Faculty of Humanities
Curtin University Sustainability Policy Institute

The Industrial Village Energy Approach: A Cost-Effective Approach To Balance Interests and Collaboratively Harness Onsite Solar Energy

Lionel Michel Daniel Hebert

This thesis is presented for the Degree of

Doctor of Philosophy

of

Curtin University

August 2020

Declaration

To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Date: 12 August 2020

Dedication

I would like to dedicate this accomplishment to my family.

To my lovely wife for her strength, patience, support and love during the four years I dedicated to this research. To my teenage children Leia, Chloe and Emilien whom I had just asked to start a new life on the other side of the world and whose lifestyle was directly impacted by the financial austerity of my career break.

To my parents, both medical doctors, who knew from the start the challenging venture I was getting into but never doubted me. To my sister for her continuous online presence and support. To the rest of my family back in France, whom I managed to surprise once again with another bold decision to “go back to school” after having a history of changing jobs, industries, and countries… true to my curious nature and passion to learn and contribute to making this world a better place.

Acknowledgements

I would like to acknowledge the following individuals and organisations for their contribution to this thesis:

Professor Peter Newman AO, who trusted me to work on, and later become the lead researcher on projects at the Curtin University Sustainability Policy Institute while I had freshly immigrated from France, and saw in me a successful PhD candidate. Thank you for relentlessly believing in me, giving me opportunities to prove myself as a researcher and a PhD candidate under your supervision, and for mentoring and supporting me all the way through. Peter's long-lasting dedication to making this world a better place and substantial international contributions to the field of sustainable development, means that he leads by example, and I feel so humbled to have had the chance to work by his side as his student and colleague.

Dr Charlie Hargroves, who brilliantly co-supervised my PhD research work and dedicated much time helping me become a better academic researcher. I'm also thankful to Charlie for showing me how academics can efficiently work with Industry, particularly while working together for the Sustainable Built Environment National Research Centre (SBEnrc). One of the research projects provided the chance for my PhD research to be applied and make a difference in the field, today. Over the journey of the thesis Dr Hargroves just became, my friend Charlie.

Adjunct Professor Rod Hayes, my industry co-supervisor without whom I would not have gained such a sharp understanding of the economic mechanisms and regulatory complexity of the electricity sector. I am grateful that Rod, a very busy entrepreneur, CEO and Chairman for making time to answer my questions, guide my research, and comment on my drafts.

My research would not have been complete without the contribution of key mentors and partners whom I met during my PhD journey and discussed embedded networks, electric utilities, and the energy sector in general. In particular, I would like to thank:

– Ian Barker (Manager infrastructure) and Ben Ziegelaar (Lead Electrical Engineer) from Perth Airport Pty Ltd whom I worked closely with as part of a project with the Sustainable Built Environment National Research Centre (SBEnrc) that informed the thesis, providing invaluable practical guidance to fill gaps in the published research.

I want to thank them both for their openness and availability to share the intricacies, difficulties, and aspirations of an embedded network operator, connecting me with other key staff (including the property manager and sustainability officer) that helped me acquire the bigger picture necessary to tackle the topic of this thesis.

- Perry Ward, Business Analyst at Balance Utility Solutions, who worked with me on the SBEnrc research project with the Perth Airport and helped me develop my energy and financial simulation skills, as well as my knowledge of the electricity sector and in particular the regulatory situation applicable to energy utilities. Perry always took the time to answer my questions even when they were clearly beyond the scope of the research project in order to inform my broader PhD research.

- Adjunct Professor Bill Grace, University of Western Australia, with whom I discussed a range of ways to present the pitfalls of the utility business models along with learning from his experience working with embedded electricity networks.

- Ray Egan, Plant Operation Manager of the Tonsley District (South Australia) for Enwave Energy, the embedded network operator. Ray kindly made himself available to discuss the management of electricity supply to the energy customers on the embedded network and the business model used by Enwave for the centralised operator-owned 6 MW solar PV farm and energy storage.

- Jason Tod, Business Development Manager at Enel X, for his insights on long term energy management strategies for commercial and industrial customers and how to align them with their business operations while leveraging market conditions.

- Jai Thomas from the Energy Transformation Taskforce, Department of Treasury WA, Project Lead of the '*Distributed Energy Resource Roadmap'* for WA, and Greg Ruthven, specialist in regulatory strategy at the Australian Energy Market Operator (AEMO). I thank them both for their patience and efforts to answer my questions and help me better understand the details of the regulation (present and likely future) of the Western Electricity Market (WEM) of Western Australia and the National Electricity Market (NEM) of the eastern and southern states of Australia, along with the regulatory challenges to integrating renewable energy generators and distributed resources on the grid.

I would like to thank the Sustainable Built Environment National Research Centre (SBEnrc) for providing the opportunity to join the research project with the Perth Airport that informed the development of the thesis, in particular the CEO, Professor Keith Hampson, who guided the research and advised on interacting with the industry partners. I would like to again thank Dr Hargroves in his capacity as the Project Manager, who supported me in my role as the Lead Investigator for the project over the three years of the project life.

Finally, I would like to thank the Australian Cooperative Research Centre for Low Carbon Living (CRC LCL) for providing my PhD Scholarship, organising opportunities to meet other PhD candidates involved in low carbon-related research, and providing valuable training to inform my research and prepare me for life after the PhD.

Abstract

While the residential sector has seen a strong and rapid uptake of photovoltaic panels on rooftops in the last decade, especially in Australia, the uptake has been much slower on commercial and industrial roofs. This research focuses on how commercial and industrial precincts fitted with an embedded electricity network can transition to cost-effective long-term onsite solar energy generation in a manner that creates multiple benefits.

Through review of academic and industry literature, the thesis first presents an understanding of how the issues and barriers found on both public and private electricity networks may explain why there has been slower uptake on commercial and industrial precincts despite its attraction to householders. The thesis then presents a review of alternative models suggested by academic and industry experts including models derived from tyre manufacture, the telecommunications sector, and water utilities. Product-Service System theory is also used to explore alternative models. Collectively, these alternative models form the basis for a new approach.

The thesis then presents a detailed, real-world case study specifically tailored for the introduction of solar on an existing commercial and industry precinct in Perth, Australia. The case study demonstrates the viability of solar energy assuming attempts are made to involve the key stakeholders in the system, including the energy customers themselves. The thesis presents the results of modelling that shows that this new approach can be cost-effective and suggests that such an approach is at the forefront of the needed transition to solar energy generation.

The thesis concludes by formalising the approach and using key lessons learned from the case study, into what was called the ‘Industrial Village Energy Approach’. This approach aims at balancing the interests of energy customers and that of the embedded network operator. It also proposes a new arrangement of roles and functions for the embedded network operator and increased participation from the customers. Furthermore, the thesis presents a new governance framework designed to make these transitions efficient and cost-effective. The concept, developed in this thesis for commercial and industrial precincts could be adapted globally to other types of embedded electricity networks along with informing public utilities of new approaches to help manage the energy sector transition to distributed solar energy generation and storage.

STATEMENT OF CONTRIBUTION

This thesis is entirely my own work and was compiled and drafted with assistance from my supervisor panel of Professor Peter Newman, Dr Charlie Hargroves and Adjunct Professor Rod Hayes.

Lionel Michel Daniel Hebert (PhD Candidate)

Professor Peter Newman (Primary Supervisor)

Dr Karlson Hargroves (Co-supervisor)

Adjunct Professor Roderick Hayes (Industry Supervisor)

Associated Publications and Reports

Throughout the development of the thesis, I have contributed to a number of co-authored works with Professor Peter Newman, Dr Karlson 'Charlie' Hargroves, Adjunct Associate Professor Roderick Hayes and Matt Rule, as listed below.

Hebert, L., Hayes, R., and Hargroves, K. (2016) *Current State Assessment of Airports Around the World Installing Solar: Overview of the Situation of the Perth Airport Embedded Electricity Network and its Regulatory Context*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2017) *Review of Onsite Energy Options and Study of the Energy Demand on the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2018) *Introduction to the Modelling of the Energy Business of the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2018) *Results and Recommendations from the Modelling of the Energy Business of the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2018) *Energy Business Modelling Applied to a Future Development on the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2019) *Governance Model for the Future Development on the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2019) *Review of Options to Develop the Role of Electricity Distribution in the Perth Airport Energy Business*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2019) *Modelling and Assessment of a New Business Model for the Embedded Network Operator of the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2019) *Business Case for the Implementation of an Energy Village Approach to Embedded Electricity Networks*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Rule, M., Hayes, R. and Hebert, L (2019) *Beyond White Gum Valley Precinct Guide: The Energy Village Concept*. The Cooperative Research Centre for Low Carbon Living.

Table of Contents

Table of Figures

Table of Tables

Table of Equations

Chapter 1: Preliminaries

1.1 Introduction

Human-made Greenhouse Gas (GHG) emissions, which trap heat in the atmosphere of the earth, are the primary cause for a number of recent changes in global climatic conditions (IPCC, 2014[1]: IPCC, 2018[2]). These changes have resulted in the amplification of a range of natural disasters and pose new threats such as the bushfires which followed many years of record high average temperatures and prolonged drought across the Australian and American continents (Jones *et al*., 2020)[3] and led to massive environmental, economic and social damages (Read and Denniss, 2020)[4] including the loss of some 1 billion wild animals (Garnett *et al*. 2020)[5].

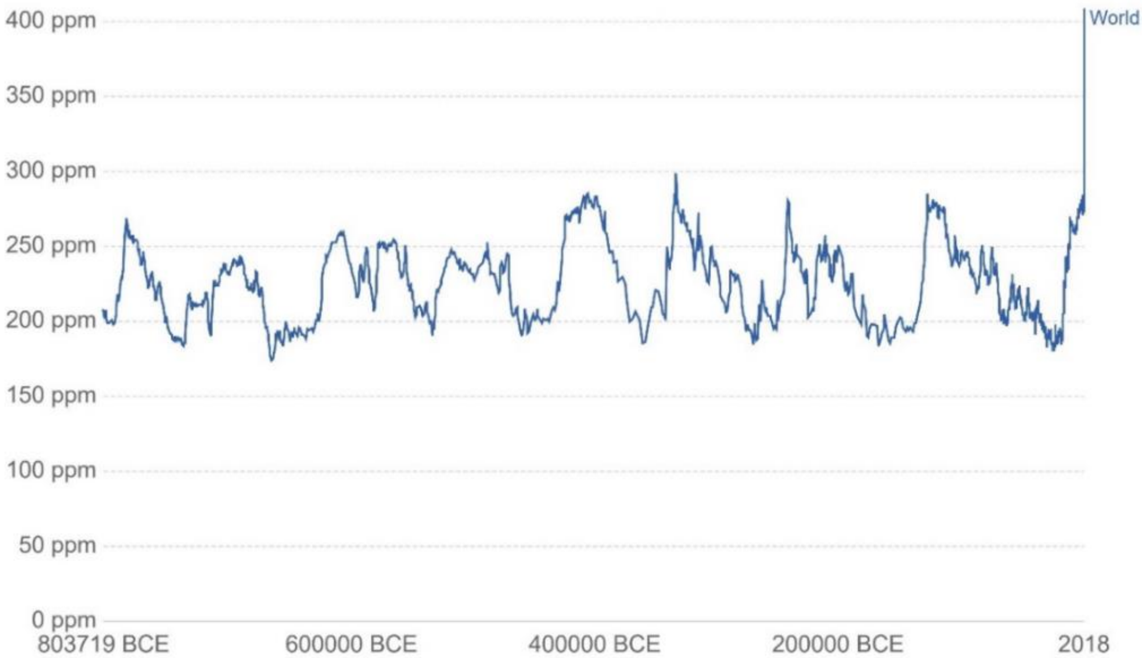

Figure 1: Long-term atmospheric CO_2 concentration since 800,000 BCE

Source: Our World in Data 2018[6] with data from EPICA (2015) and NOAA (2018)

[1] IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p 151.

[2] IPCC (2018) Global warming of 1.5°C. [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Intergovernmental Panel on Climate Change

[3] Jones, D., Braganza, K., and Tobin, S. (2020) Weather bureau says hottest, driest year on record led to extreme bushfire season, The Conversation.

[4] Read, P. and Denniss, R. (2020) With costs approaching $100 billion, the fires are Australia's costliest natural disaster. The Conversation.

[5] Garnett, S., Wintle, B., Lindenmayer, D., Woinarski, J., Maron, M. and Legge, S. (2020) Conservation scientists are grieving after the bushfires – but we must not give up. The Conversation.

[6] Ritchie, H. and Roser, M. (2017) CO_2 and Greenhouse Gas Emissions. OurWorldInData.org.

Since the industrial revolution and the initiation of the combustion of coal and oil for energy, the global concentration of CO_2 in the atmosphere, which is responsible for some 80 per cent of GHG emissions (Bureau of Meteorology and CSIRO, 2014)[7], has increased well above geological maximums recorded over the last eight hundred thousand years (NOAA, 2018)[8] as shown in Figure 1. This trend accelerated from the nineteen fifties with levels now above 400 parts per million (ppm) (NOAA, 2018)[9], as shown in Figure 2. When combined with non-CO_2 gases, GHG emissions reached over 454 ppm (European Environment Agency, 2017)[10].

