behaviour from that home in relation to electricity user fee increases or decreases as the whole sale figure of electricity will finally influence the selling pricing of electricity.

6.7.5 Balancing Loop Of Capital Expenditures B3

The increase in capital expenditure synchronous with the increase in rehabilitation rate of a household unit will affect the availability of funds to balance for the extent of rehabilitation works (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

6.7.6 Reinforcing Loop of Operational Expenditures R3

This feedback loop encompasses four variables: Home Condition; Funds Balance; Operational Expenditures; and home Rehabilitation (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The deterioration of a household not only depends on the scale of consumption and the home readability regarding renewable energy, but this scale also rises and falls according to consumers‘ behaviours (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). Both scenarios incur additional costs for the grid utility unless consumer behaviours do not return operational benefit when rehabilitating the household electricity infrastructure (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

The losses of end users' non-linear dynamic behaviour will directly increase the operational expenditures and reduce the availability of funds for the future rehabilitation (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). When households are less rehabilitated, the condition of the homes will further deteriorate and conduct in the cycle of deterioration to accelerate (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). The above discussion describes electrical household management systems involving multiple interacting feedback loops (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

Recent research has shed light on understanding how the loops contribute to deliver sustained activities that affect the activity patterns (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). The exhibited process of self-sustaining activity is influenced by the temporal memory of the individual agents that use the technique of short loops (within a household) rather than long loops (within a grid system) (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015).

In addition, recently enacted policies and standardisations in Australia and elsewhere require electrical utilities to be more efficient and self-sustaining over both the long-term and the short term loops of operation (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

As we understood from the above discussion; the underlying mechanism of self-sustaining activity comes as a collective effort of feedback loops through the existence cycles of a system (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). This implies that dealing with the phenomena of peak/off-peak is a significant issue which comes as the result of end-users‘ consumption of electricity (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

6.8 Home Practical Conceptual Model

We should not deny that the word model is a systematic description of a phenomenon or object that shares essential characteristics with a phenomenon which commonly occurs in everyday life. Further, the word 'model' is quite common in traditional management-speak, such as risk models, procurement models or stakeholder models, but it still presents a challenge in complexity management-speak. It is a presentation of an electricity grid system (in our case) which is intentionally designed to study some aspects related to the selected system as a whole (Cooper, D & Schindler, P 2010). Overall, a conceptual model is an abstraction of the way researchers decide to comprehend a particular part, aspect, property or function of reality (Jonker, J & Pennink, BW 2010).

The words ‘framework’ and ‘model’ are used interchangeably for the same purpose, which attempts to infer either abstract or observable phenomena. In practice, the conceptual model converges and commercialises more with specifics of the research process than the broader divergences and theoretical frameworks, which mainly tend to focus on abstract concepts. With that, the proposed practical operator model in this study is a framework which helps to reveal the relationships of the various constructs under investigation, along with the focus and direction of the research study. It belongs significantly to the theories developed from the literature review in different chapters which on many occasions have been formed into a ‘theoretical framework‘ or ‘model’ to commence the subsequent research.

It is essential to note that the literature discussed in the previous chapters, is used to describe the influence of electricity consumers upon the composition of the electricity market and the. Regulations provided that are supported by regulatory policies and rules. The model illustrates multiple modes of connection that influence consumers’ behaviours. The previous chapters described that the consumers of electricity connected with the grid through contractual tariff methods (Time of Using Tariffs (TOU), capacity & demand based tariffs and the use of non-utility based communications tariffs), as highlighted in Network Tariffs report (2015). The research gap lies in the absence of a model that is able to tune the demand of different consumers on the electricity grid network to achieve the optimal desired outcomes that reduce energy losses and gas emission. This gap has been ignored in previous studies.

To date, a few models have captured the self-sustaining ‘Long Loop’ within a system. Rather, than data no model has captured the self-sustaining household scale arising from complex philosophies and system dynamics of ‘short loops’ (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011). It has long been a concern of many researchers and the subject of recent observations, that many efficient complex systems do not necessarily need to have long loops since the traces of the users are very treelike, with comparatively short loops (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015). Therefore, it is essential to propose a different kind of mechanism of self-sustaining cascades that involves short feedback loops within an optimum operational scale of a household (Allahverdyan, A. E., Steeg, G. V. & Galstyan, A. 2015).Subsequently, a novel contribution of this research is to develop an applicable complex system dynamic model that can be exploited for self-sustaining loops as a strategic network management (Rehan, R., Knight, M.A., Haas, C.T. & Unger, A.J.A. 2011).

In an attempt to overcome the gaps in previous studies and assessment models of electricity demand management, 'a home operator model,' illustrated in Figure 6.6 to comprise all factors influencing consumers' demand behaviour was developed, consisting of the following: dimensions:

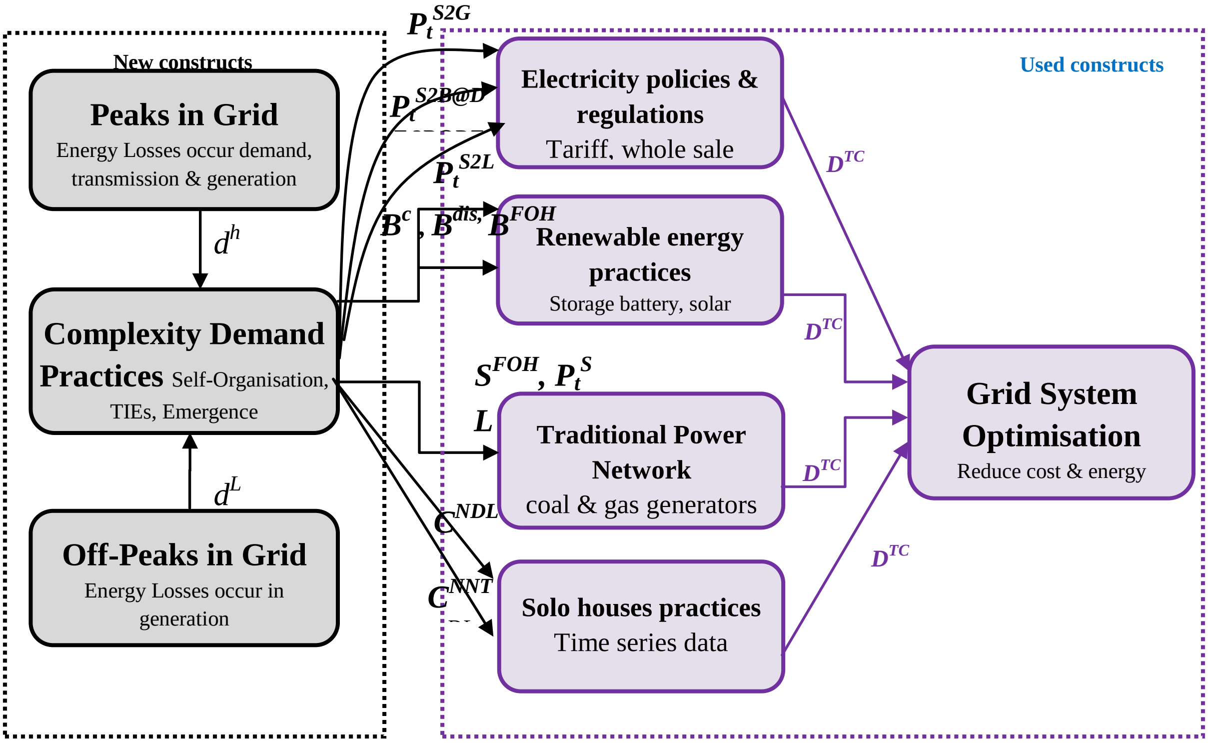

Figure 6.5 : The assumed Conceptual Model of 'Home Operator Model' (Combined by the Author)

6.9 The model variables

Optimising demand and supply of electricity is a complex task. Therefore, the tested model consists of thirteen variables which are:

d^h : *Highest demand load for each consumer*
d^L : *Lowest demand load for each consumer*
B^c: *Battery in Charging status*
B^{dis}: *Battery in discharging status*
C^{NDL} : *Power capacity available at home, but not needed in the period of Day Light*

C^{NNT} : *Power capacity available at home, but not needed in the period of Night Time*
B^{FOH} : *Battery capacity used from homes to serve other homes achieve Averages*
S^{FOH} : *Solar capacity used from homes to serve other homes achieve Averages*
P_t^S : *Timely power needed from solar at home*
L: Load = other homes demand that need to support to achieve average demand
P_t^{S2L}: *Timely power needed from solar to load*
$P_t^{S2B@DT}$: *Timely power needed from solar to battery at day time*
P_t^{S2G} : *Timely power needed from solar to grid*
D^{TC} : *Desired Timely Consumption*

The variables exhibited to manipulate how the grid system alternatively operates, whereas the results aim to achieve an optimum operational model. All details about the proposed operator model and the analysis results are found in chapter six.

6.10 Conclusion

The key aspect of this chapter discussed that the proposal that managing for sustainability is possible. The intentional argument made for the self-sustaining process is theoretically supported by evidence from the literature and socially constructed for the optimisation meaning. As a consequence, socially constructing an optimisation means that it is possible to achieve by developing a collective vision and shared insights and strategies amongst households, in order to sustain smart grid systems of practice. Evidence for support of this position has been adapted from complexity philosophy, that is, that a self-sustaining process can be collaboratively established among end-users of electricity. Undoubtedly, a self-sustaining process can be based on shared instructional values and norms which assist in maintaining the grid optimisation through reform efforts.

Certainly, there is no shortage of agreement about the lack of management knowledge for self-sustaining, which apparently stems from physical and biological scientific disciplines. As we have seen, studying and adapting self-sustaining methods could be utilised to apply the ecosystem approach, complementing but not displacing the existing efforts of systems. If so, the big question is how? Without good theories, good management can only happen by accident. Without practice, all theories are suspect. Are there ways to combine science and management in a way that builds on the strengths of both? Definitely. Thus, the attempt made in this research and explained in chapter six represents a trial to find a way to combine the managerial perspective and the scientific, in ways that builds on the strengths of both to learn more about how to achieve a sustainable human future.

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Chapter 7

Analysis Results

Acronyms

ARIMA: Autoregressive Integrated Moving Average

ARR: Accounting Rate of Return

AEMO: Australian Energy Market Operator

Ave: Average Demand of Electricity

CBA: Cost Benefit Analysis

CL: Controlled Load at Household Level

CPAM: Capital Pricing Asset Model

DCF: Discount Cash Flow Technique

DNSP: Distribution Net Work Service Provider

GC: General Consumption Load of Residential Houses

GG: Solar General Production Power of Residential Houses

IRR: Internal Rate of Return

NPV: Net Present Value

OP: Off-Peak Demand of Electricity

P: Peak Demand of Electricity

PP: Project Pay Back Period

PV: Present Value

ROA: Return on total assets ratio

RR: Rate of Return

Lessons Learned from Chapters One, Two, Three, Four, Five & Six

This chapter depicts the meaning of system sustainability based on complexity theory literature, by applying the conceptual model of sustainable houses. The proposed model offers a way forwards in managing the complex execution of reform within available electricity systems operational approaches. Thus, in the previous chapter, complexity theory inspired an integrated, sustainable approach to maintaining cognitive control of the dynamic electricity demand process which is now designed to adapt to desirable change in a complex environment. This chapter describes how a complex theoretical basis can help to determine a structural model that is consistent with the characteristics of the research problem and the most suitable methodologies to address it.

Chapter Outline

This chapter portrays how the proposed hypotheses, theories, and models discussed in the previous chapters, were tested. The analysis goal is to understand the complex practice of human non-linear dynamic behaviour in electrical smart grid systems in Australia. This includes outlining the mathematical analysis undertaken for this research. The results are exhibited in two stages of analysis, based upon particular analytical tasks. Stage one of analysis will be provided in this chapter to shows the problem of end-users' behaviours due to significantly consuming at peak and off-peak demand levels, rather than at desirable average demand levels. Stage two will discuss a proposal of an optimal average scheduling model. This model will be designed and experimentally tested.

7.1 Introduction

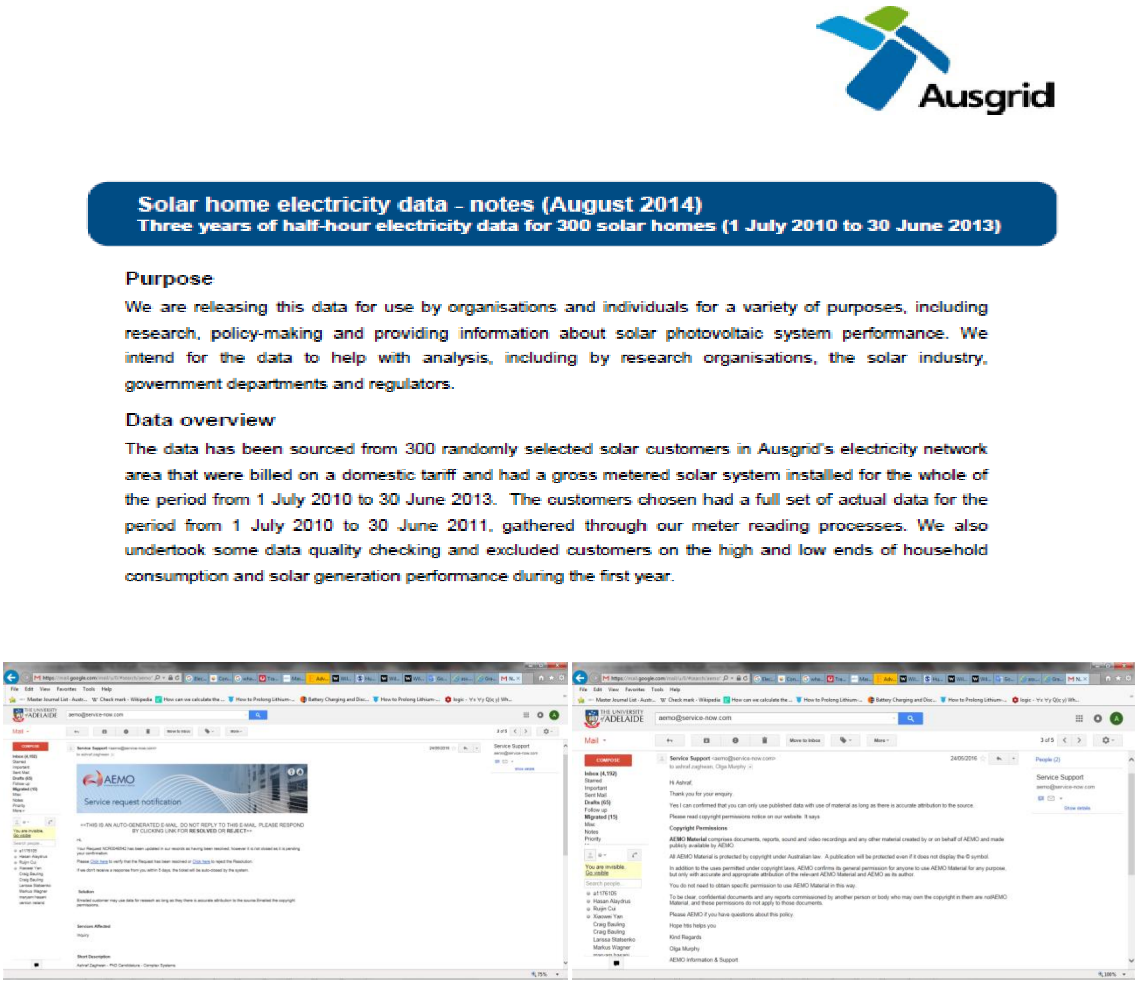
Strategy and execution are continually moving domains in a social system. The research domains of this thesis focus on a better understanding of the complexity of dynamic human systems for the strategic formation and implementation of new solutions. Two research spaces in chapters four and six have presented the main domains in two spaces: the theoretical constructs of complexity theory and the practical application of multiple sets of complexity theory spaces. A range of research areas relevant to the primary research, the study of 'system complexity ' are also presented in chapters one, two, three and five. These chapters represent the research domain in three other spaces: the issue, the objective and the theoretical solution spaces. These research areas are not mutually exclusive nor exhaustive of the discipline under study, in providing new strategies and solutions. However, while all are crucial, this thesis focuses on complexity systems as they were exclusively presented in chapters four and six: in a strategic conceptual model for execution.

The thesis may enter other research areas when they are judged to impact significantly on the central complexity study, exploring them no further than is suitable for the primary purpose of the thesis. Where other questions may arise in these areas, they are proposed for further research. In chapters one to six, the research progressively forms a framework of ideas and methodologies based largely on complexity learning, to advance the findings of the thesis in chapter seven, for testing the proposed complexity approach. Hence, chapter seven translates complexity theory into practice, through adapting the complexity approach to the conceptualised execution of a proposed sustainable model; this, then validates the new approach of complexity strategy capability.

7.2 Data Collection

The data collected is a time series data of electricity consumption for three hundred residential houses in New South Wales - Australia. The data was recorded every half an hour forty-eight times a day, for three years and for each house. The total data used for analysis is equivalent to 3 (Years) x 365 (Days) x 48 (Times/Day) which equal (15,768,000) millions. The permission for using the data collected was achieved directly from the Australian Energy Market Operator (AEMO), the publisher of the data, and from the owner of the data company which is named ‘Ausgrid’. The Ausgrid firm is a ‘Distributor Network Service Provider’ (DNSP). For more information about the role of the Ausgrid company in the New South Wales’ electricity market, refer to chapter two; Figure 20: Electricity Market in NSW -

(Shaun McGushin & Adam Seeto 2012). Snapshots of the permission letter for using the data is shown in Figure 7.1 below; evidence of messages between me, AEMO, & Ausgrid are exhibited, as well. The purpose of testing this data is to provide evidence of the influence of non-linear and non-equal electricity end-users’ behaviour that leads to creating peak and off-peak phenomena, and also to provide a sustainable solution toward this issue.



Ausgrid

Solar home electricity data - notes (August 2014)
Three years of half-hour electricity data for 300 solar homes (1 July 2010 to 30 June 2013)

Purpose

We are releasing this data for use by organisations and individuals for a variety of purposes, including research, policy-making and providing information about solar photovoltaic system performance. We intend for the data to help with analysis, including by research organisations, the solar industry, government departments and regulators.

Data overview

The data has been sourced from 300 randomly selected solar customers in Ausgrid's electricity network area that were billed on a domestic tariff and had a gross metered solar system installed for the whole of the period from 1 July 2010 to 30 June 2013. The customers chosen had a full set of actual data for the period from 1 July 2010 to 30 June 2011, gathered through our meter reading processes. We also undertook some data quality checking and excluded customers on the high and low ends of household consumption and solar generation performance during the first year.

AEMO

Service request notification

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Solution

Services Affected

Inquiry

Short Description

Ashraf Zaghwan - PhD Candidature - Complex Systems

Service Support <aemo@service-now.com>
to ashraf zaghwan, Olga Murphy
24/05/2016

Hi Ashraf,

Thank you for your enquiry.

Yes I can confirmed that you can only use published data with use of material as long as there is accurate attribution to the source.

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Olga Murphy

AEMO Information & Support

Figure 7.1: Letter of Permission to use the collected data for analysis

7.3 The Stages of Analysis

The analysis consists of two stages. Stage one is to depict the issue of non-linearity and stage two is to provide a proposed solution based on these analytical stages that are associated with the issue of end-users‘ non-linearity and dissimilarity in demand for electricity.

Finally, having reached these analysis goals, other solutions and future studies are also proposed. Thus, prior to starting stage one, it is important to find suitable software tools for use in visualising and reporting the diversity of end-users and their influences on the grid system. This is because stage one aims to magnify uncertainties that are created by end-users and quantify the levels of dissimilarity, diversity and non-linearity of different consumers. This analysis must show evidence that is completely different when the demand for electricity is dealt with from micro levels rather than macro levels.

In this sense, I made a review of related materials to establish criteria for the formulation pursued under the causations of peak/off-peak phenomena of electricity. The sensitivity analysis technique as described by Frey, H, & Patil, S (2002), is used along with a different description provided by Isukapalli, S.S. (1999). The former author depicts sensitivity analysis either based on statistical methods, mathematical methods or graphical methods (Frey, H & Patil, S 2002). In case the purpose of the analysis is to measure and evaluate the sensitivity of the output regarding the range of values of the input parameters, then 'mathematical methods' refer to the underlying methodology (Frey, H & Patil, S 2002). 'Statistical methods' are suitable for the probability distributions of model inputs to perform repeated calculations of the model output in order to assess the influence of input variance on the output distribution (Frey, H & Patil, S 2002). Graphic methods are visual methods which illustrate sensitivity through graphs, surfaces and charts (Frey, H & Patil, S 2002).

Isukapalli, S.S. (1999) also portrays sensitivity analysis testing methods through three types. The first type, 'analytical methods' uses governing model equations to determine sensitivity. The second type, computer algebra methods, immediately manipulates computer code to determine sensitivity information. The third type, sampling based methods, create relationships between model outputs and inputs in terms of the value obtained. This model is basically running a large number of different parameter combinations (Isukapalli SS. 1999).

Under the above taxonomy, the adopted analysis approach for stage one is a mix of two methods. One approach, adopted from the perspective of Frey, H & Patil, S (2002) was assumed to be graphical methods. The second sensitivity analysis approach, was adopted from Isukapalli,S. S. (1999) and which was defined as the 'computer algebra method'. To this end, the following steps were performed in stage one of the analysis:

The proposed analysis framework on which Matlab is based assumes a categorising methodology in order to provide a coherent basis for constructing a reminder of the final solution model. The light of sensitivity analysis has been used to find the maximum and minimum combined variations of data parameters that cause a change in the ranking of the three assumed management options: Peak (P), Average (Ave), & Off-Peak (OP) of timely electricity consumption. I am also altering the ‘Average’ as a preferred management decision since peak, and off-peak demands are permanently defined as unfavourable (Ravalico K. J, Maier, H. R, Dandy, G.C. 2009).

In this sense, the set of parametric vector values, of which the three management options are separately ranked to indicate their different values where then the management decision would alter upon peak and off-peak phenomena, from that ‘average consumption’ where it would not. Following this step and in section two of the analysis, the sensitivity of a decision to model parameters can be measured via the change required in model parameters to alter the decision (Frey, H, & Patil, S 2002); (Ravalico K. J, Maier, H. R, Dandy, G.C. 2009).

7.4 Proposed Analysis of Stage One

1) Measuring the level of dissimilarity of electricity consumption for end of 300 consumers with three years of data by measures every half an hour and comparing the demand.
2) Rating the level of dissimilarity of the consumption for each consumer separately.
3) Specifying the total probability of dissimilarity consumption over the three years.
4) Showing how much the capacity of solar panels installed in each household that are based on the weather pattern, can moderate the non-linear behaviour of consumption.
5) Showing the consumption strains that create peak, average and off-peak demand by considering the consumption levels as following:

0 – 0.14 KWh (low consumption);

0.14– 0.29 KWh (off-peak consumption);

0.291 – 0.459 KWh (Average desired consumption);

0.46 – 0.57 KWh & above (peak consumption).

The above scale is achieved from the Table 7.1 below.

6) Compare the figure of consumption for different houses to provide a better understanding of the significance of different consumers’ behaviours.
7) Use appropriate models to compare the consumption of micro levels (at households) with regional and country ones.
8) Compare the scale of actual consumption times for consumers with the time of use

tariff that counts the charge of electricity used at specific times during the day and as described below. This analysis will review the level of deviation between the schema of ‘Time of Use’ tariff and actual demand.

From literature findings; the losses classified into two categories; one losses occurred off-peak times mainly due to high specific fuel consumption, and the other losses at peak times mainly due to increase the rate of heat radiations from transmission and distribuiton conductors	Total annual consumption in NSW recorded 9,500 KWh per year. In this calculation assumed	Demand of electricity classified to low, off-peak, Average & peak consumption		This coloumn shows the half hourly consumption when being at off-peak, peak and average. This coloumn useful to be used along the data to understand the consumers fluctuations between peak, off-prak and average and also to configure the losses value as per the coloumn I J (i.e. 0.03 of consumption means 16.76 C/KWh losse
(Brinsmead, T.S, Hayward, J & Graham, P 2014, p. 54) **(Energy Efficiency Opportunities In Electricity Networks 2013)** **(frontier economics 2015, p. 10); (Intelligent Energy System 2004)**	**KWh** **(AEMC 2014, P. 79)**	**KWh** **(AEMC 2014, P. 79)**	**%**	**KWh per half an hour** **(Mark Cully, 2016, p. 17)**
Status	**KWh Generated for Demand**	**Generation Demand & Capacity**		**Assumed electricity consumption per capita**
	0	**Zero**	**0%**	0.00
Losses for increase specific fuel consumption per generated KWh	**500**	**Low consumption**	**5%**	0.03
Losses for increase specific fuel consumption per generated KWh	**1000**	**Low consumption**	**10%**	0.06
Losses for increase specific fuel consumption per generated KWh	**1500**	**Low consumption**	**15%**	0.09
Losses for increase specific fuel consumption per generated KWh	**2000**	**Low consumption**	**20%**	0.11
Losses for increase specific fuel consumption per generated KWh	**2500**	**Low consumption**	**25%**	0.14
Losses for increase specific fuel consumption per generated KWh	**3000**	**Off-peak consumption**	**30%**	0.17
Losses for increase specific fuel consumption per generated KWh	**3500**	**Off-peak consumption**	**35%**	0.20
Losses for increase specific fuel consumption per generated KWh	**4000**	**Off-peak consumption**	**40%**	0.23
Losses for increase specific fuel consumption per generated KWh	**4500**	**Off-peak consumption**	**45%**	0.26
Losses for increase specific fuel consumption per generated KWh	**5000**	**Off-peak consumption**	**50%**	0.29
Desired Consumption	**5500**	**Average consumption**	**55%**	**0.31**
Desired Consumption	**6000**	**Average consumption**	**60%**	**0.34**
Desired Consumption (Optimum Average)	**6500**	**Average consumption**	**65%**	**0.37**
Desired Consumption	**7000**	**Shoulder consumption**	**70%**	**0.40**
Desired Consumption	**7500**	**Shoulder consumption**	**75%**	**0.43**
Transmission & Distribution Losses (operational & heat raditation)	**8000**	**Peak consumption**	**80%**	0.46
Transmission & Distribution Losses (operational & heat raditation)	**8500**	**Peak consumption**	**85%**	0.49
Transmission & Distribution Losses (operational & heat raditation)	**9000**	**Peak consumption**	**90%**	0.51
Transmission & Distribution Losses (operational & heat raditation)	**9500**	**Peak consumption**	**95%**	0.54
Transmission & Distribution Losses (operational & heat raditation)	**10000**	**Peak consumption**	**100%**	0.57

Table 7.1: The rate of electricity consumption ‘Peak’, ‘Average’ & ‘Off-peak’ at homes level

7.5 Stage One Results

Data analysis is a modelling process of a prepared data with the goal of discovering useful information to support decision making and to suggest conclusions. Therefore, the task of analysing data requires a careful pre-processing step which can also be described as data preparation. Three steps are essential to evaluate data set (Figure 7.2), and these are as follows:

a) Data Preparation
b) Data Mining
c) Data Analysis

Therefore, within the context of 'data preparation,' it was necessary to provide a manipulation of data in a form that is suitable for the purpose of the required analysis. As in this process, it needs to create different manual programming tasks as a first step of data manipulation, in which no such possible step can be fully automated. The assumption that this is a major step, is based on the fact that any significant mistake will lead to different results. Referring to the literature of Data Preparator (2017), the data preparation assumes from 60 to 80 per cent of the total time consumed during any analysis project.

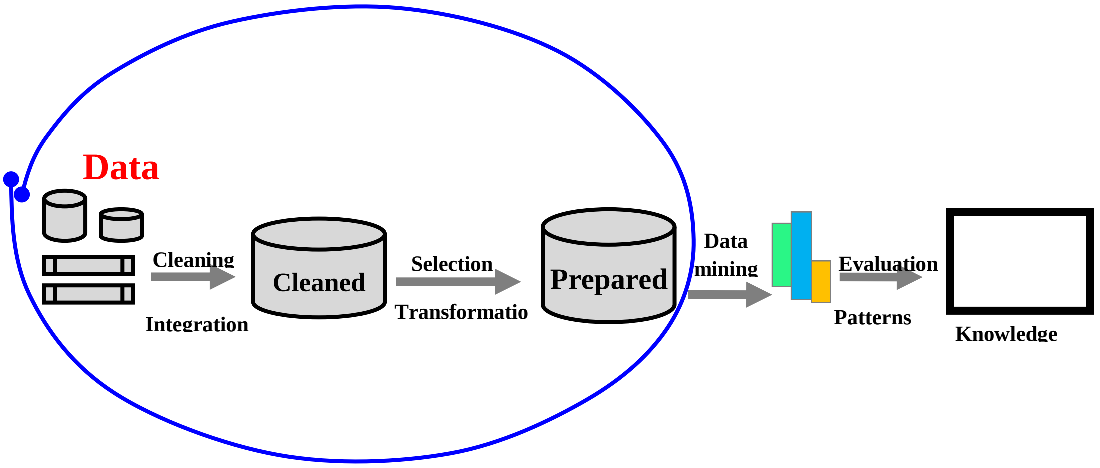


Figure 7.2: Processes of Data Preparation: Processing & Exploration for Data Mining & Data Analysis (Data Preparator 2017)

7.6 Data Preparation

7.5.1 Data Collection

First, the collected data of electricity consumption for 300 consumers were divided into three.csv Excel files for the coming subsequent years: 2010/11, 2011/12 & 2012/13 and for which the following format has been used for the three mentioned years; three times for each consumer for three hundred consumers:

House1Profile2010_11.csv........... House300Profile2010_11.csv

House1Profile2011_12.csv............ House300Profile2011_12.csv

House1Profile2012_13.csv............ House300Profile2012_13.csv (1)

7.6.2 Data Import

In this step, the data was imported from Excel files to Matlab software, which was mainly used in this step to get the data into the environment of Matlab software for analysis purpose. To make the import task, a specific function has been used which called “import file.m”. Therefore, ‘Import’ function done by providing the following inputs:

-Filename : csv file name

-startRow : first row

-endRow : last row

Importing data to Matlab programming language as following:

Function HouseProfile = importfile(filename, startRow, endRow) (2)

The output function for previously injected (1) of all HouseProfiles would be a table which contains the below information:

- Customer : customer number (3)
- Generator Capacity : capacity of the generator
- Consumption Category : GC, CL and GG (one row for each of them)
- Date : date of a specific day (format “dd/mm/yyyy”)
- Period1 to Period48 : energy consumption from 00:00 (Period1) to 23:30 (Period48) with 30 minutes step for each period.

7.6.3 Matlab Code used for Data Import

The following is the used Matlab code for the process of “importfile.m” function.

```
function HouseProfile = importfile(filename, startRow, endRow)

%% Initialize variables.

delimiter = ',';
if nargin<=2
startRow = 3;
endRow = inf;
end
formatSpec =
```

7.6.4 DATA MERGING

In this step, it is essential to merge all of the 300 files of the nominated houses in order to put all of the data in a single format that contains all the needed information for analysis. For this reason, a second script is made under a name “data_merging.m”. To complete this task, all the imported .mat files described in the previous step are loaded subsequently to the Matlab “Workspace” and merged into three unique matrices, in relation to the three above mentioned consumption categories (GC, CL, & GG). Assumption also provided that once any data is missed or not available, then it will be considered a zero value. Moreover, at this step of merging data, a particular matrix for each year which depends on the identified first day of the year was created and named “days”. This step assists while categorising data when comparing the consumers‘ demand based on Time of Use Tariff (TOU).

- Year 2010/11 first day was Thursday
- Year 2011/12 first day was Friday
- Year 2012/13 first day was Sunday

Therefore, the achieved output data in Matlab which was called “data_merging.m” script will deliver the same as the following information:

- dataGC : matrix containing the data related to the Consumption Categories GC for all the 300 consumers
- dataCL : matrix containing the data related to the Consumption Categories CL for all the 300 consumers
- dataGG : matrix containing the data related to the Consumption Categories GG for all the 300 consumers

- timestamp : timestamps related to each 30 minutes (for example 01/07/2010 00:30:00) as
- provided in the previous script “data_ import.m”
- days : matrix containing the information of the days in the year

7.6.5 Matlab Code Used For Data Merging

The code used for data merging used thirty pages, and we will exhibit only a sample as written below (see Appendix):

```
default_path=cd;
year=input('Year? (1,2,3): ');
%% Merge data in folder 2010-2011
if year==1
   tic
   cd([default_path,'/ 2010 -2011 Consumer Data File'])
   files_in_folder=what;
   files_mat=files_in_folder.mat;
   for g1=1:size(files_mat,1)
      load(files_mat{g1,1})
      if g1==1
         data_all_GC=data(:,1);
         data_all_CL=data(:,2);
         if size(data,2)>2
            data_all_GG=data(:,3);
         else
            data_all_GG=zeros(size(data,1),1);
         end
```

7.7 Analysis Results: Data of General Consumption (GC) for the Year 2010/11

The results in figure 3 show the consuming trends of 300 consumers, which used only the general consumption (GC) category in this analysis for the first year, 2010/11. It is obvious that there is no way to distinguish a single consumer trend from the collective macro view, because the electricity consumption instantaneously overlapping which the red line in the figure represents the overlapping average of consumed electricity.

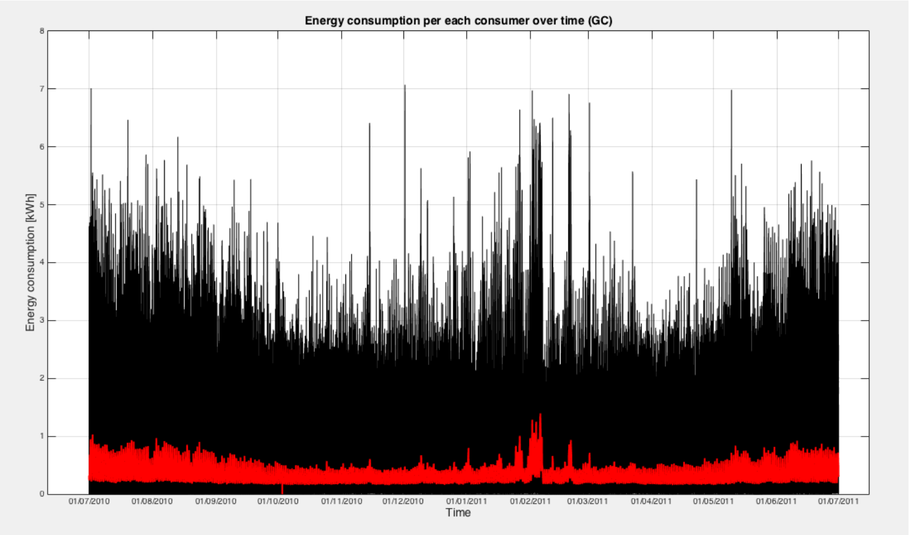


Figure 7.3: Energy consumption over time per each consumer

As we can also easily realise, that when zooming the above Figure 7.3, we will not retrieve any insights into consumer‘s behaviour and their specific demand (Figure 7.4 & 7.5).