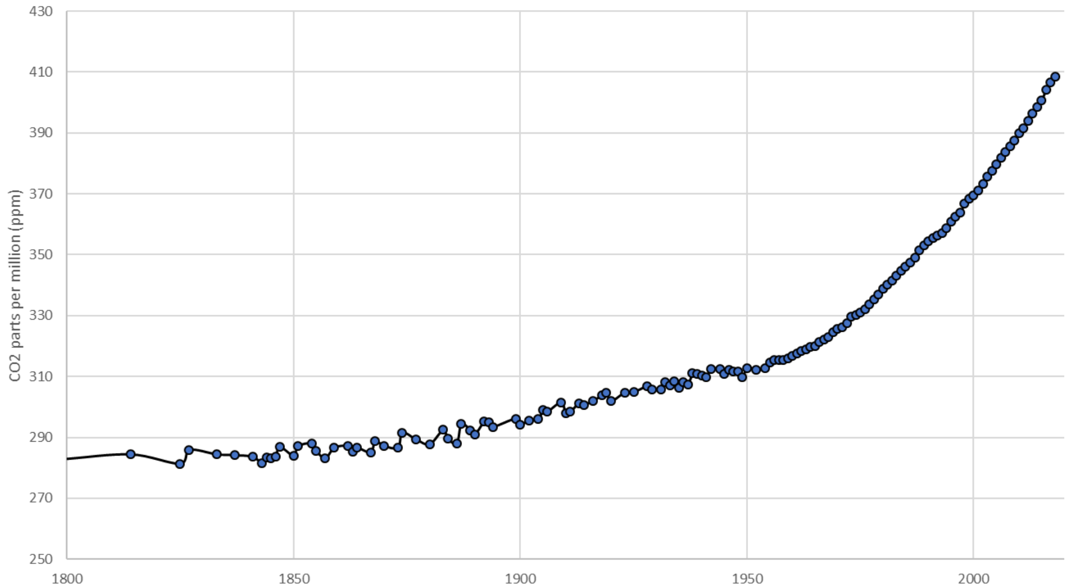

Figure 2: Medium-term atmospheric CO_2 concentration between 1800 and 2018

Source: Data from Our World in Data, 2018[11]

At the country scale, data from the World Bank on levels of CO_2 emissions (World Bank, 2018)[12] shows that Australia is, per capita, one of the largest emitters in the world (Figure 3). This is an important context for this thesis, with the findings having the potential to inform greater GHG emissions reductions in commercial and industrial precincts.

[7] CSIRO (2011) Climate Change. Science and Solutions for Australia. CSIRO Science and Solutions for Australia Series, CSIRO (eBook).
[8] NOAA (2018) Trend in Atmospheric Carbon Dioxide, dataset. National Oceanic and Atmospheric Administration (USA)
[9] NOAA (2018) Trend in Atmospheric Carbon Dioxide, dataset. National Oceanic and Atmospheric Administration (USA)
[10] European Environment Agency (2019) Atmospheric greenhouse gas concentrations. European Environment Agency.
[11] Ritchie, H. and Roser, M. (2017) CO_2 and Greenhouse Gas Emissions. OurWorldInData.org.
[12] World Bank (2018) World Development Indicators, World Bank.

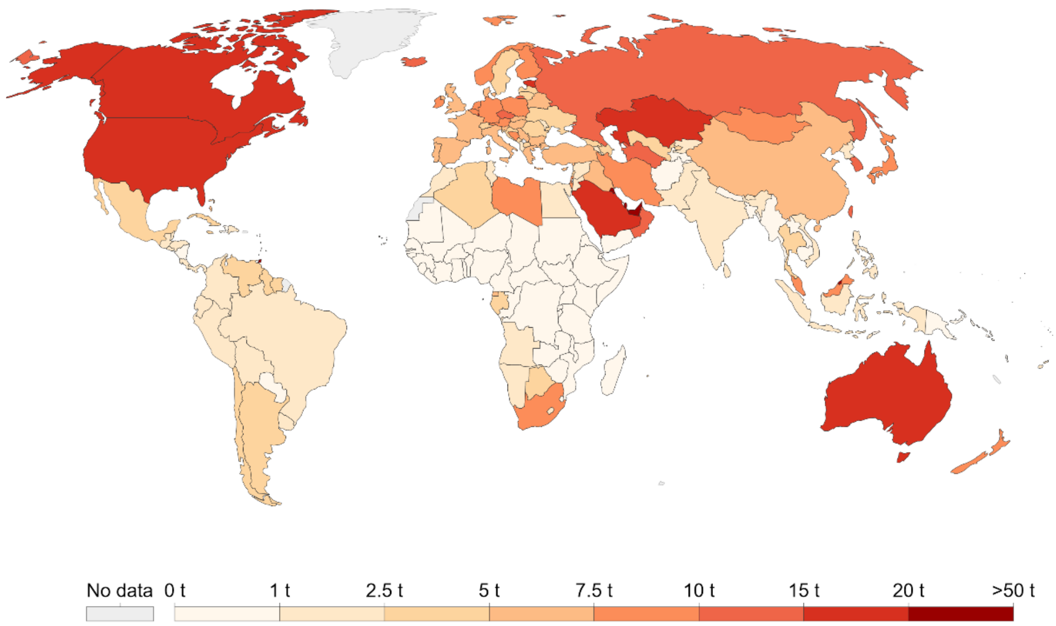

Figure 3: CO_2 emissions per capita, 2017 (tonnes per year)

Source: Our World in Data[13]

Not only are Australia's per capita emissions among the highest in the world, but the level of emissions is also significant in absolute terms. For example, in 2014 France emitted 303 megatons of CO_2e with a population of 66.3 million which equates to 4.57 tonnes per person, while Australia emitted 361 megatons with a population of 23.5 million which equates to 15.37 tonnes CO_2e per person (World Bank, 2018)[14].

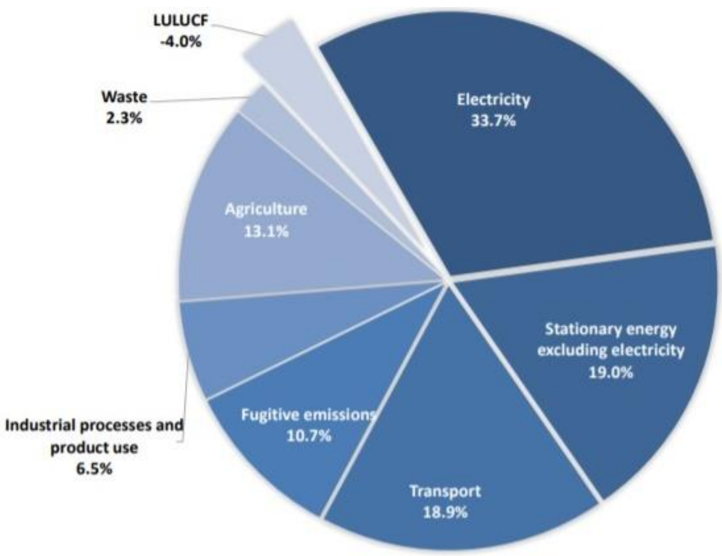

Figure 4: GHG emissions contribution by sector, Australia, 2018

Source: DOEE, 2018

[13] Ritchie, H. and Roser, M. (2017) CO_2 and Greenhouse Gas Emissions. OurWorldInData.org.
[14] World Bank (2018) World Development Indicators, World Bank.

When looking closer at the distribution of GHG emissions by sector in Australia, electricity generation appears to be the most significant contributor (DISER, 2018a)[15], as shown in Figure 4, largely due to combustion of coal, as Figure 5 shows.

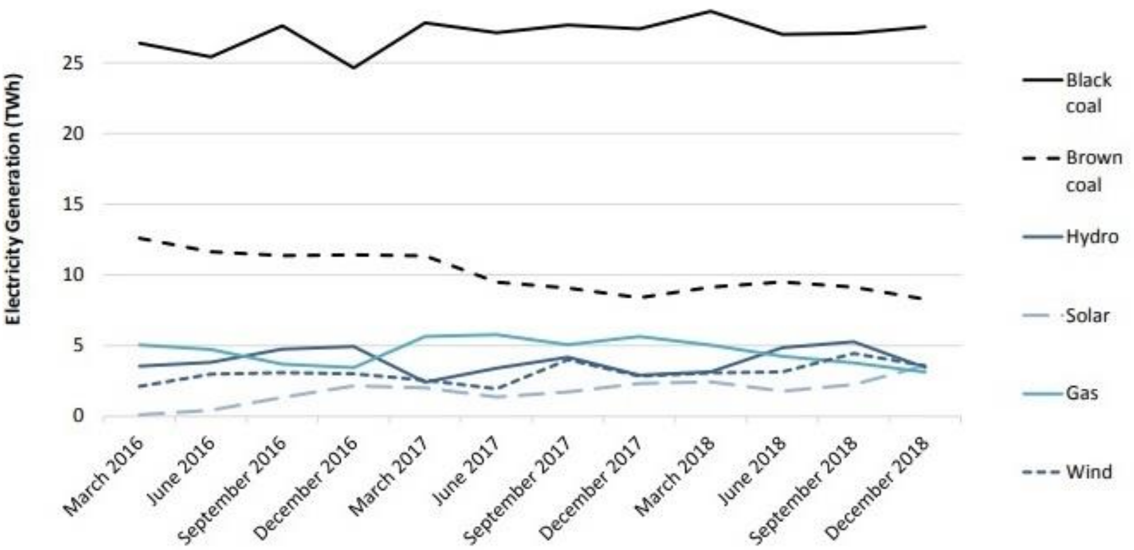

Figure 5: Primary energy used in electricity generation in the National Electricity Market, 2016-18

Source: Department of Industry, Science, Energy and Resources, 2018

Therefore, in order to reduce greenhouse gases emissions from the production of electricity, two approaches exist: 1) Reduce the demand for electricity, such as by increasing energy efficiency and improving demand management, and 2) Generate low- or zero-emissions electricity, ideally for localised use. Among the low-emissions solutions, solar photovoltaic (PV) systems have been very popular in urban settings, particularly in Australia, and as such this technology has been selected for further investigation as part of this research.

The Intergovernmental Panel on Climate Change (IPCC) identified that of all sectors the industry sector is the one that lags most in term of efforts to reduce GHG emissions and in seeking low emission alternatives (IPCC, 2014)[16]. This is particularly true in Australia where installations of photovoltaic systems on commercial and industrial buildings are uncommon. As can be seen in Figure 6, solar installations on residential roofs (under 10kW) account for the majority of the Australian solar capacity compared to rooftop solar

[15] Department of Industry, Science, Energy and Resources (2018a) Quarterly Update of Australia's National Greenhouse Gas Inventory: Department of the Environment and Energy September 2018. pps 7,12.

[16] IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp 151.

systems on commercial and industrial (C&I) roofs (typically in the range of 10 to 500kW capacity). Therefore, it is clear that the strong uptake of solar systems in the residential sector is not happening at the same pace in the commercial and industrial sector.

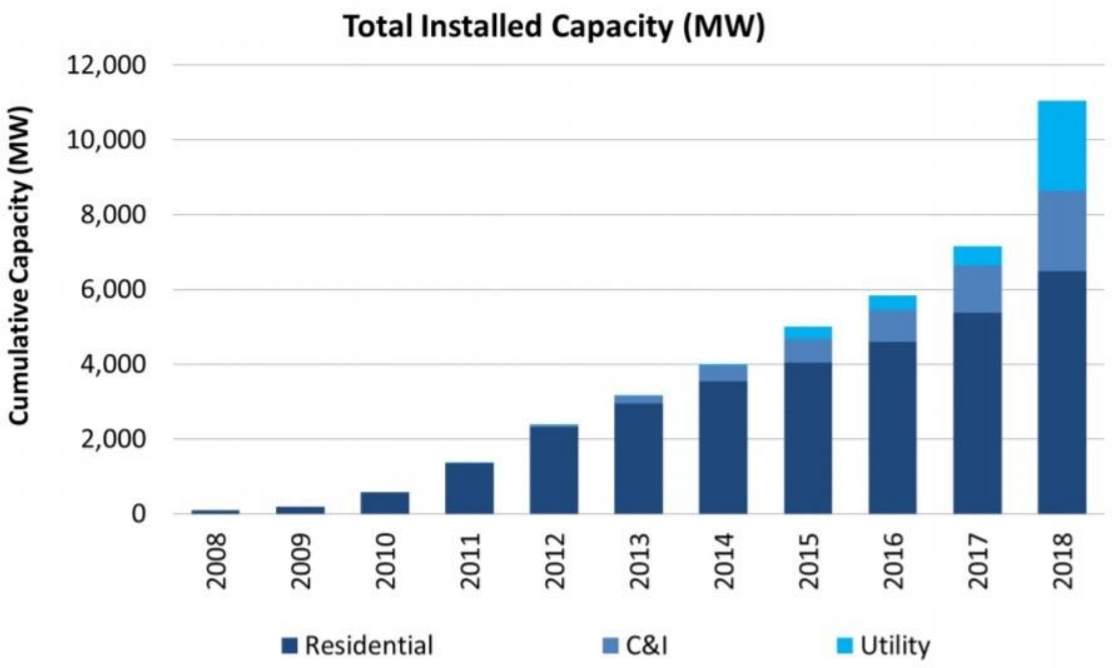

Figure 6: Cumulative Australian photovoltaic installations by category, 2008-2018
Source: 2018 AIPV annual report, 2019[17]

These observations motivated this research to investigate the slow uptake of solar energy in non-residential energy customers and more particularly commercial and industrial customers. Industrial and large commercial businesses often gather in industrial precincts in, or at the fringes of cities. In some cases, these precincts have their own electricity distribution network, called Embedded Electricity Network (EEN), connected to the public grid which is privately managed.

Such precincts with private EENs were selected as the focus of this research as their private network offers a subset of the larger electricity grid that is more easily investigated because:

– EENs are a simpler version of the grid with fewer generators and users, and are more concentrated geographically,

[17] Egan, R. (2018) National survey report of PV power applications in Australia. *Australian PV Institute*

- EENs on private estates can innovate more rapidly and avoid complications faced on the public grid (Tayal and Rauland, 2017)[18] which is a strength when working on potential innovative business models, and

- The findings from research on EENs can be effectively scaled up to inform efforts on the main grid.

As EENs aggregate energy consumption across a number of customers in a precinct, collectively they are large consumers in the electricity sector, effecting the economics and functioning of the wider grid. The vast roof and land space of commercial and industrial precincts means that transitioning to onsite solar energy generation stands to make a significant contribution to the reduction of greenhouse gas emissions of cities. Nevertheless, why is this not happening, or if it is, why is it not happening faster?