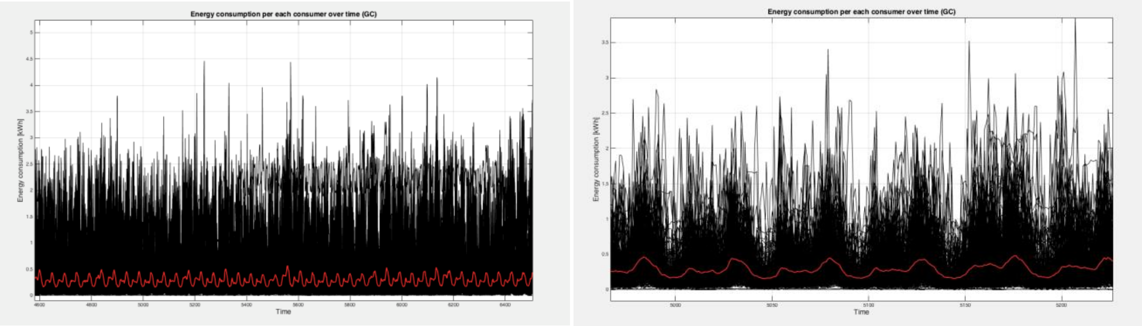


Figure 7.4: Half Hourly Demand per Consumer (zoom 1 & 2)

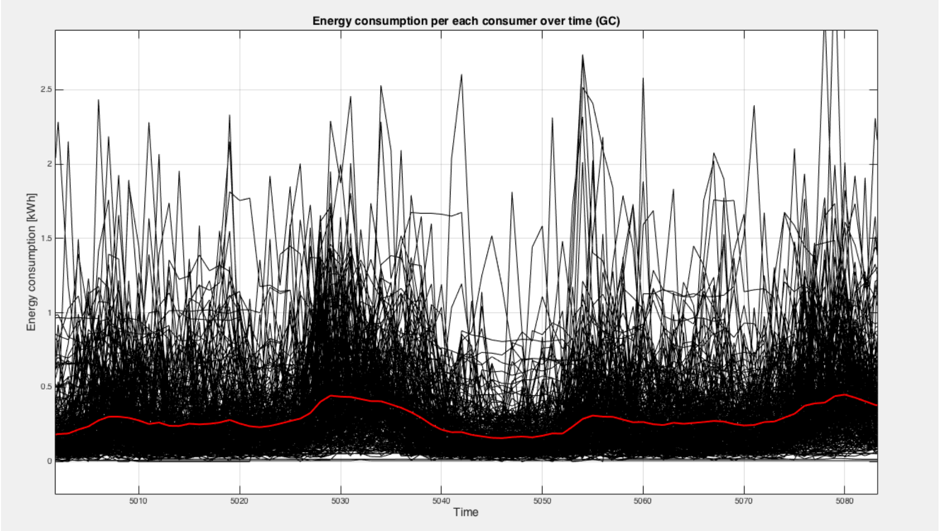


Figure 7. 5: Half Hourly Consumption per each consumer (zoom 3)

From the above analysis, we only can conclude that the consumers are behaving as follows:

- The half hourly electricity consumption within the range zero and 7 kWh/30min.
- The average electricity consumption allows us to understand the periodical behaviour of consumers.
- The energy consumption is correlated with seasons in which the higher consumption rate occurred, that is during the winter and summer seasons.

7.9 Analysis Results: Comparing Actual Demand with TOU for the Year 2010/11

According to the ambiguity of the achieved analysis (as above) it was decided to compare the consumers' consumption behaviour based on Time of Use Tariff (TOU) to realise the trends of consumption similarity during weekdays, as represented in Table 7.2.

Table 7.2: Time of Use Tariff (ToU)

Time Period	**Day of Week**	**Time of Day**
Peak	***Monday to Friday***	***7am to 9am*** ***5pm to 8pm***
Shoulder	***Monday to Friday***	***9am to 5pm*** ***8pm to 10pm***
Off-Peak	***Monday to Friday***	***10pm to midnight*** ***Midnight to 7am***
	Saturday, Sunday & Public Holidays	***All***

To start this step of analysis, the electricity consumption (GC+CL – GG) will be used. This evaluation was done every 30 minutes by using the following formula:

$$(GC + CL - GG)_j = \frac{1}{M} \cdot \sum_{i=1}^{M} (GC + CL - GG)_i \qquad j=1,2,\ldots,300$$

Where j is the consumers; i is the observation (over time); M is the total number of observations corresponds to 17520 which equivalent to one year of observations for 48 times per day (365 x 48 = 17520). In the meanwhile, the data manipulated in regard to the above categories of the TOU tariff 'week hours which the results categories into five different groups of data and they are as following:

- Peak

- Shoulder weekdays (part 1)
- Shoulder weekdays (part 2)
- Off-Peak weekdays
- Off-Peak weekend

To understand the consumers' trends and their different behaviours, the data have been analysed according to the following ranges of consumption. These ranges of consumption are defined from different materials in the attempt to provide a meaningful view upon various levels of consumptions (Peak, Average, & Off-Peak) within a household demand level. These ranges of energy consumption are processed in Matlab by using the function of "In if…else" to classify the data into four groups. These groups were tailored to suit four criteria and these are Peak consumption, Average consumption, Off-peak consumption and Low consumption, for which their assumed ranges in this analysis were as follows:

Low consumption: 0 - 0.17 KWh per half an hour

Off-Peak consumption: 0.17 - 0.34 KWh per half an hour

Average consumption : 0.29 - 0.459 KWh per half an hour

Peak consumption: 0.46 - 2 KWh per half an hour

From the manipulated time series data of houses consumption, it is considered that only the actual timely consumption results from adding 'GC' (general consumption) to the 'CL' (controlled load). The result in the figure below revealed the actual percentage of consumers' consumption at the Peak times of TOU tariff (Monday to Friday & at 7am-9am & 5pm-8pm) which TOU tariff assumed peak times about five hours per day. It seems that most consumers during the year 2010/11, consumed energy within Peak Consumption ranges, since the red dots in Figure 7.6 and red colours in Figure 7.7 of pie and bar charts are strongly confirm this fact.

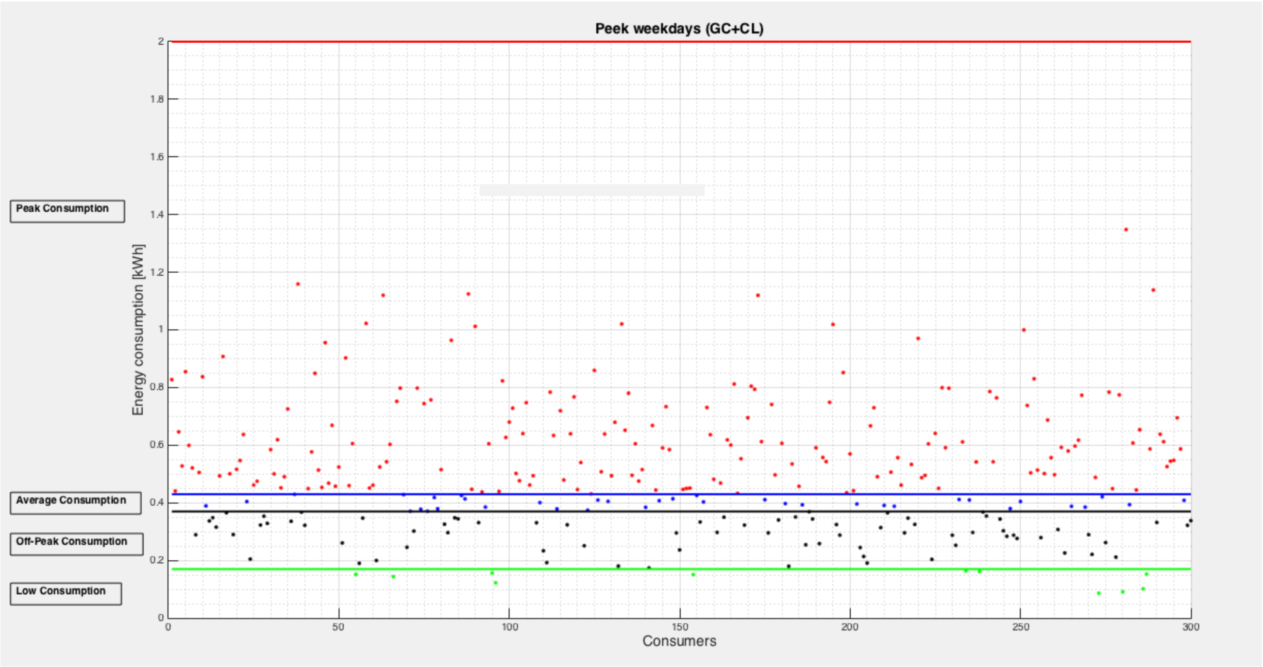


Figure 7.6: Consumers Behvaiour within Peak Times of TOU

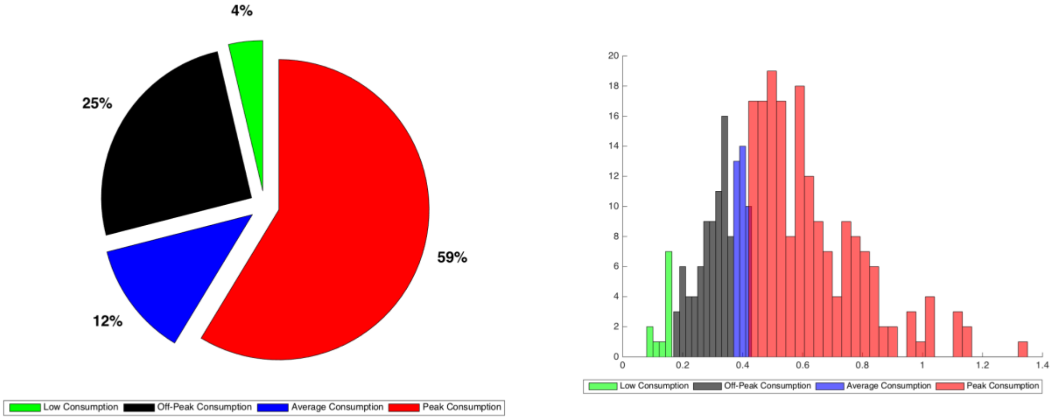


Figure 7. 7: Peak times of Pie chart & Histogram

The same procedure of previous analysis has been followed to test Shoulder/average and off-peak times of TOU (see Figures 7.8, 7.9, 7.10 & 7.11).

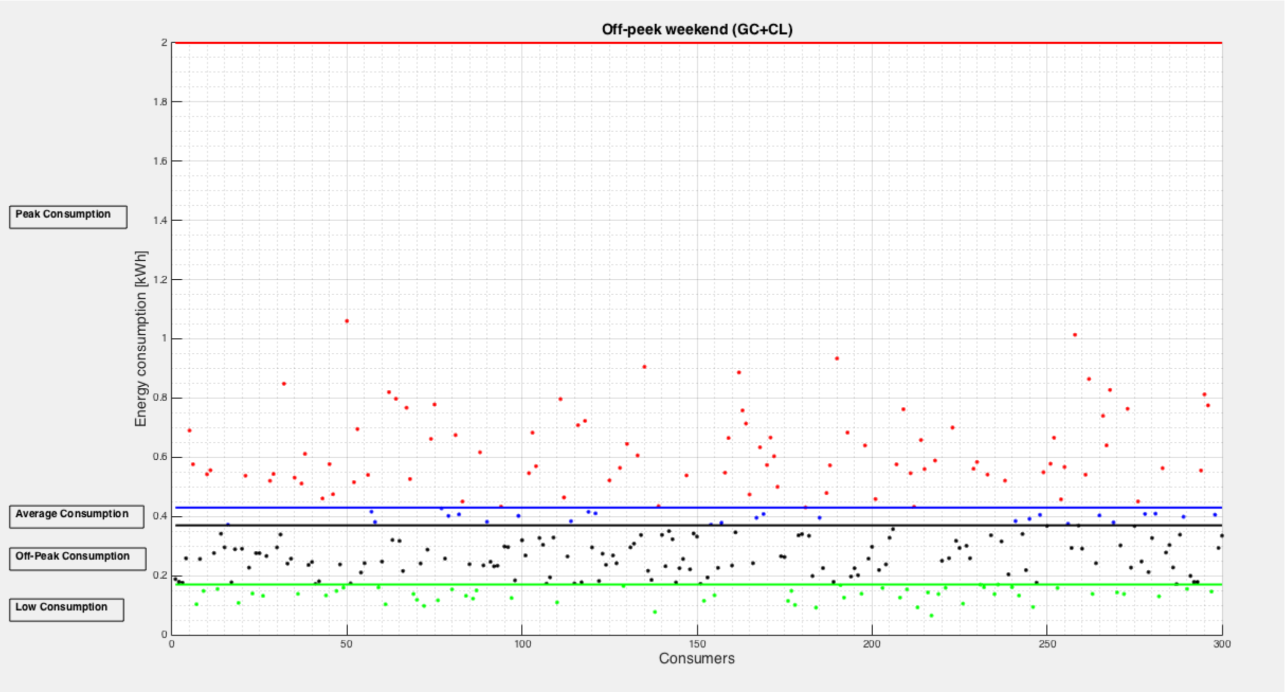


Figure 7.8: Consumers behavior at off-peak of TOU – weekdays

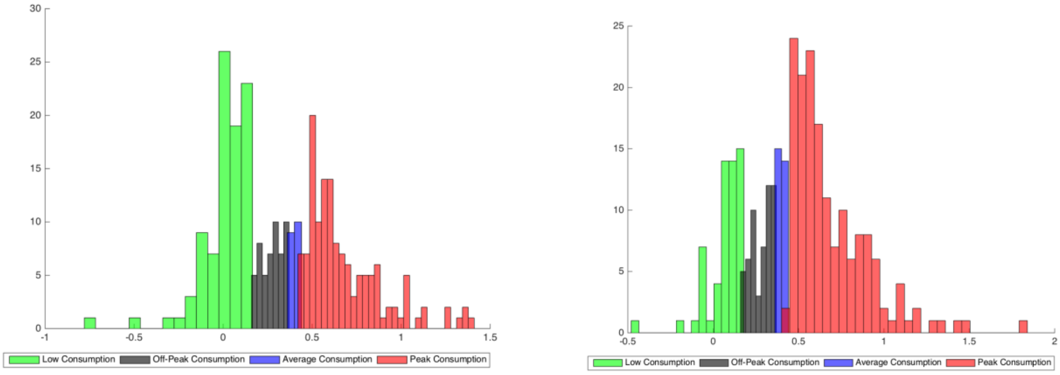


Figure 7. 9: Off-Peak Weekdays (9:00am-5:00am) & (8:00pm-10pm)

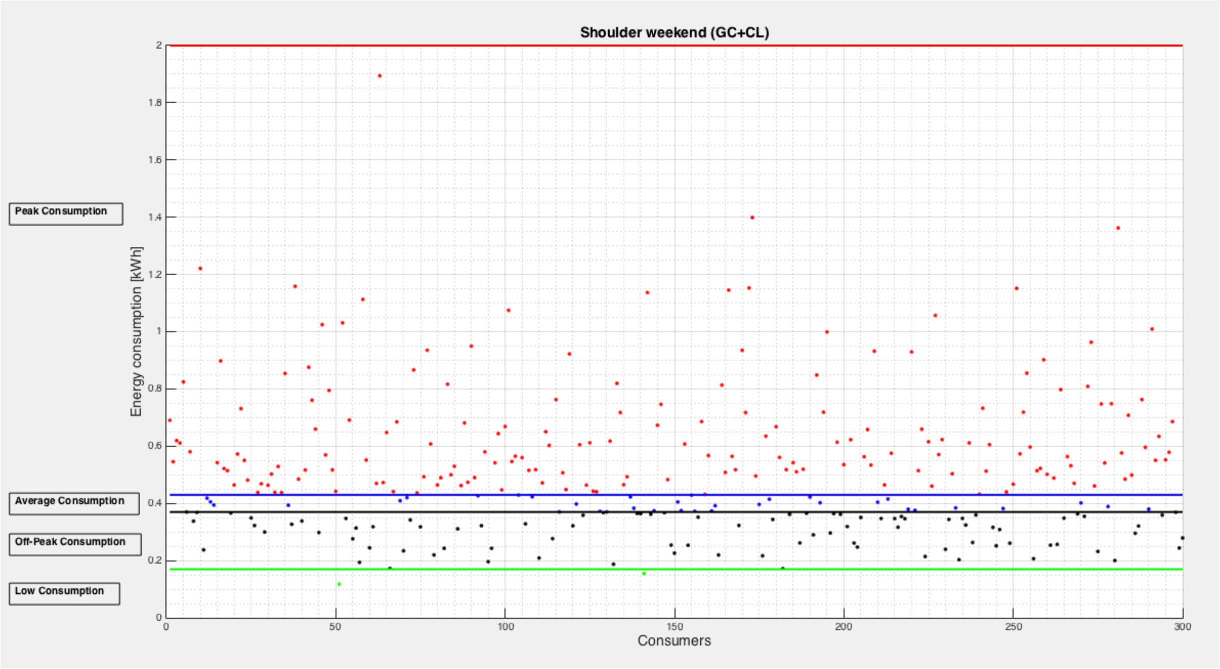


Figure 7.10: Consumers behavior at Shoulder TOU

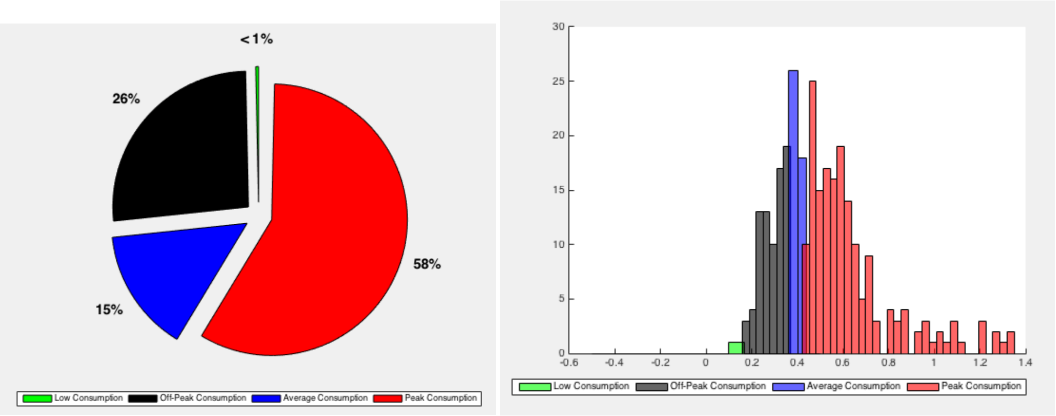


Figure 7. 11: Shoulder Weekdays Pie Chart & Histogram (9:00am-5:00am)

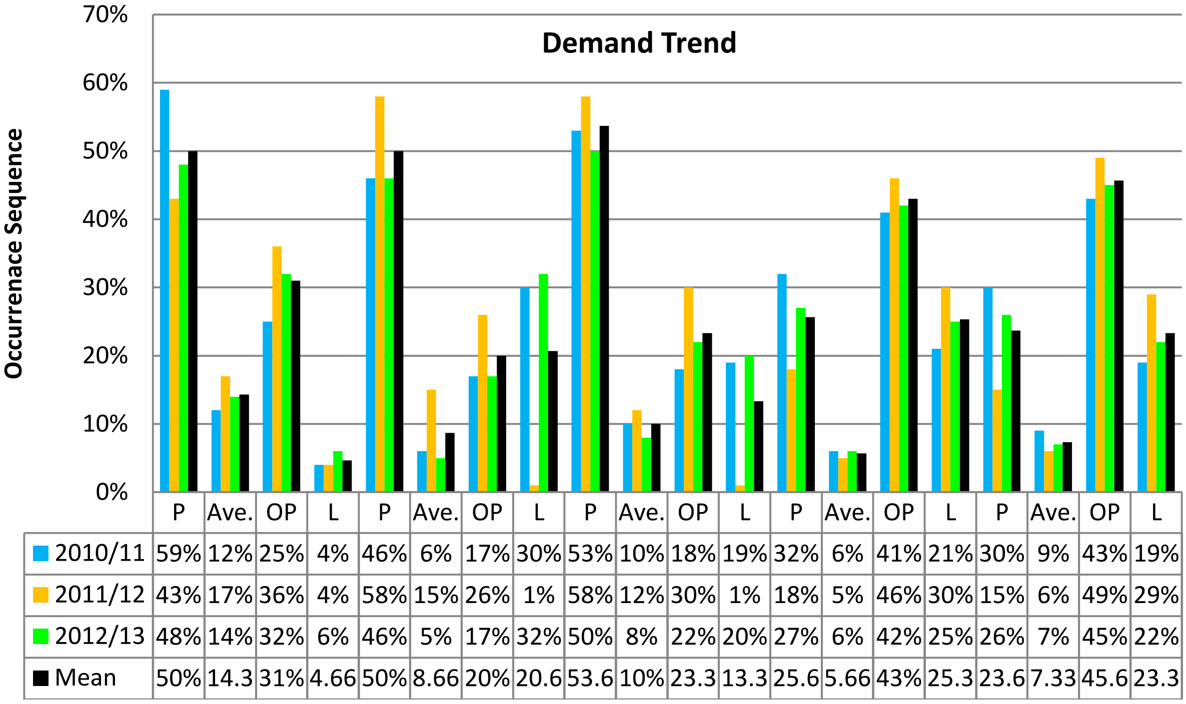
7.10 Conclusion

Table 7.3 below shows the total analysis findings in regard to actual consumption trends illustrated in Figure 7.12 which exhibit peak, average, off-peak, and low consumption during the years of 2010/11, 2011/12, and 2012/13. There is strong evidence showing that from 59% to 15% of the total residential consumers have random peak demands during all weekdays. The phenomenon of Off-Peak demands comes second as a welcome trend from consumers which lies from 17 to 49% of total daily consumption, belonging to this tier of consumption. The average daily consumption is assumed as the most desired demand in the grid. However, these results show exactly the opposite, that the consumers are barely within average ranges and the statistics of daily basis consumption shows the range of Average consumptions as between 5% and 17% of the total consuming trend. Low consumption is also evidently less desired by end-users. Overall, the majority of daily consumption of all consumers at peak and off-peak ranges is rarely at average levels, which is problematic and causes high energy losses in electrical grid systems (see appendix 1).

Table 7.3: Total analysis Results

TOU Tariff	Actual Consumption	2010 - 2011	2011-2012	2012-2013	Average
Peak weekdays	Peak	59 %	43 %	48 %	50 %
	Average	12 %	17 %	14 %	14.33 %
	Off-Peak	25 %	36 %	32 %	31 %
	Low	4 %	4 %	6 %	4.66 %
Shoulder weekdays	Peak	46 %	58 %	46 %	50 %
	Average	6 %	15 %	5 %	8.66 %
	Off-Peak	17 %	26 %	17 %	20 %
	Low	30 %	< 1 %	32 %	20.66 %
Shoulder weekend	Peak	53 %	58 %	50 %	53.66 %
	Average	10 %	12 %	8 %	10 %
	Off-Peak	18 %	30 %	22 %	23.33 %
	Low	19 %	< 1 %	20 %	13.33 %
Off-Peak weekdays	Peak	32 %	18 %	27 %	25.66 %
	Average	6 %	5 %	6 %	5.66 %
	Off-Peak	41 %	46 %	42 %	43 %
	Low	21 %	30 %	25 %	25.33 %
Off-Peak weekdays	Peak	30 %	15 %	26 %	23.66 %
	Average	9 %	6 %	7 %	7.33 %
	Off-Peak	43 %	49 %	45 %	45.66 %
	Low	19 %	29 %	22 %	23.33%

Note: P = Peak, Average = Ave., Off-Peak = OP & Low Consumption = L



	P	Ave.	OP	L	P	Ave.	OP	L	P	Ave.	OP	L	P	Ave.	OP	L	P	Ave.	OP	L
🟦 2010/11	59%	12%	25%	4%	46%	6%	17%	30%	53%	10%	18%	19%	32%	6%	41%	21%	30%	9%	43%	19%
🟨 2011/12	43%	17%	36%	4%	58%	15%	26%	1%	58%	12%	30%	1%	18%	5%	46%	30%	15%	6%	49%	29%
🟩 2012/13	48%	14%	32%	6%	46%	5%	17%	32%	50%	8%	22%	20%	27%	6%	42%	25%	26%	7%	45%	22%
⬛ Mean	50%	14.3	31%	4.66	50%	8.66	20%	20.6	53.6	10%	23.3	13.3	25.6	5.66	43%	25.3	23.6	7.33	45.6	23.3

Figure 7. 12: Demand Trend

7.11 Stage Two of Analysis

The analysis results of the electricity consumption for residential homes over three years are displayed in Figure 7.13. The result, as discussed in chapter seven, shows a wide range of electricity consumption by houses which varies from the lowest rate at 915.71 KWh per year to the highest recorded rate of up to 15067.32 kWh per year.

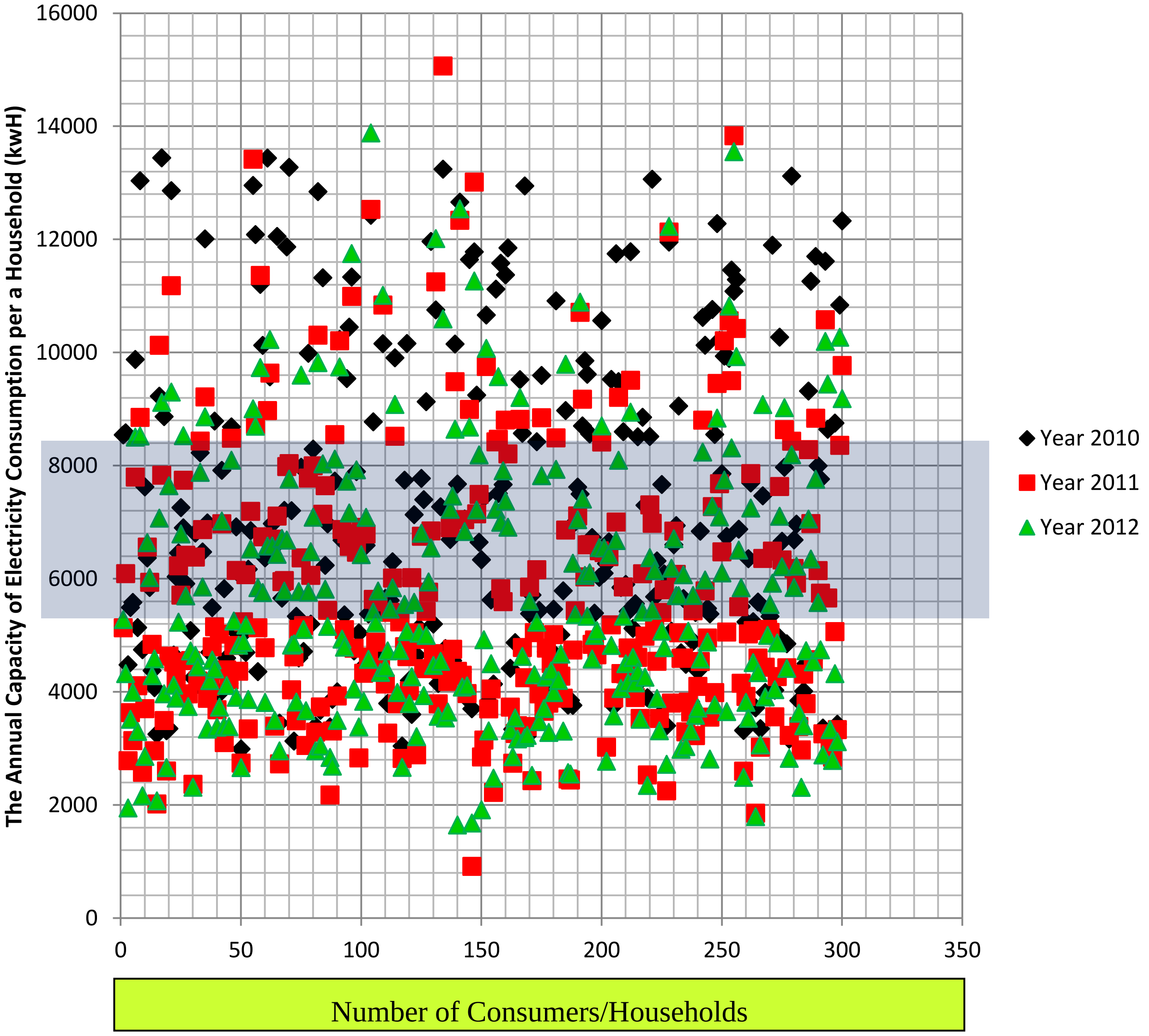


Figure 7.13: The Actual Trend of Electricity Consumption of 300 Residential Homes in NSW

The loss of energy occurred due to the demand for electricity, which was partially caused by peak and off-peak phenomena. These phenomena will be managed by designing a sustainable average scheduling model for residential households to use supported by solar and storage batteries at residential homes. The following parameters are collected from related literature and reports and will be used in this analysis as following (AEMC 2014; Mark Cully 2016; Australian

Energy Update 2016):

- 300 regional residential homes in New South Wales (NSW) - Australia.
- The cost of generation capacity of traditional power in New South Wales (NSW) from 0% to 100%.
- The cost of power generated by OCGT gas turbine (10.4% of total consumption).
- The cost of power generated by CCGT gas turbine (10.4% of total consumption).
- The cost of power generated by Coal plants (63% of total consumption).
- Peak generation cost.
- Off-peak generation cost.
- Timely losses which occur at peak times.
- Timely losses which occur at off-peak times.
- Peak consumption ranges for residential homes (>0.459 KWh per half an hour).
- Off-peak consumption ranges for residential homes (<0.29 KWh per half an hour).
- Average (desirable) consumption ranges for residential homes (<= 0.459 & >= 0.29 KWh per half an hour).
- Comparing the figure of consumption for different houses to create a better understanding of the significance of different consumers' behaviours.
- Using appropriate models to compare the consumption of micro levels (at households) with regional and country households.
- Comparing the scale of actual consumption times for consumers with the time of use tariff that counts the charge of electricity use at specific times during the day and as described below. This analysis will review the level of deviation between the schema of 'Time Of Use' tariff and actual demand.

7.12 Designing a Home's Sustainable Model

Sustainable Scheduling Model for Resolving the Complexity Problem of peak & Off-peak Loads in Residential Homes in Household Area Network (HAN) (see Table 7.4).

S.N.	Parameter	Variable	Constraints	Objective Function	Abbreviations	Meaning
*1	✓				∀	All values of SC, Bc & every value of CC will satisfy ∀SC ∀BC ∀LC, DC(SC, BC, DC)
2	✓				∀SC	A universal quantification of a predicate logic for solar capacity needed at home
3	✓				∀BC	A universal quantification of a predicate logic for battery capacity needed at home
4	✓				∀LC	A universal quantification of a predicate logic for load capacity at home
5	✓				t	Index of time
6	✓				P	Index of power
7	✓				AVD	Average Daily optimum consumption (24 hours)
8	✓				PD	Peak Daily consumption (24 hours)
9	✓				OPD	Off-Peak Daily consumption
10	✓				LCD	Low Daily consumption (24 hours)
11	✓				AVT	Average Half hourly consumption (optimum)
12	✓				PT	Peak Half hourly consumption
13	✓				OPT	Off-Peak Half hourly consumption
14	✓				LCT	Half hourly ‘Low Consumption’
*15	✓				GC	General consumption at homes from the grid (from the historical data)
*16	✓				CL	Controlled Consumption load at homes from the grid (from the historical data)
*17	✓				GG	Solar power installed at homes (from the historical data)
18			✓		CTC	Total timely consumption of electricity (from the historical data)
19			✓		PL	
20				✓	DTC	Desired timely consumption (Average)
21		✓			dh	Highest demand load for each consumer
22		✓			dL	Lowest demand load for each consumer
23		✓			Bc	Battery in Charging status
24		✓			Bdis	Battery in discharging status
25	✓				HTDC	Home Total Day Consumption
26	✓				HTNC	Home Total Night Consumption
27		✓			CNDL	Power capacity available at home, but not needed in the period of Day Light
28		✓			CNNT	Power capacity available at home, but not needed in the period of Night Time
29		✓			BFOH	Battery capacity used from homes to serve other homes achieve Averages
30		✓			SFOH	Solar capacity used from homes to serve other homes achieve Averages
31			✓		SNT	Total Power capacity needed at Night Time for each home
32			✓		SDT	Total Power capacity needed at Day Time for each home
33			✓		STC	Total maximum Solar capacity needed for a whole day for each home
34			✓		BNT	Battery maximum required capacity during night time based on worst night scenario
35			✓		BDT	Battery maximum required capacity during day light time based on worst day scenario
36			✓		BTC	Battery total capacity required at home
37	✓				UPS	Unit Price of Solar

	✓				PSH	Cost of Solar at home
38	✓				UPB	Unit Price of Battery
	✓				PBH	Cost of battery at home
39		✓			PtS	Timely power needed from solar at home
40		✓			L	Load = other homes demand that need to support to achieve average demand.
41		✓			PtS2L	Timely power needed from solar to load
42		✓			PtS2B@DT	Timely power needed from solar to battery at day time
43		✓			PtS2G	Timely power needed from solar to grid
44	✓				NCB	Maximum number of cycling charge and discharge for battery
45	✓				ηchB	Efficiency of charging the battery
46	✓				ηdischB	Efficiency of discharging the battery
47	✓				RCB	Rate of Battery charge
48	✓				RDB	Rate of Battery discharge
	✓				PR1E	Price of Electricity during different demands average/peak/off-peak (according to historical data)
	✓				PR2E	Price of Electricity during different demands average/peak/off-peak (after using the new model)
				✓	NPO	Net payoff
				✓	NProf	Net Profit

*Notice: all the above variables are matrices (300 houses so a 1*300 matrices)*

Table 7. 4: Proposed Model Parameters, Variables & Constraints

7.13 Objective function

The main purpose of this proposal is to control the power consumed by residential homes and to identifying the benefit by ensuring a smooth load profile at average consumption levels. For this purpose, it is considered that there is a Supplier (Government and retailer), that wishes to invest in solar panels and battery units, to install them in 300 houses in a residential area network. This investment will facilitate coverage of homes‘ demand from solar, battery and grid.

The proposed objective is to minimise energy losses, which then minimise the total electricity cost and enlarge the benefit (that is, total revenue minus the cost). The average of consuming electricity is the optimal level of consumption which falls between peak and off-peak consumption levels.

The scale of energy losses is financially determined according to the timely consumption of electricity either above or below the average consumption levels (minimum and maximum average levels). Thus, the cost of the battery and solar at different homes will be counted against the losses of energy to calculate the feasibility of renewable energy investment in homes to reduce the effect of peak and off-peak demand and then, to reduce the losses of energy and increase the profit.

Additionally, power stored and generated by battery and solar will feed into the power grid according to the timely consumption by the houses. In other words, solar and storage battery form the defending line at homes to timely bring these homes to use electricity within Average demand levels. This process is designed to smooth the load's profile on an individual basis for each home separately and to ensure that its consumption is within the desired range at average power usage.

The desired range is defined based on the perspective of the power grid. Subsequently, beyond running the designed model, we will estimate exactly the capacity of battery charges/discharges and the needed capacity of PV which the power output from these two components of renewable energy will always feed into the grid system, to make each house range act within the desired range (average level).