Whereas most public grids have allowed customers to install rooftop solar energy equipment, referring to this as a 'Distributed Energy Resource' (DER), private networks (such as EENs) have chosen another approach. This approach involves the embedded network operator operating (and often owning) solar energy generation infrastructure that is installed in a central location on the precinct. On the one hand, the model used to introduce solar energy on the public grids in most developed countries often results in a de-stabilising of the quality of the supply, puts pressure on the finance of the network operator, and creates inequity amongst customers.

This is seen as a potential threat to utilities with a possible ‘death spiral’ of decreasing markets and increasing costs for the traditional grid (Grace, 2014)[19]. On the other hand, the model commonly used on private networks seems to keep the penetration of solar energy at conservative levels and does not encourage or, in some cases, even allow customers to participate in their energy supply. This is a missed opportunity to reduce even more greenhouse gas emissions, and it is creating rising tensions between embedded utilities and their energy customers, as the latter have become more interested in being

[18] Tayal, D., and Rauland, V. (2017) Future business models for Western Australian electricity utilities. *Sustainable Energy Technologies and Assessments, 19*, 59-69.
[19] Grace, W. (2014) Exploring the death spiral – a system dynamics model of the south west interconnected system. Australian: Urban Design Research Centre (AUDRC).

part of the energy business given the rising costs, leading to a trend of 'energy democracy' (Hess, 2018[20]; Van Veelen, 2018[21]).

As presented above, the problem of the introduction of solar energy to commercial and industrial precincts is complex and multi-dimensional. Therefore, as an overarching scaffolding, the research selected the aim of achieving overlapping economic, social, and environmental outcomes, as shown in Figure 7. Hence the research sought to investigate innovative business, ownership and governance models that could enable the accelerated uptake of onsite solar energy generation in EENs while delivering multiple outcomes, rather than dwell on the pace of innovation in associated technologies.

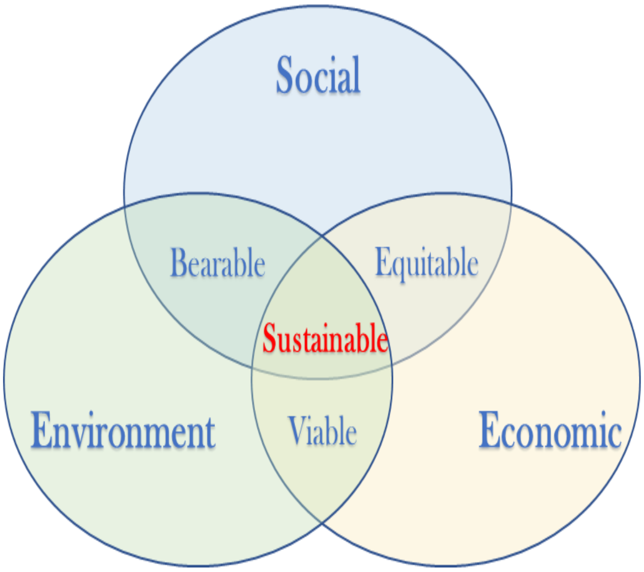

Figure 7: A framework for considering the viability of overlapping outcomes
Source: International Union for Conservation of Nature, 2006[22]

For the purpose of this research:

1. The environmental aspect is focused on achieving a reduction in greenhouse gas emission by reducing the amount of electricity generated from fossil fuels;

2. The economic aspect is focused on the economic benefits for the precinct owner, the embedded network operator, and the customers.

[20] Hess, D. (2018) Energy democracy and social movements: A multi-coalition perspective on the politics of sustainability transitions. *Energy research & social science*, *40*, 177-189.
[21] Van Veelen, B. (2018) Negotiating energy democracy in practice: Governance processes in community energy projects. *Environmental Politics*, *27*(4), 644-665.
[22] Adams, W. (2006) The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006.

3. The social aspect is focused on the involvement of energy customers to enable better outcomes for all parties.

The challenge is, therefore, to design an appropriate approach for commercial and industrial precinct owners to accelerate the transition to onsite solar energy generation. Such an approach would need to clarify: who would own and maintain the solar energy equipment? what would be the role of energy storage, and how would it work? how would the energy be metered and charged? how would the overall system be managed? and importantly what would be the benefits for the precinct owner, the embedded network operator, and the customers? These and other questions have given rise to this research with the hope that a robust investigation will inform efforts to increase such solar and low carbon onsite energy generation in a manner that provides acceptable risks and benefits to all stakeholders. An increase in the uptake of solar energy in commercial and industrial precincts would then contribute to a reduction in society's greenhouse gas emissions while spurring demand for such technologies in the market that will lead to even greater technological advances and associated cost reductions.

1.2 Research Questions

The research question chosen for this thesis was:

'*How can an industrial precinct, fitted with an embedded electricity network, transition to cost-effective long-term onsite solar energy?'*

The sub-questions explored as part of the thesis, and main tasks undertaken to inform the research question were:

Research sub-question #1 *Are existing traditional academic theories and mainstream models capable of supporting the effective introduction of solar energy on an industrial precinct?*

Research Tasks:

- Research the history of the electric utility to understand the traditional approaches and business models.
- Literature review of mainstream models to introduce solar generation on a network.
- Assessment of these models in the context of commercial and industrial precincts and identification of issues, barriers and knowledge gaps.

- Literature review of existing types of energy storage and functions to support the introduction of solar energy on a network.

Research sub-question #2 *What suggested models, systems and theories could help support the effective transition of an industrial precinct to solar energy?*

Research Tasks:

- Literature review of alternatives to traditional approaches suggested by researchers and industry experts in the field.
- Literature review of alternatives to traditional approaches outside the field of energy economics and utility theory.

Research sub-question #3: *"What are the lessons learnt from the simulation of different models to introduce solar energy generation and storage on an existing commercial and industrial precinct?"*

Research Tasks:

- Undertake a research case study to examine if the findings of the literature review and analysis of a new approaches can be cost-effective and attractive as a potential model. This includes an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) of the case study precinct and its energy business to understand what are the potential forces that could drive the need to transition to onsite solar energy generation and what could be the co-benefits for the landowner, the embedded network operator and the customers.
- Design of a methodology for use in case study, including the selected scenarios and the use of the 'Energy Business Analysis Tool' created by Balance Services to be used for the modelling and simulations.
- Presentation of the results and discussion about how the different models compare financially, from the perspective of the embedded network operator and the energy customers.

As a result of the research, as part of the answer to the research question, the thesis proposes a new approach called the 'Industrial Village Energy Model' based on the sharing of the risks, effort, and reward, which is driven by the need to balance interests between the embedded network operator and the energy customers. The new model has the following core components:

– New roles for the embedded network operator and the energy customers.

– New governance approaches based on the village model.

– New agreements and arrangements, including a new approach to electricity network tariffs.

1.3 Research Methodology

The following research methodology was designed to ensure that contributions to answering the research question, and sub-questions, were sourced from existing literature, both within the field of research and broader, and enhanced by new research undertaken as part of a detailed case study:

1. The consideration of traditional academic theories and mainstream models to identify both elements that could benefit the introduction of solar energy and those that are not optimum, not suited, or cause implementation issues.
2. The assessment of existing academic theories yet to be applied to the area of research but that stand to resolve some of the issues identified in traditional approaches.
3. The investigation of methods to resolve remaining issues and deliver a unique contribution to the academic literature, including an in-depth case study.
4. The aggregation of findings to propose a new model.

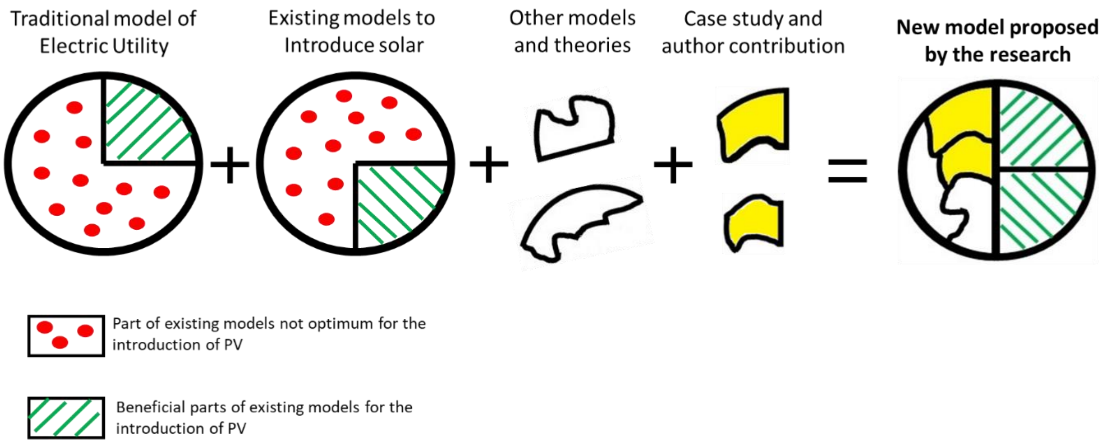

Figure 8: Infographic representing the Research Methodology

1.4 Thesis Structure

The thesis begins by presenting research findings based on the consideration of the feasibility of traditional responses by precinct-scale energy utilities to the potential to introduce solar energy technology onsite. The findings identify specific barriers and benefits related to the application of existing models in order to inform new approaches to underpin the effective transition to solar energy. At this point, the thesis presents gaps in the literature concerning the introduction of solar generation on commercial and industrial precincts fitted with an embedded electricity network. More particularly, a gap in the study of the introduction of solar energy on an existing precinct with real-life scenarios and feedback from the stakeholders.

To fill this gap, the thesis presents findings from a literature review of suggested new models and theories from a range of expected and perhaps less expected sources, in Chapter 5. This exercise gave rise to suggestions of what could be a new approach. The thesis then presents findings of a practical research project on an existing commercial and industrial precinct looking at introducing solar energy to create a case study, detailed in Chapter 6, in order to see if the new approach could be cost-effective and efficient for all parties concerned.

Finally, from the assessment of mainstream models, the support of suggested new models and theories, and the lessons learnt from the case study, the thesis aggregates research findings to propose a suite of new approaches in Chapter 7 as part of the 'Industrial Village Energy Model'. The proposed new model provides the basis to answer the main research question, namely:

'*How can an industrial precinct, fitted with an embedded electricity network, transition to cost-effective long-term onsite solar energy?*'

The approach to each question is summarised in the following schematic flow chart (Figure 9) to show what was done to answer them.

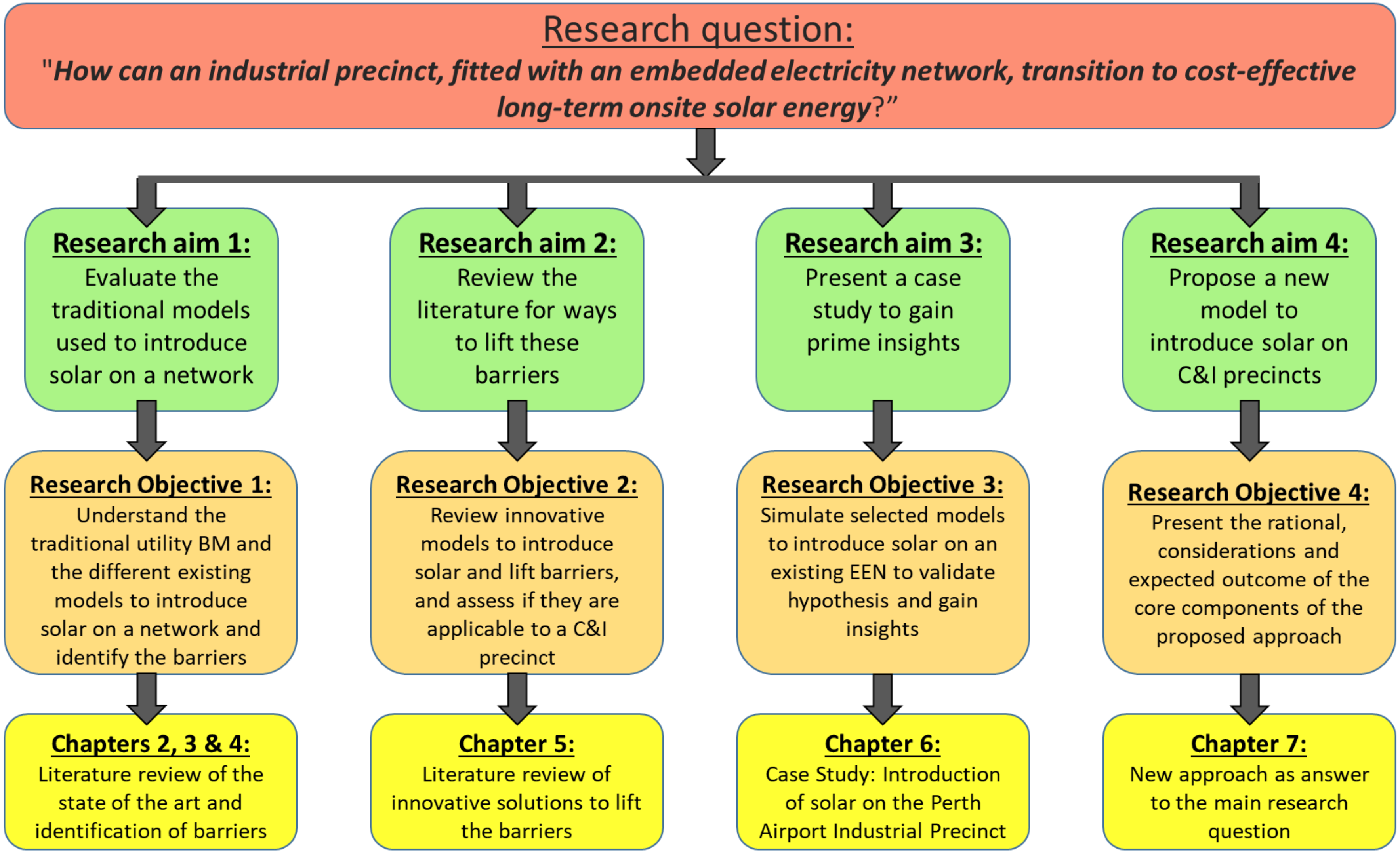

Figure 9: Schematic flow chart illustrating the research framework, and the connection between the main research question, the aims and the objectives.