Therefore, the objective function for the Government's/retailer's self-scheduling model and the constraints are defined as follows:

$$\boldsymbol{max}\sum_{\boldsymbol{t\epsilon T}}[\boldsymbol{\pi_t^{s2G}}\Big(\boldsymbol{P_t^{B2G}}+\boldsymbol{P_t^{PV2G}})+\boldsymbol{\pi_t^{s2l}}(\boldsymbol{P_t^{B2l}}+\boldsymbol{P_t^{pv2l}}\Big)-\boldsymbol{\pi_t^{b}}(\boldsymbol{P_t^{G2l}}+\boldsymbol{P_t^{G2B}})-\ IniCost^{PV}\ -\ IniCost^{B}\,]$$

7.14 Solar Panel constraints

To calculate the required solar panel and battery capacity for each house, we consider a worst case scenario. As we have the data for three years for every half an hour, we consider the peak load and the difference of this peak amount with the average ideal load. The whole amount of power produced from PV units in every time slot is consumed by the load, sold to the grid or is used for battery charge. When the capacity of installed PV units is known and then, based on the weather prediction, P_t^{pv} will be known.

$$Cap^{pv} = max\left(PL_{t_d}^{base}\right) - P^{av} + Cap^{B}$$

$$Cap^{B} = max\left(PL_{t_n}^{base}\right) - P^{av}$$

$$P_t^{pv2l} + P_t^{pv2B} + P_t^{PV2G} = P_t^{pv} \qquad \forall t$$

7.15 Load and Grid power constraints

$$PL_t^{base} = P_t^{G2l} + P_t^{pv2l} + P_t^{B2l} \qquad \forall t$$

$$P_t^{min.b} \leq P_t^{b} \leq P_t^{max.b} \qquad \forall t$$

$$P_t^{b} = P_t^{G2l} + P_t^{G2B} \qquad \forall t$$

7.16 Storage units constraints

The batteries will be charged either way: by PV units or by the grid power during off-peak times. For each house there is one storage unit and its maximum capacity will be calculated according to maximum needed capacity for each home. The total number of charge and discharge cycles is limited as per the last formula below.

$$SOC_t^{B} = SOC_{t-1}^{B} + s_t^{B,ch}\eta^{ch.B}\left(\frac{P_t^{pv2B} + P_t^{G2B}}{Cap^{B}}\right) - s_t^{B,dis}\left(\frac{P_t^{B2G} + P_t^{B2l}}{\eta^{dis,B}Cap^{B}}\right) \qquad \forall t$$

$$SOC^{B,min} \leq SOC_t^{B} \leq SOC^{B,max} \qquad \forall t$$

$$0 \leq (SOC_t^{B} - SOC_{t-1}^{B}) \leq \eta^{ch.B}RC^{B} \qquad \forall t$$

$$0 \leq (SOC_t^{B} - SOC_{t-1}^{B})\eta^{dis.B} \leq RD^{B} \qquad \forall t$$

$$SOC_t^{B} = SOC_t^{B0} \qquad \forall t = 1$$

$$\sum_{t \in T}(s_t^{B,ch} + s_t^{B,dis}) \leq NC^{B}$$

$$s_t^{B,ch} + s_t^{B,dis} \leq 1 \qquad \forall t$$

7.17 Power distribution network in Australia

In this project, we will perform a detailed analysis of the data obtained from the power distribution network in Australia.

7.18 About the Data

The data we have is for 300 different residential households in New South Wales, Australia, and their power consumption during the calendar years 2010-2011, 2011-2012 and 2012-2013. This data shows the timely consumption of electricity every half an hour, so power consumption is recorded 48 times during every day of the nominated three years. The individual data file contains consumed power in kilowatt hours (kWh) in the half-hourly period for a whole day along the columns. All the records for each day in a calendar year have been listed along rows in the table. The format of the data files is CSV.

7.19 Various sources of power Generation

- Open Cycle Gas Turbine (OCGT) - Out of all power generated in Australia, 10.40% is generated through OCGT
- Closed Cycle Gas Turbine (CCGT) - 10.40% power is generated through CCGT
- Coal- This constitutes the major portion of power generation at 63%.
- Renewable Sources- Rest of the power is generated from renewable sources like hydro, solar and wind.

7.20 How the Power is Consumed

1. General Consumption (GC) (different home appliances)
2. Controlled load (CL) (i.e. Air conditioning, irrigation system, swimming pool, outdoor lighting)

In the data files, we have these two categories of power consumption for each of the households. Apart from these, there are records for solar power at home denoted as (GG) in data files. This generated power is sent back to the grid which operated under “feed-in-tariff” contracts.

7.21 Python v3.0

“Python” is a programming language that has criteria suited for general purpose use to achieve several outcomes, from testing micro structures, to building video games. Python resembles the English language, which gives sense to its functions and contains a number of existing third-party libraries.

7.22 Packages for the analysis of data

The following six packages were used through Python programming language in stage two to complete the task of deterministic analysis for 47,304,000 million data items.

Code: In [1]:

```
import pandas as pd
import numpy as np
import Plotly
```

```
import Cufflinks
import pickle
import gzip
```

7.22.2 Numpy

“Numpy” is a library which providing an array of data structure to hold and exhibit any regular data in a structured manner using Numpy to add value to Python lists in order to make the analysis faster during access in writing and reading items, more compacting data and increasing the analysis efficiency.

7.22.3 Pandas

“Pandas” is a software library designed to be used for Python Programming language. The main purpose of Pandas software is for data manipulation and analysis which helps data structures and operations to handle time series data and numerical tables.

7.22.4 Plotly

“Plotly“ is a collaborative and interactive data analysis and graphing tool. Through the Python programming software, all ‘Plotly’ functions can be accessed and through which figures and data can then be tracked and accessed from the graphs.

7.22.5 Cufflinks

“Cufflinks“ is a complementary program that can be used as a tool from the library of Python programming language. Cufflinks is mainly used to analyse biological data which suits the purpose of Python as used for bioinformatics data.

7.22.6 pickle

It is a Python object serialisation. It is a programming process whereby a Python object hierarchy converted into a byte stream. Importing pickle module applies binary protocols for serialising a Python object structure.

7.22.7 gzip

This module provides a simple interface for compressing and decompressing files thus it will looks like an ordinary file object.

7.23 Calculate the Cost of Energy Losses incurred by each Home

From the literature in chapters one, two, three, four and five, the maximum average demand during any half-hourly period is assumed is 0.459 KWh. Thus, the maximum average consumption during the whole day becomes 0.459 * 48 = 22.032 kWh/day. The minimum average demand is assumed during any half-hourly period to be 0.3 KWh. Therefore, any home electricity demand in between [0.3 KWh,0.459 KWh] is considered to be within optimum consumption limit (average consumption). If the power consumption at any single home goes above this range, it is called peak consumption, otherwise off-peak consumption. For power consumption within the optimum range, there is no loss in terms of cost. However, if the consumption goes beyond that range, a peak or off-peak loss occurs.

To generate power, there are running costs associated with the operation of the generator. If the power consumption is off-peak, then the cost of running the generator increases due to the low generation of power which has higher specific fuel consumption. The loss at peak times occurs mainly due to heating radiation coming from the conductors of transmission and distribution lines.

To calculate the peak losses, we have chosen the following hypothesis for estimation:

In this hypothesis, we assume that as the power consumption is increased over the optimum range, the losses associated with it also increase. To obtain these losses, we use interpolation and extrapolation model for estimating them beyond the given range.

In the following cell, x_OP denotes off-peak demand and y_OP is corresponding off-peak losses in cents associated with x_OP. Similarly, for peak losses, we have x_P and y_P for peak demand and peak losses, respectively.

```
In [2]:
avg_consump = 0.459
y_OP=[16.76,10.89,6.36,4.41,3.10,2.17,1.48,0.99,0.67,0.30]
x_OP=[0.03,0.06,0.09,0.11,0.14,0.17,0.20,0.23,0.26,0.29]
y_P = [1.79,2.92,3.55,4.24,4.24,4.24,4.24,4.24,4.24]
x_P = [0.46,0.49,0.51,0.54,0.6,0.7,1.0,1.5,2.5]
```

7.24 Importing the “CSV” Data

The data files are present in a local directory of the system in path 'data_path'. Each of these data files is comma separated variables (CSV) format wherein a comma separates all the entries in a row. Each row corresponds to a day in a calendar year and for a specific type of power consumption, i.e., either GC, CL, or GG. In some of the data files for households, CL rows are absent.

7.25 Pre-processing the raw data

We import these data files one-by-one for each house and each calendar year in a pandas’ data-frame. We also created a Python dictionary of data-frames for each house. The keys of these dictionaries are the year names, i.e., '2010', '2011' and '2012' representing the calendar years 2010-2011, 2011-2012 and 2012-2013 respectively. We also separated these data files into three different data-frames according to the type of power consumption, that is, GC, CL, and GG. For all these purposes, a function clean_data() is written which is in data_processing.py module. This function cleans the raw data file and converts it into a dictionary of pandas’ data frames. Each dictionary has keys according to Year name and type of consumption names. The index of data-frames has also been reset to the date of the day in the year. Any missing values in the data files have been replaced by ‘0’ value. All the column headings are renamed.

7.26 Calculate Demands & losses of Electricity

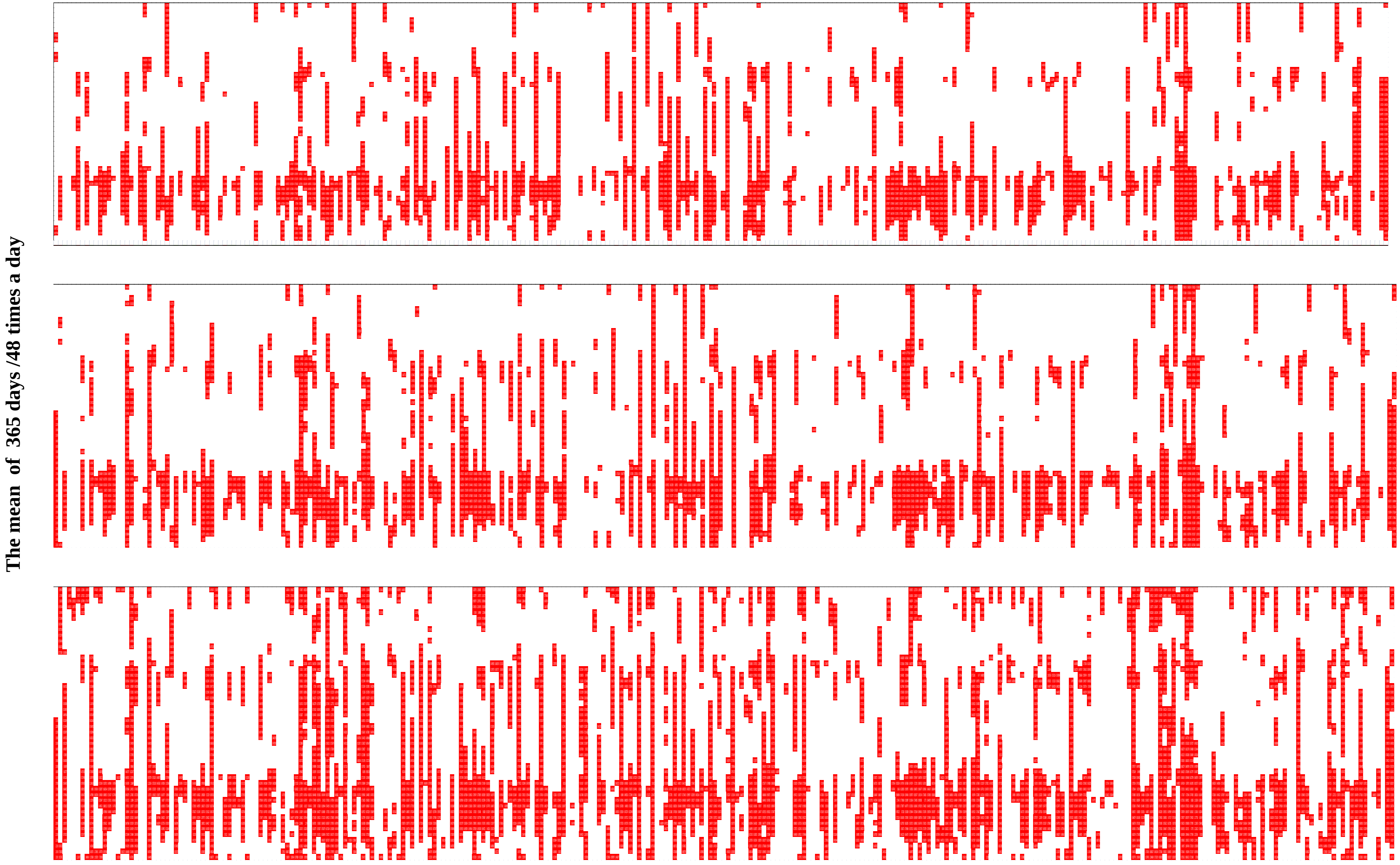
We utilise the functions calc_consump() and calc_cost() in module calc.py to calculate the power consumption and associated loss. We save all these data frames into pickles. For this purpose, a function has been written to_pkle() which readily dumps any Python object into a pickle. This function is in data_processing.py module. Finally, we run all these steps on each household and for each calendar year through a loop and save the resulting Python dictionaries of Pandas data frames into pickles for further analysis.

```
Code: In [3]:
filename={'2010':{},'2011':{},'2012':{}}
fname={'2010':{},'2011':{},'2012':{}}
Years=['2010','2011','2012']
for i in range(1,301):
   filename['2010'][i] = 'House%dProfile2010_11.csv' %i
   filename['2011'][i] = 'House%dProfile2011_12.csv' %i
   filename['2012'][i] = 'House%dProfile2012_13.csv' %i
filepath={}
```

```
filepath['2010']=(data_path + '2010_2011_RESIDENTIAL_HOUSE_DATA/')
filepath['2011']=(data_path + '2011_2012_RESIDENTIAL_HOUSE_DATA/')
filepath['2012']=(data_path + '2012_2013_RESIDENTIAL_HOUSE_DATA/')
for key in Years:
    for i in range(1,301):
        fname[key][i] = filepath[key] + filename[key][i]
for i in range(1,301):
    consum_id = i
    clean_data(fname, consum_id)
    pkl_name='df_cleaned_%d.pklz' %consum_id
    df_cleaned=from_pklz(pkl_path,pkl_name)
    df_vol_dschg=calc_vol_dschg(df_cleaned)
    df_interval=calc_night_interval(df_cleaned)
    df_consump=calc_consump(df_cleaned)
    df_cost=calc_consump_cost(df_consump,x_OP,y_OP,x_P,y_P,consum_id)
    df_cost_geom=calc_consump_cost(df_consump,x_OP,y_OP,x_PG,y_PG,consum_id)
    df = df_cost
    pkl_name='df_cost_%d.pklz' %consum_id
    to_pklz(df,pkl_path,pkl_name)
 df = df_cost_geom
    pkl_name='df_cost_geom_%d.pklz' %consum_id
    to_pklz(df,pkl_path,pkl_name)
```

The following Figure 7.14 exhibit a general view of the peak and off-peak incidences which occurred at different homes at the same interval time. It is clear that the consumption rates and timing differ between different consumers, and also that the individual consumers are not exactly repeating their same patterns.

Peak half hourly consumption for 300 consumers (each column exhibit a single consumer behaviour during the three years 2010/11 & 12)



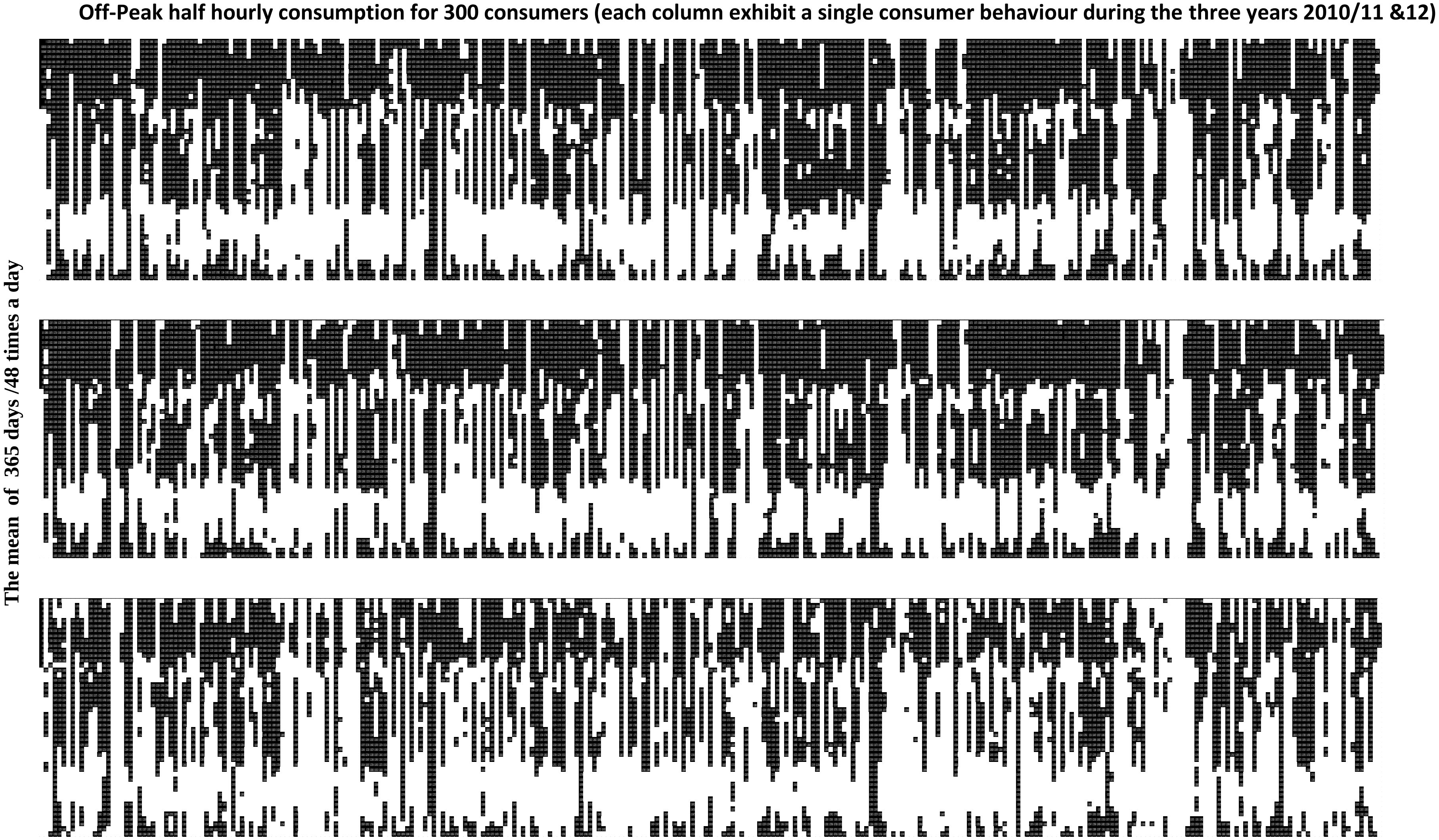


Figure 7.14: Peak & Off-Peak Demands for 300 Consumers for 3 Years

7.27 Analysis for 300 residential homes (Python Programming Software)

Three different types of figures are produced. These plots are saved in the plots folder.

- The Mean Consumption for six samples of houses out of 300 houses is exhibited below. For the purpose of illustration, houses no. 1, 50, 100, 200, 250, and 300 are samples shown below. Mean consumption is obtained for each month and is plotted against the various half-hourly periods occurring throughout the day.
- Present the energy losses in each month for calendar years 2010-2011, 2011-2012 and 2012-2013. These energy losses are plotted for every half-hourly period.
- Finally, we display the total energy losses in each month for calendar years 2010-2011, 2011-2012, and 2012-2013. Here the total losses are displayed in grouped bar-charts, with each bar in the group representing each calendar year.

Code: In [ ]:

```
import pandas as pd
import numpy as np
import plotly
import plotly.plotly as py
import plotly.graph_objs as go
from plotly import tools
import pickle
import gzip
#import cufflinks as cf
apikey = open('/home/pankaj/Documents/Ashruf/plotlyapikey.txt','r').read()
plotly.offline.init_notebook_mode() # run at the start of every notebook
#plotly.tools.set_credentials_file(username='pankajs.phy', api_key=apikey)
#plotly.tools.set_config_file(world_readable=True)
In [ ]:
from helper.calc import *
from helper.plot_plotly import *
from helper.data_processing import *
from helper.calc import *
pkl_path='/home/pankaj/Documents/Ashruf/data/pickles/'    # path to the saved pickles which are
generated
# from Analysis.iypnb notebook
In [ ]:
for consum_id in [1,50,100,200,250,300]:
pkl_name='df_cleaned_%d.pklz' %consum_id
df_cleaned=from_pklz(pkl_path,pkl_name)
 df_consump=calc_consump(df_cleaned)
Title='Mean Consumption (in kWh) across a financial year for Consumer %d' %consum_id
```

7.28 Eenergey Demand for 300 Residential Homes (47 million data)

Six homes will be exhibited as a sample from the total 300 residential homes, home number one as illustrated in Figure 7.15. Please see the rest of Figures in Appendix 2.

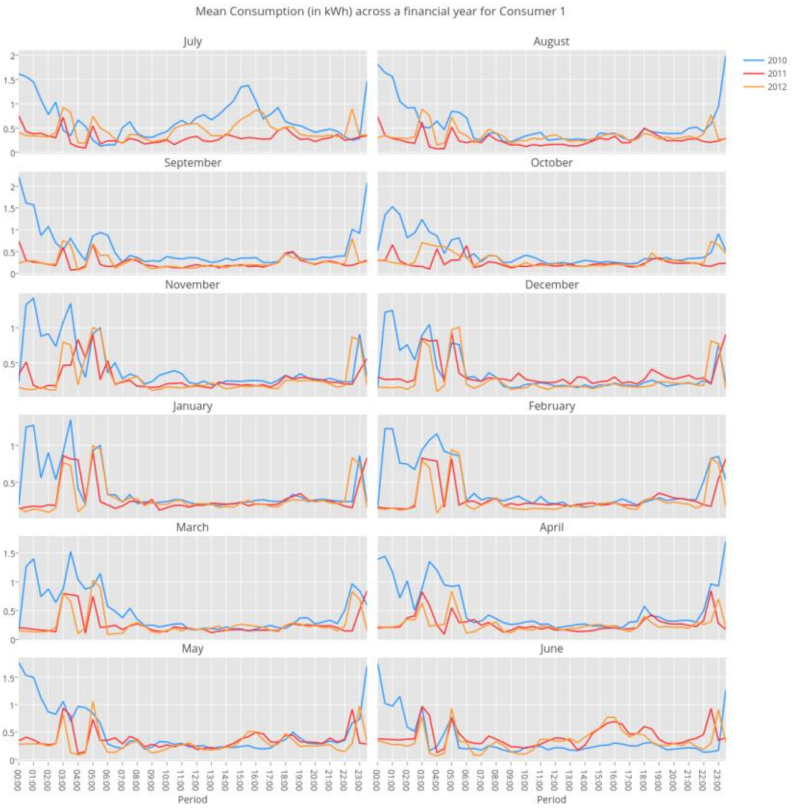


Figure 7. 15: Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 1

The analysis reveals the following facts:

- The residential homes separately have uncertain, similar repeated individual trends of daily consumption of electricity.
- The consumption of electricity for all nominated samples of homes is uncertain since the curves of three years of demands exhibit a lack of certainty involved with ambiguity and variability.
- There is uncertainty about the size of parameters (half hourly demand) which needs to be investigated to reveal useful facts.
- There is also ambiguity about what the demands of individual consumers for following years will be.
- Demand curves of electricity show different ranges of possible outcomes reflecting vary

discrete demand ranges for each consumer (Moavenzadeh, F 2009).

For all 300 residential homes, the analysis has been conducted by using Python programming software to calculate the losses of energy occurring within peak and off-peak demands. The following Figures 7.16, 7.17, 7.18, 7.19, 7,20 & 7.21 are snap shots of the analysis findings:

7.29 Energy Losses-Analysis Results for 300 Homes

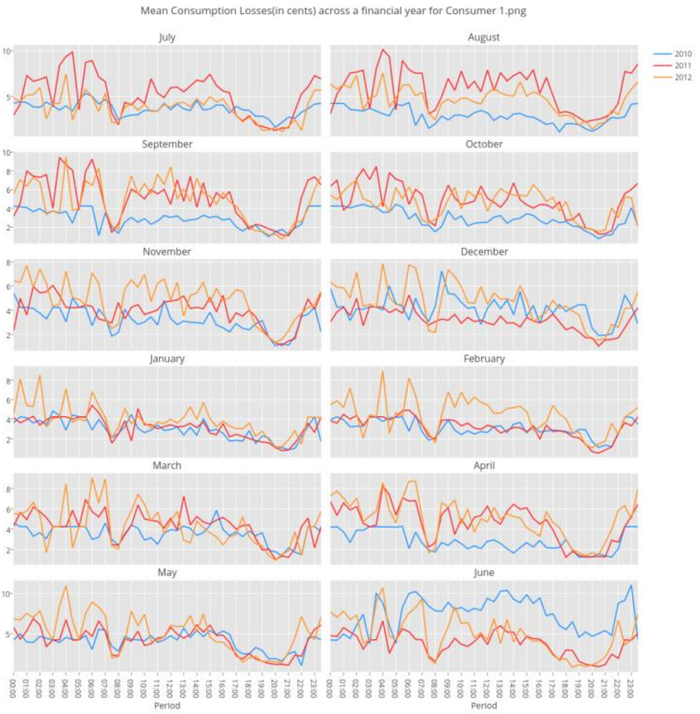


Figure 7.16: Energy losses occurred during the years 2010/11/12 for Home numbers 1

Figure 7.17: Energy losses occurred during the years 2010/11/12 for Home numbers 50

Figure 7. 18: Energy losses occurred during the years 2010/11/12 for Home numbers 100

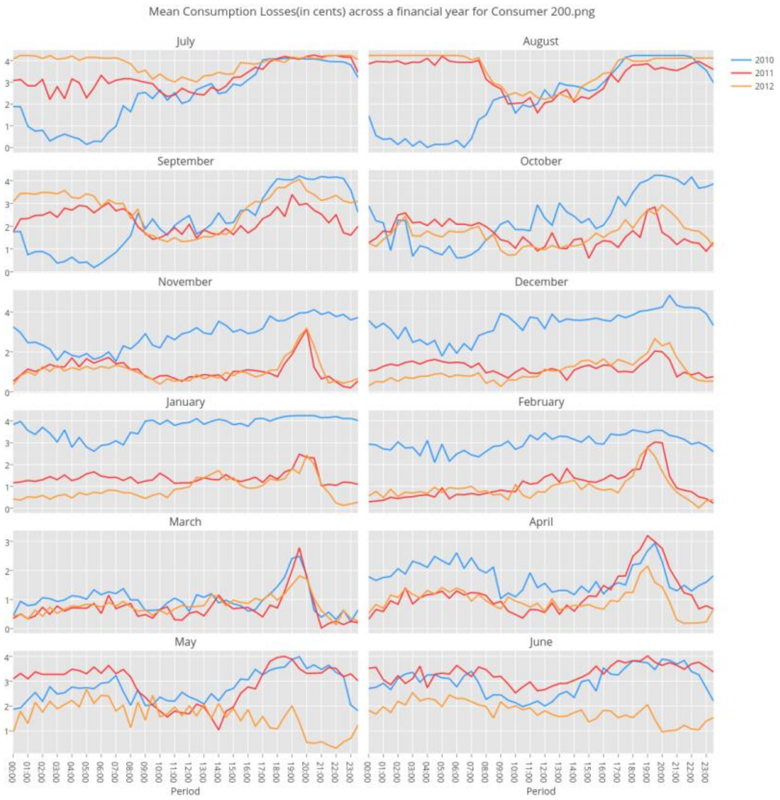


Figure 7.19: Energy losses occurred during the years 2010/11/12 for Home numbers 200

Figure 7. 20: Energy losses occurred during the years 2010/11/12 for Home numbers 250

Figure 7.21: Energy losses occurred during the years 2010/11/12 for Home numbers 300

The results regarding energy losses those occur in residential homes during peak and off-peak demands.

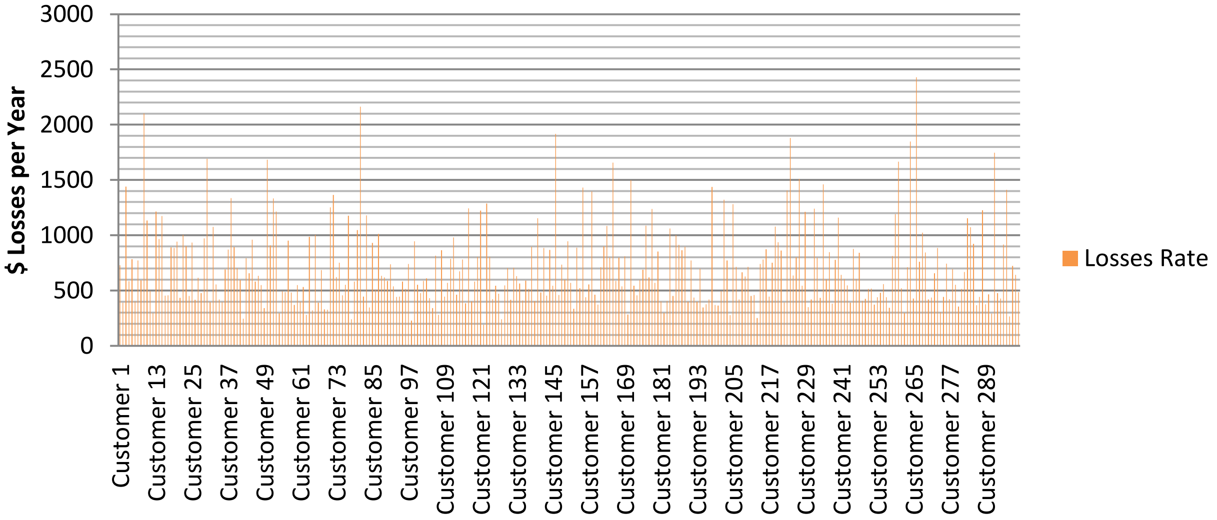


Figure 7.22: Average Cost of Energy Losses per Year incurred by each Residential Home

Each consumer has a repeated uncertain trend that varies highly when compared with other consumers' demand. The above losses are not only for peak times, but these are also collective mix losses occurring during peak and off-peak times. Using the above principle, these losses of energy have been calculated monthly for the same consumers by using the function ‘plot_bar_group’. The result of energy losses has been plotted for each month of the calendar years. The total consumption losses are plotted in the form of grouped bars with each bar corresponding to each calendar year as shown in figure 7.35.

The results figure 7.36 are explicit that the energy losses incurred by each consumer are not a constant since they vary from one year to another, and also, they are not certain. The variation in occurrences of energy losses also increases among different consumers for whom that increases uncertainties’ levels of electricity demand.

By using Python software, the analysis results achieved through the designed model, based on 47,304,000 millions of data items for 300 consumers over three years, delivers the following findings (The findings support the hypothesis three):

- Total annual consumption of electricity per home (KWh) for the years 2010/11, 2011/12 & 2012/13.
- The highest rate of annual consumption per home for the years 2010/11, 2011/12 & 2012/13.
- Solar needed (KWh) per year per home.
- Total solar capacity needed for 300 homes.
- Losses of energy cost per home for years 2010/11, 2011/12 & 2012/13.
- Total annual financial losses ($) for 300 homes.
- Battery charging capacity per home for years 2010/11, 2011/12 & 2012/13.
- Battery discharging capacity per home for years 2010/11, 2011/12 & 2012/13.
- Maximum total battery capacity needed for each home.
- Total battery capacity needed for all homes.

The sample of outcomes of the analysis is shown in Figures 7.5, 7.6 & 7.7 have been achieved from Python programming software and the results used in the following section to calculate the cost benefit analysis. Please see appendix 2.

Table 7.5: Solar capacity required in homes to mitigate peak & off-peak phenomena

Home no.	Total_Consumption of electricity (KWh)			Highest Recorded consumption (kWh)	New Fact 1 Solar required for 300 home (KWh)
	Year 2010	Year 2011	Year 2012		261633
					Solar needed (KWh) Max. Ave = 0.459*48*365= 8041.68 KWh per year Min. Ave = 0.29*48*365= 5080.80KWh per year
1	8544.36	5133.55	5279.88	**8544.36**	**502.68**
2	8581.55	6091.45	4323.61	**8581.55**	**539.87**
3	4479.32	2784.28	1948.26	**4479.32**	**0**
4	5493.11	3633.19	3516.35	**5493.11**	**0**
5	5582.54	3138.68	3995.31	**5582.54**	**0**
6	9877.75	7798.37	8505.29	**9877.75**	**1836.07**
7	5137.49	4109.56	3301.13	**5137.49**	**0**
8	13038.2	8853.72	8525.27	**13038.2**	**4996.52**
9	4745.96	2578.73	2163.02	**4745.96**	**0**
10	7624.9	3703.27	2859.72	**7624.9**	**0**
:	:	:	:	:	:
:	:	:	:	:	:
290	7996.7	6145.46	5580.75	**7996.7**	**0**
291	7763.22	5746.34	4744.95	**7763.22**	**0**
292	3361.24	3259.32	2885.92	**3361.24**	**0**
293	11614.5	10580.77	10197.12	**11614.5**	**3572.82**
294	8643.12	5661.13	9443.47	**9443.47**	**1401.79**
295	3194.7	3136.47	3332.76	**3332.76**	**0**
296	3032.91	2844.46	2788.39	**3032.91**	**0**
297	8753.17	5066.02	4322.61	**8753.17**	**711.49**
298	3428.7	3333.99	3119.84	**3428.7**	**0**
299	10839.34	8359.71	10270.76	**10839.34**	**2797.66**
300	12328.69	9771.49	9186.4	**12328.69**	**4287.01**

Table 7. 6: Annual Financial Losses for 300 houses

Home no.	Losses of Energy Cost			**New Fact 2** Annual financial losses ($)-300 homes
	Year 2010	Year 2011	Year 2012	**216123.69** Average of energy losses ($)
	$ Dollar	$ Dollar	$ Dollar	
1	631.90	750.44	803.08	**728.48**
2	499.34	360.77	308.09	**389.40**
3	1166.62	1448.12	1702.95	**1439.23**
4	561.37	585.40	605.03	**583.94**
5	558.94	861.66	927.84	**782.81**
6	515.71	353.12	336.70	**401.85**
7	964.00	557.48	799.19	**773.56**
8	614.90	580.38	586.89	**594.06**
9	1850.68	2138.66	2319.95	**2103.10**
10	779.99	1163.17	1459.13	**1134.10**
:	:	:	:	:
:	:	:	:	:
290	414.10	437.71	544.53	**465.44**
291	268.91	237.12	373.17	**293.07**
292	1622.88	1683.19	1932.90	**1746.33**
293	522.86	462.72	449.00	**478.20**
294	442.06	458.47	384.24	**428.26**
295	990.58	924.18	839.35	**918.04**
296	1438.69	1417.05	1377.53	**1411.09**
297	288.96	200.38	307.35	**265.57**
298	676.62	751.71	738.15	**722.16**
299	631.81	655.91	639.59	**642.43**
300	544.53	471.24	439.75	**485.17**

Table 7.7: Annual financial losses incurred required due to homes' peak & off-peak phenomena

	Battery Scharging capacity 2010/11/12 in homes				Battery Discharging capacity 2010/11/12 in homes				**New Fact 3**
Home no.	Charging Capacity (KWh)			Max. Charg. Cap.	Discharging Capacity (KWh)			Max. Discharg. Cap.	Total capacity of batteries
	Year 2010	Year 2011	Year 2012	KWh	Year 2010	Year 2011	Year 2012	KWh	in 300 homes (KWh)
									7160.62
1	7.99	4.75	5.8	**7.99**	17.29	16.61	19	19	**19**
2	11.35	22.09	10.97	**22.09**	14.79	14.35	15.02	15.02	**22.09**
3	6.97	6.8	9.76	**9.76**	19.85	19.52	19.75	19.85	**19.85**
4	5.19	7.29	9.2	**9.2**	17	17.53	17.41	17.53	**17.53**
5	0.2	-1.2	10.49	**10.49**	22.02	19.09	21.73	22.02	**22.02**
6	14.6	13.08	17	**17**	20.41	17.45	12.82	20.41	**20.41**
7	5.13	12.94	8.97	**12.94**	20.1	19.01	19.08	20.1	**20.1**
8	44.68	23.61	24.39	**44.68**	15.07	16.39	16.22	16.39	**44.68**
9	-0.39	19.59	2.54	**19.59**	21.16	21.39	22.03	22.03	**22.03**
10	14.04	14.5	3.63	**14.5**	18.9	20.37	20.28	20.37	**20.37**
:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:
290	1.58	7.95	5.14	**7.95**	17.19	17.36	19.17	19.17	**19.17**
291	5.9	0.54	0.07	**5.9**	8.84	11.18	12.94	12.94	**12.94**
292	11.12	6.47	4.95	**11.12**	19.41	20.63	21.22	21.22	**21.22**
293	25.07	35.56	27.99	**35.56**	13.58	14.98	14.36	14.98	**35.56**
294	11.83	5.03	36.15	**36.15**	15.61	15.18	13.76	15.61	**36.15**
295	8.19	1.12	1.63	**8.19**	18.01	19.5	18.13	19.5	**19.5**
296	4.12	-0.24	2.85	**4.12**	20.7	20.3	20.42	20.7	**20.7**
297	1.02	1.96	5.77	**5.77**	13.7	12.46	13.93	13.93	**13.93**
298	1.74	2.67	-0.01	**2.67**	16.67	17.67	17.57	17.67	**17.67**
299	46.19	49.93	55.63	**55.63**	18.08	17.99	17.58	18.08	**55.63**
300	29.52	27.59	19.59	**29.52**	11.41	14.31	15.09	15.09	**29.52**

7.30 Cost Benefit Analysis (CBA)

7.30.1 Problems/Opportunities

The competitive business environment and market challenge reverse the understanding of the 'Electricity Industry', to define opportunities that may emerge, if changes are made in the organisational structure of electricity marketing and to influence the industrial economic activity. The electricity industry has been strongly executing a renewable energy growth strategy over several years. It is one of the essential sectors in Australia, and all around the world.