Chapter 2: The Traditional Electric Utility Business Model

Sub-question #1: Are the traditional theories and existing mainstream models capable of supporting the effective transition of an industrial precinct to solar energy?

Aim of Chapter 2: Set the foundation of the research by presenting an understanding of the traditional business model and theories underpinning the electric utility.

Objective of Chapter 2: Literature review of the origin and history of the electric utility and the business model that was consequently developed. Understand the related principles and theories and why they have become obsolete. Identify gaps in the traditional approach for further consideration.

2.1 Introduction

Both grid scale energy utilities and embedded utilities around the world are using a variety of business models; however, at their core they are often minor variations of the business model adopted by the early electric utilities that has been used globally for the major part of the twentieth century. Therefore, it was necessary for this research to begin with the study of the origins of the electric utility in the late nineteen hundreds and the business models and economic theories that developed from it. To set a robust foundation for the study of the introduction of solar energy on the network, the research also looked at how the traditional business model evolved over the twentieth century and into the twenty-first century, and the disruptions that have forced this model to evolve.

2.2 History of the electric utility and its business model

2.2.1 A brief history of electricity technology

The discovery of electricity as a source of energy and its first applications date back to the eighteenth century with the invention of the battery by Alessandro Volta, which was improved by other scientists during the beginning of the 19th century (Hausman *et al.*, 2008)[23]. These batteries were charged by replacing their chemicals rather than with a generator, and supplied electricity to industrial processes such as electroplating, while also being used as part of early trials of electric lighting (De Santillana, 1965)[24]. The invention of the electric generator in 1831 accelerated the development of electricity and slowly began to replace these batteries.

The technology used in the first generators was not robust enough to allow the expansion of the use of electricity, but that changed in the 1860s with the development of 'dynamo-generators'. By the mid-1870s, they were powerful enough to run several lights in series for street lighting or to supply private users such as factories and large buildings. However, all applications still used isolated power plants to serve local needs. By the beginning of the 1880s, electricity reached the transport industry and started to replace the steam engine or the draft animal in trams with electric motors.

[23] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.
[24] De Santillana, G. (1965) Alessandro Volta. *Scientific American*, 212(1), 82-91.

Following closely on the footpath of the Americans and the Europeans, Australia began to use electricity commercially in 1882 in Brisbane in Queensland, and in Tamworth in New South Wales which was the first town in the Southern Hemisphere to light its streets with electricity on 9 November 1888 (The Australian Geographic, 2013)[25]. At the time, electricity networks were privately owned and locally operated, with the generation as close as possible to the end-users in order to limit the length and cost of the distribution network (Trebing, 1985)[26]. This situation translated into a multitude of utility companies each running their own assets and business model. For example, each tram company had its own generator located close to the line, and the network was limited to the tram line and neighbouring streetlights. Each tram company had its own utility company and energy assets. It was a highly decentralised system, one that is now seeing a renaissance.

While Edison is often remembered as the inventor of the incandescent light bulb, he also created a new form of electricity network to compete with gas-lighting, and, with it, the birth of the modern electric utility (Hargadon and Douglas, 2001)[27]. The idea immediately took off, and Edison’s company General Electric went on to be one of the largest companies in the world. Unlike gas-lighting, which had distribution systems already well established, electric-lighting was reserved for large-scale users as it had to be operated by trained staff from the utility company. Edison understood that to compete with gas-lighting, electric lights had to be individually controlled, and the control had to be in the hands of the customers, not the utility (Hausman *et al.*, 2008)[28]. In response to this, Edison developed a new type of distribution system, using Alternative Current (AC) instead of the existing Direct Current (DC) system used by arc lights, and allowing every light bulb to be operated independently from the others and operated simply via a switch near the lamp (Hargadon and Douglas, 2001)[29].

As electricity became the energy of choice over gas and more and more users were asking for it, economy of scale became possible. Utility companies had to manage the expansion of the distribution network to serve more and more consumers, as well as

[25] The Australian Geographic (2013) On this day Sydney gets electricity. The Australian Geographic.
[26] Trebing, H. M. (1985). America's Electric Utilities: Past, Present, and Future. *The Energy Journal*, *6*(3).
[27] Hargadon, A., and Douglas, Y. (2001) When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, 46(3), 476-501.
[28] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.
[29] Hargadon, A., and Douglas, Y. (2001) When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, 46(3), 476-501.

the construction of larger power stations called 'central power plants'. Utility companies also had to build the associated transmission network since new central power plants were located well away from users (mostly in cities) where real estate was less expensive or where the primary source of electricity was: close to coal mines or steep hills for hydroelectricity. The quickly growing distribution and transmission network also allowed multiple generators to contribute electricity to the system which increased reliability, whereas connecting a higher diversity of customers having needs at different times of the day contributed to steadying the demand (Hausman *et al.*, 2008).

Electricity quickly became key to economic and social development, leading governments in developed countries to create reforms to ensure it developed as rapidly, equitably and cheaply as possible. It started in 1907 with the states of New York and Wisconsin, who created a public utility regulatory commission to control electric companies (Throgmorton, 1996)[30]. The latter would be structured with vertical integration of the various functions along the supply chain (i.e. generation, transmission, distribution, and retail) for ease of regulation. Moreover, because of the capital-intensive infrastructure required and the intention to promote the economy of scale, these new companies were enshrined as ‘natural monopolies’ over the service area that corresponded to their government jurisdiction (Hausman *et al.*, 2008[31] and Brady, 1996)[32].

2.2.2 Development of the electric utility governance model

With the creation of the public regulatory commission in 1907 (called the ‘energy regulator’ in Australia), the electricity sector effectively set up a governance model that is still in use today in most countries. The role of the energy regulator is to ensure the utility delivers reliable and affordable (and now clean) electricity to all users while providing the utility’s investors with a fair return on investment by setting the rates. Effectively, the energy regulator is responsible for the balance of interests between the energy customers and the electric utility. The energy regulator represents the customers’ expectations, but as voters, energy customers can also voice their opinions

[30] Throgmorton, J. A. (1996) Planning as persuasive storytelling: The rhetorical construction of Chicago's electric future. University of Chicago Press.
[31] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.
[32] Brady, F. (1996). Contribution on Australia: A dictionary on electricity. In *international conference on large high voltage electrical systems. Australia National Committee of CIGRE*.

and expectations through the government, who then commands the energy regulator. In this instance, the government acts as a buffer between consumers and the energy regulator as well as an aggregator of voices to inform the regulator of shifts in expectations.

The diagram shown in Figure 10 gives a simplistic representation of the governance on the public electricity grid.

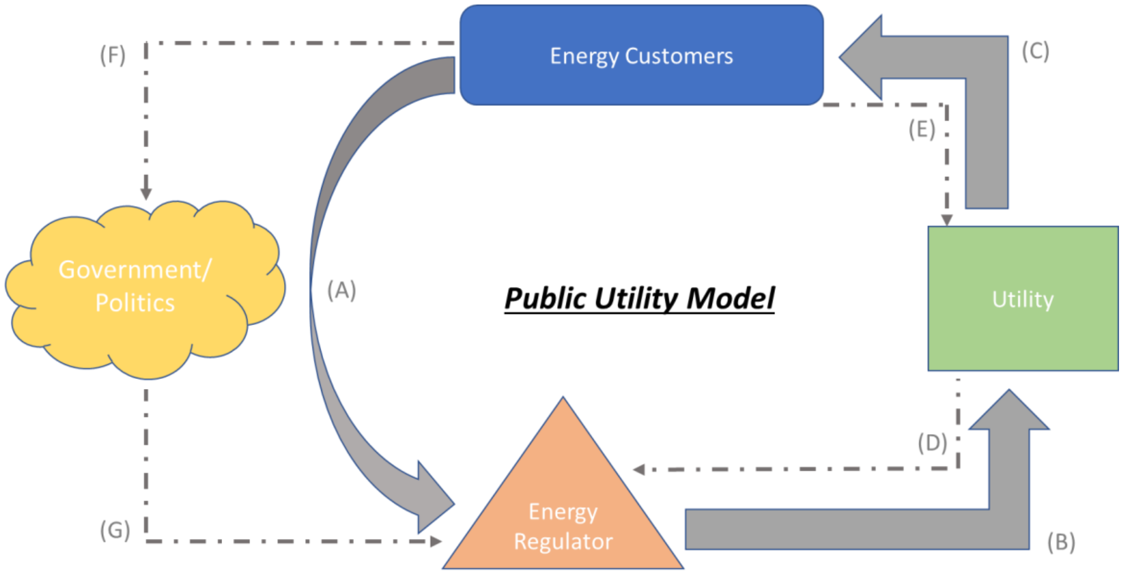

Figure 10: Simplistic representation of the governance model on the public Grid

With:

(A) The energy regulator representing customers' expectations

(B) The energy regulator sets the rates and targets for the utility.

(C) The utility delivers the service (network and energy).

(D) The utility can propose alternative solutions (e.g. rate change, rule change, new business models) to the energy regulator.

(E) More recently, energy customers have started sending direct and indirect feedback to the utility (e.g. switching energy retailer or investing in behind-the-meter rooftop solar energy and battery).

(F) Energy customers, as voters, can also voice their preference directly to the government (e.g. appetite for clean energy) who would then pass it on to the energy regulator for implementation.

2.2.3 *The traditional economic theory of utilities: The 'Cost Recovery' Theory*

The energy regulators were placed in charge of setting energy rates for customers, using a modernist approach to rate regulation (Gormley, 1983)[33]. The energy regulator would base the rates on the revenue required by the utility company to fulfil its duty of offering reliable and affordable energy to the largest possible customer base. This revenue was calculated taking into account, on the one hand, the investment necessary to generate and distribute energy, plus related dividends to investors, called 'fair rate-of-return', and on the other hand, the operating costs including the cost of fuel, labour and taxes (Phillips Jr., 1993)[34].

This approach is called the 'Cost Recovery' model (also called the 'cost-of-service' model mostly in the USA) and it is based on forecast sales of electricity, resting on the assumption of continued growth in energy sales (Sioshansi, 2012[35] and Rochlin, 2016[36]). Utility revenue is therefore regulated by the energy regulator who must also approve new investments since growing the asset base will automatically increase the rates (Throgmorton and Fisher, 1993)[37]. Nevertheless, since utility companies have the duty to provide for future needs of the population (growing load) and to supply electricity to all customers in the name of social equity (including regional and new developments), they have been steadily investing in new generation and in expanding the network, therefore increasing the base of tangible assets used to calculate the dividends in the rates, which increased accordingly.

This model continued for decades, but with the post-war baby-boom and the sprawl of cities on the one hand, and the development of electrical equipment and home appliances in the other, investment in new generation and network assets grew significantly in the fifties and sixties in developed countries. Nevertheless, the increase in the regulated revenue was balanced by a growing number of ratepayers as well as a growing volume of electricity sold, so that the impact on the rates (end-users electricity bills) was minimal and largely unnoticed.

[33] Gormley Jr, W. (1983) The politics of public utility regulation, University of Pittsburgh Press.
[34] Phillips, Jr., C. (1993) The Regulation of Public utilities: Theory and Practice (3rd ed.) Public Utilities Reports, INC., Arlington Va. USA
[35] Sioshansi, F. P. Telaretti the Time Has Arrived to Rethink the Electric Business Model. *The Electricity Journal*, 25(7), 65-74
[36] Rochlin, C. (2016) Distributed renewable resources and the utility business model. *Electricity Journal*, 29(1), 7-12.
[37] Throgmorton, J. and Fisher, P. (1993) Institutional change and electric power in the city of Chicago, *Journal of Economic Issues* 27(1): 117. P67

2.2.4 Considering the Cost Recovery Model

The cost recovery model is still used today for the part of the utility that remains regulated, which in most cases is the part in charge of the transmission and distribution networks. Figure 11 from the Grattan Institute (Wood *et al*., 2018)[38] shows the average distribution of the source of utility revenues, with depreciation as the value of the capital invested in the infrastructure and the Weighted Average Cost of Capital (WACC) as the return on the capital invested.

This portion of the network revenue is dependent on the net invested capital which corresponds to the gross capital invested minus the accumulated depreciation (AEEI, 2018)[39]. However, to serve as a base to define the depreciation and the WACC, the infrastructure corresponding to this invested capital must be recognised as used and useful by the energy regulator. It is consequently called the Regulated Asset Base (RAB) and the revenue from it is called the RAB revenue (shown as the blue sections of Figure 11), which has a major impact on the rates (i.e. on how much customers pay).

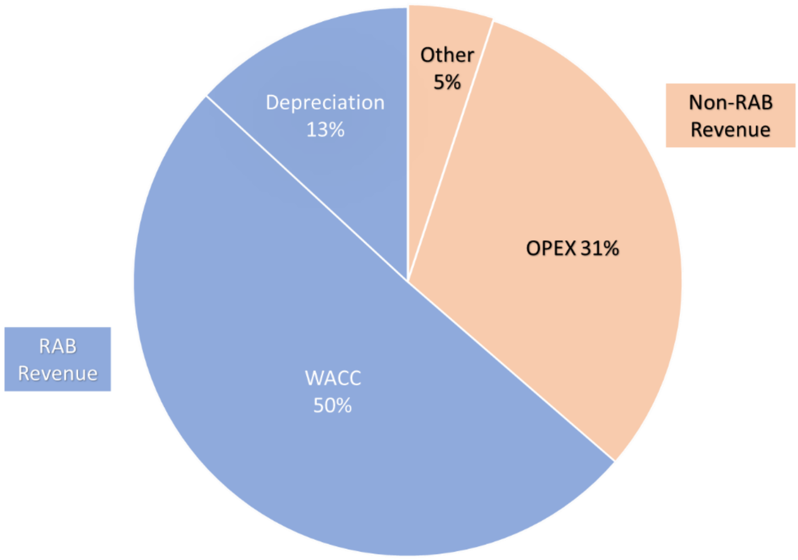

Figure 11: Average share of network revenue on the NEM 2017-18

Source: Data from Grattan analysis for the Australian energy regulator, 2018

The WACC takes a large portion of the revenue required by the utility because it is necessary for a utility with capital-intensive services to attract investors to finance infrastructure replacement, modernisation and expansion. Understandably, investors

[38] Wood, T., Blowers, D., and Griffiths, K. (2018) Down to the wire: A sustainable electricity network for Australia. Grattan Institute.