The electrical sector in Australia has independently generated and owns multiple generating plants, such as coal generators, gas turbines, reciprocating diesel generators, wind turbines, solar PV, hydro, Bioenergy, and geothermal sources. The Australian retail trade of electricity products reached to $m 25 957.2 in May 2017. The electricity industry assumes solar and wind sources of renewable energy as essential parameters to improve the total performance of the electricity industry and electricity selling prices (see Figure 7.23). The Australian Energy Market Operator still implements and looks for new strategic plans under capital investment programs.

The electricity industry has over recent years passed through microeconomic reform measures which led to a restructuring of this sector, which has made it difficult to settle on one measurement of the index of statistics over time. For instance, net performance measures in regard to profits and value added, have been affected much less than gross performance measures such as total expenses, turnover and sales, as illustrated by the graph below (Electricity Industry 2017). Most notably, turnover has risen massively over the past year as restructuring continues.

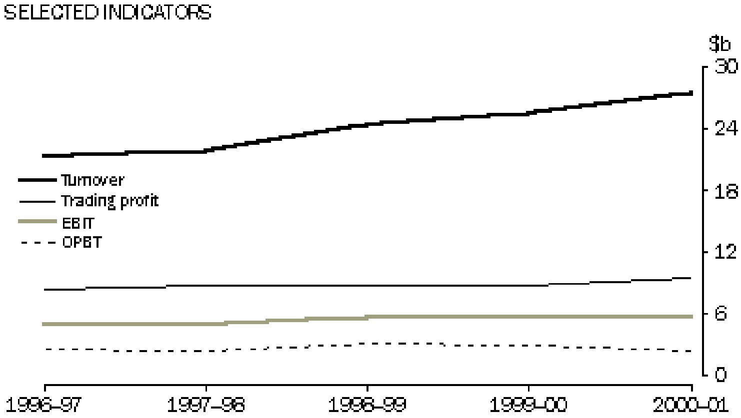


Figure 7. 23 Electricity Industry Performance Measures (Australian Bureau of Statistics 2017)

The outcomes of $14.6 billion of electricity industry value added in 2006-07 are exhibited an increase of $395 million (3%) over the preceding year.

7.30.2 Solution indication

In this project, two important points are taken into account:

- Positioning residential homes' value toward electricity generation, transmission and distribution. This aim will be one of the strategies to innovate new solutions and to serve suppliers, retailers, and consumers equally, while likely to improve the grid optimisation and raise the industry's profit.
- The endeavour to improve the business mostly bends to how the individual residential homes will reshape the rest of the economic activity, as well as the new changes, which may open a path to a much greater and more profound transition to new forms of economic structures.

7.30.3 Feasibility

The electricity industry has considerable success are business and in using resources efficiently. It also has a successful monetary obligation due to financial decisions in respect of liquidity and acceptable gearing measurement. However, the electricity industry continues to thrive against the uncertainties of electricity demand. Thus, when suppliers and retailers invest money to cover the demands of electricity, they are always concerned to take into account the ability to reduce energy losses, to decrease technical faults and to increase profits.

The information in Table 7.8 relating to electricity distribution in Australia has been collected from the IBISWorld industry report 'D2630' annual reports:

- Net profit after tax from the year 2010 to 2017.
- The average of Profit change from 2010 to 2017 to estimate an average profit increase or decrease in the year 2018.
- The assumption that eradicates the losses incurred from the peak and off-peak phenomena which estimated 7.6% of total used Energy (please refer to chapter one).

Table 7. 8: Estimated Profit for 2017/18

Year	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**
Net Profit ($Million)	15,680.3	17,188.3	18,952.2	18,440.2	17,796.3	16,469.6	16,750.2
Increase the profit %	0.6%	9.6%	10.3%	-2.7%	-3.5%	-7.5%	1.7%
Estimated profit in (2017-18)	∑ % {(2010-11) + (2011-12) + (2012-13) + (2013-14) + (2014-15) +(2015-16) + (2016-17)} / 7 = 1.214% (Profit estimation increase in (2017-18) The assumed profit for the year 2018 = 1.214% × 16,750.2 = $20,334.74 million						

The results of the Python analysis produce the following findings (The findings support the hypothesis four):

- Total capacity needed of Solar PV for 300 residential homes = 261,633 kWh per year. (The finding supports the hypothesis two).
- Total capacity of storage batteries needed for 300 homes per day = 7160.62 kWh.
  (The finding supports the hypothesis two).
- Total cost of lost energy (300 homes) = $ 216123.69 AUS.
  (The finding supports the hypothesis five).
- Expected profit after installing renewable energy at 300 homes = $ 216123.69 AUS.
  (The finding supports the hypothesis six).

The following Tables 7.9 and 7.10 shown the cost and operation of solar and storage battery installations in homes for the next twenty five years including net profit and any expected disposal that may occur.

Table 7. 9: Cost Installation of Renewable Energy at Residnetial Homes

(Gellings, C, Horst, G, McGranaghan, M, Myrda, P, Seal. B, & Siddiqui, O 2011)

	Life cycle	**30 Years**	**Cost**
Solar per 1 KW System (with inverter & installation)	Average daily production	3.9KWh	
	Cost $/KW	1400	{[261633 (KWh per year) / 3.9 (KWh)] / 365 days} x $1400= $257,313.80
Customers' share 50%			257,313.80/2 = 128,656.9
Lithium-Ion Battery with installation	Life cycle	10 years	$443 (cost $/KWh) x 5453.08 (KWh per day) = $ 2,415,714.44 million every ten years
	O&M / 5 years	$300	
	Charging time	1 hour	
	Discharging time	1 hour	
	Cost $/KWh	$443	
Customers' share 50%			2,415,714.44/2 = 1,207,857.22
Battery Inverter with installation	Life cycle	10 years	7160.62 (KWh per day)/24 (hrs)=298.36 (KWh per hr) x 514 ($/KW) = $153,357.04
	O&M / 5 years	$300	
	Cost $/kW	$514	
	Installation Cost	$400	
Customers' share 50%			153,357.04 / 2 = $76678.52
*** Advanced Meter Infrastructure (AMI)**	Life cycle	10 Years	$140 X 300 + $15 X 300 + $11 X 300 = $49,800
	Cost/Customer	$70 (low) - $140 (high)	
	Installation of Residential Meters	$7 (low) - $15 (high)	
	Ongoing System Maintenance	$3 (low) – $11(high)	
Customers' share 50%			49,800 / 2 = $ 24,900
In-home displays	Life Cycle	10 Years	$50 X 300 =$15,000
	Cost	$20 (low) – $50 (high)	
Customers' share 50%			15,000 / 2 = $7,500
****Direct Load Control (not integrated with AMI)**	Life Cycle	10 Years	$100 X 300 = $30,000
	Cost	$100 (low) – $100 (high)	
Customers' share 50%			30,000 / 2 = $15,000
Total			$ 1,460,592.64 AUS millions for 300 homes

Table 7.10: Life Cycle Operation for the Proposed Project

Millions $'000,000		**Project Cash flow ($millions)**	**Cumulative year ($)**
Immediate Payment	**The cost of Solar PV, Storage Batteries, Inverters, smart meters & Operation and maintenance (O&M).**	**1,460,592.64**	
1 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(1,244,468.95)
2 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(1,028,345.26)
3 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(812221.57)
4 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(596,097.88)
5 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(379,974.19)
6 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(163850.5)
7 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	52273.19
8 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	268396.88
9 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	484520.57
10 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	700644.26
Immediate Payment	The cost of new Storage Batteries, Inverters, smart meters & Operation and maintenance (O&M).	1,331935.1	(631290.84)
11 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(415167.15)
12 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	(199043.46)
13 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	17080.23
14 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	233203.92
15 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	449327.61
16 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	665451.3
17 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	881547.99
18 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,097698.68
19 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,313822.37
20 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,529946.06
Immediate Payment	The cost of new Storage Batteries, Inverters, smart meters & Operation and maintenance (O&M).	1,331935.1	198010.96
21 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	414134.65
22 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	630258.34
23 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	846382.03

24 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,062505.72
25 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,278629.41
26 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,494753.1
27 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,710876.79
28 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	1,927000.48
29 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	2,143124.17
30 years' time	Net profit after tax & before depreciation = $ 216123.69	216123.69	2,359247.86
Estimated 10% recycling profit (solar + battery + inverters) = 0.1 × (1,460,592.64 + 1,331935.1 + 1,331935.1) = $412446.284			
Total profit = 2359247.86 + $412446.284 = 2,771694.144			

7.30.4 Accounting Rate of Return (ARR)

This method aims to estimate the investment opportunities of renewable energy at homes based on the solution proposed in this research. This technique is a useful one on which to draw a comparison between different solutions toward the same issue of peak and off-peak phenomena.

$$\textbf{Average Annual Profit Before Depreciation} = \frac{\mathbf{216123.69 \times 30}}{\mathbf{10}} = \$\mathbf{216123.69} \text{ ....(1)}$$

(times 10 because the annual profit is a constant profit every year that equivalent to the losses of energy)

Annual depreciation charge = [(total cost) $ 1,460,592.64 – (expected selling price of the solar & storage

battery at the end of life time) $146059.2] / 10 years = $131453.344 ……….................(2)

Average annual profit after depreciation = (1) ─ (2)

= 216123.69 – 131453.344 = $ 84670.346 ....(3)

The estimated average investment at closing balance sheet appears at the immediate payment of the first year that equal to $1,460,592.64 (millions). Therefore, the estimated price of renewable energy installations during the thirty years of the project will be as illustrated in Table 7.11:

Table 7.11: Average of Investment of Renewable Energy at Homes

End of Years Renewable Energy Price	Immediate Payment ($)	Average annual profit after depreciation ($)	Asset Esstimate Remaining ($)
End of Year 1	1460592.64	84670.346	1375922.294
End of Year 2	1375922.294	84670.346	1291251.948
End of Year 3	1291251.948	84670.346	1206581.602
End of Year 4	1206581.602	84670.346	1121911.256
End of Year 5	1121911.256	84670.346	1037240.91
End of Year 6	1037240.91	84670.346	952.570.564
End of Year 7	952570.564	84670.346	867900.218
End of Year 8	867900.218	84670.346	783229.872
End of Year 9	783229.872	84670.346	698559.526
End of Year 10	698559.526	84670.346	613889.18
The Average of Investement			**331635.2457**

The average of investment = $ 331635.2457..(4)

Only ten years from the total life cycle of the project will be considered in this calculation.

Residual value after ten years = (1,460,592.64) – (84670.346 × 10 years) = $ 583 ..... (5)

Accounting Rate of Return (ARR) = Average annual profit after depreciation/average of investment

ARR = (3) / (4)

$$ARR = \frac{84670.346}{331635.2457} \times 100 = 25.53\% \quad \text{...(6)}$$

(ARR) Helps to decide whether the feasibility of this project is affordable for businesses or not. The highest ARR per cents is more demanded, which displays the expected return generated from net income of the proposed capital investment. The ARR of this project exhibits that this project is expected to earn 25.53 cents out of each dollar invested (annually). For this project, I will assume the required rate of return is equal to or greater than 20% which the result of ARR shows that this project is above that desired limit.

7.30.5 Project Pay Back Period (PP)

The above table of the project life cycle shows the cash flow becomes positive in year six. Storage Battery needs to be changed every ten years which leads in year ten to the cash flow return being negative for a couple of years. Total negative years are eight years. Therefore, the estimated payback period would be as follow:

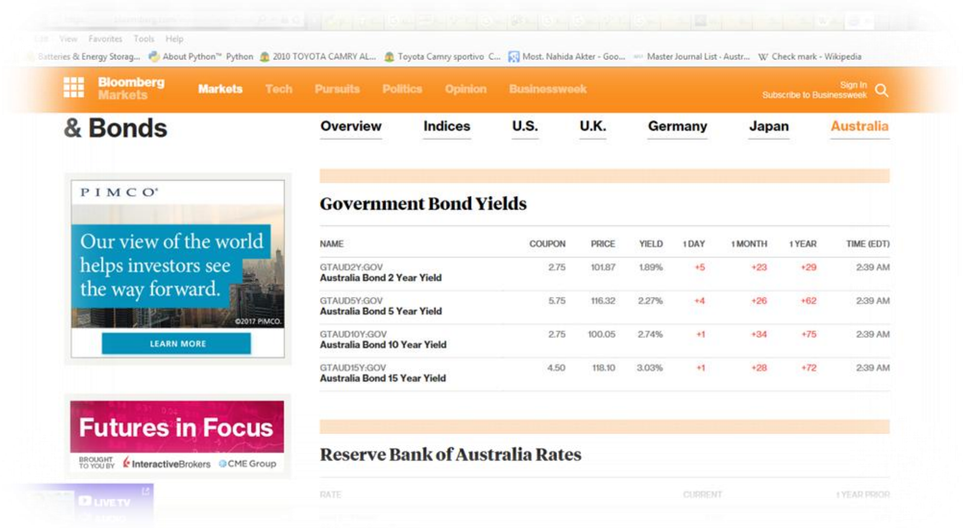
7 years + (52273.19/216123.69) = 7.24 years ....(7)

7.30.6 Cost of Capital/CPAM (Capital Pricing Asset Model)

It can be calculated by using the following equation

K = the required rate of return on the shares in question
KRF= the risk-free rate, usually that of long-term government bonds
b = the beta coefficient of the shares in question
KM= the required rate of return on average risk shares (or of a market portfolio of all shares)

Government yield point equal to 3.03% regarding Bloomberg web site viewed below.



Government Bond Yields

NAME	COUPON	PRICE	YIELD	1 DAY	1 MONTH	1 YEAR	TIME (EDT)
GTAUD2Y:GOV **Australia Bond 2 Year Yield**	2.75	101.87	1.89%	+5	+23	+29	2:39 AM
GTAUD5Y:GOV **Australia Bond 5 Year Yield**	5.75	116.32	2.27%	+4	+26	+62	2:39 AM
GTAUD10Y:GOV **Australia Bond 10 Year Yield**	2.75	100.05	2.74%	+1	+34	+75	2:39 AM
GTAUD15Y:GOV **Australia Bond 15 Year Yield**	4.50	118.10	3.03%	+1	+28	+72	2:39 AM

Reserve Bank of Australia Rates

RATE	CURRENT	1 YEAR PRIOR

FIGURE 7.45 GOVERNMENT YIELD POINT

The average Risk premium rate in Australia as found in working paper 2011 published by IESE Business school of Navarra, was equal to 5.8% (Fernandez, P, Aguirreamalloa, J, and Corres, L 2011).

Beta coefficient expresses on the market sensitivity, and according to the web site, Yahoo Finance, beta was 0.82 to the electricity industry and has been considered in this project (Beta Estimation: Considerations For The Economic Regulation Authority 2013).

7.30.7 Equity Required Rate

$$K_E = K_{RF} + K_P \times b$$

$$= 3.03\% + (5.8\% \times 0.82) = 7.786\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Commonwealth Bank Interest rate equal 8.41in regard to the web site of financial comparison of interest rate.

K_D = Interest rate × (1 – T)

K_D = 8.41 × (1 – 0.3) = 5.887% ....(9)

Rate of Return (RR)

K = K_E × (Capital equity %) + K_D × (Capital debt%)

K = [7.786% × (0.7%)] + [5.887% × (0.3%)] = 7.21% ....(10)

7.30.8 Profit Estimate/DCF Technique

Using a combination of tools and techniques that will be used later as input to the spread sheet shown below.

7.30.9 Net Present Value (NPV)

Present value (PV) is an indication of the current worth for a future sum of cash flows or money to indicate the rate of return. Discount rate opposite to future cash flows which lower the discount rate, the higher the present value of the future cash flows. The Net Present Value (NPV) is defined as the difference between the present value of cash outflows and the present value of cash inflows. Therefore, for Net Present Value (NPV) it is useful to be aware of capital budgeting to investigate the profitability of an investment in a project (see Table 7.12).

Total Present Value calculated in the table in regards of follows equation.

$$\text{PV} = \sum_{n-1}^{N} CF_n \;/\; (1+r)^n$$

CF: Cash flow of some year

n: A year number $(1+r)^n$ *r:* Investment opportunity

Net Present Value (NPV) = Residual Value + Total present values – Initial cost

7.30.10 Internal Rate of Return (IRR)

We can simplify the equation as follows and on aspect of the calculated data in DCF project tables:

$$\boldsymbol{IRR}\ (\boldsymbol{Internal\ rate\ of\ return}) = \boldsymbol{RR2}\ \% + \frac{\boldsymbol{NPV2} \times (\boldsymbol{RR1}\% - \boldsymbol{RR2}\%)}{\boldsymbol{NPV2} + (-\boldsymbol{NPV1})}$$

Estimated rate of return 1

Discount rate (Year 1) = $1/(1+K)^1$ = $1/(1+0.1735)^1$ = 0.8474......(11)

Discount rate (Year 2) = $1/(1+K)^2$ = $1/(1+0.1735)^2$ = 0.7181.....(12)

Discount rate (Year 3) = $1/(1+K)^3$ = $1/(1+0.1735)^3$ = 0.6086.....(13)

Discount rate (Year 4) = $1/(1+K)^4$ = $1/(1+0.1735)^4$ = 0.5157.....(14)

Discount rate (Year 5) = $1/(1+K)^5$ = $1/(1+0.1735)^5$ = 0.4371.....(15)

Discount rate (Year 6) = $1/(1+K)^5$ = $1/(1+0.1735)^6$ = 0.3704.....(16)

Discount rate (Year 7) = $1/(1+K)^5$ = $1/(1+0.1735)^7$ = 0.3139.....(17)

Discount rate (Year 8) = $1/(1+K)^5$ = $1/(1+0.1735)^8$ = 0.2660.....(18)

Discount rate (Year 9) = $1/(1+K)^5$ = $1/(1+0.1735)^9$ = 0.2254.....(19)

Discount rate (Year 10) = $1/(1+K)^5$ = $1/(1+0.1735)^{10}$ = 0.1910..(20)

Table 7.12: Net Present Value

Sustainable Model Project for Residential Homes												
$’000,000 m												
Immediate cost	1.46059264											
Residual value *	**0.58388918**											
Years		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	
Profit before depreciation		0.2161237	0.21612369	0.2161237	0.2161237	0.2161237	0.2161237	0.2161237	0.2161237	0.2161237	0.2161237	
Depreciation *		**0.131453**	**0.131453344**	**0.131453**	**0.131453**	**0.131453**	**0.131453**	**0.131453**	**0.131453**	**0.131453**	**0.131453**	
Net profit after depreciation		0.08467	0.084670346	0.08467	0.08467	0.08467	0.08467	0.08467	0.08467	0.08467	0.08467	
Tax (30%) *		0.025401	0.025401104	0.025401	0.025401	0.025401	0.025401	0.025401	0.025401	0.025401	0.025401	
Net profit after tax		0.059269	0.059269242	0.059269	0.059269	0.059269	0.059269	0.059269	0.059269	0.059269	0.059269	
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Rate of Return 1		7.21%	0.0721									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.93275	0.870020344	0.81151	0.756935	0.706031	0.658549	0.614261	0.572951	0.53442	0.498479	
PRESENT VALUE (PV)	1.46059264	0.177896	0.16593253	0.154773	0.144365	0.134656	0.1256	0.117153	0.109275	0.101926	0.095071	
Total present value												1.3266483
Initial cost = Immediate cost												1.4605926
Net Present Value 1												**0.44994487**
Rate of Return 2		10%	0.1									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.90909	0.826446281	0.751315	0.683013	0.620921	0.564474	0.513158	0.466507	0.424098	0.385543	
PRESENT VALUE (PV)	1.46059264	0.173384	0.157621972	0.143293	0.130266	0.118424	0.107658	0.097871	0.088973	0.080885	0.073532	
Total present value												1.1719077
Initial cost												1.4605926
Net Present Value 2												0.2952043
Rate of Return 3		12%	0.12									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.89286	0.797193878	0.71178	0.635518	0.567427	0.506631	0.452349	0.403883	0.36061	0.321973	
PRESENT VALUE (PV)	1.46059264	0.170288	0.152042878	0.135753	0.121208	0.108221	0.096626	0.086273	0.07703	0.068776	0.061408	
Total present value												1.0776251
Initial cost = Immediate cost												1.4605926
Net Present Value 3												0.2009217
Rate of Return 4		14%	0.14									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.87719	0.769467528	0.674972	0.59208	0.519369	0.455587	0.399637	0.350559	0.307508	0.269744	
PRESENT VALUE (PV)	1.46059264	0.167301	0.146754837	0.128732	0.112923	0.099055	0.086891	0.07622	0.06686	0.058649	0.051446	
Total present value												0.9948311
Initial cost = Immediate cost												1.4605926
Net Present Value 4												0.1181276
Rate of Return 5		16%	0.16									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.86207	0.743162901	0.640658	0.552291	0.476113	0.410442	0.35383	0.305025	0.262953	0.226684	
PRESENT VALUE (PV)	1.46059264	0.164416	0.141737951	0.122188	0.105334	0.090806	0.078281	0.067483	0.058175	0.050151	0.043234	
Total present value												0.9218056
Initial cost = Immediate cost												1.4605926
Net Present Value 5												0.0451022
Rate of Return 6		17%	0.17									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.8547	0.730513551	0.624371	0.53365	0.456111	0.389839	0.333195	0.284782	0.243404	0.208037	
PRESENT VALUE (PV)	1.46059264	0.163011	0.139325434	0.119082	0.101779	0.086991	0.074351	0.063548	0.054314	0.046423	0.039677	
Total present value												0.8885009
Initial cost = Immediate cost												1.4605926
Net Present Value 6												0.0117975
Rate of Return 7		17.35%	0.1735									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.85215	0.726162491	0.618801	0.527312	0.44935	0.382914	0.326301	0.278058	0.236948	0.201915	
PRESENT VALUE (PV)	1.46059264	0.162525	0.138495588	0.118019	0.10057	0.085701	0.07303	0.062233	0.053032	0.045191	0.03851	
Total present value												0.8773072
Initial cost = Immediate cost												1.4605926
Net Present Value 7												0.0006037
Rate of Return 8		18%	0.18									
Net profit after tax before depreciaton		0.190723	0.190722586	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	0.190723	
Residual value *												**0.58388918**
Discount rate	1	0.84746	0.71818443	0.608631	0.515789	0.437109	0.370432	0.313925	0.266038	0.225456	0.191064	
PRESENT VALUE (PV)	1.46059264	0.161629	0.136973992	0.11608	0.098373	0.083367	0.07065	0.059873	0.050739	0.043	0.03644	
Total present value												0.8571238
Initial cost = Immediate cost												1.4605926
Net Present Value 8												-0.0195797

7.30.11 Discount Cash Flow (DCF)

Net Present Value (NPV) per \$1 investment $= \frac{NPV}{Investment}$

NPV per \$1 investment $= \frac{449944.87}{1460592.64} = \$0.308$..(21)

Internal Rate of Return (IRR)

IRR is a discount rate which measures the profitability of potential investments and makes the net present value (NPV) of all cash flows equal to zero.

$$\mathbf{IRR} = 17.35\ \% + \frac{0.0006037\times(18\%-17.35\%)}{0.0006037+0.0195797} = 17.369\ \% \text{ ....(22)}$$

7.30.12 Return on total assets ratio (ROA)

Assets that owned the business and the net profit generated by the same business will be compared as a percentage to reveal the efficiency and the effectiveness in regards to asset usage. Tax variable over time, which is preferable to comparing inputs as assets to output as profits before taxation.

$$ROA = \frac{\text{Net profit before interest \& } taxation}{\text{Average total asset}} \times 100\%$$

- Net profit generating the business has been estimated from the year 2017 to 2026 (see Table 7.13) (the findings support the hypothesis one).
- Assets have been estimated regarding the expected annual depreciation (10%). This calculation will be revised in the future when more data available:

Table 7.13: Estimate of Net Profit generating

2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
1460592.64	1314533.37	1183080.03	1064772.03	958294.83	862465.34	776218.81	698596.93	628737.23	565863.51

- Annual depreciation charge = \$131453.344 achieved above in the equation number (2) under the above section of ‘Accounting Rate of Return’ (ARR).

Expected ROA measures the efficiency and the effectiveness on respect of asset used.

$$\boldsymbol{ROA}(2026) = \frac{206123.7}{\frac{565863.51 + 628737.23}{2}} \times 100\% = 34.50\%$$

$$\boldsymbol{ROA}(2025) = \frac{206123.7}{\frac{628737.23 + 698596.93}{2}} \times 100\% = 31.05\%$$

$$\boldsymbol{ROA}(2024) = \frac{206123.7}{\frac{698596.93 + 776218.81}{2}} \times 100\% = 27.95\%$$

$$\boldsymbol{ROA}(2023) = \frac{206123.7}{\frac{776218.81 + 862465.34}{2}} \times 100\% = 25.15\%$$

$$\boldsymbol{ROA}(2022) = \frac{206123.7}{\frac{862465.34 + 958294.83}{2}} \times 100\% = 22.64\%$$

$$\boldsymbol{ROA}(2021) = \frac{206123.7}{\frac{958294.83 + 1064772.03}{2}} \times 100\% = 20.37\%$$

$$\boldsymbol{ROA}(2020) = \frac{206123.7}{\frac{1064772.03 + 1183080.03}{2}} \times 100\% = 18.33\%$$

$$\boldsymbol{ROA}(2019) = \frac{206123.7}{\frac{1183080.03 + 1314533.37}{2}} \times 100\% = 16.50\%$$

$$\boldsymbol{ROA}(2018) = \frac{206123.7}{\frac{1314533.37 + 1460592.64}{2}} \times 100\% = 14.85\%$$

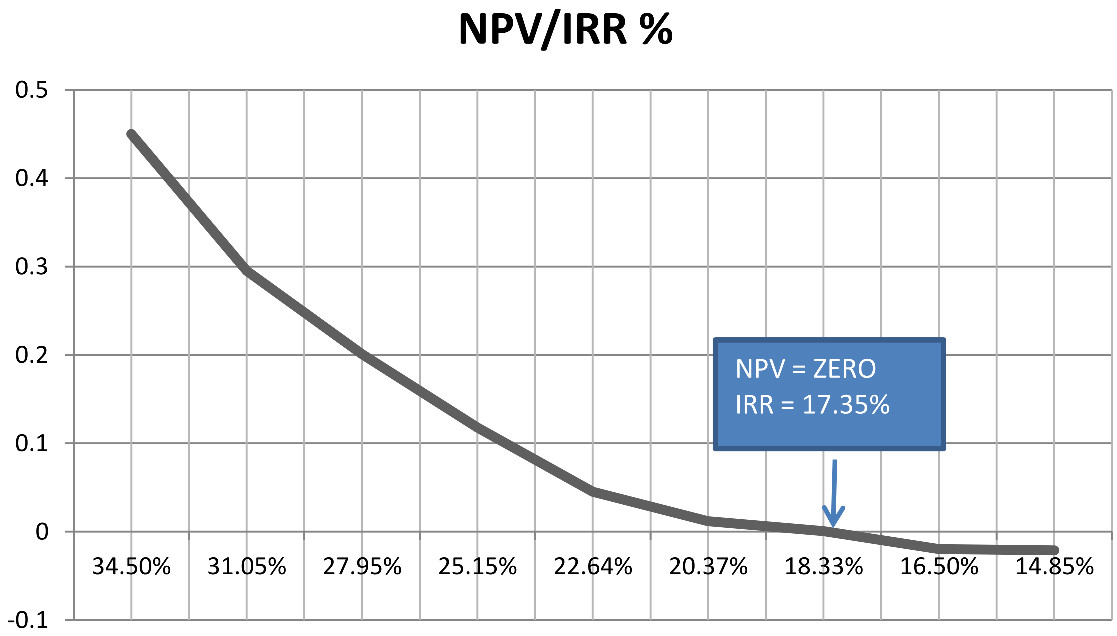


Figure 7. 24: Net Present Value & Internal Rate of Return

Table 7. 14 The Results of the Cost Benefit Analysis

Net Present Value (NPV) per $1 investment	$ 0.308
Net Present Value (NPV) @ K= 7.21% (rate of return)	$ 449944.87
Internal Rate of Return (IRR)	17.639 %
Accounting Rate of Return (ARR)	25.53%
Payback Period (PP)	7.24 years
Return on Total Asset (ROA) 2018	14.85%
Return on Total Asset (ROA) 2019	16.50%
Return on Total Asset (ROA) 2020	18.33%
Return on Total Asset (ROA) 2021	20.37%
Return on Total Asset (ROA) 2022	22.64%
Return on Total Asset (ROA) 2023	25.15%
Return on Total Asset (ROA) 2024	27.95%
Return on Total Asset (ROA) 2025	31.05%
Return on Total Asset (ROA) 2026	34.50%

The analysis and results above in Figure 7.24 and Table 7.14 are exhibit a positive, healthy research result and support the hypothesis one. The results are possibly improve when accurate information is collected and precise technical data gathered from the related industry. The analysis and results view residential households' models as having three potential sources of electricity power (fossil fuel electricity power, solar power, and storage battery power) which must all be included as power sources in every single home using the method argued in this study, in order to achieve homes' sustainability.

The following section addresses future work with regard to this thesis. This following section will provide further useful analysis by using an ARIMA model through Python programming language. The analysis in this section will be linked to the analysis adopted in chapters eight and nine to pursue suppliers and consumers towards the first step in designing smart devices for residential homes, to serve the goal of achieving average demand and to mitigate the issues of peak and off-peak phenomena that cause energy losses in the grid system.

7.31 Future Continue Analysis for Proposing Smart Devices at Homes

The power consumption data is a time series data as the observations are a sequence in time and date for 300 residential homes and for 47,304,000 millions data items. In this particular part of the analysis, we perform a time series analysis of the power consumption data.

The objective of this analysis was as follows:

- Identifying the important features of the data.

- Explaining how past events affect the future and how they are correlated.
- Forecasting the future values of the time series.
- Describing the time series in analytical form and creating a model for time series.

7.31.1 Autoregressive Integrated Moving Average Model (ARIMA)

In this part of analysis, we will consider ARIMA (Auto Regressive Integrated Moving Average) models, where the present values of the series are related to past values and prediction errors.

‘ARIMA’

ARIMA is a helpful tool for a univariate time series analysis for a sequence of measurements of the same variable (KWh) that in our case often made at a regular time (every half an hour) and collected over time (three years data for each consumer/household). The fundamental objective of this programming task is to determine a model to define its pattern of the time series. Thus, time series analysis (TSA) which ARIMA one of its tools can describe the feature of the time series in use. Also, it can lead us to reveal how the past impacts the future in terms of two-time series ‘interact’. And to forecast future value of time series that we investigate.

The ARIMA Models need input parameters in the form of p, d and q, which represent the orders for AR (Autoregressive), difference and MA (Moving Average) parts. We need to obtain the proper values of p, d and q in order to fit the model. First, we plot the time series for power consumption for one consumer and other characteristic plots. It can be remarked from the figure 7.50 that the time series is not stationary. Thus we take the first difference of the series, that is, a series which is obtained by taking the difference of subsequent elements of the series and is shown below.

- p: Named the lag order and express on the number of lag observations defined in the model.
- d: Named the degree of differencing and express on the number of times when the raw observations are differences.
- q: Named the order of moving average and express on the size of moving average window.