[39] AEEI (2018) Utility earnings in a service-oriented world, San Francisco, CA: Advanced Energy Economy Institute.

would support the utility only if the rate of return on their investment is competitive to other investments with similar risk and term (Tomain *et al*., 2004)[40].

2.2.5 Ratemaking

Rates

Rates were created as part of the formation of the electric utility, and their design (referred to as 'ratemaking') became more focused and complex in the first half of the twentieth century (Dakin, 1963)[41]. Based on the regulated revenue approach described above, the utility defines a *rate structure* approved by the energy regulator, that designates the rates to be charged (Throgmorton, 1996)[42]. In 1961, J. Bonbright came up with the five principles of rate design (Bonbright, 1961)[43] which became the fundamental criteria for any Cost Recovery (or *Cost of Service*) ratemaking:

1. Capital attraction.
2. Reasonable energy pricing.
3. Incentive to be efficient.
4. Demand control and consumer rationing.
5. Income transfer.

The function of 'capital attraction' to sustain necessary investments was explained in the previous section. 'Reasonable energy pricing' relates to the principle of affordable electricity supply expected from an organisation providing public services and also supports the principle of gradualism to restrict utilities from imposing sudden rate increases (Moran and Ball, 2018)[44]. The 'incentive to be efficient' and 'demand control and consumer rationing' items relate to the law of demand stating that "*conditional on all else being equal, as the price of a good increases, quantity demanded decreases; conversely, as the price of a good decreases, quantity demanded increases*" (Nicholson and Snyder, 2012)[45].

[40] Tomain, J., Cudahy, J., Trotta, J., and Cudahy, R. (2004) Energy law in a nutshell. *Energy Law Journal*, *32*: 631.
[41] Dakin, M. (1963) Review of *Principles of Public utility Rates*. Journal of Legal Education. Vol. 15, No. 3 (1963), pp. 358-362
[42] Throgmorton, J. (1996) Planning as persuasive storytelling: The rhetorical construction of Chicago's electric future: University of Chicago Press.
[43] Bonbright, J., Danielsen, A., and Kamerschen, D. (1961) Principles of public utility rates. New York: Columbia University Press.
[44] Moran, C. and Ball, C. (2018) Structuring Better Caps for Sustainability Incentive Programs. *Idaho Law Review*. 54: 177-211
[45] Nicholson, W. and Snyder, C. (2012) Microeconomic Theory: Basic Principles and Extensions (11 ed.). Mason, OH: South-Western. pp. 27-154.

This means that the price of electricity must be set high enough to promote efficiency on the customer side and, associated with time, for example, can support the utility in controlling the demand. Finally, ratemaking serves to 'transfer income' from the users (the energy customers) to the provider (the utility).

Phillips (1993)[46] noted that the goals of ratemaking could conflict. For example, between 'reasonable energy pricing' and both 'incentive to be efficient' and 'capital attraction'. He explained that ratemaking supports the interests of the utility and its shareholders, and is a wrestle between the energy regulator that defends the interest of the consumers and the general public (and by some extent, the international competitiveness of the nation). Ratemaking is, therefore, an economic and technical but also a political and social exercise (Averch and Johnson, 1962)[47].

Costs covered by the electricity bills

Throgmorton summarised the costs to supply electricity to customers into three categories (Throgmorton, 1996):

1. Demand costs dependent on the customer’s peak demand (expressed in kW), to cover the utility’s generating capacity and cost of building it.

2. Energy costs dependent on the volume of energy imported by the customer (expressed in kWh), to cover the utility’s [primary] energy and other operating costs.

3. Customer costs dependent on the number of customers [and the number of days served], to cover the utility’s cost of metering, accounting, and billing its customers.

Using the three categories 'peak demand', 'energy volume' and 'number of customers',

Table 1 attempts to list the costs involved in the supply chain, grouped by actors in a typical electricity sector supply chain found around the world. Each cost is then

[46] Phillips, Jr., C. (1993) The Regulation of Public utilities: Theory and Practice (3rd ed.) Public Utilities Reports, INC., Arlington Va. USA
[47] Averch, H. and Johnson, L. (1962) Behavior of the Firm Under Regulatory Constraint. *The American Economic Review*, 52(5): pp. 1052-1069.

identified to be dependent on either peak demand (PD), energy volume (E) or number of customers (C).

Table 1: Factors influencing the costs of the electricity supply in a typical deregulated electricity supply chain

DEREGULATED ELECTRICITY SECTOR		
Actor	**Cost**	**Factor**
Generator	Plant (CR)	PD
	M&O	E
	Fuel	E
TSO/DSO	Transformers (CR)	PD
	Poles&wires (CR	PD
	M&O	PD
	Quality Mgt (CR)	PD
Market operator	Forecast	C
	Scheduling	C
	Market Mgt	PD
	Reserve capacity	PD
Retailer	Metering	C
	Accounting	C
	Billing	C

As the capital cost of power plants and network assets are mostly driven by their peak capacity (Glover *et al*., 2016[48]), their capital recovery costs (noted ‘CR’ in the table) are peak demand dependent. This simple table allows us to visualise that the costs incurred by the transmission system operator (TSO) and the distribution system operator (DSO) are mostly dependent on peak demand, including the regulation of voltage level and frequency (i.e. electric power quality management noted ‘Quality Mgt’ in the table) involving specialised features at sub-stations and in transformers (Glover et *al*., 2016). Overall, most costs incurred in the supply chain are peak demand dependent.

An adapted version of Table 1 is shown in Table 2 for the case of a ‘basic embedded network’ defined as an embedded network with no embedded generation (all electricity imported from the main grid or other external sources). All the costs ‘greyed’ are considered throughput to the embedded customers. Table 2 again

[48] Glover, D., Overbye T. and Sarma, M. (2016) Power System Analysis & Design. 6th ed., Cengage Learning, Inc., Mason, OH, United States.

reinforces that the costs incurred by the embedded network operator are not dependent on the volume of energy but mostly on peak demand.

Table 2: Factors influencing the costs of the electricity supply on a basic embedded network

BASIC EMBEDDED NETWORK		
Actor	**Cost**	**Factor**
Main grid	Plant (CR)	PD
	M&O	E
	Fuel	E
Embedded utility	Transformers (CR)	PD
	Poles&wires (CR	PD
	M&O	PD
	Quality Mgt (CR)	PD
Embedded utility	Forecast	C
	Scheduling	C
NA	Market Mgt	PD
Main grid	Reserve capacity	PD
Embedded utility	Metering	C
	Accounting	C
	Billing	C

However, since it is easier to meter and understand 'energy' compared with 'power' (peak demand), historically the utility has been using the volume of energy imported (and therefore consumed) by the customers as a reference to cover most of the costs (listed in Table 2). This method, though working with averages and approximations, has served energy utilities and their customers reasonably well for most of the twentieth century. At least as long as utilities were vertically integrated, and the payments from customers was covering the cost of the entire supply chain(Pérez-Arriaga and Bharatkumar, 2014)[49].

Nevertheless, customers are not aware of the actual fixed costs incurred to supply them with electricity, called the 'non-energy services', such as the transmission and distribution infrastructure, balancing of supply and demand, and managing a reserve of capacity (Wood and Hemphill, 2016)[50]. Moreover, there is a general misunderstanding by customers that the variable portion pays for energy generation

[49] Pérez-Arriaga, I. and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.
[50] Wood, L. and Hemphill, R. (2016) Recovery of utility fixed costs: utility, consumer, environmental and economist perspectives. Lawrence Berkeley National Laboratory. Future Electric utility Regulation, Report 5.

and the fixed portion and the demand charge pay for all the other costs, including the network. The reality is that many fixed costs are covered by the variable energy portion of the bill. Consequently, this method has led to the current situation where some important costs not related to the volume of energy delivered, like the network costs, are effectively billed in proportion to the energy delivered to the customers.

Categories of customers and tariffs

With the growing number of customers and the diversity of consumption patterns during the first half of the twentieth century, utility companies grouped customers in classes of users with *a priori* similar energy consumption patterns, and on the type of connection to the network (Pérez-Arriaga and Bharatkumar, 2014)[51]. A retail tariff was then defined for each class which has largely been maintained. For example, Synergy[52], the government-owned electricity supplier in Western Australia, publishes the regulated tariffs for business customers depending on the voltage connection and average volume of energy, as follows:

- M1 and T1 tariffs for business customers who have electricity supplied at a high voltage (e.g. 6.6kV, 11kV, 22kV or 33kV).
- R1 and R3 tariffs available for both low/medium voltage (240V/415V) and high voltage (e.g. 6.6kV, 11kV, 33kV) connections.
- L1, L3 and S1 tariffs for business customers who have electricity supplied at low/medium voltage (240/415 volts).

Therefore, on the South-West Interconnected System (SWIS) of Western Australia, two levels of connection voltage are used to define customer classes: Low/Medium Voltage (L/MV, 240V/415V) and High Voltage (HV, 6.6kV to 33kV). Residential and small business customers connected to the low voltage lines, for example, are expected to have insignificant peak demand (individually) and are gathered on tariffs with no demand component, only a variable portion based on energy import, in $/kWh and a fixed portion (regardless of energy usage) in dollars per day. The price of electricity may be flat across all hours of the day or vary based on time of consumption (Alt,

[51] Pérez-Arriaga, I. and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.
[52] Synergy (2020) Electricity plans for your business. Synergy.

2006)[53]. Larger consumers, such as commercial and industrial customers are often directly connected to a medium voltage and even a high voltage line and have an additional component in their bill, based on their peak demand, expressed in dollars per kW.

An alternative exists called “unbundled bills”. In this format, energy, network and other costs are calculated and displayed separately on the bill. For example, an unbundled bill from Synergy would include the following components:

- An on-peak energy charge based on energy consumption during on-peak time.
- An off-peak energy charge based on energy consumption during the off-peak time.
- A supply charge based on the number of days in the billing period.
- A capacity charge to contribute to ancillary services.
- A renewable energy scheme charge to fund renewable energy programs.
- A network charge to pay for the use of the network, based on a Contracted Maximum Demand (CMD).
- An excess network usage charge as a penalty for when the peak demand exceeds the CMD.
- A fiscal tax applied to the total.

This format is not preferred by the energy retailer as it provides less freedom to average calculations and allows closer scrutiny of the usage and associated charges by the customer. Therefore, this format is usually reserved for very large customers whose impact on the public grid and energy market is significant.

[53] Alt, L. (2006) Energy utility Rate Setting, Lulu.com.

2.3 Weaknesses revealed through disruptions of the established model of the electric utility

2.3.1 The traditional model did not foster efficiency

The traditional structure of the electric utility and its business model that have been used with some success for almost a century was disrupted for the first time when the two oil crises struck the world in the seventies. Back in the fifties, because fossil fuel prices were increasing slowly and steadily, regulators accepted that the rates would need to be adjusted automatically by the utility according to variations in fuel costs. In the same period, the volume of electricity consumed rose steadily, and investors enjoyed a comfortable rate of return since investing for future demand growth was always met by that growth in the volume of energy sold. This comfortable financial situation, free of competition or other pressure, allowed the utilities to carry on with business successfully without having to seek further efficiencies (Hausman *et al.*, 2008)[54]. In the sixties, Averch and Johnson (1962)[55] criticised this model and warned that it had a weakness in that it was not encouraging utilities to seek efficiency or promote investment optimisation.

In the seventies, the price of oil became unstable following a suite of events outside the control of developed countries. The price increases started in 1971 with a small price rise imposed by the Organization of the Petroleum Exporting Countries (OPEC), followed by a sixfold price increase of crude oil during the 1973 Arab–Israeli War (‘*Kippur war*’), and a further three fold increase after the invasion of Iran by Iraq in 1980 (Castaignede, 2018)[56]. It was only when oil and gas prices spiked so dramatically that the weakness of the system was confirmed. The rapid rise in fuel cost triggered automatic rate rises until the regulators took control back over the adjustment of rates (Throgmorton and Fisher, 1993)[57].

The short-term reaction of the energy regulators was to disavow some of the investments made in energy generating assets that were made ahead of an anticipated growth in demand that would now not happen as expected (Hausman *et al.*, 2008)[58].

---

[54] Hausman, W., Hertner, P. and Wilkins, M. (2008) Global Electrification, Cambridge Books.
[55] Averch, H. and Johnson, L. (1962) Behavior of the Firm Under Regulatory Constraint, *The American Economic Review*, 52(5): 1052-1069.
[56] Castaignede, L. (2018) “Airvore ou la face obscure des transports” Ecosociete, Montreal, Canada.
[57] Throgmorton, J. and Fisher, P. (1993) Institutional change and electric power in the city of Chicago, *Journal of Economic Issues* 27(1): 117.
[58] Hausman, W., Hertner, P. and Wilkins, M. (2008) Global Electrification, Cambridge Books.

However the longer-term solution was to encourage efficiency gains across the energy generation sector by introducing competition. The solution, implemented in the 1980s in the US and Europe and the 1990s in Australia, was to break the vertical monopolies through deregulation, occasionally opening them back to privatisation, including to foreign investors, in the hope of fostering innovation and efficiency (Hausman *et al*., 2008).

According to the World-Bank in 2003: "*Since the 1950s, the power sector had been dominated by government-owned monopolies over the full range of sector activities from production to distribution. This was in accordance with the prevailing notion that large-scaled technologies and their high fixed costs favored state financing, and that monopoly stewardship by the state enhanced consumer welfare. The sector was also considered critical to national security and a tool with which governments might pursue social equity objectives in their development efforts. These views prevented competition and discouraged foreign investments. From the 1980s, however, the promise of greater efficiency through market-base competition and technological advances encouraged the vertical unbundling of power generation and an increase in private investment.*" (Manibog, 2004)[59]

Nevertheless, the restructuring of the industry by unbundling the generation, transmission, distribution and retail of energy did not trigger a change in the established 'Cost Recovery' strategy. Indeed, if unbundling and privatisation fostered competition, the electricity industry remained a specialised and capital-intensive market, and the number of new players remained limited. Consequently, the 'Cost Recovery' model remained largely unchanged.

2.3.2 Signs of change and beginning of the transition

Large-scale renewable energy plants, made financially viable by the introduction of competition in the generation sector and the development of the photovoltaic technology for space applications (Meinel and Meinel, 1977)[60], grew in response to the awareness of the risk, following the oil crisis, for countries to be dependent on fossil fuel sources. It started as early as 1982, with a 1 MW solar park near Hesperia,

[59] Manibog, F. (2004) Power for Development: A Review of the World Bank Group's Experience with Private Participation in the Electricity Sector, Washington, DC, World Bank.
[60] Meinel, A. and Meinel, M.(1977) Applied solar energy: an introduction. NASA STI/Recon Technical Report A, 77.

California (Arnett *et al*., 1983)[61], followed by 5.2 MW in Carrizo Plain, California in 1984 (Wenger *et al*., 1991)[62]. However, these large-scale renewable energy systems such as hydro turbines, wind turbines and solar farms were still centralised, away from the users and connected to the existing transmission network, just like the traditional centralised fossil-fuel generators. Therefore, they did not seem to disrupt the vertical organisation of utilities, their business model and the one-way flow of energy from generation to consumption.

Nevertheless, something new was introduced: the possibility for consumers to buy “green energy”, i.e. to pay a premium to link their consumption to the production of electricity from specific forms of generation. This was the first real disruption in the established model as it created, for the first time, a link between the consumers downstream, and the generators upstream. At the time the disruption was minimal since the link was not physical but rather financial with all forms of generated electricity being merged in the network.

However, its social impact was a real disruption as it kick-started the idea that for the first time end-users could have a say in the type of generation that was fulfilling their expectations. This practice came at a time when people were starting to become aware of global warming and began to question where their energy was coming from. Indeed, while for decades electricity was seen as a resource “by default” for which consumers didn't pay much attention to (in cities at least) as long as the lights would turn on, it suddenly became part of the discussion about the possible exhaustion of the fossil fuel stocks and, most importantly, about the impact of energy generation on our health and the health and quality our planet in general (Shannon, 2016)[63].

2.3.3 The traditional model strives on an ever-growing demand

With the oil crisis of the seventies, energy supply, energy consumption, energy bills and energy scarcity became widely used terms and became concerns consumers , businesses and industries. It became clear that using less energy was beneficial for economic, environmental and health reasons and more so that it was feasible. Indeed,

[61] Arnett, J., Schaffer, L., Rumberg, J., and Tolbert, R. (1984) Design, installation and performance of the ARCO Solar one-megawatt power plant. Proceedings of the Fifth International Conference, Athens, Greece. EC Photovoltaic Solar Energy Conference: 314

[62] Wenger, H., Schaefer, J., Rosenthal, A., Hammond, B., and Schlueter, L. (1991) Decline of the Carrisa Plains PV power plant. Photovoltaic Specialists Conference, Conference Record of the Twenty Second IEEE. IEEE.

[63] Shannon, R. (2016) Bringing the customer to the market: A new utility business model, *The Electricity Journal*, 29(5): 15-18.

in reaction to the rate rise, consumers and industries reduced their consumption of electricity by changing their behaviour and looking for energy efficiency solutions.

However, it was not until the nineties, when global warming was seen as a clear public responsibility and responding to it became a global effort, that reducing electricity consumption to reduce greenhouse gas emissions from fossil-fuel power plants became a primary concern. Simultaneously, utility companies began to see a quicker way to match generation by using demand management rather than by building new power plants (Ford, 1997)[64]. Therefore, from the end of the nineties governments around the world introduced incentives to promote – or regulations to enforce – energy efficiency solutions to greater or lesser extent.

The consequence was a demand curve that left its fast-growing trend at the end of the seventies to slow down and eventually plateau in early 2010s. If the trend-change in the late seventies early eighties can be explained by a general slow-down in industrial activity (due to the price spike of energy), it does not apply to the following decades where there is a clear decoupling between energy demand and growth in GDP, or energy demand and growth in the population (Newman, Beatley and Boyer, 2017)[65]. Consequently, utilities struggled to plan the construction of additional power plants with this ever changing energy demand (Rochlin, 2016)[66] and regulators, entrenched in their Modernist rate-making practice, struggled to find a way to keep the rates down and protect the utilities at the same time.

2.3.4 From efficient consumers to prosumers

At the turn of the new millennium (or later for some countries), on top of seeking to use less energy, largely for the first time consumers could generate their own electricity, and this has caused significant disruption to the energy sector. This led to customers generating electricity with low-emissions renewable energy generators that where installed on the customers' premises, mostly on the roof, which was referred to as 'behind-the-meter' generation. By that time, the roll out of large-scale solar farms was well on its way and the photovoltaic (PV) technology was reaching maturity and

[64] Ford, A. (1997) System dynamics and the electric power industry, System Dynamics Review, *The Journal of the System Dynamics Society*, 13(1), 57-85.
[65] Newman, P, Beatley T and Boyer H (2017) Resilient Cities: Overcoming Fossil Fuel Dependence, Island Press, Washington DC.
[66] Rochlin, C. (2016) Distributed renewable resources and the utility business model, *Electricity Journal*, 29(1), 7-12.

cost started to fall. With a lower initial capital investment, PV systems became more accessible and more financially viable, allowing the spread of smaller installations, initially for remote off-grid applications and then to early adopters who installed solar PV panels on the roof of their houses and businesses.

With the help of government incentives, rooftop solar became even more affordable and hence available to a larger part of the population. Then, following the successful subsidisation of uptake came economies of scale and the unit price of solar panels plummeted to the point that it remained affordable even without subsidies. The spread of rooftop solar systems quickly grew with the proportion of roofs with PV installed reaching some 30 percent in some Australian suburbs by 2015 (Newton and Newman, 2015)[67]. In Australia, consumers are allowed to consume the electricity produced by their rooftop solar installation, referred to as 'auto-consumption'. Then, if the generation was greater than the load of the building, the excess energy could be fed back into the grid. The consumer exporting electricity to the grid is called a 'prosumer'.

At the scale of a consumer, the energy produced onsite and auto-consumed displaces the energy that was imported before the installation of rooftop solar. At the scale of the local distribution (a group of consumers in a street or a precinct), not only the auto-consumption reduces the energy need of that consumer, but the excess energy feeds neighbouring consumers without solar energy, thus reducing the energy need of that entire section of the distribution network (Ranamuka *et al.*, 2015)[68]. Consequently, both energy efficiency programs and rooftop solar installations have reduced the volume of energy needing to be delivered to consumers via central distribution systems. Figure 12 and Figure 13 show the demand for electricity on Australia’s National Energy Market which has decreased since a peak period in 2007-2009.

[67] Newton, P. and Newman, P. (2015) Critical Connections: The Role of the Built Environment Sector in Delivering Green Cities and the Green Economy, *Sustainability*, 7, 9417-9443.

[68] Ranamuka, D., Agalgaonkar, A., Muttaqi, K., and Alam, M. (2015) Mitigating Tap Changer Limit Cycles in Modern Electricity Networks Embedded With Local Generation Units, *IEEE Transactions on Industry Applications*, 52(1), 455-465.

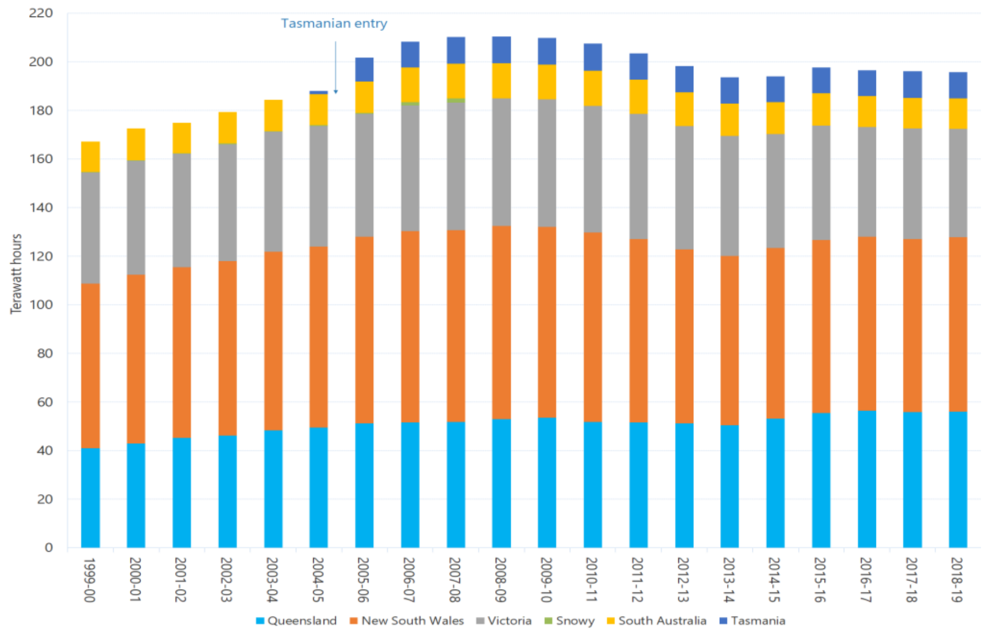

Figure 12: Actual energy consumption on the Australian National Energy Market (the NEM, which does not include WA)

Source: AER and AEMO, 2019[69]

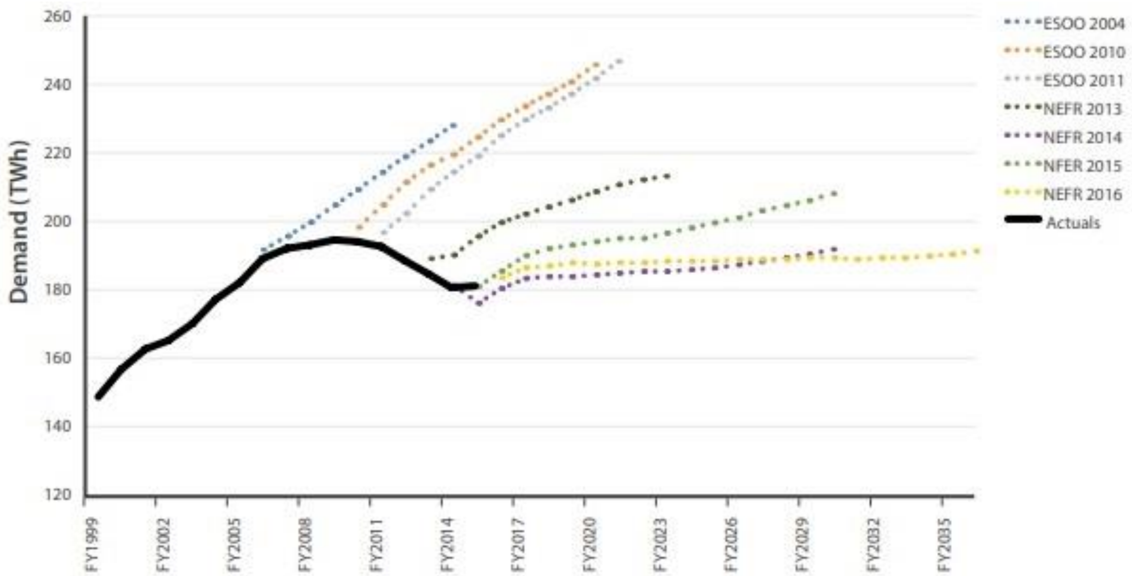

Figure 13: Demand forecast - actual vs historical

Source: Finkel, et al, 2017[70]

[69] AER (2019) Annual electricity consumption - NEM, dataset. Australian Energy Regulator.
[70] Finkel, A., Moses, K., & Munro, C. (2017) Independent review into the future security of the national electricity market: blueprint for the future [Finkel review].

The consequences of the uptake of customer-owned distributed solar, mostly on rooftops, and energy efficiency efforts, on the traditional utility business model are explained in the following sections.

Electricity bills cover demand-related costs with the sale of energy

As explained in Section 2.2.5, in the traditional model the variable portion of an electricity bill (based on energy consumption) also contributes to non-energy related costs such as the cost associated with the network or reserve capacity. Furthermore, energy efficiency programs and rooftop solar reduce the average consumption of electricity but have a limited influence on the peak demand. Consequently, these options may reduce the revenue of service providers by reducing overall demand without reducing their cost to deliver electricity given the peak is relatively untouched, such as maintaining and expanding the network and ancillary services (Faruqui and Lessem, 2014)[71].

Since a large portion of the revenue for the utilities is based on the overall sale of energy and the rate of growth in the demand for energy has typically reduced (As shown in Figure 13), energy regulators have often been pressured to approve an increase in rates to allow the utilities to receive preferred revenues. However, the result of this is typically to encourage customers to seek to lower their energy consumption even more in order to reduce their energy bill, which in turn reduces revenue for utilities even further. This phenomenon was called the "*Utility Death Spiral*" by Professor Andrew Ford in 1997 (Ford, 1997)[72] and has gained popularity in the 2010s with the rapid growth in the uptake of rooftop solar. This uptake of customer-owned generation created an endless loop where the reduced sale of energy would undermine network provider revenues, who would then request the energy regulator to raise the rates, encouraging more customers to invest in rooftop solar.