In this analysis, the attempt is made to capture a pavilion of different standard temporal structures from time series data we have. A univariate time series is a concatenation of measurements of the corresponding variable gathered over time. Most often, the measurements are obtained at regular time intervals. One characteristic of a time series is that the ordering of the observations taken matters and data are not entirely independent.

$$\varphi(B)(\omega_t - \mu) = \theta(B)a_t$$

$\varphi(B)$ = Autoregressive operator

$\theta(B)$ = Moving average operator

B = Backshift operator

ω_t = Response series after differencing

t = Time index

μ = Intercept or mean term

a_t = Sequence of random shocks

The sample autocorrelation function (ACF) provides correlations between the series xt and the lagged values of the series. The ACF also gives the possible structure of time series data.

$$R(s,t) = \frac{E[(X_t + \mu_t)\,(X_s - \mu_s)]}{\sigma_t \sigma_s}$$

t = time 1

s = time 2

X_t = the value produced by a given run of the process during time t

$\boldsymbol{\mu_t}$ = mean

$\boldsymbol{\sigma_t^2}$ = variance

E = expected value operator

R(s, t) = Autocorrelation between time (t) & (s)

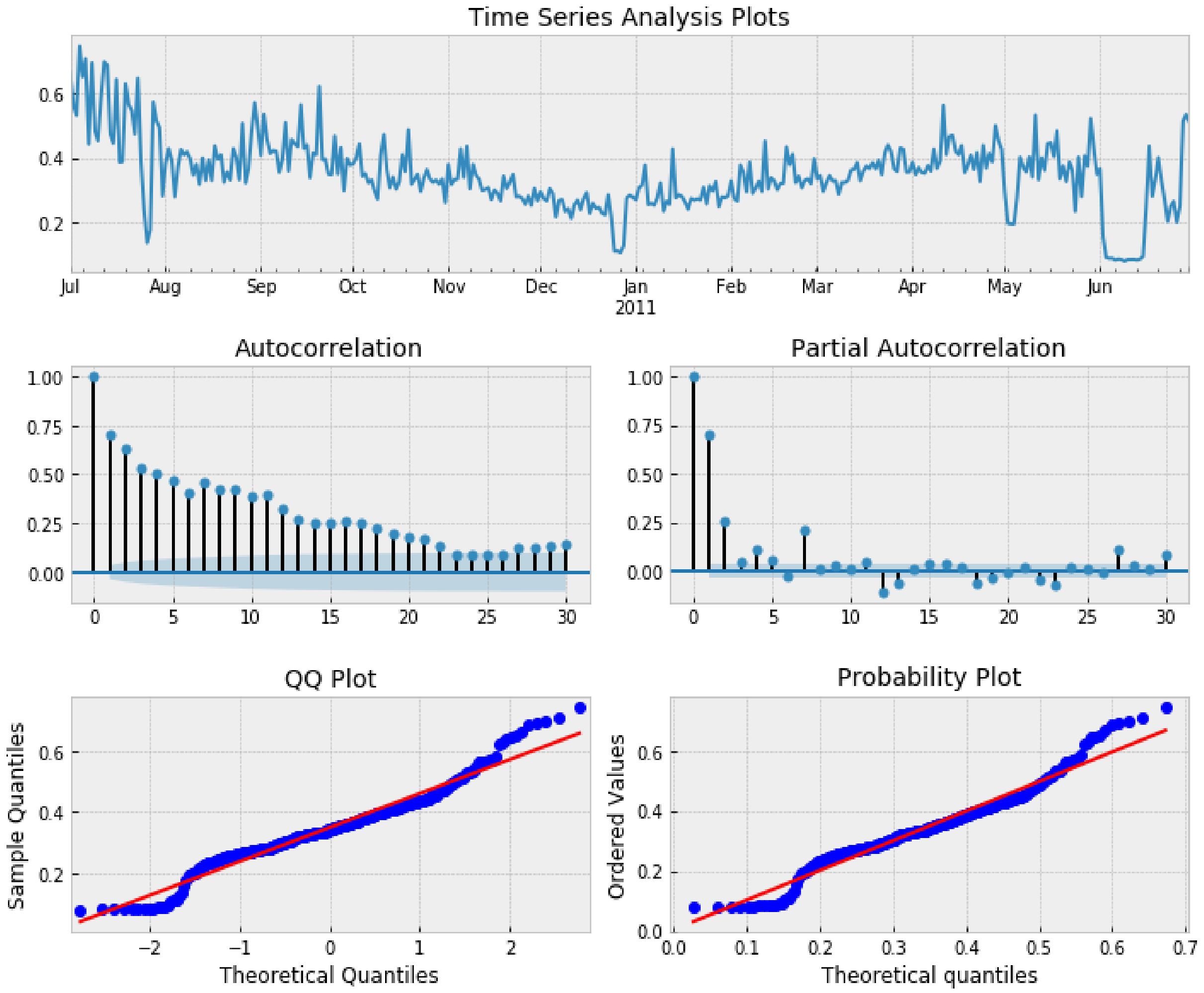


Figure 7. 25: Time series plots for the power consumption of consumer 1 for the year 2010-2011

An essential concept in time series analysis is the stationary series. For ACF to make sense, the series must be stationary. A stationary series satisfies following properties: a) Mean E(xt) must be constant, b) The variance of xt must be the same for all t and c) covariance between xt and xt-h is the same for all t.

‘Autocorrelation (AC)’

Autocorrelation is a randomness measurement tool that is making a serial correlation of a signal with a delayed copy of itself as a function of delay. It might also be better defined as the measurement of the similarity between observations using the function of the time lag between them. Thus, by referring to the figure 7.50 when the x axis (lag of time) is above +0.25 or below -0.25 then it shows a significant autocorrelation, and that is not a good result.

‘Partial Autocorrelation Function (PACF)’

A partial correlation is a conditional correlation between two variables under the proposed assumption which takes into account other values related to another set of variables. Assuming the y axis represents the response variable, and the x axis is the predictor variable, the partial correlation between y and let's say x5 it is, in fact, taking into account how both y and x5 are related to x1, x2, x3 & x4 in the x axis. However, we correlate the “parts” of y and x5 that are not predicted by x1, x2, x3 & x4.

‘Stationary Process’

It is a stochastic processing of the data to measures the level of consistency of the joint probability, mean and variance regarding the time series data as they are present they do not change over time.

‘Quantile’

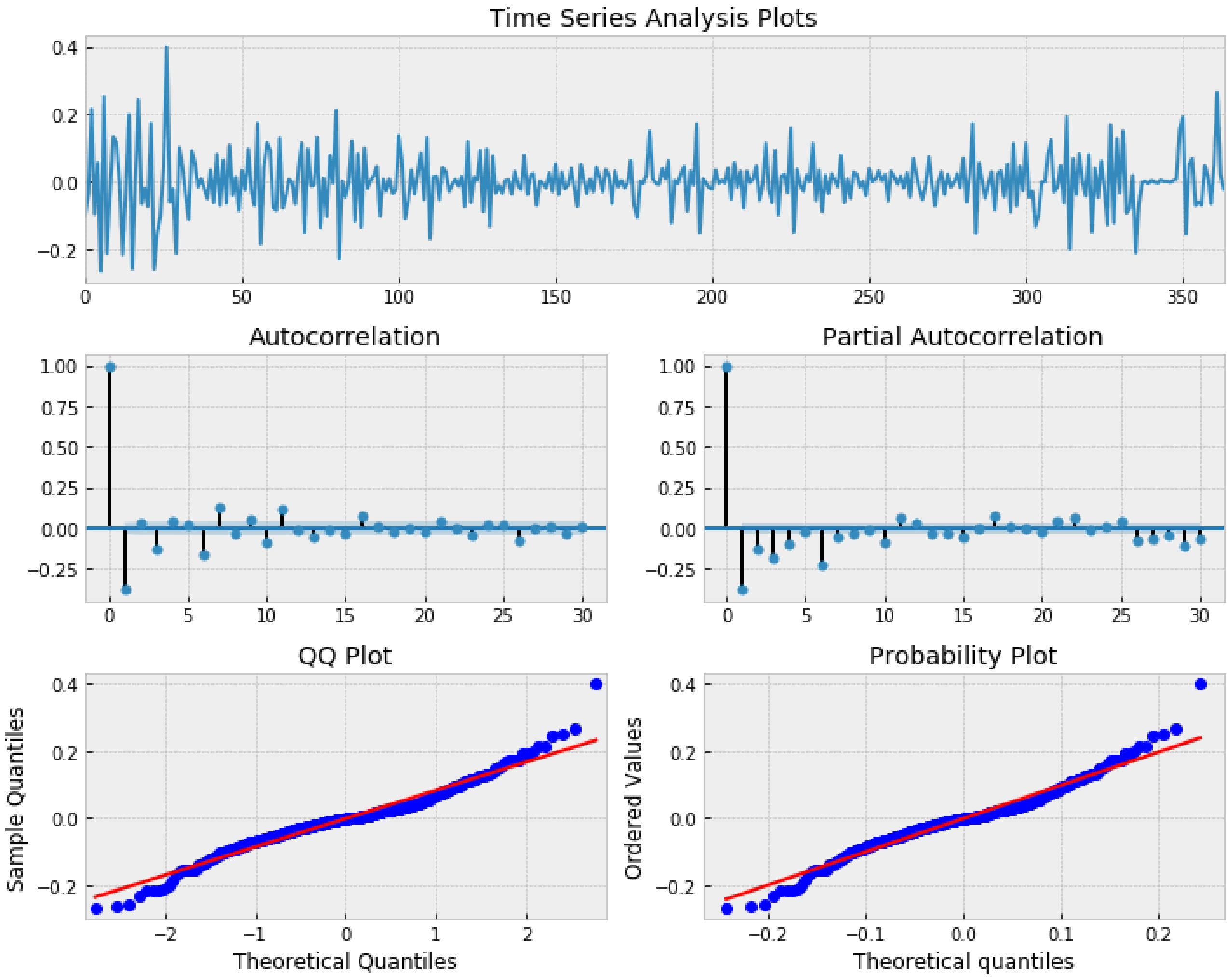
It is a point in a distribution in a data set and relates to the rank order of values in that distribution. Thus, the middle value in a data set equal to the 50th percentile and known as the median.

‘QQ Plot’

Statistically defined as a quantile-quantile Plot it compares the quantiles of a standardised theoretical from a particular family of distributions by plotting their quantiles against each other. The line generated between x and y axis is a parametric curve between the data values of the interval for the quantile.

‘PP Plot’

It is a probability plot, and it is a graphical technique to compare a data set based on its empirical cumulative distribution function against a particular theoretical cumulative distribution function. This comparison to reveal how much a data set follows a given distribution like the normal one that plotted in a straight line.



Time Series Analysis Plots

Autocorrelation

Partial Autocorrelation

QQ Plot

Probability Plot

Figure 7.26: Time series plots for the power consumption of consumer 1 for the year 2010-2011

We can see in the figure (7.26) that the time series now looks stationary. Now, we proceed to find the values of p, d and q for the ARIMA model. For this, we range over p~(0, 4), d~(0, 2) and q~(0, 4) and evaluate AIC values (Akaike Information Criteria). This is a widely used measure of a statistical model which mainly quantifies the successfulness of fit, and the parsimony/simplicity, of the model into a single statistics. AIC will be used to compare various ARIMA time series models. The model which gives lowest AIC values is chosen as the best model. The sample above is for only one home for the year 2010/11. The various values achieved for the AIC for different models are following:

aic:-843.92073 | order:(0, 0, 1)
aic:-847.85608 | order:(0, 0, 2)
aic:-855.94039 | order:(0, 0, 3)
aic:-759.52710 | order:(0, 1, 1)
aic:-824.46412 | order:(1, 0, 0)
aic:-852.19415 | order:(1, 0, 1)

```
aic:-852.67805 | order:(1, 0, 2)
aic:-854.76717 | order:(1, 0, 3)
aic:-596.47724 | order:(1, 1, 0)
aic:-828.43892 | order:(2, 0, 0)
aic:-854.04173 | order:(2, 0, 1)
aic:-853.45474 | order:(2, 0, 2)
aic:-853.63947 | order:(2, 0, 3)
aic:-649.32693 | order:(2, 1, 0)
aic:-839.47038 | order:(3, 0, 0)
aic:-853.78702 | order:(3, 0, 1)
aic:-851.92300 | order:(3, 0, 2)
aic:-854.56150 | order:(3, 0, 3)
aic:-695.03174 | order:(3, 1, 0)
aic:-827.05738 | order:(3, 1, 1)
aic:-855.94039 | order:(0, 0, 3)
```

Thus, we see that ARIMA(0, 0, 3) is the most suitable model for the time series under study. The results of the fit and coefficients of the model are in Table 7.15:

Table 7. 15: ARIMA Model Fit Results

```
ARIMA Model Results
====================================================================================
==
Dep. Variable:                      y   No. Observations:                  364
Model:                     ARMA(0, 3)   Log Likelihood                 431.970
Method:                           mle   S.D. of innovations              0.074
Date:                Sat, 22 Jul 2017   AIC                           -855.940
Time:                        11:59:35   BIC                           -840.352
Sample:                             0   HQIC                          -849.745
==============================================================================
                 coef    std err          z      P>|z|      [0.025      0.975]
------------------------------------------------------------------------------
ma.L1.y       -0.5031      0.053     -9.467      0.000      -0.607      -0.399
ma.L2.y       -0.0560      0.054     -1.031      0.303      -0.163       0.050
ma.L3.y       -0.1690      0.053     -3.171      0.002      -0.273      -0.065
                                    Roots
=============================================================================
                 Real           Imaginary           Modulus         Frequency
-----------------------------------------------------------------------------
MA.1            1.2172           -0.0000j            1.2172           -0.0000
MA.2           -0.7745           -2.0647j            2.2052           -0.3071
MA.3           -0.7745           +2.0647j            2.2052            0.3071
```

7.31.2 Time Series Forecasting

With the ARIMA (0,0,3) model and the obtained coefficients, we perform the forecasting on the future time series. We have created this model with the 2010-2011 data and are now forecasting for 2011-2012. Here we carry out the one-step ahead forecast and take the past n values for the predicting the current value in the series. The plot for the prediction and actual observation is shown below:

$$\hat{y}_t = \mu + \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} - \theta_1 e_{t-1} - \ldots - \theta_q e_{t-q}$$

ϕ = A slope coefficient

(θ's) = Average parameters

Y = Predicted value a weighted sum of one or more recent values of the errors

μ = Coefficient

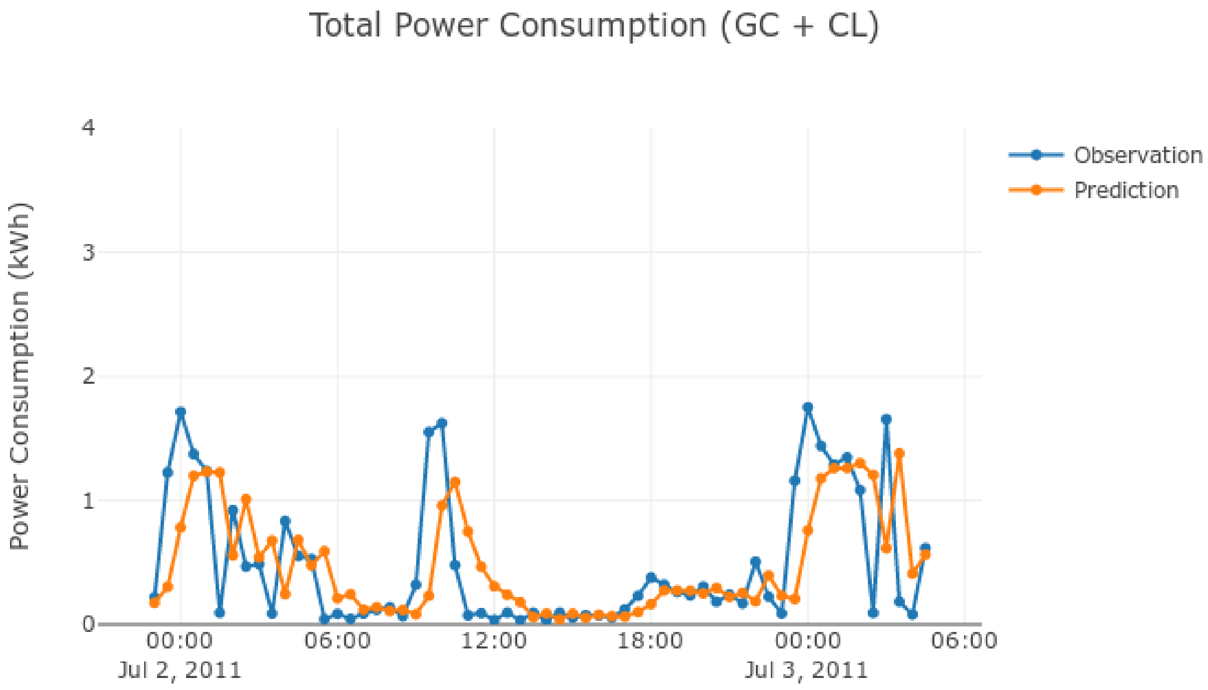


Figure 7. 27**: ARIMA Model fit results for a residential home**

Overall, t model is valid to apply to other time series data of electricity consumption of residential homes. Collecting more accurate data upon timely power generation, the cost of generation at peak, average and off-peak times, and energy losses at peak times at different loads, will help to deliver more precise investigation and more accurate outcomes. The time series forecasting work in the section above (7.31.2) and Figure 7.27 must be considered as a part of the future work in applying the concept of this thesis to design a residential home smart device to serve the goal of managing the use of the right capacity of renewable energy at homes to mitigate the influence of peak and off-peak phenomena that emerge from different houses in different ways.

Chapter Eight
Summary

Acronyms

CCGT: Combined Cycle Gas Turbine

HAN: Home Area Network

NSW: New South Wales

OCGT: Open Cycle Gas Turbine

OP: Off-Peak Load

P: Peak Load

TIEs: Tiny Initiated Events

ToU: Time of Use Tariff

Lessons Learned from Chapters 1, 2, 3, 4, 5, 6 & 7

In chapter 7, soft methods were used by designated computer systems to analyse 47 million data items forming an electricity demand case study, based on 300 residential houses. The analysis outcomes were structured to provide interventions based on the usage relationships and patterns of the analysed elements (households). Three testing methods were applied in two analytical stages. The first analytical stage captured the models of changeability and dissimilarity of residential houses in electrical grid systems which found significance. The second analytical stage tested the proposed residential households' models which were significantly found to require renewable sources of electricity that should be used in a very particular way, to achieve homes' sustainability. Complexity theory is demonstrated to be helpful in managing the situational complexities involved in conducting analysis that calls for instantaneous decision making when consumers demand to play a role in electrical smart grid systems. This phenomenon became involved in designing a complex force structure that is fit for purpose in meeting the diverse stakeholders' needs for a given cost. These synthesised processes and tools have been carefully developed over preceding chapters, to support the proposed model's role in effectively mitigating losses at micro and macro levels, of the current electricity smart grid systems. This benefits both the energy producers and customers.

Chapter Outline

This chapter provides a summary of all thesis chapters. It reviews the rationale and the aim of this study, the methodology in relation to the thesis goal, and its theoretical and practical importance. In this chapter, a compilation of the explored findings will be related back to the research questions. The chapter then outlines the contribution to knowledge and possible practical implications of the findings. A discussion of the limitations of this study is included along with suggested directions for future research.

8.1 Introduction

This chapter summarises the author's contribution to bodies of knowledge on complex systems. At its conception, this work focuses on introducing a solution to a chronic electricity problem in Australia and all over the globe. In its creation, this work has taken a journey beyond the electricity industry as a single area of concern, to deliver insight into the application of complexity theory and practice in wider strategic applications to other fields, such as transportation, health and other broader national domains. While the work is just beginning, and should continue to progress, this thesis at this point in time supports conclusions to be told in terms of its contribution to knowledge, its applicability to new approaches to design and to the various related disciplines which would benefit from the application of complexity approaches.

8.2 Logical Basis for this Study

The study investigated the process and the key determinant factors of the sustainability of residential homes in electrical smart grid systems. This study also emphasised the roles of residential households in this process; explored what constitutes electrical smart grid optimisation; described the new role of renewable energy to mitigate energy losses and established the operational drivers that lead to desirable grid optimisation through the sustainability concept presented for homes.

The poverty of existing studies of complexity theory in relation to the uncertainties of complex systems, emergence and tiny initiated events (TIE) required an explanatory and descriptive in-depth investigation that would shed light on the mechanism needed and the major determinants of human complex behaviours. In this sense, the study adopted a quantitative research method and a case study technique. The case study technique is the methodological centre for research on "uncertainties, emergences & tiny initiated events". This research is an attempt to verify the individual and clustering effects of human behaviours while consuming electricity in a complex grid system in Australia. It provides a greater understanding of these chaotic interactions, which, in turn, will facilitate efficiency improvement. The large sample size of this study has been selected to review the maximum variation and to examine the phenomena of emergence in diverse contexts while being able to identify solutions between different patterns that 'cut across variety'.

This study has advanced the existing body of knowledge of complex systems. Complexity theory is a relatively new field of study that grew out of the General Systems Theory from the 1960s in response to examining the nonlinearity and uncertainty of systems. The philosophy of complexity is an interdisciplinary theory emphasising interactions and accompanying loops of feedback that constantly observe and change the system, which is acknowledged in the literature, Allahverdyan, A E ; Steeg, G Ver ; Galstyan, A 2015); (Urken, Arnold B. ; "buck" Nimz, Arthur & Schuck, Tod M. 2012); (Agostinho, C & Jardim-Goncalves, R 2015); (Stötzer, M., Member, S., Stein, J., & Member, N, 2012); (Lin, C Y-Y 2004, p. 3)].

Behaviour categorisation is a widely studied domain, either from the perspective of genetic programming (GP) or machine learning in particular (McIntyre, AR, & Heywood, MI 2011). However, little is known about the complexity approaches that describe end-users' demand as a multi-criterion problem. It is important to think of the best way to make a trade-off between some intangible and some tangible factors, some of which may conflict (K, J. J, D, G. S, G. A, Soumya, B & Partha, D. 2011).

Although there is a growing body of literature covering many aspects of end users' behaviour in the electricity industry, it is still widely understood that the empirical validation of demand management and optimisation in relation to the supply of electricity in electrical systems is limited, and the contribution of complexity theory to such an issue is rarely studied. The scalability of electricity consumption and the clustering interactions among the consumers' behaviours appear to be ignored and in need of further examination. This research attempts to centralise the consumer's behaviour to remove peaks and troughs and to mitigate the gap between supply and demand for electricity. Thus, it provides a greater understanding of end-user demand, which in turn, will improve the total performance of the grid systems.

This study synthesised three bodies of literature in order to produce a theoretical framework for a sustainable model that would be used through empirical investigations to address the broad research problem. The literature review featured complexity theory and related approaches, through which the origin of losses caused by consumers in the electricity industry of Australia were analysed. This research takes into account the nature of the phenomenon of interest (uncertainty, emergences, scalability & tiny initiated events) and connects them with the nature and level of both the research questions and practical considerations in relation to the research environment. The literature review identified answers to a number of gaps in understanding the complexity norms mentioned above, in order to answer the formulated research questions. This research is significant from both practical and theoretical viewpoints.

This study contributes to the theory of complexity and the research makes a significant connection with practice through moderation of consumption behaviours measures and compares these with guiding policies for electricity, such as the Time of Use tariff (ToU). Many countries, such as the United States, Germany and Australia, consider it a priority to develop new cost-effective techniques to reduce greenhouse gas emissions and to enable systems for very high penetration of renewable energy generation, in order to reduce and balance electricity consumption. In Australia, this objective critically important and needs more research efforts to draw narrower parameters and to more accurately draw on the progress of science, technology and innovation. In addition, better-defined roles for universities, government, industry, and society at large are vital. The practical value of this research is to assist in reshaping new policies in the electricity industry, to contribute to a more precise quantification of energy losses and to the development of a new methodology for manage the use of renewables at residential home scale.

The following section compiles the findings of the three research questions explored in this thesis.

8.3 Synthesis of findings through the research questions

The research questions used for this study were:

1) *How can the total losses in the electrical grid system, use of non-traditional power, and battery system be significantly reduced?*

Answers to this question were provided with evidence, through the analysis in chapters seven and eight which concludes with the following findings:

The average/mean of the population consumption reflects the total capacity of electricity needed.

Residential homes are widely different in electricity consumption, and their demand cannot be dealt with collectively.

A number of homes, regions and cities are unable to get rid of peak and off-peak phenomena.

Individual homes and utilities are separately to mitigate/ get rid of peak and off-peak events.

Residential homes have dissimilar consumption behaviours.

A single home has a repeated similar response with an uncertainty of discrepancy levels.

Solar and storage batteries at individual residential homes are able to manage homes against peak and off-peak phenomena.

2) *What is the influence of the intervention of complex system approaches in residential homes on the rate of controlling (maximising/minimising) the consumption variation during peak and*

off peak times?

Using the principle of Complexity theory captures the influence of micro levels.

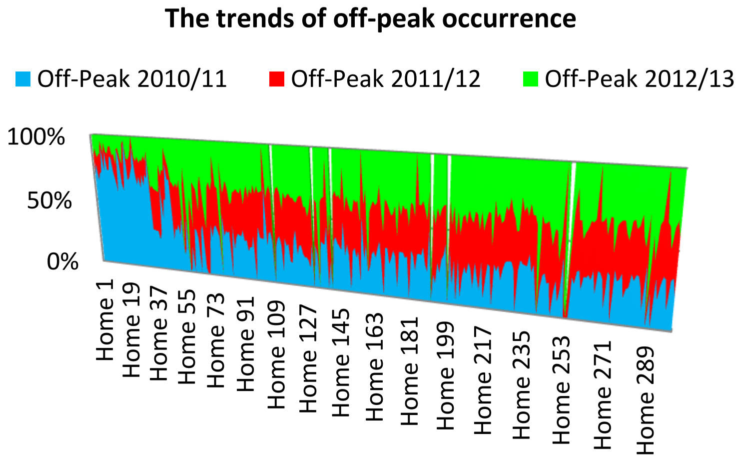
The Complexity approach of emergence gave sense to the meaning of tiny initiated events.

The Complexity approach of tiny initiated events (TIEs) gave sense to systems' scalability.

The Complexity approach of scalability gave sense to uncertainty.

The Complexity approach of uncertainty gave sense to the nature of peak and off-peak phenomena.

Figure 8.1 below illustrates the outcome of 47,304,000 data points are used to explain and compare the nature of peak and off-peak phenomena between different consumers through three years of electricity consumption, in which the variation among them support the argument that is discussed in this thesis.



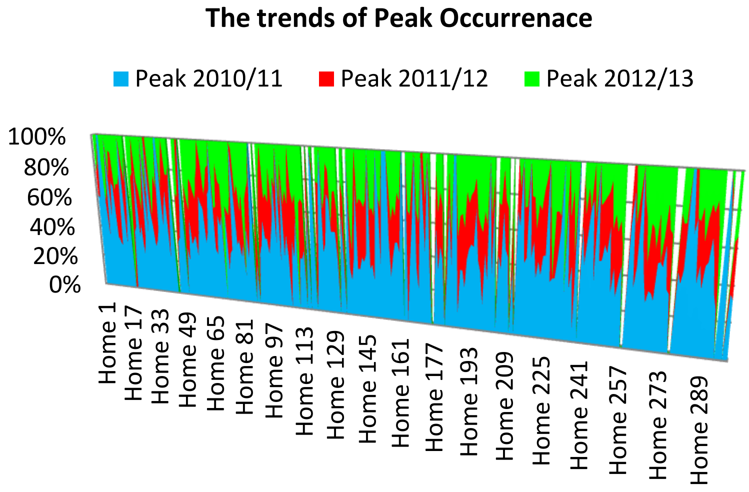


Figure 8.1: The Comparison of Peak & Off-Peak phenomena for three years

3) *What are the factors that contribute to suppliers/retailers perception for assessing and optimising end user's consumption behaviour at home area network?*

- Common factors of the losses incurred by suppliers, retailers and consumers are traditionally are unrelated.
- Common factors of the losses suffered by vendors, retailers and consumers are related through complexity theory. Operating the system through traditional/hierarchical structures will not solve the peak/off-peak problems.
- Running the system through complex structure will solve the peak/off-peak problems.
- Peak (P) and off-peak (OP) problems are two different problems caused by two different causes.
- An uncertainty of timely consumption of electricity requires a high level of system agility at residential homes level.
- Optimising electrical grid systems needs a different capacity for solar and storage battery at each single home.
- The asset of renewable energy at each home will act completely differently to serve the grids' optimisation goal.
- The smart devices of renewables at each home will manage these resources differently, but all houses will use the same principle to optimise their different demands.

8.4 Contribution to Theory

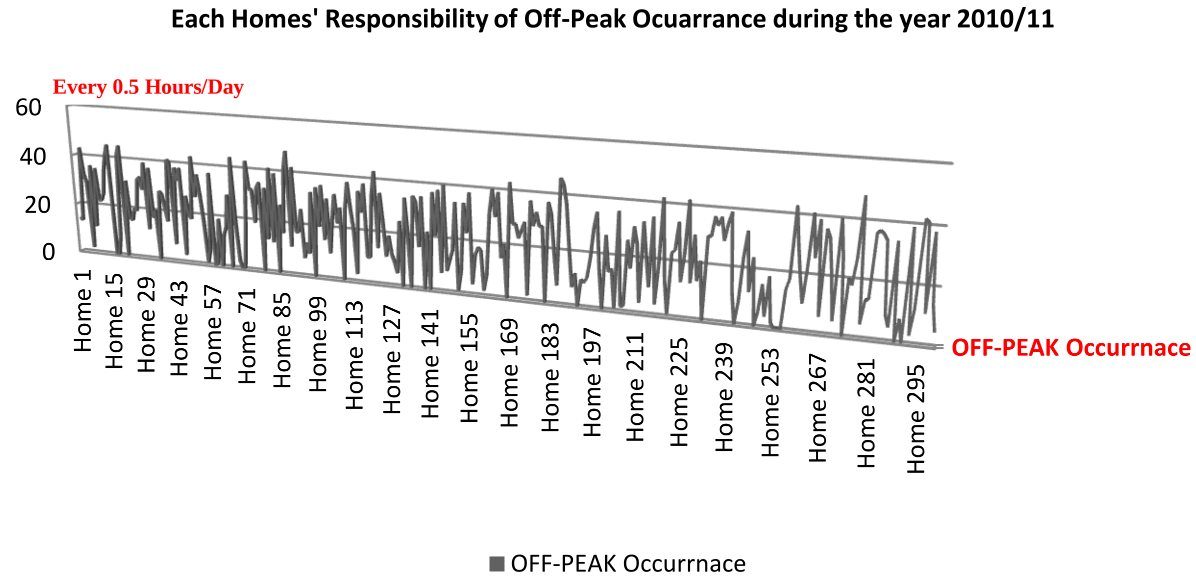
By investigating research question one, this study has contributed to electrical smart grid systems by improving the integration of the relationships between electricity suppliers, retailers and end-users. The goals involving the daily use of electricity by different end-users are the same, but the everyday consumption activities undertaken by end-users differ significantly from one home to another. This is because the consequence of electricity consumption, as seen in the analysis results from unlikely similar and likely dissimilar demands, but never the same or identical demands. With the dialogue in smart grid systems development focusing on its supplying electricity tasks, the unavoidable nature of that dialogue is a triangulation three elements: Peak demands, Off-peak demands and Average demands.

Thus, it is essential to focus on these different demands as can be worth or useful to each residential home/consumer. The current research study detects the source of the energy losses problem lay in the peak and off-peak phenomena. To enable smart grid systems to close this "gap in explanation" between end-users' demands and emerging peak/off-peak phenomena, it must address these challenges head on by taking action at residential home levels. It can then estimate financial value in a greater depth, and gather all suppliers, retailers and consumers as business partners as this opportunity can exploit equally with no conflict between these stakeholders.

This study suggests that the decision-making processes should adequately deal with the concerns raised with ‘natural’ culture of the end-users’ demand of electricity. Dealing with the status quo of peak and off-peak phenomena while end-users’ detachedly consume electricity requires adapting to the emergent properties of time to enhance their impact on the acquisition of systems’ grid capability. Overall, setting the demand of individual homes at average levels is an essential means to mitigate energy losses of the electrical grid.

Figure 8.2 also exhibits the incidence of peak and off-peak phenomena by individual residential homes, during 48 intervals per day. The dissimilarity is very clear between the sample of 300 houses. The phenomena of peak and off-peak emerge in that way of consuming electricity and every day during the year which is impossible to deal with collectively or from a macro side of view.

By investigating research question two, the study revealed the existence of the influence of end user's non-linearity behaviours. Electricity suppliers and retailers need to understand this effect in order to successfully establish a new cognitive linkage with, and embed in, a target electricity distribution system. While technicians, engineers, suppliers, retailers and policy makers know the facts of the consumption variation of different residential homes that influence the total supply of electricity, the pertinent socio-technical concepts of complex management theories do illustrate a more advanced stage of energy demand management. This basis of argument requiring a more sophisticated understanding of the micro-scales of single consuming behaviours in electrical smart grid systems that appear in the figures below and are not necessarily understood by electrical engineers or policy makers. Better Performance in electrical systems is facilitated by understanding and considering demand variations emerging unequally and differently from single residential home.



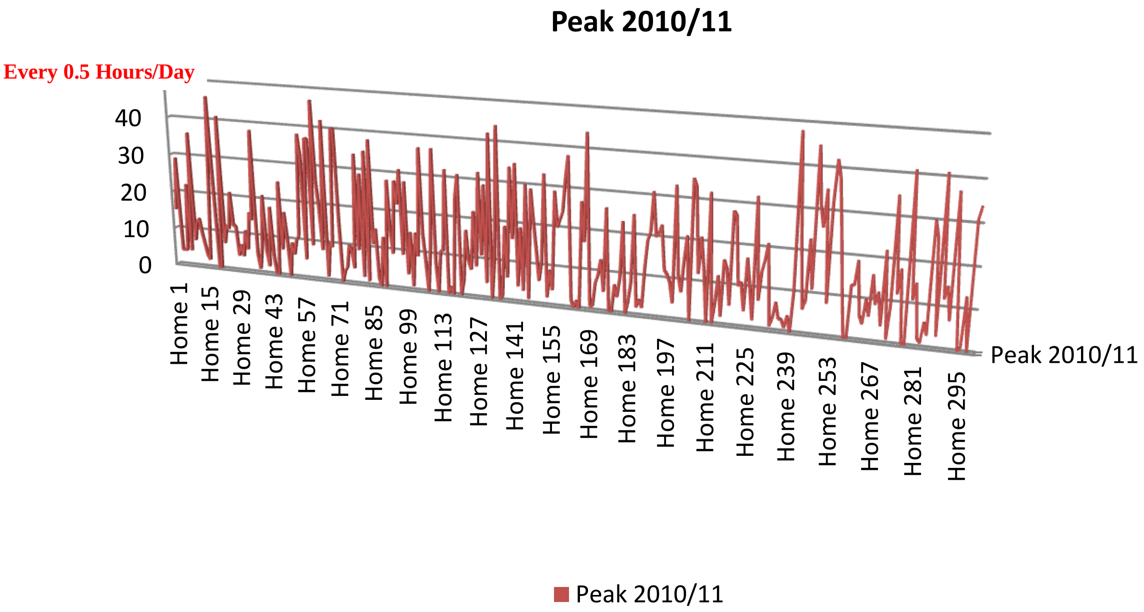


Figure 8.2: The Sequence of occurrence of Peak & Off-Peak phenomena by single homes

By investigating research question three, this study proposed a sustainable scheduling model for resolving the complexity problem of peak and off-peak loads in residential homes in household area networks (HAN). This model is tested from the perspective of the norms discussed that relate to complexity theory (TIEs, emergence, scalability and uncertainty). The proposed sustainable model enables electricity practitioners to establish a new cognitive linkage with and embedded in, a target electricity distribution system.

Synthesising across the three research questions made a further contribution to theory by presenting a model of homes’ sustainability, a definition of the capacity of solar and storage battery needed at each home and a framework for explaining the way of optimising each home differently to reach the same grid goal.

Taken as a whole, this study makes two major contributions to theory. First, it advances our under-standing of how an individual residential home and its individual demand influence the process of peak and off-peak phenomena in electrical grid systems. To date and within a context of electrical smart grid systems, few studies have attempted to explain, the causal relationship for a particular situation when isolating factors that cause a problem. The other extant studies have not mentioned the issue from the angle that was investigated in this research study. The extant studies are fragmented and are not grounded in a strong theoretical operational model. Rather, the current study used tools from complexity theory that, at this stage, provide a new way of thinking about the issue of peak and off-peak phenomena, as well as, providing a new framework for explaining, predicting and controlling specific consumption behaviours of electricity. The analysis results of this new finding proved to be prolific in the context of explaining the roots of the peak/off-peak phenomena.