Nowadays, this loop is fuelled by customers investing in behind-the-meter energy storage, reducing further their energy demand from the grid with some customers generating enough onsite electricity not to need the grid. In the case that a substantial amount of customers go 'off-grid' network utilities would see their customer base

[71] Faruqui, A. and Lessem, N. (2014) Comments on Massachusetts Department of Utilities Notice, DPU 14-04, Investigation by the Department of Public Utilities into its own motion on Time Vary Rates. Technical report, The Brattle Group.

[72] Ford, A. (1997) System dynamics and the electric power industry. System Dynamics Review: The Journal of the System Dynamics Society, 13(1), 57-85.

shrink, this time reducing their revenue from the fixed charge these customers were paying, while still having to maintain the same network. Therefore, the traditional design of rates based on the principle that some capital cost can be recovered through sales of energy is not compatible with the evolution of the energy system with growing levels of behind-the-meter generation along with consumers seeking to reduce overall demand through energy efficiency (York and Kushler, 2011[73]; Sioshansi, 2012)[74].

2.3.5 The traditional utility model makes it difficult to engage with customers

After the second world war, electricity became a resource 'by default' for which consumers forgot to care about, at least in cities (Hausman *et al*., 2008)[75]. They typically did not want to be involved in energy supply and, as Hausman *et al*. (2008) [76] pointed out, customers just wanted "*the light to turn on when the switch was flipped*" and affordable bills. Even some eight years later Shannon (2016)[77] pointed out that *"most people did not care where their electricity was coming from and how it was delivered to their homes and businesses; the most important things were that the lights would come on and the price was low"*.

Reciprocally, electric utilities considered their customers passive end-users and called them by what they represented to them: ratepayers. Commercially, the product supplied to customers was self-explanatory, and its sale was an 'automatic' business (Helm, 2016)[78]. However, as its price was regulated, the goal of utilities was to produce the largest possible quantity of electric energy at the lowest possible cost. As a result, this business approach was based on short-term oriented, impersonal and standardised relations between utilities and customers (Helm, 2016). One of the interviewees from Helm's research, the head of sales of a utility company, said "*In fact we have never actually sold; the customer came to us, he wanted something and then we served him. Today we have to go to the customer*".

[73] York, D., and Kushler, M. (2011) The Old Model Isn't Working: Creating the Energy utility for the 21st Century. White paper. American Council for an Energy Efficient Economy.
[74] Sioshansi, F. P. (2012) Why the Time Has Arrived to Rethink the Electric Business Model. *The Electricity Journal*, 25(7), 65-74.
[75] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University press.
[76] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University press.
[77] Shannon, R. S. (2016) Bringing the customer to the market: A new utility business model. *The Electricity Journal,* 29(5): pp. 15-18.
[78] Helms, T. (2016) Asset transformation and the challenges to servitize a utility business model, *Energy Policy*, *91*, 98-112.

Indeed, today, utilities are realising the importance of energy customers as they have evolved to become active network users, not only caring about where the electricity comes from (in reference to the environmental impact) and taking greater control over their consumption pattern, thanks largely to energy storage systems, programmable equipment and EV charging (Wainstein and Bumpus, 2016)[79], but also injecting energy back into the distribution network. On that topic, Perez-Arriaga and Bharatkumar (2014)[80] mentioned that until the proliferation of rooftop solar, electric utilities have typically built, operated, and maintained the network infrastructure necessary to supply energy customers, with limited feedback from those customers nor visibility or control over customers' activity behind the meter.

Even before the uptake of rooftop solar, Sioshansi (2000)[81] described how energy customers were interested in accessing their billing and consumption information online while most electric utilities did not provide this sort of information. Talking about the information available on utilities' web sites, he said: "*what customers want is not what they get.*". By 2014, Moreno-Munoz *et al*. (2016)[82] explained that energy customers were looking for personalised supports just like they had become used to receiving such support from other industries which had evolved to become consumer-friendly such as Banking and Telecommunications. Moreno-Munoz *et al*. added that this expectation of personalised support is complemented by *"a growing desire to regain sovereignty over the way they consume energy"*. More recently a 2019 survey from the Smart Energy Consumer Collaborative (SECC, 2019)[83] found that US consumers were also more educated and more willing to engage in tracking, understanding and controlling their energy consumption, with 40 percent of the respondents considering themselves "*Selectively engaged*" and 44 percent considering themselves as, "*Always engaged*".

---

[79] Wainstein, M. and Bumpus, A. (2016) Business models as drivers of the low carbon power system transition: a multi-level perspective. *Journal of Cleaner Production*, 126, 572-585.

[80] Pérez-Arriaga, I. and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. *MIT Center for Energy and Environmental Policy Research*.

[81] Sioshansi, F. (2000) E-commerce and the Energy Sector: The Pioneers May Not Get It Right; The Procrastinators Are Likely to Become History. The Electricity Journal, 13(5): 42-49

[82] Moreno-Munoz, A., Bellido-Outeirino, F., Siano, P., and Gomez-Nieto, M. (2016) Mobile social media for smart grids customer engagement: Emerging trends and challenges. *Renewable and Sustainable Energy Reviews*, *53*, 1611-1616.

[83] The Smart Energy Consumer Collaborative (2019) *Consumer Pulse and Market Segmentation Study*. The Smart Energy Consumer Collaborative.

Customer engagement and participation is, therefore, increasingly important in the quickly evolving energy sector (Verbong *et al*., 2013)[84]. Nevertheless, even if utilities understand that in order to enable more efficient and sustainable operations they need to consider network users as partners, they are struggling to engage with them (Sioshansi, 2000[85]; Moreno-Munoz *et al*., 2014[86]; Shannon, 2016[87]). Hence the findings of the research suggest that there is a gap between what customers want and what utilities offer, and that utilities are struggling to engage with their energy customers, and particularly their prosumers, leading to the need for new approaches.

2.3.6 Consequences of the lack of consultation and engagement with customers

The traditional utility approach also fails to consult customers to understand their priorities and levels of acceptance of the current situation in order to offer them the best service. Catney *et al*. (2014)[88] who studied societal justice through the emergence of community solar projects noticed than energy customers are not often consulted about where, when, nor how, renewable energy projects, private or utility-owned, are built. Similarly, Gui and MacGill (2018)[89] observed that in response to perceived inadequacy of utility decisions regarding electricity offers and investments, customers, who have become active energy users, are challenging the established regime where the utility dominates the decision-making process.

Along with electric utilities, the energy regulators can also lack consultation and engagement with energy customers, contributing to the gap between what customers want and what utilities decide and deliver. Hausmann *et al*. (2008)[90] explained that when energy regulators were created at the beginning of the twentieth century, consumers were passive end-users, so commissions adopted need-based criteria to regulate the utilities’ expenditures. These need-based criteria could be summarised by providing a 'reliable' and 'affordable' energy supply. However, with customers

[84] Verbong, G., Beemsterboer, S., and Sengers, F. (2013) Smart grids or smart users? Involving users in developing a low carbon electricity economy. *Energy Policy*, 52, 117-125.

[85] Sioshansi, F. (2000) E-commerce and the Energy Sector: The Pioneers May Not Get It Right; The Procrastinators Are Likely to Become History. The Electricity Journal, 13(5): 42-49

[86] Moreno-Munoz, A., Bellido-Outeirino, F., Siano, P., and Gomez-Nieto, M. (2016) Mobile social media for smart grids customer engagement: Emerging trends and challenges. *Renewable and Sustainable Energy Reviews*, *53*, 1611-1616.

[87] Shannon, R. (2016) Bringing the customer to the market: A new utility business model. *The Electricity Journal*, 29(5): 15-18.

[88] Catney, P., MacGregor, S., Dobson, A., Hall, S., Royston, S., Robinson, Z., and Ross, S. (2014) Big society, little justice? Community renewable energy and the politics of localism. *Local Environment*, 19(7), 715-730.

[89] Gui, E. M., and MacGill, I. (2018) Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. *Energy Research & Social Science*, 35, 94-107.

[90] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.

becoming more educated and less passive this list of criteria has evolved along with the ranking of priorities, which has been largely missed by energy regulators who have lagged. For example, Shannon (2016)[91] pointed out that with raising awareness of customers about the origin of their electricity and the associated pollution, combined with greater understanding of the reality and impact of climate change, a growing number of electricity customers desired cleaner sources of electricity. He observed that these customers may even prefer clean energy over low-cost energy. Nevertheless, energy regulators have failed to incorporate this trend when evaluating utility projects. This is supported by Petersen (2016)[92], who noted that engaging communities in the decision-making process on investments in the electricity system that supplied them could reveal local interests and priorities that can enhance the overall business case.

Another consequence from the lack of consultation with electricity customers is the trade-off between the reliability of supply and the cost of electricity for customers. The literature suggests that without proper consultation the energy regulator could be mistaken about the level of reliability customers are expecting and how much they are willing to pay for it. For example, Australian energy efficiency expert Professor Alan Pears (2018)[93] argued that customers could accept rare and short black-outs if this would translate into a significant reduction in their bills. He explained that the undisputed objective of our electrical system is to ensure *"the light is always on"* but the energy regulator translated that into "*keep the light on always and at all costs*", and raised the reliability target to challenging levels without anticipating the consequence on customers' bills. The consequence is what has been called 'gold plating' the system with overbuilding of transmission lines and back-up generators to satisfy an over-estimated demand and limit the occurrence of black-outs down to zero (Hill and Whitfeld, 2015)[94].

At the Australian National Energy Market (NEM) level, a 2018 report from the Grattan Institute (Wood *et al*., 2018)[95] explains how between 2005 and 2014 the asset base of the transmission and distribution network of the NEM grew from $50 billion to $90

[91] Shannon, R. (2016) Bringing the customer to the market: A new utility business model. *The Electricity Journal* 29(5): 15-18.
[92] Petersen, J. (2016) Energy concepts for self-supplying communities based on local and renewable energy sources: A case study from northern Germany. *Sustainable Cities and Society*, 26, 1-8.
[93] Pears, A. (2018) *Risky Business?* ReNew magazine #149.
[94] Hill, J. and Whitfled, A. (2015) The Big Disconnect. Background Briefing – ABC Radio National.
[95] Wood, T., Blowers, D., and Griffiths, K. (2018) *Down to the wire: A sustainable electricity network for Australia*. Grattan Institute.

billion with, according to the report, $20 billion considered excessive and unjustified. In the same period, Senator Thistlewaite said in a speech to the Electricity Prices Committee at the Senate:

> "*In the committee's view, the most significant of these unfair increases [in electricity prices] is due to overinvestment in network infrastructure by predominantly state government owned network businesses. This has been commonly referred to as gold-plating. The current rules of our electricity market mean that there is a perverse incentive for network businesses to spend more than they need to on their assets. This inefficient overinvestment in network infrastructure — the poles and wires—must stop.*"

Senator Matt Thistlewaite, 2012[96]

Similarly, in Western Australia, the amount of reserve capacity in 2016-17 was estimated at 1061 MW or 23 percent of the total capacity of the local energy market, that cost $116 million to electricity consumers (Department of Finance of the Government of Western Australia, 2016)[97]. In an effort to reduce the cost of reserve capacity to consumers, the WA Government decided on a reform to change the Reserve Capacity Mechanism by lowering payments to both power stations and demand-side management providers (meaning the large customers capable and willing to reduce their demand during occasional extreme peak demand or a generator failure)(Australian energy Council, 2016)[98]. This reform pushed many demand-side management providers to exit the reserve capacity market for commercial reasons and with them a more environmentally friendly solution than paying fossil fuel generators to sit running at idle and wait in case they are needed.

As part of a reliability frameworks review in 2017 the Australian Energy Market Commission recognised the trade-offs inherent in the reliability of energy supply and more specifically between the cost of additional reliability (such as reserve generators)

[96] Thistlethwaite, M. (2012) The Senate Proof Committees – Electricity Prices Committee Report.
[97] Government of Western Australia, Department of Finance (2016) *Final Report: Reforms to the Reserve Capacity Mechanism*, 7 April 2016, p.3
[98] AEC (2016) Reforms to Reserve Capacity Mechanism: WA seeks to get the balance right. Australian Energy Council

and the cost of unserved energy (black-outs) (AEMC, 2017)[99]. However, as Mountain (2019)[100] explained, energy regulators are difficult to blame because under public-interest theory they are always assumed to seek public interest and so *"outcomes that do not serve the public interest are attributed to well-intended but unanticipated flaws in regulatory design or conduct"*.[101] Again it is clear that there is a gap between what customers want and what utilities offer, and that it is difficult to find a balance of interest with the traditional model used by the public electric utility.

2.4 Summary of Chapter and Contribution to Thesis

This chapter set the foundation of the research by presenting an understanding of the traditional business model underpinning electric utility businesses. This was done by a literature review of the history of the electric utility, the birth of its business model and the theories of utility economics, such as the cost recovery theory and the ratemaking process. The chapter described how and why this business model, which worked well for over a century, became obsolete when some inputs, believed to be immutable, started to evolve. This included a drastic change in the price of primary energy used to produce electricity which triggered a crisis of electricity systems and revealed the inefficiency and stagnation that had settled in incumbent utilities. Further the introduction of energy efficiency programs and measures across the grid suggested that demand growth was not eternal. And more recently, the uptake of distributed energy resources on households and businesses, such as rooftop solar, are reshuffling the cards between suppliers and consumers and changing the rules of the electricity supply game.

From the literature review of the traditional business model of electric utilities, the research identified two initial challenges when considering the question "*Are the traditional theories and existing mainstream models capable of supporting the effective transition of an industrial precinct to solar energy?*", namely:

[99] AEMC (2017) Reliability Frameworks Review, Interim Report, 19 December 2017, Sydney. Australian Energy Market Commission

[100] Mountain, B. (2019) Ownership, regulation, and financial disparity: The case of electricity distribution in Australia. *Utilities Policy*, 60, 100938.

[101] Mountain, B. (2019) Ownership, regulation, and financial disparity: The case of electricity distribution in Australia. *Utilities Policy*, 60, 100938.