Second, this study confirms that sustainable operation requires micro-macro strategic technique to develop which are needed competencies of residential homes in electrical grid systems. Either the same or a similar model to the proposed sustainable model in this study is required at residential homes’ levels to deal with regional and national demand variations that are becoming somewhat exacerbated with an annual increase in global electricity demand. This conclusion is an outcome of converging these research findings from diverse theoretical perspectives that are discussed from chapters one to six. The most no-table contribution of this study is in investigating the roots of the strength and weaknesses of the non-linear dynamic behaviours of consumers, with the objective of improving the system outcomes. The study opens up future research areas by considering complex theory in the context of avoiding chaotic outcomes by organising tiny initiated events and small changes for desirable outcomes.

8.5 Contribution to Practice

The findings of this thesis in Table 8.1 introduce practical implications for academic researchers in energy demand management, designing electricity distribution area and home area network (HAN). Further, it invites the participation of practitioners in the electricity industry including policy makers, engineers, technicians, suppliers, retailers and end-users (residential, commercial & industrial).

From a policy making perspective, the study provides insights that could be used for alteration of the existing electricity tariff in the electricity market.

The study can help further postgraduate studies that are involved in complex systems0 studies in promoting the integration of technological, cultural, human, political and environmental systems. The sustainable model developed through this study and its outcomes provides curriculum guidance for complexity studies. It would be highlighted that these complexity studies need to undertake further re-search to shape its interventions and to address the factors which were neglected or unrealised. The goal of addressing new complexity factors to perceiving complex systems is a desirable and feasible option. This is essential because the current redistribution of traditional systems into more complex ones is giving rise to the need for new complex plans that increase with diverse, autonomous and independent systems to add capability to systems, services and products.

This study provides a definition of micro-macro perspective in electrical smart grid systems and a sustainable model for residential homes that could guide suppliers and providers of electricity. The policy makers may borrow the models and frameworks conceptualised in this thesis along with electricity systems’ designers and business development services, to improve the outcomes of electricity grid systems.

This research has practical implications for practising and aspiring further complexity studies. It out-lines a way of optimising a complex system for superior and efficient performance. The following table simplifies the study results achieved from savings through solar and probably wind generation of electricity supported by batteries at homes.

Table 8.1: Estimated Energy Losses against the Capacities of Solar & Battery needed

	Energy losses per home		Solar capacity required per home		Specifications of battery required per home (KWh)		
	Per day ($)	Per year ($)	Per day (KWh)	Per year (KWh)	Max. Charging	Max. Discharging	Home capacity
Mean	1.97	720.41	2.39	872.11	18.26	18.09	23.87
Minimum	0.52	190.00	0.00	0.00	0.00	7.51	12.84
Maximum	6.66	2430.17	19.25	7025.64	72.69	22.03	72.69
homes	300	300	300	300	300	300	300
Sum	592.12	216123.69	716.80	261633.00	5479.09	5427.07	7160.62
Largest(1)	6.66	2430.17	19.25	7025.64	72.69	22.03	72.69
Smallest(1)	0.52	190.00	0.00	0.00	0.00	7.51	12.84

Additionally, the research results of this study, supported by some other studies, exhibit that the annual power generation performance of gas turbines is relatively poor when compared with coal thermal power generators. For instance, the graph in Figure 8.3 shown the total cost of electricity production for each type of three generators as a function of their hours of operation.

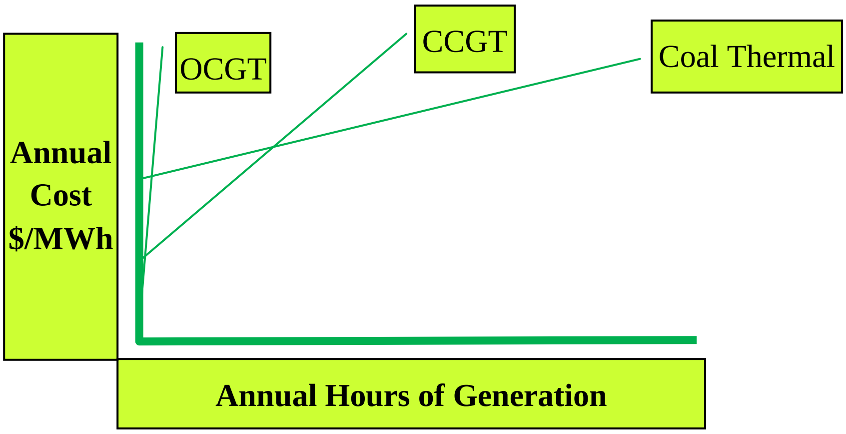


Figure 8.3: Theoretical Market Plant Mix and Spot Prices in NSW

The features and roles of the three types of generators in Figure 8.3 can be concluded as follows:

- The thermal coal generator plant is a base load plant that runs all the time.
- The Open Cycle Gas Turbine (OCGT) is a peaking generator for low capacity factor usage.
- The Combined Cycle Gas Turbine (CCGT) is an intermediate generator for unsteady capacity factor usage.

The combination of Gas turbine generators (OCGT and CCGT) are mainly required to meet the specified loads in peak and off-peak, and transition times of load in New South Wales. Of particular note is that there is massive saving of annual cost when the power generation systems avoid the peak and off-peak phenomena, since there is no further need to use OCGT and CCGT generators, as illustrated in Table 8.2.

Table 8.2: Annual Cost Required by Generator in NSW

Average Load MW	Generators	Time Segment % of Time	Annual Cost Required by Generators $M
10000	OCGT	14%	401
7000	CCGT	55%	491
5000	Coal	100%	1840

Finally, the analysis results also exhibit that the attitude of the proposed sustainable model to individual residential houses and demonstrates an extremely feasible approach, with practical involvement to energy demand activities. The following table number 8.3 conclude the data used in the analysis, as well as, it shows the conclusion of the analysis results regarding the expected annual cost of energy losses per home.

Table 8. 3: The saving of individual houses using Solar & Storage Battery

Table to simplify results of savings through solar of electricity supported by batteries at individual houses	
Mean of houses demand of electricity (KWh) per year	*7204.78*
Standard Error	*163.72*
Median of houses demand of electricity (KWh) per year	*6646.29*
Standard Deviation	*2835.65*
Sample Variance	*8040919.21*
Kurtosis	*-0.62*
Skewness	*0.60*
Range	*12077.02*
Minimum electricity demand of houses (KWh) per year	*2990.30*
Maximum electricity demand of houses (KWh) per year	*15067.32*
Sum of electricity demand of 300 houses (KWh) per year	*2161434.92*
Number of residential examined houses	*300.00*
Annual cost without peak & off-peak losses per house ($)	*1440.96*
Possible annual savings through individual houses when cut Peak & off-peak losses ($)	*720.41*
Annual cost with peak & off-peak losses per home ($)	*2161.37*
Possible saving per house when changing their usage patterns (%)	*33.33*
Net Present Value (NPV) per $1 investment	*$0.31*

8.6 Summing Up of the Research Hypothesis

The summary of this research hypothesis devised in the following Table 8.4.

Table 8.4: Summary of the Hypothesis Relationship

No.	Hypothesis	Rejected/Support	The Big Picture
H1	Electrical grid systems using fossil fuels to deliver electricity to sustainable houses (installed specific capacity of solar + battery) can reduce and control grid energy losses.	Supported	The current analysis of this research confirmed that the function of the proposed model is able to fulfil the constraints of non-linear dynamic behaviours of consuming electricity and provide options of renewable energy at homes that able to reach the proposed research objectives.
H2	Sustainable houses that have separately installed renewable energy (solar + storage battery) can reduce energy losses in the grid system.	Supported	The strategic plan for using the proposed sustainable model at home it was for enabling the current analysis of this research which confirmed that high penetration of renewable energy at homes serve the concept of averaging the houses demand of electricity and smoothening the load profile between supply and demand of electricity which attains the goal of homes' sustainability. (please refer to chapter 6).
H3	Theorise the capacity of renewable energy of each residential home to reduce the effects of peak/off-peak consumption, is better able to minimise energy loss in electrical smart grid systems.	Supported	The current research confirm that; the usefulness of complexity theory makes sense of the behaviours of people, who are defined as the qualitative aspect, while doing their daily activities. These behaviours influence electrical grid systems in a quantitative manner to create peak and off-peak demand of electricity. Therefore, complexity principles used to enable new approaches to theorise and develop distributed control and self-organising with less dense of specifications.
H4	Solar and/or wind generation capability, supported by storage battery, helps to reduce energy losses that occur during peak and off-peak	Supported	The current research confirmed that the power generated by solar panels and stored by battery is essential to feed it back into power grid according to the levels of timely consumption of the houses. Solar panels and storage battery are the defending line at homes to response timely and make those homes within average demand levels. The purpose of renewable energy at homes is a crucial to act according to the designed process to smooth the load's profile within individual basis for each home separately and make it within the

	consumption times.		desired average ranges.
H5	Residential houses that have installed renewable energy sources better support the electrical grid to control and reduce peak and off-peak electricity consumption, based on the demand of the inhabitants.	Supported	The current research confirms that; end-users lie at the heart of the internal factors that influencing and hovering around the electricity business performance by making an inconstant demand, affecting cost and, hence, price. Little attention has been devoted to the sole impact of each of individual end-users’ demand and their level of amenability to management control. The likely significance in general terms that solo end-users must be targeted to reduce energy losses in the grid system. The focus on solo end-users is valid to reform a new policy and develop the customer’s tariff incentives.
H6	The use of renewable energy in residential homes provides greater benefit than using renewable energy at the macro level (from supply and transmission to distribution to homes).	Supported	The current research analysis reveals that the residential homes separately have uncertain, similar repeated individual trends daily. The results of demand curves of electricity show different ranges of possible outcomes reflecting vary discrete demand ranges for each consumer require dealing with each one of them separately to reduce the power losses and use which this is cannot be achieved when assess the electricity demand as a whole and without considering the residential houses seperately.

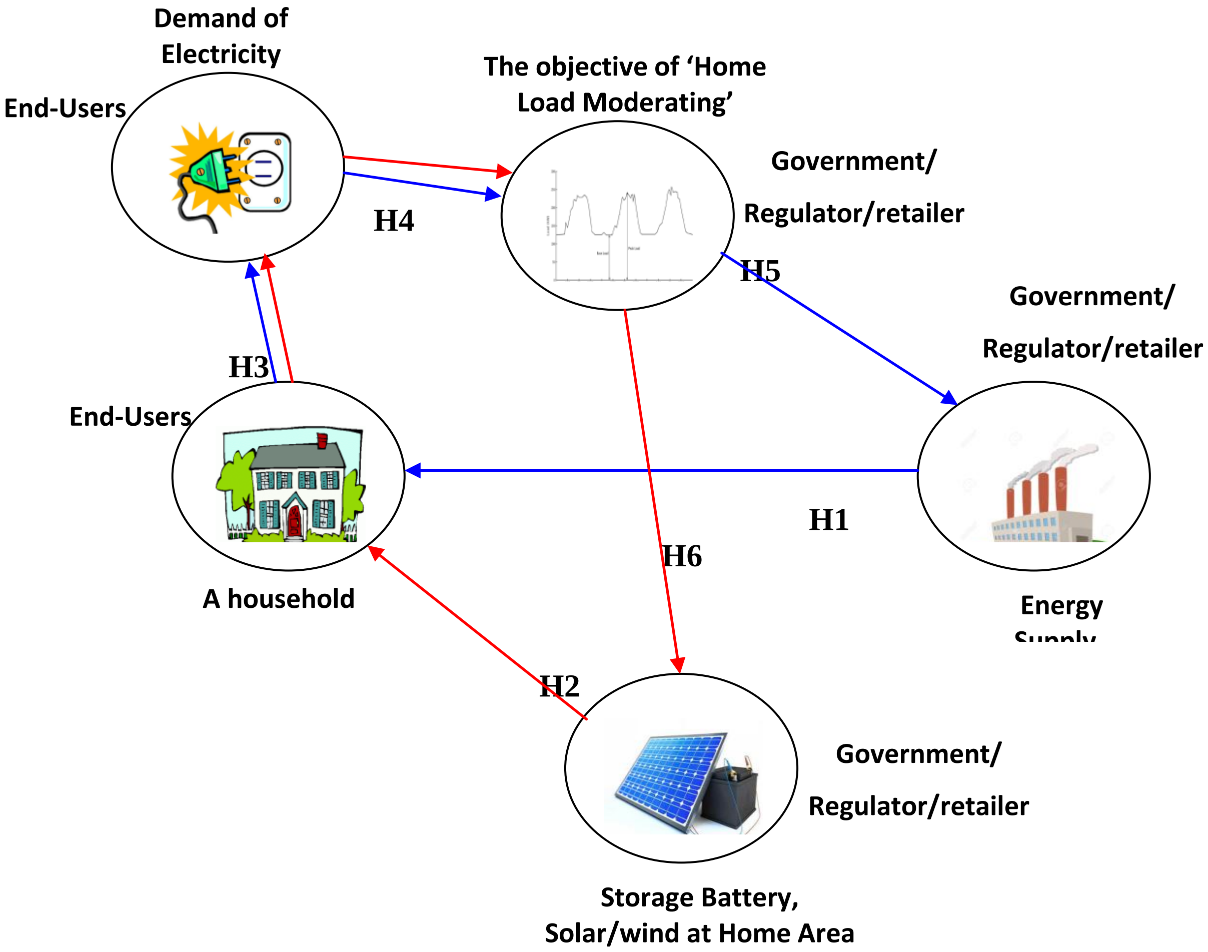


Figure 8.4: Home Load Moderating

The following section points out some limitations of this research.

8.7 Limitation of the study

The first limitation of this study is due to using approaches from complexity theory to grasp the philosophical issues behind the research design and clarify which insights suit what kind of evidence, thus identifying the data that is needed to be collected, including the answers to the research questions delineated by the theory of complexity.

The second limitation is that the methodology of this study used a mostly quantitative approach which describes and explains a complex phenomenon in-depth more than exploring and confirming that phenomenon. This research attempts to centralise the consumers' behaviour to get rid of peaks and off-peaks and to mitigate the gap between supply and demand for electricity. Thus, the research provides a greater understanding of end-users demand, which in turn, will improve the total performance of the grid systems. The context of this study is also limited in regard to selected sample criteria. The context is limited to a particular demographic area in New South Wales in Australia (NSW) and is also limited to residential houses which installed renewable energy, as overall, that was opposed by the data availability and access.

This research used the concepts of complexity theory not to debate the role of end-users, but to investigate how to understand the clustering of different consumer's behaviours when consuming electricity. The purpose of using the complexity theory is to define appropriate solutions for reducing the energy losses in the grid systems by understanding the electricity consumptions and the optimum transition between peak and off-peak times by diverse consumers.

A limitation of this study is that it focused on a segment of residential households in the state of New South Wales. The limited sample size, the demographic and weather circumstances will be considered as restrictions that inevitably influence the results. For generalisation, it needs to use use the same perspective of the complexity philosophy to commit further analysis to other national locations to make sure that the findings might be used in the same manner around Australia.

The next section exhibits directions for future research.

8.8 Directions for Future Research

This study mainly uses complexity theory that probably opens multiple avenues for future research. Future quantitative research must investigate the applicability of the findings of the current study in different contexts, such as using the same measurements and evaluations for recent years and different regions in Australia for generalisation purpose. The research on end-users' behaviour in a complex system would benefit from exploring the research questions liberated for this study. However, that would be more accurate when the data is in the context that using a scale of a second or a minute instead of 30 minutes where the very process of end-users will be obtained through more precise data; that is the scale of operational demands will further enhance the process of economic value creation.

The current study opens the way for further quantitative studies. The sustainable model proposed in this study is transitory only and should develop by using further programming techniques such as 'machine learning technique'. This will be an essential step in promoting practice by providing more robust results toward the concept of homes' sustainability in electrical smart grid systems.

The current study has provided initial insights into the contribution of complexity theory to resolve one of the major issues related to the energy losses' in electrical smart grid systems. The outcomes of this research can be used as a basis for assessing a single home demand with subsequent validation using quantitative methodology. Residential households have already proven to be promising construct in electrical smart grid systems that assist in refining our focus in supporting potential and existing residential Home Areas Networks (HANs).

This study proposed a conceptual model for home sustainability (figure 6.6). The interrelationships among the model constructs exhibited in this framework are supported by the findings of the empirical shreds of evidence in chapter seven and eight subsequently and the results have been derived quantitatively. To enhance the finding of this study and continue practising complexity theory-building exercise, the following future step should be provided through two main steps. First, by generating further discussion with electricity stakeholders and policy makers. Second thing, by formulating more related hypotheses and testing more demographical samples for accuracy achievement before going to the step of generalisation.

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Appendix 1

Programming Code Used For Data Merging

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
default_path=cd;
year=input('Year? (1,2,3): ');
%% Merge data in folder 2010-2011
if year==1
    tic
    cd([default_path,'/ 2010 -2011 Consumer Data File'])
    files_in_folder=what;
    files_mat=files_in_folder.mat;
    for g1=1:size(files_mat,1)
        load(files_mat{g1,1})
        if g1==1
            data_all_GC=data(:,1);
            data_all_CL=data(:,2);
            if size(data,2)>2
                data_all_GG=data(:,3);
            else
                data_all_GG=zeros(size(data,1),1);
            end
        else
            data_all_GC=[data_all_GC data(:,1)];
            data_all_CL=[data_all_CL data(:,2)];
            if size(data,2)>2
                data_all_GG=[data_all_GG data(:,3)];
            else
                data_all_GG=[data_all_GG zeros(size(data,1),1)];
            end
        end
    end
    data_GC=data_all_GC;
    data_CL=data_all_CL;
    if size(data,2)>2
        data_GG=data_all_GG;
    end
    % 01/07/2010 was Thursday
    days=zeros(size(data,1),7);
    for d=1:7
        for k=0:7:364
            days(48*k+48*(d-1)+1:48*(k+1)+48*(d-1),d)=1;
        end
    end
    days(365*48+1:end,:)=[];
    % Days reordering
```

```
   days=days(:,[5:7,1:4]);
   % Creating structure
   year2010_2011.data_GC=data_GC;
   year2010_2011.data_CL=data_CL;
   year2010_2011.data_GG=data_GG;
   year2010_2011.timestamp=timestamp;
   year2010_2011.days=days;
   cd(default_path)
   save('year_2010_2011.mat','year2010_2011')
   clear data_all_GC data_all_CL g1 files_mat files_in_folder data_GC data_CL timestamp days k d year
   if size(data,2)>2
      clear data_all_GG data_GG
   end
   toc
   disp('---------')
elseif year==2
   %% Merge data in folder 2011-2012
   tic
   cd([default_path,'/2011-2012 Consumer Data File'])
   files_in_folder=what;
   files_mat=files_in_folder.mat;
   for g2=1:size(files_mat,1)
      load(files_mat{g2,1})
      if g2==1
         data_all_GC=data(:,2);
         data_all_CL=data(:,1);
         if size(data,2)>2
            data_all_GG=data(:,3);
         else
            data_all_GG=zeros(size(data,1),1);
         end
      else
         data_all_GC=[data_all_GC data(:,2)];
         data_all_CL=[data_all_CL data(:,1)];
         if size(data,2)>2
            data_all_GG=[data_all_GG data(:,3)];
         else
            data_all_GG=[data_all_GG zeros(size(data,1),1)];
         end
      end
   end
   data_GC=data_all_GC;
   data_CL=data_all_CL;
   data_GG=data_all_GG;
   % 01/07/2011 was Friday
   days=zeros(size(data,1),7);
   for d=1:7
      for k=0:7:364
```

```
            days(48*k+48*(d-1)+1:48*(k+1)+48*(d-1),d)=1;
        end
    end
    days(365*48+1:end,:)=[];
    % Days reordering
    days=days(:,[4:7,1:3]);
    % Creating structure
    year2011_2012.data_GC=data_GC;
    year2011_2012.data_CL=data_CL;
    year2011_2012.data_GG=data_GG;
    year2011_2012.timestamp=timestamp;
    year2011_2012.days=days;
    cd(default_path)
    save('year_2011_2012.mat','year2011_2012')
    clear data_all_GC data_all_CL g1 files_mat files_in_folder data_GC data_CL timestamp days k d
year
    if size(data,2)>2
        clear data_all_GG data_GG
    end
    toc
    disp('---------')
elseif year==3
    %% Merge data in folder 2012-2013
    tic
    cd([default_path,'/2012-2013 Consumer Data File'])
    files_in_folder=what;
    files_mat=files_in_folder.mat;
    for g2=1:size(files_mat,1)
        load(files_mat{g2,1})
        if g2==1
            data_all_GC=data(:,2);
            data_all_CL=data(:,1);
            if size(data,2)>2
                data_all_GG=data(:,3);
            else
                data_all_GG=zeros(size(data,1),1);
            end
        else
            data_all_GC=[data_all_GC data(:,2)];
            data_all_CL=[data_all_CL data(:,1)];
            if size(data,2)>2
                data_all_GG=[data_all_GG data(:,3)];
            else
                data_all_GG=[data_all_GG zeros(size(data,1),1)];
            end
        end
    end
    data_GC=data_all_GC;
    data_CL=data_all_CL;
```

```
    data_GG=data_all_GG;
    % 01/07/2012 was Sunday
    days=zeros(size(data,1),7);
    for d=1:7
        for k=0:7:364
            days(48*k+48*(d-1)+1:48*(k+1)+48*(d-1),d)=1;
        end
    end
    days(365*48+1:end,:)=[];
    % Days reordering
    days=days(:,[2:7,1]);
    % Creating structure
    year2012_2013.data_GC=data_GC;
    year2012_2013.data_CL=data_CL;
    year2012_2013.data_GG=data_GG;
    year2012_2013.timestamp=timestamp;
    year2012_2013.days=days;
    cd(default_path)
    save('year_2012_2013.mat','year2012_2013')
    clear data_all_GC data_all_CL g1 files_mat files_in_folder data_GC data_CL timestamp days k d year
    if size(data,2)>2
        clear data_all_GG data_GG
    end
    toc
    disp('---------')
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

6.6 Stage one Data Analysis

Following the above data preparation; the data now ready for starting the proposed analysis. As first step adopted in this stage of the analysis is adding a script in order to create a separate folder for each simulation of each year which the results will be automatically saved. Doing that, to review each year results separately and get the proposed insights.

6.6.1 Matlab code for the “data_analysis.m” script

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%
all_files=dir;
p=1;
for r=1:size(all_files,1);
    if all_files(r).isdir==1
        folders(p,1)=all_files(r,1);
        p=p+1;
    end
end
folder_list=cell(size(folders,1),1);
for w=1:size(folders,1)
    folder_list{w,1}=folders(w).name;
end
simulation_folders=find(strncmpi(folder_list,'Sim',3));
```

```
if isempty(simulation_folders)==0
   actual_folder=['Sim',num2str(length(simulation_folders)+1)];
   mkdir(actual_folder)
else
   actual_folder='Sim1';
   mkdir(actual_folder)
end
year=input('Year? (1,2,3): ');
%% Data in folder 2010-2011
if year==1
   load('year_2010_2011.mat')
   cd(actual_folder)
   data_GC=year2010_2011.data_GC;
   data_CL=year2010_2011.data_CL;
   data_GG=year2010_2011.data_GG;
   timestamp=year2010_2011.timestamp;
   days=year2010_2011.days;
   for k=1:size(timestamp,1)
      timestamp_double(k,1)=datenum(timestamp{k},'dd/mm/yyyy HH:MM:SS');
   end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%
   % 1) Energy consumption GC per each consumer over time (overlapped trends)
   figure('Name','1 - Energy consumption per each consumer over time
(GC)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_GC(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (GC)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
   plot(timestamp_double,mean(data_GC,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'1 - Energy consumption per each consumer over time (GC).png')


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%

   % 2) Energy consumption CL per each consumer over time (overlapped trends)

   figure('Name','2 - Energy consumption per each consumer over time
(CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])

   for d=1:300
      plot(timestamp_double,data_CL(:,d),'k')
```

```
      hold on
   end

   title('Energy consumption per each consumer over time (CL)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on

   plot(timestamp_double,mean(data_CL,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')

   saveas(gcf,'2 - Energy consumption per each consumer over time (CL).png')


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

   % 3) Energy consumption GC+CL-GG per each consumer over time (overlapped trends)

   figure('Name','3 - Energy consumption per each consumer over time (GC+CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])

   for d=1:300
      plot(timestamp_double,data_GC(:,d)+data_CL(:,d)-data_GG(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (GC+CL-GG)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
plot(timestamp_double,mean(data_GC,2)+mean(data_CL,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'3 - Energy consumption per each consumer over time (GC+CL-GG).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % 4) Energy consumption GC+CL and GC+CL-GG inside TOU
   % Extract Peak hours for weekdays
   peak_weekdays=zeros(size(days,1),1);
   off_peak_weekdays=zeros(size(days,1),1);
   shoulder_weekdays=zeros(size(days,1),1);
   off_peak_weekend=zeros(size(days,1),1);
   shoulder_weekend=zeros(size(days,1),1);
   total_days=size(days,1)/48;
   for day_counter=1:total_days
      for h=1:48
         if find(days(48*(day_counter-1)+h,:))<6
            if h>=15 && h<=18 || h>=35 && h<=40
               peak_weekdays(48*(day_counter-1)+h,1)=1;
```

```
            elseif h>=1 && h<=12 || h>=45 && h<=48
               off_peak_weekdays(48*(day_counter-1)+h,1)=1;
            elseif h>=19 && h<=34 || h>=41 && h<=44
               shoulder_weekdays(48*(day_counter-1)+h,1)=1;
            end
         elseif find(days(48*(day_counter-1)+h,:))>5
            if h>=1 && h<=14 || h>=45 && h<=48
               off_peak_weekend(48*(day_counter-1)+h,1)=1;
            elseif h>=15 && h<=44
               shoulder_weekend(48*(day_counter-1)+h,1)=1;
            end
         end
      end
   end
week={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday';'Saturday';'Sunday'};
   weekdays={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday'};
   weekends={'Saturday';'Sunday'};
   % Data manipulation (GC+CL) & (GC+CL-GG)
   % Data GC
   data_GC_peak_weekdays=data_GC(find(peak_weekdays),:);
   data_GC_off_peak_weekdays=data_GC(find(off_peak_weekdays),:);
   data_GC_off_peak_weekend=data_GC(find(off_peak_weekend),:);
   data_GC_shoulder_weekdays=data_GC(find(shoulder_weekdays),:);
   data_GC_shoulder_weekend=data_GC(find(shoulder_weekend),:);
   % Data CL
   data_CL_peak_weekdays=data_CL(find(peak_weekdays),:);
   data_CL_off_peak_weekdays=data_CL(find(off_peak_weekdays),:);
   data_CL_off_peak_weekend=data_CL(find(off_peak_weekend),:);
   data_CL_shoulder_weekdays=data_CL(find(shoulder_weekdays),:);
   data_CL_shoulder_weekend=data_CL(find(shoulder_weekend),:);
   % Data GC+CL
   data_GC_CL_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays;
data_GC_CL_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays;
data_GC_CL_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend;
data_GC_CL_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays;
data_GC_CL_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend;
   % Data GG
   data_GG_peak_weekdays=data_GG(find(peak_weekdays),:);
   data_GG_off_peak_weekdays=data_GG(find(off_peak_weekdays),:);
   data_GG_off_peak_weekend=data_GG(find(off_peak_weekend),:);
   data_GG_shoulder_weekdays=data_GG(find(shoulder_weekdays),:);
   data_GG_shoulder_weekend=data_GG(find(shoulder_weekend),:);
   % Data GC+CL-GG
data_GC_CL_GG_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays-
data_GG_peak_weekdays;
data_GC_CL_GG_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays-
data_GG_off_peak_weekdays;
data_GC_CL_GG_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend-
data_GG_off_peak_weekend;
```

```
data_GC_CL_GG_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays-
data_GG_shoulder_weekdays;
data_GC_CL_GG_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend-
data_GG_shoulder_weekend;
   % Consumers
   n=size(data_GC,2);
   X=[1:n];
   % Range limits
   LC_min=0;
   LC_max=0.17-10^-10;
   OP_min=0.17;
   OP_max=0.37-10^-10;
   AV_min=0.37;
   AV_max=0.43;
   P_min=0.43+10^-10;
   P_max=2;
   colors_mean={'.g';'.k';'.b';'.r'};
   % --- %
   % Peek weekdays
   figure('Name','4 - Energy consumption per each TOU (Peak
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   %M=mean(data_GC_CL_peak_weekdays,1)';
   M=mean(data_GC_CL_GG_peak_weekdays,1)';
   LC=0;
   OP=0;
   AV=0;
   P=0;
   LC_data=NaN(n,1);
   OP_data=NaN(n,1);
   AV_data=NaN(n,1);
   P_data=NaN(n,1);
   hold on;
   for w=1:n
      if M(w,1)<LC_max
         LC=LC+1;
         LC_data(w,1)=M(w,1);
         plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
      elseif M(w,1)>OP_min && M(w,1)<OP_max
         plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
         OP=OP+1;
         OP_data(w,1)=M(w,1);
      elseif M(w,1)>AV_min && M(w,1)<AV_max
         plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
         AV=AV+1;
         AV_data(w,1)=M(w,1);
      elseif M(w,1)>P_min && M(w,1)<P_max
         plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
         P=P+1;
         P_data(w,1)=M(w,1);
```

```
        end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
    annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Peek weekdays (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'4 - Energy consumption per each TOU (Peak weekdays).png')
    % Pie chart
    figure('Name','5 - Energy consumption per each TOU (Peak weekdays) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'5 - Energy consumption per each TOU (Peak weekdays) - Pie chart.png')
    % Histogram
    figure('Name','6 - Energy consumption per each TOU (Peak weekdays) - Histogram')
    hold on;
    histogram(LC_data,4,'FaceColor','g');
    histogram(OP_data,10,'FaceColor','k');
    histogram(AV_data,3,'FaceColor','b');
    histogram(P_data,30,'FaceColor','r');

    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'6 - Energy consumption per each TOU (Peak weekdays) - Histogram.png')
    % --- %
    % Off-peek weekdays
    figure('Name','7 - Energy consumption per each TOU (Off-peak
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
    %M=mean(data_GC_CL_off_peak_weekdays,1)';
    M=mean(data_GC_CL_GG_off_peak_weekdays,1)';
    LC=0;
```

```
   OP=0;
   AV=0;
   P=0;
   LC_data=NaN(n,1);
   OP_data=NaN(n,1);
   AV_data=NaN(n,1);
   P_data=NaN(n,1);
   hold on;
   for w=1:n
      if M(w,1)<LC_max
         LC=LC+1;
         LC_data(w,1)=M(w,1);
         plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
      elseif M(w,1)>OP_min && M(w,1)<OP_max
         plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
         OP=OP+1;
         OP_data(w,1)=M(w,1);
      elseif M(w,1)>AV_min && M(w,1)<AV_max
         plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
         AV=AV+1;
         AV_data(w,1)=M(w,1);
      elseif M(w,1)>P_min && M(w,1)<P_max
         plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
         P=P+1;
         P_data(w,1)=M(w,1);
      end
   end
   plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
   plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
   plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
   plot(X,ones(n,1)*P_max,'r','LineWidth',2)
   string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
   grid on
   grid minor
   title('Off-peek weekdays (GC+CL)','FontSize',14)
   xlabel('Consumers','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   saveas(gcf,'7 - Energy consumption per each TOU (Off-peak weekdays).png')
   % Pie chart
   figure('Name','8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart')
   percentages=[LC/n;OP/n;AV/n;P/n];
   explode=[1 1 1 1];
   kk=pie(percentages,explode);
   set(kk(1,1),'FaceColor','g')
   set(kk(1,2),'FontSize',15,'FontWeight','bold')
```

```
set(kk(1,3),'FaceColor','k')
set(kk(1,4),'FontSize',15,'FontWeight','bold')
set(kk(1,5),'FaceColor','b')
set(kk(1,6),'FontSize',15,'FontWeight','bold')
set(kk(1,7),'FaceColor','r')
set(kk(1,8),'FontSize',15,'FontWeight','bold')
legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
saveas(gcf,'8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart.png')
% Histogram
figure('Name','9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram')
hold on;
histogram(LC_data,10,'FaceColor','g');
histogram(OP_data,10,'FaceColor','k');
histogram(AV_data,5,'FaceColor','b');
histogram(P_data,25,'FaceColor','r');
legend(string,'Location','southoutside','Orientation','horizontal')
saveas(gcf,'9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram.png')
% --- %
% Off-peek weekend
figure('Name','10 - Energy consumption per each TOU (Off-peak weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
%M=mean(data_GC_CL_off_peak_weekend,1)';
M=mean(data_GC_CL_GG_off_peak_weekend,1)';
LC=0;
OP=0;
AV=0;
P=0;
LC_data=NaN(n,1);
OP_data=NaN(n,1);
AV_data=NaN(n,1);
P_data=NaN(n,1);
hold on;
for w=1:n
    if M(w,1)<LC_max
        LC=LC+1;
        LC_data(w,1)=M(w,1);
        plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
    elseif M(w,1)>OP_min && M(w,1)<OP_max
        plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
        OP=OP+1;
        OP_data(w,1)=M(w,1);
    elseif M(w,1)>AV_min && M(w,1)<AV_max
        plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
        AV=AV+1;
        AV_data(w,1)=M(w,1);
    elseif M(w,1)>P_min && M(w,1)<P_max
        plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
        P=P+1;
        P_data(w,1)=M(w,1);
```

```
      end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Off-peek weekend (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'10 - Energy consumption per each TOU (Off-peak weekend).png')

    % Pie chart
    figure('Name','11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart.png'
    % Histogram
    figure('Name','12 - Energy consumption per each TOU (Off-peak weekend) - Histogram')
    hold on;
    histogram(LC_data,10,'FaceColor','g');
    histogram(OP_data,10,'FaceColor','k');
    histogram(AV_data,5,'FaceColor','b');
    histogram(P_data,25,'FaceColor','r');
    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'12 - Energy consumption per each TOU (Off-peak weekend) - Histogram.png')
    % --- %
    % Shoulder weekdays
    figure('Name','13 - Energy consumption per each TOU (Shoulder
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
    %M=mean(data_GC_CL_shoulder_weekdays,1)';
    M=mean(data_GC_CL_GG_shoulder_weekdays,1)';
```

```
    LC=0;
    OP=0;
    AV=0;
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
        if M(w,1)<LC_max
            LC=LC+1;
            LC_data(w,1)=M(w,1);
            plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
        elseif M(w,1)>OP_min && M(w,1)<OP_max
            plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
            OP=OP+1;
            OP_data(w,1)=M(w,1);
        elseif M(w,1)>AV_min && M(w,1)<AV_max
            plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
            AV=AV+1;
            AV_data(w,1)=M(w,1);
        elseif M(w,1)>P_min && M(w,1)<P_max
            plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
            P=P+1;
            P_data(w,1)=M(w,1);
        end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)

    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Shoulder weekdays (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'13 - Energy consumption per each TOU (Shoulder weekdays).png')
    % Pie chart
    figure('Name','14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
```

```
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart.png')
    % Histogram
    figure('Name','15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram')
    hold on;
    histogram(LC_data,15,'FaceColor','g');
    histogram(OP_data,7,'FaceColor','k');
    histogram(AV_data,2,'FaceColor','b');
    histogram(P_data,30,'FaceColor','r');
    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram.png')
    % --- %
    % Shoulder weekend
    figure('Name','16 - Energy consumption per each TOU (Shoulder weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
    %M=mean(data_GC_CL_shoulder_weekend,1)';
    M=mean(data_GC_CL_GG_shoulder_weekend,1)';
    LC=0;
    OP=0;
    AV=0;
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
      if M(w,1)<LC_max
        LC=LC+1;
        LC_data(w,1)=M(w,1);
        plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
      elseif M(w,1)>OP_min && M(w,1)<OP_max
        plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
        OP=OP+1;
        OP_data(w,1)=M(w,1);
      elseif M(w,1)>AV_min && M(w,1)<AV_max
        plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
        AV=AV+1;
        AV_data(w,1)=M(w,1);
      elseif M(w,1)>P_min && M(w,1)<P_max
        plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
```

```
          P=P+1;
          P_data(w,1)=M(w,1);
       end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Shoulder weekend (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'16 - Energy consumption per each TOU (Shoulder weekend).png')
    % Pie chart
    figure('Name','17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart.png')
    % Histogram
    figure('Name','18 - Energy consumption per each TOU (Shoulder weekend) - Histogram')
    hold on;
    histogram(LC_data,15,'FaceColor','g');
    histogram(OP_data,7,'FaceColor','k');
    histogram(AV_data,2,'FaceColor','b');
    histogram(P_data,30,'FaceColor','r');
    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'18 - Energy consumption per each TOU (Shoulder weekend) - Histogram.png')
    %% Data in folder 2011-2012
elseif year==2
    load('year_2011_2012.mat')
    cd(actual_folder)
    data_GC=year2011_2012.data_GC;
    data_CL=year2011_2012.data_CL;
```

```
   data_GG=year2011_2012.data_GG;
   timestamp=year2011_2012.timestamp;
   days=year2011_2012.days;
   for k=1:size(timestamp,1)
      timestamp_double(k,1)=datenum(timestamp{k},'dd/mm/yyyy HH:MM:SS');
   end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

   % 1) Energy consumption GC per each consumer over time (overlapped trends)
   figure('Name','1 - Energy consumption per each consumer over time
(GC)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_GC(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (GC)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
   plot(timestamp_double,mean(data_GC,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'1 - Energy consumption per each consumer over time (GC).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % 2) Energy consumption CL per each consumer over time (overlapped trends)
   figure('Name','2 - Energy consumption per each consumer over time
(CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_CL(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (CL)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
   plot(timestamp_double,mean(data_CL,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'2 - Energy consumption per each consumer over time (CL).png')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % 3) Energy consumption GC+CL-GG per each consumer over time (overlapped trends)
   figure('Name','3 - Energy consumption per each consumer over time
(GC+CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_GC(:,d)+data_CL(:,d)-data_GG(:,d),'k')
      hold on
```

```
    end
    title('Energy consumption per each consumer over time (GC+CL-GG)','FontSize',14)
    xlabel('Time','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    grid on
  plot(timestamp_double,mean(data_GC,2)+mean(data_CL,2),'r','LineWidth',2)
    datetick('x','dd/mm/yyyy','keeplimits')
    saveas(gcf,'3 - Energy consumption per each consumer over time (GC+CL-GG).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%
    % 4) Energy consumption GC+CL and GC+CL-GG inside TOU
    % Extract Peak hours for weekdays
    peak_weekdays=zeros(size(days,1),1);
    off_peak_weekdays=zeros(size(days,1),1);
    shoulder_weekdays=zeros(size(days,1),1);
    off_peak_weekend=zeros(size(days,1),1);
    shoulder_weekend=zeros(size(days,1),1);
    total_days=size(days,1)/48;
    for day_counter=1:total_days
        for h=1:48
            if find(days(48*(day_counter-1)+h,:))<6
                if h>=15 && h<=18 || h>=35 && h<=40
                    peak_weekdays(48*(day_counter-1)+h,1)=1;
                elseif h>=1 && h<=12 || h>=45 && h<=48
                    off_peak_weekdays(48*(day_counter-1)+h,1)=1;
                elseif h>=19 && h<=34 || h>=41 && h<=44
                    shoulder_weekdays(48*(day_counter-1)+h,1)=1;
                end
            elseif find(days(48*(day_counter-1)+h,:))>5
                if h>=1 && h<=14 || h>=45 && h<=48
                    off_peak_weekend(48*(day_counter-1)+h,1)=1;
                elseif h>=15 && h<=44
                    shoulder_weekend(48*(day_counter-1)+h,1)=1;
                end
            end
        end
    end  week={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday';'Saturday';'Sunday'};
    weekdays={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday'};
    weekends={'Saturday';'Sunday'};
    % Data manipulation (GC+CL) & (GC+CL-GG)
    % Data GC
    data_GC_peak_weekdays=data_GC(find(peak_weekdays),:);
    data_GC_off_peak_weekdays=data_GC(find(off_peak_weekdays),:);
    data_GC_off_peak_weekend=data_GC(find(off_peak_weekend),:);
    data_GC_shoulder_weekdays=data_GC(find(shoulder_weekdays),:);
    data_GC_shoulder_weekend=data_GC(find(shoulder_weekend),:);
    % Data CL
    data_CL_peak_weekdays=data_CL(find(peak_weekdays),:);
```

```
   data_CL_off_peak_weekdays=data_CL(find(off_peak_weekdays),:);
   data_CL_off_peak_weekend=data_CL(find(off_peak_weekend),:);
   data_CL_shoulder_weekdays=data_CL(find(shoulder_weekdays),:);
   data_CL_shoulder_weekend=data_CL(find(shoulder_weekend),:);
   % Data GC+CL
   data_GC_CL_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays;
data_GC_CL_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays;
data_GC_CL_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend;
   data_GC_CL_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays;
data_GC_CL_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend;
   % Data GG
   data_GG_peak_weekdays=data_GG(find(peak_weekdays),:);
   data_GG_off_peak_weekdays=data_GG(find(off_peak_weekdays),:);
   data_GG_off_peak_weekend=data_GG(find(off_peak_weekend),:);
   data_GG_shoulder_weekdays=data_GG(find(shoulder_weekdays),:);
   data_GG_shoulder_weekend=data_GG(find(shoulder_weekend),:);
   % Data GC+CL-GG
data_GC_CL_GG_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays-
data_GG_peak_weekdays;
data_GC_CL_GG_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays-
data_GG_off_peak_weekdays;
data_GC_CL_GG_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend-
data_GG_off_peak_weekend;
data_GC_CL_GG_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays-
data_GG_shoulder_weekdays;
data_GC_CL_GG_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend-
data_GG_shoulder_weekend;
   % Consumers
   n=size(data_GC,2);
   X=[1:n];
   % Range limits
   LC_min=0;
   LC_max=0.17-10^-10;
   OP_min=0.17;
   OP_max=0.37-10^-10;
   AV_min=0.37;
   AV_max=0.43;
   P_min=0.43+10^-10;
   P_max=2;
   colors_mean={'.g';'.k';'.b';'.r'};
   % --- %
   % Peek weekdays
   figure('Name','4 - Energy consumption per each TOU (Peak
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   %M=mean(data_GC_CL_peak_weekdays,1)';
M=mean(data_GC_CL_GG_peak_weekdays,1)';
   LC=0;
   OP=0;
   AV=0;
```

```
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
        if M(w,1)<LC_max
            LC=LC+1;
            LC_data(w,1)=M(w,1);
            plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
        elseif M(w,1)>OP_min && M(w,1)<OP_max
            plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
            OP=OP+1;
            OP_data(w,1)=M(w,1);
        elseif M(w,1)>AV_min && M(w,1)<AV_max
            plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
            AV=AV+1;
            AV_data(w,1)=M(w,1);
        elseif M(w,1)>P_min && M(w,1)<P_max
            plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
            P=P+1;
            P_data(w,1)=M(w,1);
        end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)

    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Peek weekdays (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'4 - Energy consumption per each TOU (Peak weekdays).png')
    % Pie chart
    figure('Name','5 - Energy consumption per each TOU (Peak weekdays) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
```

```
set(kk(1,4),'FontSize',15,'FontWeight','bold')
set(kk(1,5),'FaceColor','b')
set(kk(1,6),'FontSize',15,'FontWeight','bold')
set(kk(1,7),'FaceColor','r')
set(kk(1,8),'FontSize',15,'FontWeight','bold')
legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
saveas(gcf,'5 - Energy consumption per each TOU (Peak weekdays) - Pie chart.png')
% Histogram
figure('Name','6 - Energy consumption per each TOU (Peak weekdays) - Histogram')
hold on;
histogram(LC_data,4,'FaceColor','g');
histogram(OP_data,10,'FaceColor','k');
histogram(AV_data,3,'FaceColor','b');
histogram(P_data,30,'FaceColor','r');
legend(string,'Location','southoutside','Orientation','horizontal')
saveas(gcf,'6 - Energy consumption per each TOU (Peak weekdays) - Histogram.png')
% --- %
% Off-peek weekdays
figure('Name','7 - Energy consumption per each TOU (Off-peak weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
%M=mean(data_GC_CL_off_peak_weekdays,1)';
M=mean(data_GC_CL_GG_off_peak_weekdays,1)';
LC=0;
OP=0;
AV=0;
P=0;
LC_data=NaN(n,1);
OP_data=NaN(n,1);
AV_data=NaN(n,1);
P_data=NaN(n,1);
hold on;
for w=1:n
   if M(w,1)<LC_max
      LC=LC+1;
      LC_data(w,1)=M(w,1);
      plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
   elseif M(w,1)>OP_min && M(w,1)<OP_max
      plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
      OP=OP+1;
      OP_data(w,1)=M(w,1);
   elseif M(w,1)>AV_min && M(w,1)<AV_max
      plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
      AV=AV+1;
      AV_data(w,1)=M(w,1);
   elseif M(w,1)>P_min && M(w,1)<P_max
      plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
      P=P+1;
      P_data(w,1)=M(w,1);
   end
```

```
   end
   plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
   plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
   plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
   plot(X,ones(n,1)*P_max,'r','LineWidth',2)
   string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
   grid on
   grid minor
   title('Off-peek weekdays (GC+CL)','FontSize',14)
   xlabel('Consumers','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   saveas(gcf,'7 - Energy consumption per each TOU (Off-peak weekdays).png')
   % Pie chart
   figure('Name','8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart')
   percentages=[LC/n;OP/n;AV/n;P/n];
   explode=[1 1 1 1];
   kk=pie(percentages,explode);
   set(kk(1,1),'FaceColor','g')
   set(kk(1,2),'FontSize',15,'FontWeight','bold')
   set(kk(1,3),'FaceColor','k')
   set(kk(1,4),'FontSize',15,'FontWeight','bold')
   set(kk(1,5),'FaceColor','b')
   set(kk(1,6),'FontSize',15,'FontWeight','bold')
   set(kk(1,7),'FaceColor','r')
   set(kk(1,8),'FontSize',15,'FontWeight','bold')
   legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
   saveas(gcf,'8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart.png')
   % Histogram
   figure('Name','9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram')
   hold on;
   histogram(LC_data,10,'FaceColor','g');
   histogram(OP_data,10,'FaceColor','k');
   histogram(AV_data,5,'FaceColor','b');
   histogram(P_data,25,'FaceColor','r');
   legend(string,'Location','southoutside','Orientation','horizontal')
   saveas(gcf,'9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram.png')
   % --- %
   % Off-peek weekend
   figure('Name','10 - Energy consumption per each TOU (Off-peak weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   %M=mean(data_GC_CL_off_peak_weekend,1)';
   M=mean(data_GC_CL_GG_off_peak_weekend,1)';
   LC=0;
   OP=0;
   AV=0;
```

```
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
        if M(w,1)<LC_max
            LC=LC+1;
            LC_data(w,1)=M(w,1);
            plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
        elseif M(w,1)>OP_min && M(w,1)<OP_max
            plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
            OP=OP+1;
            OP_data(w,1)=M(w,1);
        elseif M(w,1)>AV_min && M(w,1)<AV_max
            plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
            AV=AV+1;
            AV_data(w,1)=M(w,1);
        elseif M(w,1)>P_min && M(w,1)<P_max
            plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
            P=P+1;
            P_data(w,1)=M(w,1);
        end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Off-peek weekend (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'10 - Energy consumption per each TOU (Off-peak weekend).png')
    % Pie chart
    figure('Name','11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
```

```
set(kk(1,5),'FaceColor','b')
set(kk(1,6),'FontSize',15,'FontWeight','bold')
set(kk(1,7),'FaceColor','r')
set(kk(1,8),'FontSize',15,'FontWeight','bold')
legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
saveas(gcf,'11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart.png')
% Histogram
figure('Name','12 - Energy consumption per each TOU (Off-peak weekend) - Histogram')
hold on;
histogram(LC_data,10,'FaceColor','g');
histogram(OP_data,10,'FaceColor','k');
histogram(AV_data,5,'FaceColor','b');
histogram(P_data,25,'FaceColor','r');
legend(string,'Location','southoutside','Orientation','horizontal')
saveas(gcf,'12 - Energy consumption per each TOU (Off-peak weekend) - Histogram.png')
% --- %
% Shoulder weekdays
figure('Name','13 - Energy consumption per each TOU (Shoulder weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
%M=mean(data_GC_CL_shoulder_weekdays,1)';
M=mean(data_GC_CL_GG_shoulder_weekdays,1)';
LC=0;
OP=0;
AV=0;
P=0;
LC_data=NaN(n,1);
OP_data=NaN(n,1);
AV_data=NaN(n,1);
P_data=NaN(n,1);
hold on;
for w=1:n
    if M(w,1)<LC_max
        LC=LC+1;
        LC_data(w,1)=M(w,1);
        plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
    elseif M(w,1)>OP_min && M(w,1)<OP_max
        plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
        OP=OP+1;
        OP_data(w,1)=M(w,1);
    elseif M(w,1)>AV_min && M(w,1)<AV_max
        plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
        AV=AV+1;
        AV_data(w,1)=M(w,1);
    elseif M(w,1)>P_min && M(w,1)<P_max
        plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
        P=P+1;
        P_data(w,1)=M(w,1);
    end
end
```

```
   plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
   plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
   plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
   plot(X,ones(n,1)*P_max,'r','LineWidth',2)
   string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
   grid on
   grid minor
   title('Shoulder weekdays (GC+CL)','FontSize',14)
   xlabel('Consumers','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   saveas(gcf,'13 - Energy consumption per each TOU (Shoulder weekdays).png')
   % Pie chart
   figure('Name','14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart')
   percentages=[LC/n;OP/n;AV/n;P/n];
   explode=[1 1 1 1];
   kk=pie(percentages,explode);
   set(kk(1,1),'FaceColor','g')
   set(kk(1,2),'FontSize',15,'FontWeight','bold')
   set(kk(1,3),'FaceColor','k')
   set(kk(1,4),'FontSize',15,'FontWeight','bold')
   set(kk(1,5),'FaceColor','b')
   set(kk(1,6),'FontSize',15,'FontWeight','bold')
   set(kk(1,7),'FaceColor','r')
   set(kk(1,8),'FontSize',15,'FontWeight','bold')
   legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')

   saveas(gcf,'14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart.png')
   % Histogram
   figure('Name','15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram')
   hold on;
   histogram(LC_data,15,'FaceColor','g');
   histogram(OP_data,7,'FaceColor','k');
   histogram(AV_data,2,'FaceColor','b');
   histogram(P_data,30,'FaceColor','r');
   legend(string,'Location','southoutside','Orientation','horizontal')
   saveas(gcf,'15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram.png')
   % --- %
   % Shoulder weekend
   figure('Name','16 - Energy consumption per each TOU (Shoulder
weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   %M=mean(data_GC_CL_shoulder_weekend,1)';
   M=mean(data_GC_CL_GG_shoulder_weekend,1)';
   LC=0;
   OP=0;
```

```
    AV=0;
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
       if M(w,1)<LC_max
          LC=LC+1;
          LC_data(w,1)=M(w,1);
          plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
       elseif M(w,1)>OP_min && M(w,1)<OP_max
          plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
          OP=OP+1;
          OP_data(w,1)=M(w,1);
       elseif M(w,1)>AV_min && M(w,1)<AV_max
          plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
          AV=AV+1;
          AV_data(w,1)=M(w,1);
       elseif M(w,1)>P_min && M(w,1)<P_max
          plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
          P=P+1;
          P_data(w,1)=M(w,1);
       end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Shoulder weekend (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'16 - Energy consumption per each TOU (Shoulder weekend).png')
    % Pie chart
    figure('Name','17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];

    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
```

```
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart.png')
    % Histogram
    figure('Name','18 - Energy consumption per each TOU (Shoulder weekend) - Histogram')
    hold on;
    histogram(LC_data,15,'FaceColor','g');
    histogram(OP_data,7,'FaceColor','k');
    histogram(AV_data,2,'FaceColor','b');
    histogram(P_data,30,'FaceColor','r');
    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'18 - Energy consumption per each TOU (Shoulder weekend) - Histogram.png')
  %% Data in folder 2012-2013
elseif year==3
    load('year_2012_2013.mat')
    cd(actual_folder)
    data_GC=year2012_2013.data_GC;
    data_CL=year2012_2013.data_CL;
    data_GG=year2012_2013.data_GG;
    timestamp=year2012_2013.timestamp;
    days=year2012_2013.days;

    for k=1:size(timestamp,1)
        timestamp_double(k,1)=datenum(timestamp{k},'dd/mm/yyyy HH:MM:SS');
    end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%
    % 1) Energy consumption GC per each consumer over time (overlapped trends)
    figure('Name','1 - Energy consumption per each consumer over time
(GC)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
    for d=1:300
        plot(timestamp_double,data_GC(:,d),'k')
        hold on
    end
    title('Energy consumption per each consumer over time (GC)','FontSize',14)
    xlabel('Time','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    grid on
    plot(timestamp_double,mean(data_GC,2),'r','LineWidth',2)
    datetick('x','dd/mm/yyyy','keeplimits')
    saveas(gcf,'1 - Energy consumption per each consumer over time (GC).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%
   % 2) Energy consumption CL per each consumer over time (overlapped trends)
   figure('Name','2 - Energy consumption per each consumer over time
(CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_CL(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (CL)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
   plot(timestamp_double,mean(data_CL,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'2 - Energy consumption per each consumer over time (CL).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%
   % 3) Energy consumption GC+CL-GG per each consumer over time (overlapped trends)
   figure('Name','3 - Energy consumption per each consumer over time
(GC+CL)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   for d=1:300
      plot(timestamp_double,data_GC(:,d)+data_CL(:,d)-data_GG(:,d),'k')
      hold on
   end
   title('Energy consumption per each consumer over time (GC+CL-GG)','FontSize',14)
   xlabel('Time','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   grid on
  plot(timestamp_double,mean(data_GC,2)+mean(data_CL,2),'r','LineWidth',2)
   datetick('x','dd/mm/yyyy','keeplimits')
   saveas(gcf,'3 - Energy consumption per each consumer over time (GC+CL-GG).png')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%
   % 4) Energy consumption GC+CL and GC+CL-GG inside TOU
   % Extract Peak hours for weekdays
   peak_weekdays=zeros(size(days,1),1);
   off_peak_weekdays=zeros(size(days,1),1);
   shoulder_weekdays=zeros(size(days,1),1);
   off_peak_weekend=zeros(size(days,1),1);
   shoulder_weekend=zeros(size(days,1),1);
   total_days=size(days,1)/48;
   for day_counter=1:total_days
      for h=1:48
         if find(days(48*(day_counter-1)+h,:))<6
            if h>=15 && h<=18 || h>=35 && h<=40
               peak_weekdays(48*(day_counter-1)+h,1)=1;
            elseif h>=1 && h<=12 || h>=45 && h<=48
```

```
               off_peak_weekdays(48*(day_counter-1)+h,1)=1;
            elseif h>=19 && h<=34 || h>=41 && h<=44
               shoulder_weekdays(48*(day_counter-1)+h,1)=1;
            end
         elseif find(days(48*(day_counter-1)+h,:))>5
            if h>=1 && h<=14 || h>=45 && h<=48
               off_peak_weekend(48*(day_counter-1)+h,1)=1;
            elseif h>=15 && h<=44
               shoulder_weekend(48*(day_counter-1)+h,1)=1;
            end
         end
      end
   end
week={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday';'Saturday';'Sunday'};
   weekdays={'Monday';'Tuesday';'Wednesday';'Thursday';'Friday'};
   weekends={'Saturday';'Sunday'};
   % Data manipulation (GC+CL) & (GC+CL-GG)
   % Data GC
   data_GC_peak_weekdays=data_GC(find(peak_weekdays),:);
   data_GC_off_peak_weekdays=data_GC(find(off_peak_weekdays),:);
   data_GC_off_peak_weekend=data_GC(find(off_peak_weekend),:);
   data_GC_shoulder_weekdays=data_GC(find(shoulder_weekdays),:);
   data_GC_shoulder_weekend=data_GC(find(shoulder_weekend),:);
   % Data CL
   data_CL_peak_weekdays=data_CL(find(peak_weekdays),:);
   data_CL_off_peak_weekdays=data_CL(find(off_peak_weekdays),:);
   data_CL_off_peak_weekend=data_CL(find(off_peak_weekend),:);
   data_CL_shoulder_weekdays=data_CL(find(shoulder_weekdays),:);
   data_CL_shoulder_weekend=data_CL(find(shoulder_weekend),:);

   % Data GC+CL
   data_GC_CL_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays;
data_GC_CL_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays;
data_GC_CL_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend;
data_GC_CL_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays;
data_GC_CL_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend;
   % Data GG
   data_GG_peak_weekdays=data_GG(find(peak_weekdays),:);
   data_GG_off_peak_weekdays=data_GG(find(off_peak_weekdays),:);
   data_GG_off_peak_weekend=data_GG(find(off_peak_weekend),:);
   data_GG_shoulder_weekdays=data_GG(find(shoulder_weekdays),:);
   data_GG_shoulder_weekend=data_GG(find(shoulder_weekend),:);
   % Data GC+CL-GG
data_GC_CL_GG_peak_weekdays=data_GC_peak_weekdays+data_CL_peak_weekdays-
data_GG_peak_weekdays;
data_GC_CL_GG_off_peak_weekdays=data_GC_off_peak_weekdays+data_CL_off_peak_weekdays-
data_GG_off_peak_weekdays;
data_GC_CL_GG_off_peak_weekend=data_GC_off_peak_weekend+data_CL_off_peak_weekend-
data_GG_off_peak_weekend;
```

```
data_GC_CL_GG_shoulder_weekdays=data_GC_shoulder_weekdays+data_CL_shoulder_weekdays-
data_GG_shoulder_weekdays;
data_GC_CL_GG_shoulder_weekend=data_GC_shoulder_weekend+data_CL_shoulder_weekend-
data_GG_shoulder_weekend;
   % Consumers
   n=size(data_GC,2);
   X=[1:n];
   % Range limits
   LC_min=0;
   LC_max=0.17-10^-10;
   OP_min=0.17;
   OP_max=0.37-10^-10;
   AV_min=0.37;
   AV_max=0.43;
   P_min=0.43+10^-10;
   P_max=2;

   colors_mean={'.g';'.k';'.b';'.r'};
   % --- %
   % Peek weekdays
   figure('Name','4 - Energy consumption per each TOU (Peak
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
   %M=mean(data_GC_CL_peak_weekdays,1)';
   M=mean(data_GC_CL_GG_peak_weekdays,1)'
   LC=0;
   OP=0;
   AV=0;
   P=0;
   LC_data=NaN(n,1);
   OP_data=NaN(n,1);
   AV_data=NaN(n,1);
   P_data=NaN(n,1);
   hold on;
   for w=1:n
      if M(w,1)<LC_max
         LC=LC+1;
         LC_data(w,1)=M(w,1);
         plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
      elseif M(w,1)>OP_min && M(w,1)<OP_max
         plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
         OP=OP+1;
         OP_data(w,1)=M(w,1);
      elseif M(w,1)>AV_min && M(w,1)<AV_max
         plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
         AV=AV+1;
         AV_data(w,1)=M(w,1);
      elseif M(w,1)>P_min && M(w,1)<P_max
         plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
         P=P+1;
```

```
      P_data(w,1)=M(w,1);
    end
  end
  plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
  plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
  plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
  plot(X,ones(n,1)*P_max,'r','LineWidth',2)
  string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
  grid on
  grid minor
  title('Peek weekdays (GC+CL)','FontSize',14)
  xlabel('Consumers','FontSize',14)
  ylabel('Energy consumption [kWh]','FontSize',14)
  saveas(gcf,'4 - Energy consumption per each TOU (Peak weekdays).png')
  % Pie chart
  figure('Name','5 - Energy consumption per each TOU (Peak weekdays) - Pie chart')
  percentages=[LC/n;OP/n;AV/n;P/n];
  explode=[1 1 1 1];
  kk=pie(percentages,explode);
  set(kk(1,1),'FaceColor','g')
  set(kk(1,2),'FontSize',15,'FontWeight','bold')
  set(kk(1,3),'FaceColor','k')
  set(kk(1,4),'FontSize',15,'FontWeight','bold')
  set(kk(1,5),'FaceColor','b')
  set(kk(1,6),'FontSize',15,'FontWeight','bold')
  set(kk(1,7),'FaceColor','r')
  set(kk(1,8),'FontSize',15,'FontWeight','bold')

  legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
  saveas(gcf,'5 - Energy consumption per each TOU (Peak weekdays) - Pie chart.png')
  % Histogram
  figure('Name','6 - Energy consumption per each TOU (Peak weekdays) - Histogram')
  hold on;
  histogram(LC_data,4,'FaceColor','g');
  histogram(OP_data,10,'FaceColor','k');
  histogram(AV_data,3,'FaceColor','b');
  histogram(P_data,30,'FaceColor','r');
  legend(string,'Location','southoutside','Orientation','horizontal')
  saveas(gcf,'6 - Energy consumption per each TOU (Peak weekdays) - Histogram.png')
  % --- %
  % Off-peek weekdays
  figure('Name','7 - Energy consumption per each TOU (Off-peak
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
  %M=mean(data_GC_CL_off_peak_weekdays,1)';
  M=mean(data_GC_CL_GG_off_peak_weekdays,1)';
```

```
   LC=0;
   OP=0;
   AV=0;
   P=0;
   LC_data=NaN(n,1);
   OP_data=NaN(n,1);
   AV_data=NaN(n,1);
   P_data=NaN(n,1);
   hold on;
   for w=1:n
      if M(w,1)<LC_max
         LC=LC+1;
         LC_data(w,1)=M(w,1);
         plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
      elseif M(w,1)>OP_min && M(w,1)<OP_max
         plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
         OP=OP+1;
         OP_data(w,1)=M(w,1);
      elseif M(w,1)>AV_min && M(w,1)<AV_max
         plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
         AV=AV+1;
         AV_data(w,1)=M(w,1);
      elseif M(w,1)>P_min && M(w,1)<P_max
         plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
         P=P+1;
         P_data(w,1)=M(w,1);
      end
   end
   plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
   plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
   plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
   plot(X,ones(n,1)*P_max,'r','LineWidth',2)
   string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
   grid on
   grid minor
   title('Off-peek weekdays (GC+CL)','FontSize',14)
   xlabel('Consumers','FontSize',14)
   ylabel('Energy consumption [kWh]','FontSize',14)
   saveas(gcf,'7 - Energy consumption per each TOU (Off-peak weekdays).png')
   % Pie chart
   figure('Name','8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart')
   percentages=[LC/n;OP/n;AV/n;P/n];
   explode=[1 1 1 1];
   kk=pie(percentages,explode);
   set(kk(1,1),'FaceColor','g')
```

```
set(kk(1,2),'FontSize',15,'FontWeight','bold')
set(kk(1,3),'FaceColor','k')
set(kk(1,4),'FontSize',15,'FontWeight','bold')
set(kk(1,5),'FaceColor','b')
set(kk(1,6),'FontSize',15,'FontWeight','bold')
set(kk(1,7),'FaceColor','r')
set(kk(1,8),'FontSize',15,'FontWeight','bold')
legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
saveas(gcf,'8 - Energy consumption per each TOU (Off-peak weekdays) - Pie chart.png')
% Histogram
figure('Name','9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram')
hold on;
histogram(LC_data,10,'FaceColor','g');
histogram(OP_data,10,'FaceColor','k');
histogram(AV_data,5,'FaceColor','b');
histogram(P_data,25,'FaceColor','r');
legend(string,'Location','southoutside','Orientation','horizontal')
saveas(gcf,'9 - Energy consumption per each TOU (Off-peak weekdays) - Histogram.png')
% --- %
% Off-peek weekend
figure('Name','10 - Energy consumption per each TOU (Off-peak weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
%M=mean(data_GC_CL_off_peak_weekend,1)';
M=mean(data_GC_CL_GG_off_peak_weekend,1)';
LC=0;
OP=0;
AV=0;
P=0;
LC_data=NaN(n,1);
OP_data=NaN(n,1);
AV_data=NaN(n,1);
P_data=NaN(n,1);
hold on;
for w=1:n
   if M(w,1)<LC_max
      LC=LC+1;
      LC_data(w,1)=M(w,1);
      plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
   elseif M(w,1)>OP_min && M(w,1)<OP_max
      plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
      OP=OP+1;
      OP_data(w,1)=M(w,1);
   elseif M(w,1)>AV_min && M(w,1)<AV_max
      plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
      AV=AV+1;
      AV_data(w,1)=M(w,1);
   elseif M(w,1)>P_min && M(w,1)<P_max
      plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
      P=P+1;
```

```
      P_data(w,1)=M(w,1);
    end
  end
  plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
  plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
  plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
  plot(X,ones(n,1)*P_max,'r','LineWidth',2)
  string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
  annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
  grid on
  grid minor
  title('Off-peek weekend (GC+CL)','FontSize',14)
  xlabel('Consumers','FontSize',14)
  ylabel('Energy consumption [kWh]','FontSize',14)
  saveas(gcf,'10 - Energy consumption per each TOU (Off-peak weekend).png')
  % Pie chart
  figure('Name','11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart')
  percentages=[LC/n;OP/n;AV/n;P/n];
  explode=[1 1 1 1];
  kk=pie(percentages,explode);
  set(kk(1,1),'FaceColor','g')
  set(kk(1,2),'FontSize',15,'FontWeight','bold')
  set(kk(1,3),'FaceColor','k')
  set(kk(1,4),'FontSize',15,'FontWeight','bold')
  set(kk(1,5),'FaceColor','b')
  set(kk(1,6),'FontSize',15,'FontWeight','bold')
  set(kk(1,7),'FaceColor','r')
  set(kk(1,8),'FontSize',15,'FontWeight','bold')
  legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
  saveas(gcf,'11 - Energy consumption per each TOU (Off-peak weekend) - Pie chart.png')
  % Histogram
  figure('Name','12 - Energy consumption per each TOU (Off-peak weekend) - Histogram')
  hold on;
  histogram(LC_data,10,'FaceColor','g');
  histogram(OP_data,10,'FaceColor','k');
  histogram(AV_data,5,'FaceColor','b');
  histogram(P_data,25,'FaceColor','r');
  legend(string,'Location','southoutside','Orientation','horizontal')
  saveas(gcf,'12 - Energy consumption per each TOU (Off-peak weekend) - Histogram.png')
  % --- %
  % Shoulder weekdays
  figure('Name','13 - Energy consumption per each TOU (Shoulder
weekdays)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
  %M=mean(data_GC_CL_shoulder_weekdays,1)';
  M=mean(data_GC_CL_GG_shoulder_weekdays,1)';
  LC=0;
```

```
    OP=0;
    AV=0;
    P=0;
    LC_data=NaN(n,1);
    OP_data=NaN(n,1);
    AV_data=NaN(n,1);
    P_data=NaN(n,1);
    hold on;
    for w=1:n
       if M(w,1)<LC_max
          LC=LC+1;
          LC_data(w,1)=M(w,1);
          plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
       elseif M(w,1)>OP_min && M(w,1)<OP_max
          plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
          OP=OP+1;
          OP_data(w,1)=M(w,1);
       elseif M(w,1)>AV_min && M(w,1)<AV_max
          plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
          AV=AV+1;
          AV_data(w,1)=M(w,1);
       elseif M(w,1)>P_min && M(w,1)<P_max
          plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
          P=P+1;
          P_data(w,1)=M(w,1);
       end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Shoulder weekdays (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'13 - Energy consumption per each TOU (Shoulder weekdays).png')
    % Pie chart
    figure('Name','14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
```

```
set(kk(1,3),'FaceColor','k')
set(kk(1,4),'FontSize',15,'FontWeight','bold')
set(kk(1,5),'FaceColor','b')
set(kk(1,6),'FontSize',15,'FontWeight','bold')
set(kk(1,7),'FaceColor','r')
set(kk(1,8),'FontSize',15,'FontWeight','bold')
legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
saveas(gcf,'14 - Energy consumption per each TOU (Shoulder weekdays) - Pie chart.png')
% Histogram
figure('Name','15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram')
hold on;
histogram(LC_data,15,'FaceColor','g');
histogram(OP_data,7,'FaceColor','k');
histogram(AV_data,2,'FaceColor','b');
histogram(P_data,30,'FaceColor','r');
legend(string,'Location','southoutside','Orientation','horizontal')
saveas(gcf,'15 - Energy consumption per each TOU (Shoulder weekdays) - Histogram.png')
% --- %
% Shoulder weekend
figure('Name','16 - Energy consumption per each TOU (Shoulder weekend)','Numbertitle','off','units','normalized','outerposition',[0 0.05 1 0.95])
%M=mean(data_GC_CL_shoulder_weekend,1)';
M=mean(data_GC_CL_GG_shoulder_weekend,1)';
LC=0;
OP=0;
AV=0;
P=0;
LC_data=NaN(n,1);
OP_data=NaN(n,1);
AV_data=NaN(n,1);
P_data=NaN(n,1);
hold on;
for w=1:n
    if M(w,1)<LC_max
        LC=LC+1;
        LC_data(w,1)=M(w,1);
        plot(X(w),M(w,1),colors_mean{1},'MarkerSize',10)
    elseif M(w,1)>OP_min && M(w,1)<OP_max
        plot(X(w),M(w,1),colors_mean{2},'MarkerSize',10)
        OP=OP+1;
        OP_data(w,1)=M(w,1);
    elseif M(w,1)>AV_min && M(w,1)<AV_max
        plot(X(w),M(w,1),colors_mean{3},'MarkerSize',10)
        AV=AV+1;
        AV_data(w,1)=M(w,1);
    elseif M(w,1)>P_min && M(w,1)<P_max
        plot(X(w),M(w,1),colors_mean{4},'MarkerSize',10)
        P=P+1;
        P_data(w,1)=M(w,1);
```

```
        end
    end
    plot(X,ones(n,1)*LC_max,'g','LineWidth',2)
    plot(X,ones(n,1)*OP_max,'k','LineWidth',2)
    plot(X,ones(n,1)*AV_max,'b','LineWidth',2)
    plot(X,ones(n,1)*P_max,'r','LineWidth',2)
    string={'Low Consumption';'Off-Peak Consumption';'Average Consumption';'Peak Consumption'};
annotation('textbox',[0.01,0.06,0.1,0.1],'String',string(1),'FontWeight','bold')
annotation('textbox',[0.01,0.13,0.1,0.1],'String',string(2),'FontWeight','bold')
annotation('textbox',[0.01,0.188,0.1,0.1],'String',string(3),'FontWeight','bold')
annotation('textbox',[0.01,0.6,0.1,0.1],'String',string(4),'FontWeight','bold')
    grid on
    grid minor
    title('Shoulder weekend (GC+CL)','FontSize',14)
    xlabel('Consumers','FontSize',14)
    ylabel('Energy consumption [kWh]','FontSize',14)
    saveas(gcf,'16 - Energy consumption per each TOU (Shoulder weekend).png')

    % Pie chart
    figure('Name','17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart')
    percentages=[LC/n;OP/n;AV/n;P/n];
    explode=[1 1 1 1];
    kk=pie(percentages,explode);
    set(kk(1,1),'FaceColor','g')
    set(kk(1,2),'FontSize',15,'FontWeight','bold')
    set(kk(1,3),'FaceColor','k')
    set(kk(1,4),'FontSize',15,'FontWeight','bold')
    set(kk(1,5),'FaceColor','b')
    set(kk(1,6),'FontSize',15,'FontWeight','bold')
    set(kk(1,7),'FaceColor','r')
    set(kk(1,8),'FontSize',15,'FontWeight','bold')
    legend(string,'Location',[0.45 0.01 0.1 0.1],'Orientation','horizontal')
    saveas(gcf,'17 - Energy consumption per each TOU (Shoulder weekend) - Pie chart.png'
    % Histogram
    figure('Name','18 - Energy consumption per each TOU (Shoulder weekend) - Histogram')
    hold on;
    histogram(LC_data,15,'FaceColor','g');
    histogram(OP_data,7,'FaceColor','k');
    histogram(AV_data,2,'FaceColor','b');
    histogram(P_data,30,'FaceColor','r');
    legend(string,'Location','southoutside','Orientation','horizontal')
    saveas(gcf,'18 - Energy consumption per each TOU (Shoulder weekend) - Histogram.png')
end
```

- **Comparison Peak Times of TOU with The Actual Consumption of Houses (2011/12)**

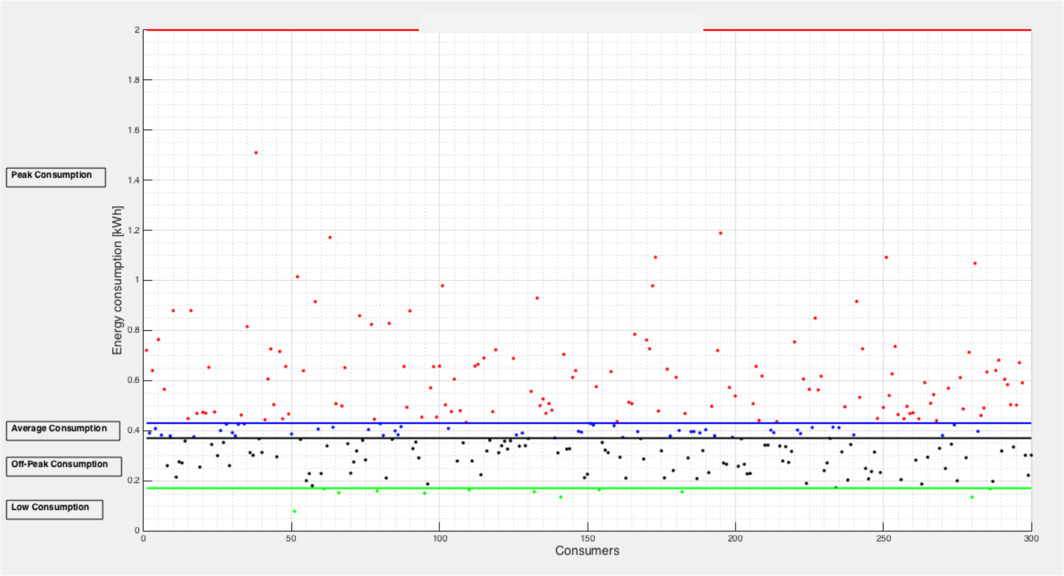

Figure 9.1: Actual Consumers behavior during the Peak of TOU Tariff

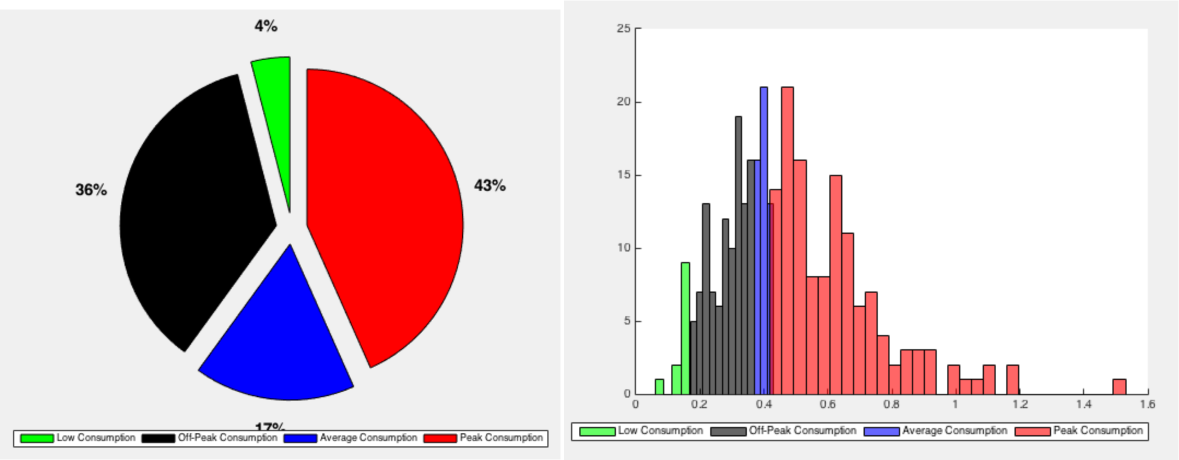

Figure 9.2: Consumers behavior at Peak TOU – weekdays

- **Comparison Shoulder Weekdays of TOU: (9:00am-5:00am)* & (8:00pm-10pm)** of TOU with the Actual Consumption of Houses (2011/12)**

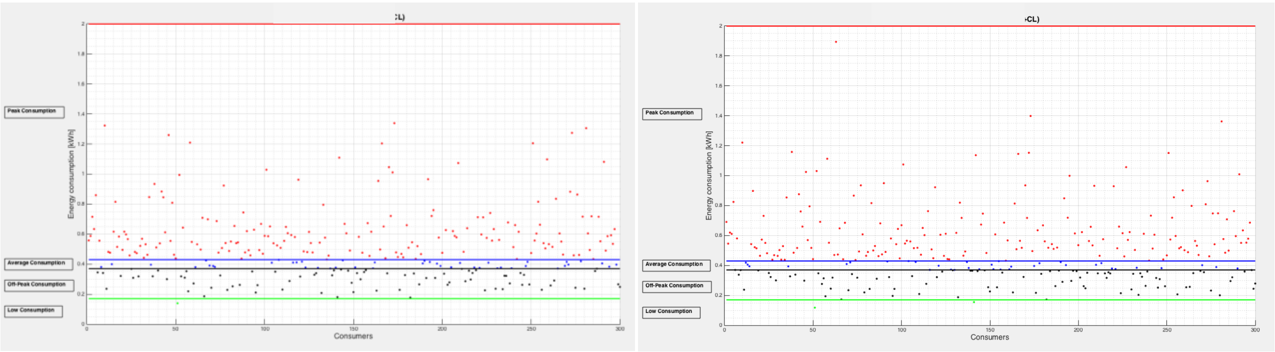

Figure 9.3: Consumers behavior at Average/Shoulder TOU – weekdays

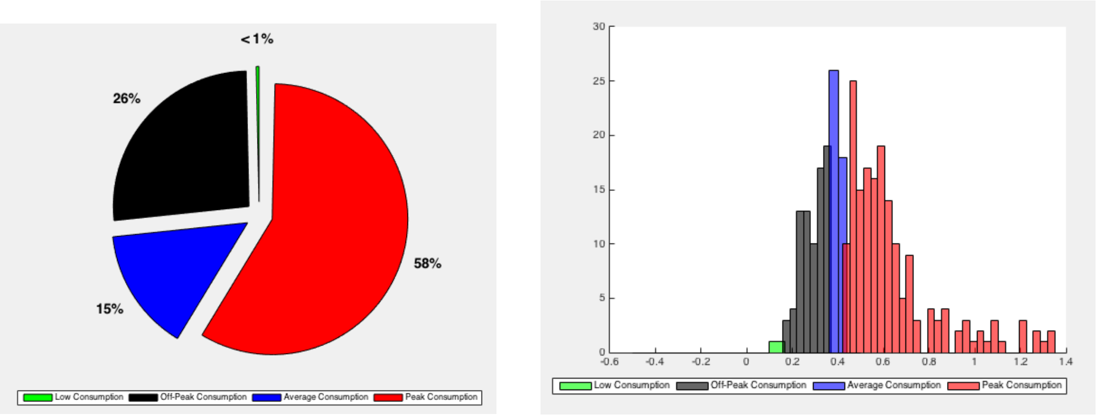

Figure 9.4: Consumers behavior at Average/Shoulder TOU – weekdays

- **Comparison Off-Peak Weekdays of TOU: (10:00pm-12:00am)* & (12:00am-7am)** of TOU with the Actual Consumption of Houses (2011/12)**

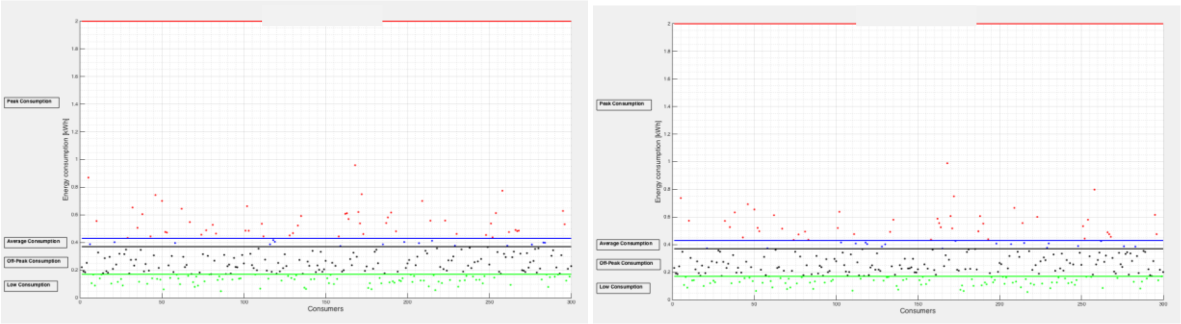

Figure 9.5: Consumers behavior at Off-Peak TOU

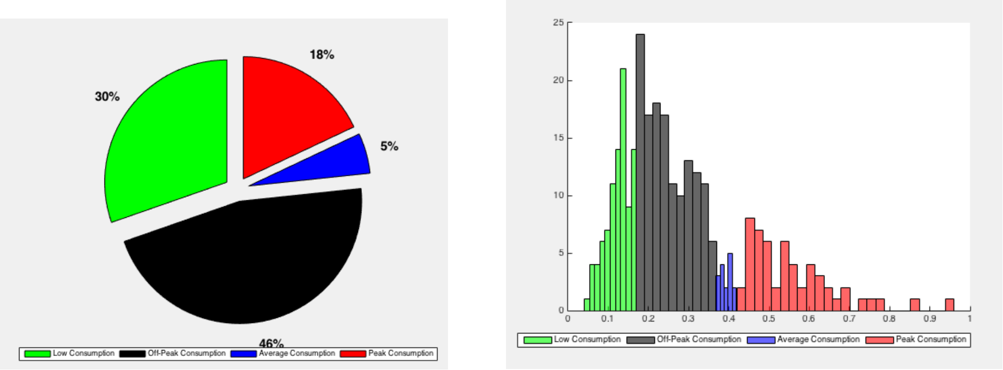

Figure 9. 6: Consumers behavior at Off-Peak TOU – weekdays Pie Chart & Histogram (10:00pm-12am)

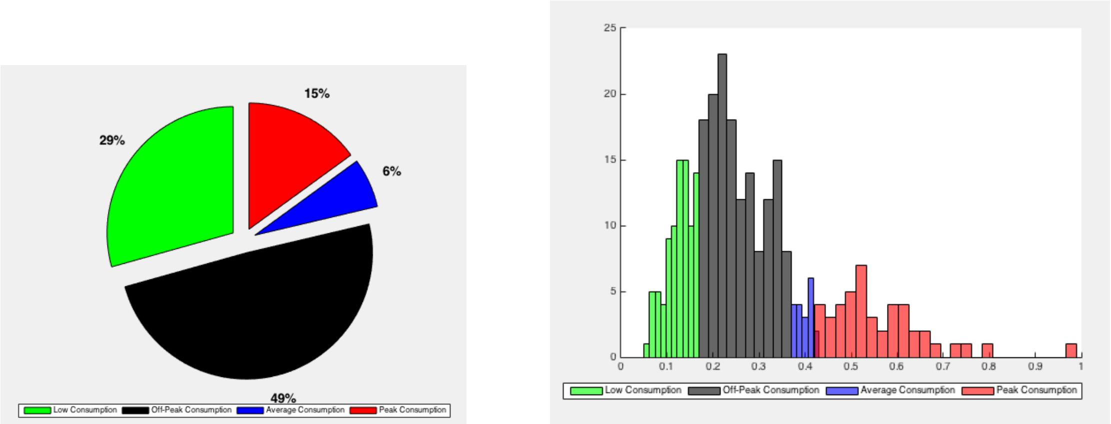

Figure 9. 7: Consumers behavior at Off-Peak Weekdays Pie Chart & Histogram (12:00am-7am)

- **Comparison Peak Times of TOU with The Actual Consumption of Houses (2012/13)**

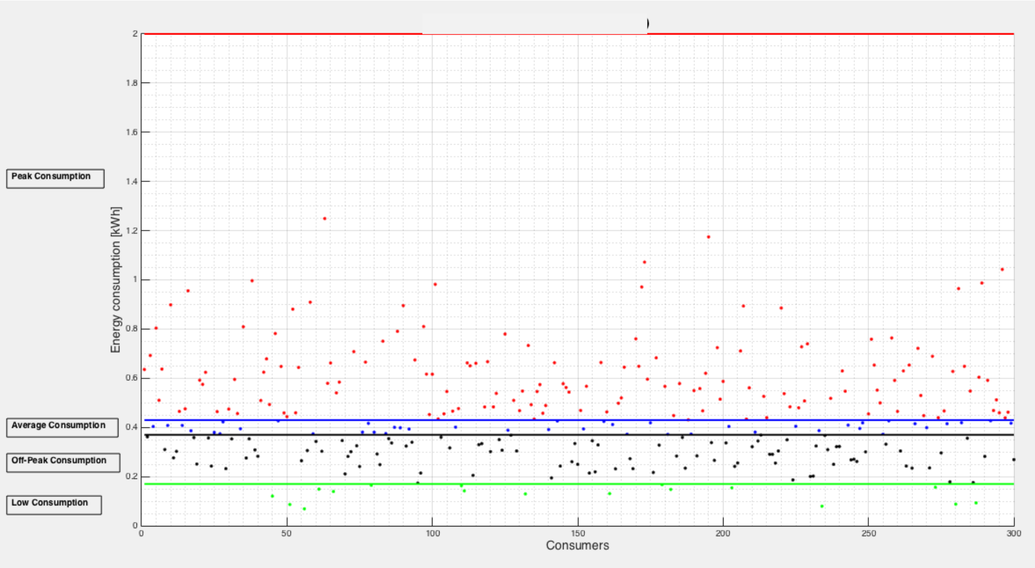

Figure 9.8: Actual Consumers behavior during the Peak of TOU Tariff

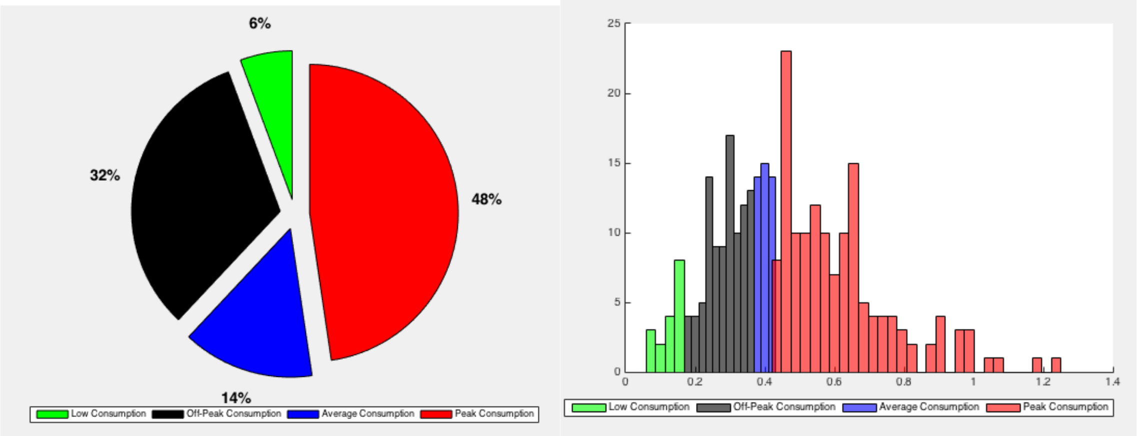

Figure 9.9: Consumers behavior at Peak TOU – weekdays

- Comparison Shoulder Weekdays of TOU: (9:00am-5:00am) & (8:00pm-10pm) with the Actual Consumption of Houses (2012/13)

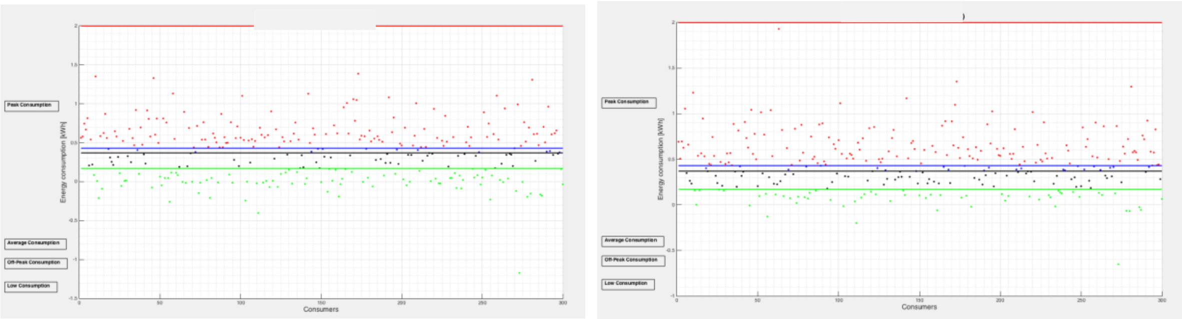

Figure 9.10: Consumers behavior at Shoulder TOU – weekdays

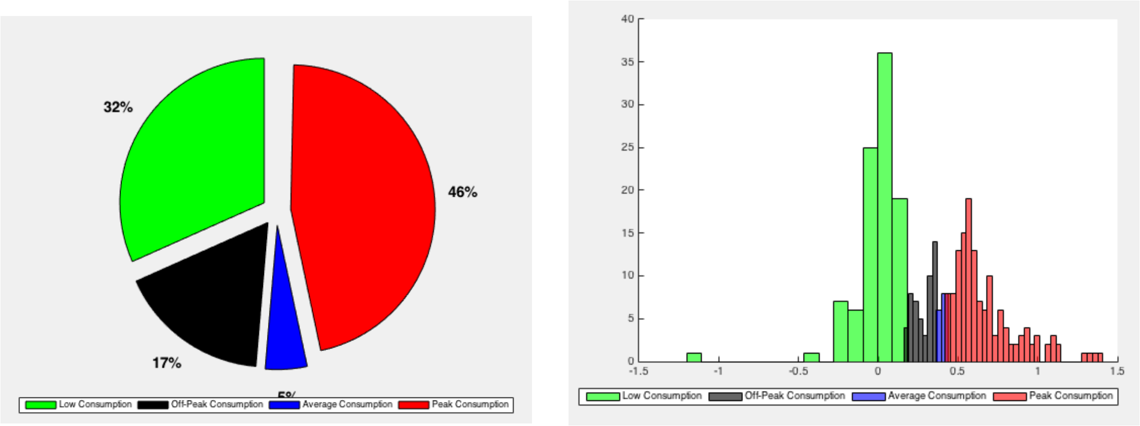

Figure 9.11: Shoulder Weekdays Pie Chart & Histogram (9:00am-5:00am)

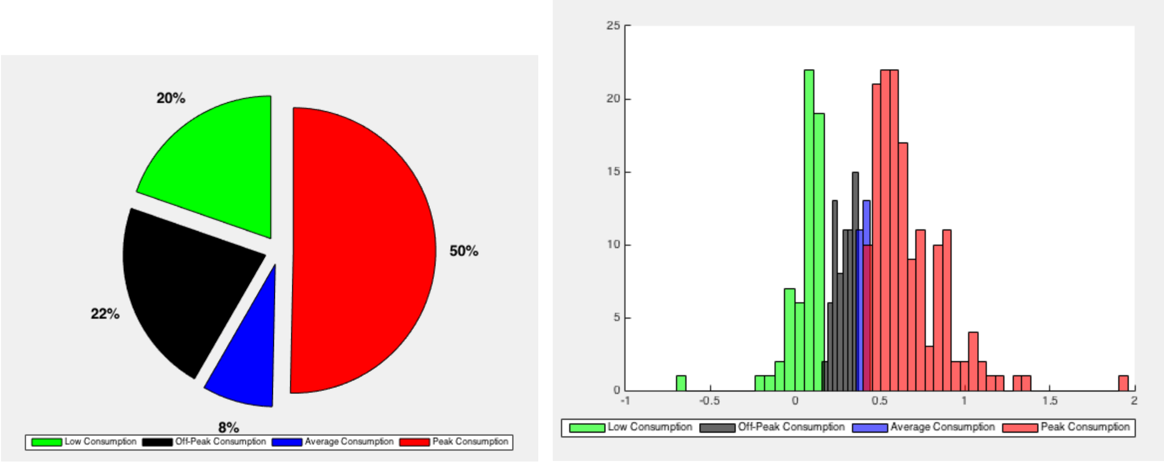

Figure 9. 12: Shoulder Weekdays Pie Chart & Histogram (8:00pm-10pm)

- **Comparison Off-Peak Weekdays of TOU: (10:00pm-12:00am)* & (12:00am-7am)** of TOU with the Actual Consumption of Houses (2011/12)**

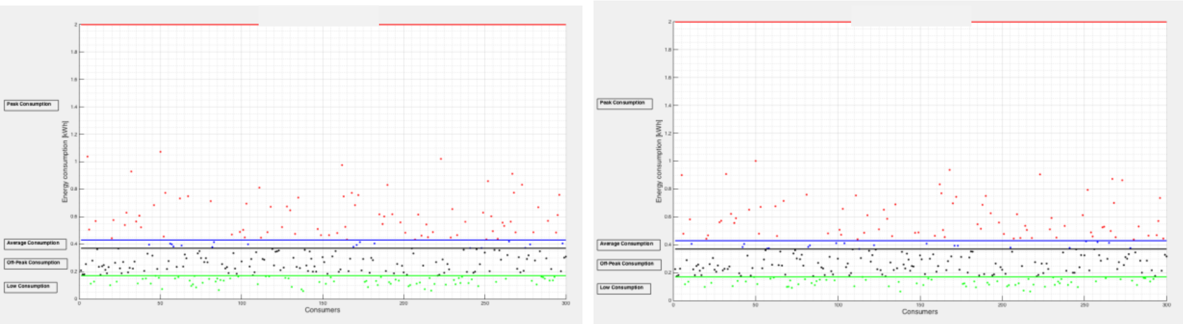

Figure 9.13: Consumers behavior at Off-Peak TOU – weekdays

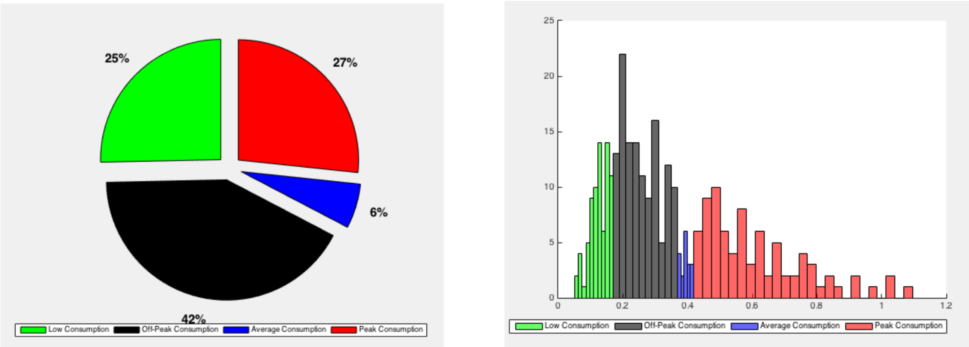

Figure 9. 14: Off-Peak Weekdays Pie Chart & Histogram (10:00pm-12am)

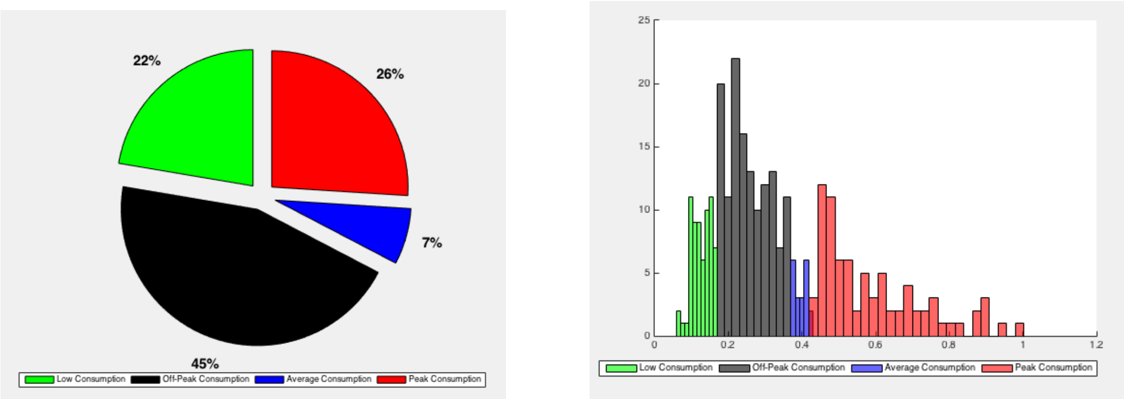

Figure 9. 15: Off-Peak Weekdays Pie Chart & Histogram (12:00am-7am)

Appendix 2

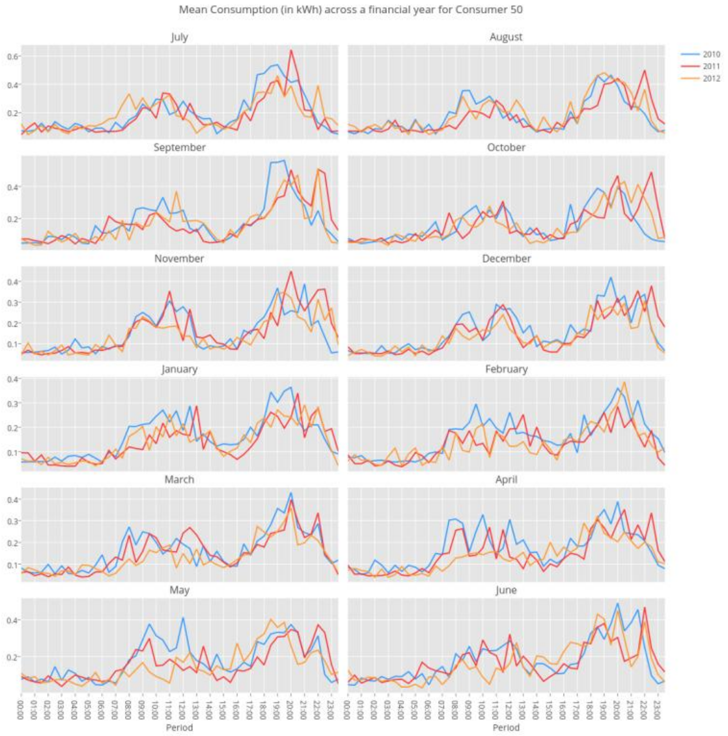

Figure 10. 1:Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 50

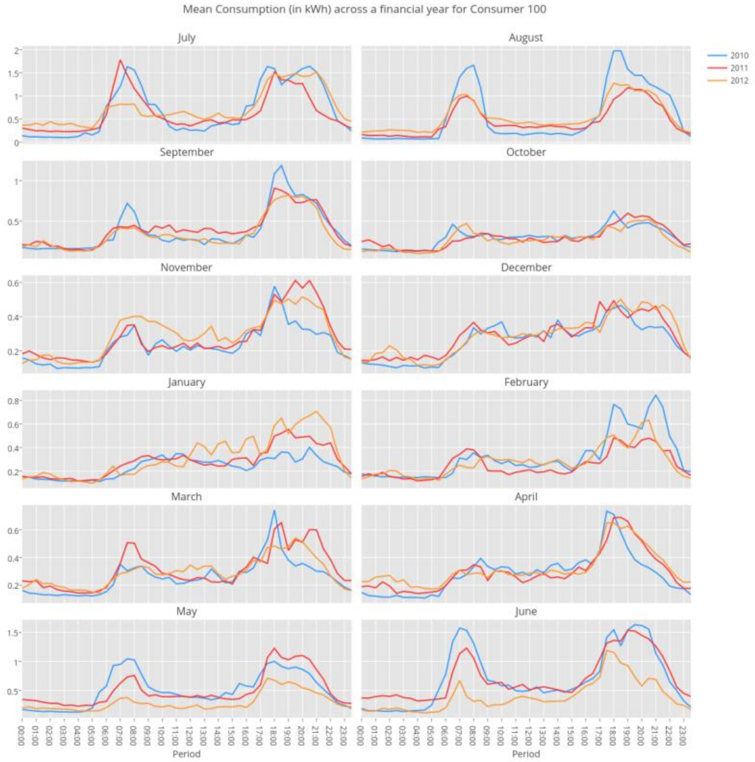

Figure 10.2: Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 100

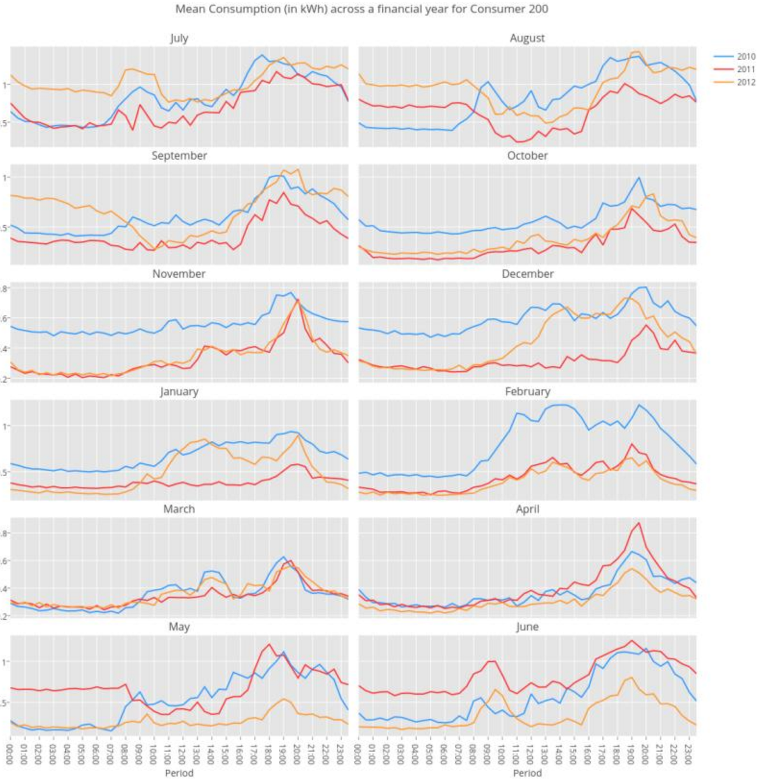

Figure 10. 3: Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 200

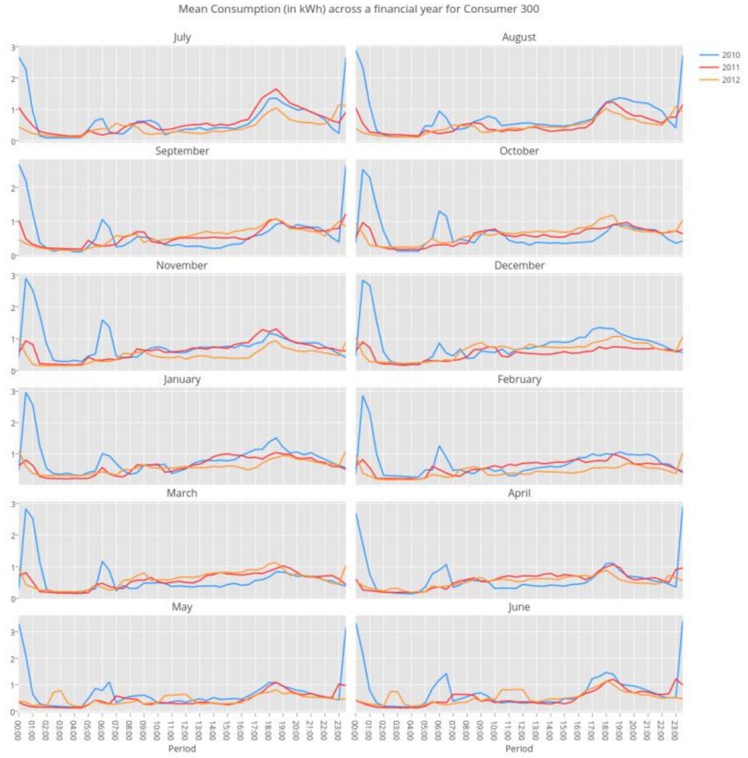

Figure 10.4: Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 300

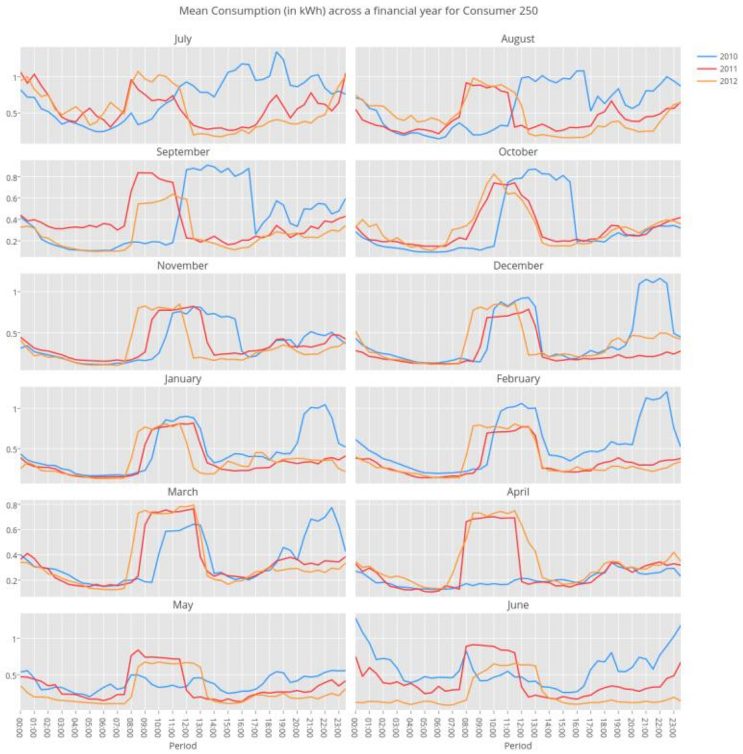

Figure 10.5: Demand Analysis of financial years 2010/11/12 for Home/Customer numbers 250