1. How to protect the revenue of the embedded network operator (particularly for its distribution and power quality management duties) when behind-the-meter solar energy systems reduce the sale of energy, and

2. How to ensure a balance of interests between the utility and the customers, and effectively undertake the corresponding customer engagement.

Chapter 3: Review of existing approaches to introducing solar on a network

Sub-question #1: Are the existing mainstream models capable of supporting the effective transition of an industrial precinct to solar energy?

Aim: Identify gaps and barriers in existing models used to introduce solar to electricity networks.

Objective: Review the literature on existing theories and models used to introduce solar energy, select the most suitable ones for the context of commercial and industrial precincts, and identify knowledge gaps for further consideration.

3.1 Introduction

When investigating theories and models related to introducing solar energy on electricity networks, the research found that much of this knowledge was presented as '*Business Models'*. However, there is little consensus on the definition of business models among scholars (Zott *et al*., 2011)[102]. In a report from the Rocky Mountain Institute (Cross-Call *et al*., 2018)[103], the business model for the utility was defined as primarily an approach to generating revenue and making profits.

The research argues that although this is the overall goal, there are a number of significant non-financial sub-goals part of the business model of utilities that must be considered given utilities must also ensure services that do not have direct economic consequences, such as the security and reliability of the supply, equity, and the more recent 'clean' attribute. Rauter *et al*. (2017)[104] gave a broader definition with "*Business models are the link between corporate strategies and operational activities*". Here again, there is more to business models than operational activities, like the social dimension that enables the operational activities.

Therefore, in this thesis, the research focused on exploring the academic literature to inform an *approach* rather than limiting the research to *business models*, with the scope of the term 'approach' covering the aspects of energy supply that are equitable, affordable, reliable, and flexible. Focusing the study on investigating the approach rather than a particular business model also allowed for a greater contribution from the current academic literature and provided the potential for higher levels of new academic learning to inform such literature. For example, the scope would then include expansion from the main focus being on economic aspects (the business models and their tariffs) to include other influential factors that affect the economic aspects such as the roles and responsibilities of the stakeholders (the governance model) and associated ownership and influence models.

From the literature, the research found many approaches to introducing solar energy on a network, depending on the configuration and the ownership, governance, and

[102] Zott, C., Amit, R., and Massa, L. (2011) The business model: recent developments and future research. *Journal of Management*, 37(4), 1019-1042.
[103] Cross-Call, D., Gold R., Goldenberg C., Guccione L., and O'Boyle M. (2018) Navigating utility Business Model Reform: A Practical Guide to Regulatory Design. Rocky Mountain Institute, Snowmass, Colorado.
[104] Rauter R., Jonker J., and Baumgartner R. (2017) Going one's own way: drivers in developing business models for sustainability, *Journal of Cleaner Production*, 140, Part 1, P144-154

business models used. The research adapted the classification proposed by Huijben and Verbong (2013)[105] based on type of ownership (customer-owned, community-owned, and third-party-owned) and added a 'utility-owned' typology. Moreover, different configurations of solar energy systems were explored, both 'Centralised' and 'Distributed', which added even more configurations. These configurations are effectively *archetype models* and based on this the thesis distinguishes the following types:

1. Customer-owned distributed solar system,
2. Community-owned centralised solar system,
3. Third party-owned distributed solar system,
4. Third party-owned centralised solar system,
5. Utility-owned centralised solar system, and
6. Utility-owned distributed solar system.

Daly and Morrison (2001)[106] noted that the term 'distributed generation' is defined differently and can include a small-scale generator installed on a single end-user's site and designed primarily to serve that end-user, to any generation asset connected directly to a distribution network. In its economic analysis of the integration of distributed energy resources on electricity grids, the Electric Power Research Institute (EPRI) considered distributed energy resources as interconnected to the electric grid at or below medium voltage of 69 kV as set by the Institute of Electrical and Electronic Engineers[107] (EPRI, 2015)[108].

[105] Huijben, J. C., and Verbong, G. P. (2013) Breakthrough without subsidies? PV business model experiments in the Netherlands. *Energy Policy*, *56*, 362-370.
[106] Daly, P. A., and Morrison, J. (2001) Understanding the potential benefits of distributed generation on power delivery systems. In *2001 Rural Electric Power Conference. Papers Presented at the 45th Annual Conference (Cat. No. 01CH37214)* (pp. A2-1). IEEE.
[107] The Institute of Electrical and Electronic Engineers sets standards for the North American market.
[108] EPRI (2015) The Integrated grid: A Benefit-Cost Framework. Palo Alto, CA, USA. Resources. Electric Power Research Institute

In this thesis, the terms 'distributed' and 'centralised' are considered at the scale of a precinct with an embedded network, namely:

- *Centralised* is used for generation connected directly to the network (in-front of customer meters) hence feeding several customers, such as a solar array owned by the precinct operator on the grounds of the precinct, while

- *Distributed* is used for generation installed behind the customer meter and feeding that customer first before exporting its excess energy to the grid, such as rooftop solar installed on customers' buildings.

Therefore, in this research, 'distributed' and 'centralised' not only refer to the spatial location of the solar energy system but also how it is connected to the embedded network. The research found that governance and business models often go together, so they have been paired in these archetypes. Since this research is focused on commercial and industrial precincts fitted with a private embedded network looking to transition to solar energy, governance and business models applicable to this specific context will be discussed for each archetype in the sections below. The analysis of each of these archetypes will be based on academic literature with, when pertinent, examples from industry. The study aims to analyse the weaknesses and strengths of each archetype taking both the perspective of the embedded utility, called the Embedded Network Operator, and the energy customers, in order to inform efforts to improve related approaches.

The investigation begins with the archetype of 'customer-owned distributed solar' as it is the most widely used archetype and the source of most issues utilities are facing around the uptake of distributed energy options. It is important to understand that each of the archetypes can work without the storage of energy, and for the sake of clarity, it was decided to leave this feature for investigation in the next chapter.

3.2 Archetype 1: Customer-owned distributed solar

3.2.1 Introduction to this archetype

The most popular setup of the 'customer-owned distributed solar' archetype is a solar energy system financed by a homeowner with solar PV panels mounted on the rooftop of the house. The same setup is also widely used by businesses, with the solar energy system financed by the business and the panels mounted on the roof of the building or a nearby structure (carport, shed).

The drop in price of solar PV panels which contributed to boosting the uptake of rooftop installations in the residential sector has also created an entry point for new entrants, both small and large, in the energy sector more generally. For more than hundred years, the incumbent utilities have made sure their market was closed to new entrants by maintaining a capital-intensive business model (thanks to ever-increasing energy demand and economy of scale for the generation, and the “natural” barrier offered by the network system between any new generator and the end-users).

By avoiding these two barriers, behind-the-meter solar energy generation and storage are now profoundly disrupting the established sectors business models. Similarly, the telecommunication industry was disrupted by mobile telephones from the end of the 70s when the incumbents believed their monopoly was safe as, at the time, they thought the capital-intensive (wired) infrastructure was required to reach the end-users (Newman, Beatley and Boyer, 2017)[109].

3.2.2 Overview of the different metering systems for rooftop solar

Many methods are described in the literature for the metering of electricity exported to the grid from customer rooftop solar. Therefore, the thesis organises the findings in three categories corresponding to the three major metering systems:

1. Net metering with a single reading meter, meaning that solar energy is first used on site and the excess if exported to the grid, but import and export use the same reading (reading backward when exporting).

2. Net metering with a dual reading meter, meaning that solar energy is first used on site and the excess if exported to the grid, but import and export use independent readings and time stamp, and

3. Gross metering, meaning that solar energy is directly exported to the grid without the possibility to be used on site first. Import and export use separate meters and independent readings.

[109] Newman, P, Beatley T and Boyer H (2017) Resilient Cities: Overcoming Fossil Fuel Dependence, Island Press, Washington DC.

Net metering with a single reading meter

The term 'Net' is used in energy metering when only the excess solar energy is metered (the portion exported to the grid), rather than the total electricity produced. It is applied to solar installations that can first feed a local load before their excess is exported to the grid. When behind-the-meter generation was still nascent, utilities would let the energy meter turn backwards when electricity was exported to the grid (Poullikkas *et al*., 2013)[110]. Since this metering system was one of the first and was widely used for a long period, it is often simply known as Net Energy Metering or NEM.

With this metering system, the solar generated energy that is exported to the grid is, therefore, given the same value as the electricity imported by customers (the retail rate of electricity), including when the latter varies with time of use. If on one day the customer is exporting more energy than is imported, the meter turns backwards to subtract the import made the night before, or otherwise, it gives the customer a head-start to future imports and not just the instant there is demand (Wan and Green, 1998)[111]. Moreover, the time boundaries for customers to use their generation to offset their consumption is usually rather long, for instance it is up to 12 months in California[112].

The most common criticism found in the literature about the NEM is that it values electricity generated by distributed solar energy systems the same as the electricity generated by centralised plants and delivered to customers. Thus this method avoids the transmission and distribution costs even when these costs are not effectively and totally avoided (McHenry, 2012)[113]. Barraco (2013)[114] called the NEM “flawed” as it operates today and explained that it is an inappropriate mechanism for allocating the value of distributed renewable energy's nonfinancial benefits because it lacks transparency and suggests giving exported energy the value of avoided cost. For

[110] Poullikkas, A., Kourtis, G., and Hadjipaschalis, I. (2013) A review of net metering mechanism for electricity renewable energy sources. *International Journal of Energy & Environment*, *4*(6).

[111] Wan, Y. and Green, H. (1998) Current Experience With Net Metering Programs. Conference proceedings Windpower '98, Bakersfield, CA USA

[112] Darghouth, N., Barbose, G., Wiser, R. (2010) The Economic Value of PV and Net Metering to Residential Customers in California. Lawrence Berkeley National Laboratory. American Solar Energy Society (ASES) National Solar Conference, Phoenix, AZ, May 17-22, 2010. SOLAR 2010 Conference Proceedings.

[113] McHenry, M. (2012) Are small-scale grid-connected photovoltaic systems a cost-effective policy for lowering electricity bills and reducing carbon emissions? A technical, economic, and carbon emission analysis. *Energy Policy*, *45*, 64-72.

[114] Barraco, J. (2013) Distributed Energy and Net Metering: Adopting Rules to Promote a Bright Future. *J. Land Use & Envtl. L.*, *29*, 365.

Sewchurran and Davidson (2016)[115], with net metering the grid acts as a virtual battery, taking energy from the customer when in excess and giving it back when in demand, except that compared to a physical battery, the storage efficiency is an ideal 100% (no charging and discharging losses), and there are no capital or maintenance expenses for the customer. Darghouth *et al*. (2011)[116] studied the savings on bills induced by distributed solar energy systems with net metering (with a single reading meter), and they found a high level of variation in bill savings across customers and PV array sizes, with no economic justification. They concluded that rewarding distributed electricity exported to the grid by solar energy systems with a different tariff than the electricity imported would reduce the variation in bill savings that occurs with net metering. They also mentioned that NEM fails to account for avoided network costs and reduced line losses.

Net metering with a dual reading meter

When the meter has the capability to read separately the volume of energy imported and the volume of energy exported, it is possible to apply a different tariff for import (such as a Retail tariff) and export (such as a Feed-in Tariff). The Feed-in Tariff can be subsidised by the government to encourage the uptake of renewable low-carbon energy generation, sometimes as high as several times the retail tariff to kick-off an uptake in renewables (Comello and Reichelstein, 2017)[117]. The Feed-in Tariff can also be set at a tariff similar to the real cost of energy (without transmission and distribution costs and losses) or to a price reflective of the avoided-cost for the utility, or even down to zero when incentives to export energy to the grid are not necessary. The Feed-in Tariff can be fixed throughout the day or vary depending on the time of day (similar to a Time-of-Use retail tariff) to reward generators which feed the grid when it is most needed (Dijkgraaf et al., 2018)[118].

Therefore, net metering with a dual reading meter gives more flexibility to the utility than single reading metering to charge or reward customers, and governments to drive the uptake of renewable low-carbon energy. Dual reading meters may also provide a

[115] Sewchurran, S. and Davidson, I. (2016) Drivers and Application of Small Scale DG on Municipal Distribution Networks in South Africa. In *Proceedings of the 24th South African Universities Power Engineering Conference,* pp. 105-114.
[116] Darghouth, N., Barbose, G., and Wiser, R. (2011) The impact of rate design and net metering on the bill savings from distributed PV for residential customers in California. *Energy Policy,* 39(9), 5243-5253.
[117] Comello, S. and Reichelstein, S. (2017) Cost competitiveness of residential solar PV: The impact of net metering restrictions. *Renewable and Sustainable Energy Reviews, 75,* 46-57.
[118] Dijkgraaf, E., van Dorp, T. P., and Maasland, E. (2018) On the effectiveness of feed-in tariffs in the development of solar photovoltaics. The Energy Journal, 39(1).

better financial return to consumers than single reading meters, as was shown by Alasadi and Abdullah (2018)[119] with up to half the payback time of the initial capital invested in the rooftop solar.

The only weakness found in the literature about this system is the initial cost of the meter. Indeed, as Poullikkas *et al*. (2013)[120] mentioned, the net metering method with separate tariffs for import and export requires a meter capable of collecting energy import and export separately, often with time-of-use capability. These meters are considered 'advanced digital meters', and when they are fitted with integrated communication with the utility are called 'smart meters' (Castillo-Cagigal *et al*., 2011)[121].

Gross metering

As noted by Motlag *et al*. (2015) [122], “Gross” Metering (GM) is used when all the solar electricity generated onsite is used and metered by the utility. This system requires the rooftop installation to be fitted with a separate meter and connected to the grid directly, without the opportunity for the customer to consume any of the energy generated on-site. With this system, the utility can monitor 100 percent of the solar energy generated with one meter and 100 percent of the electricity consumed by the customer with another. This is the traditional set-up adopted in many European countries at the beginning of the uptake of residential solar energy systems. More recently, it has also been adopted by electric utilities using what is called a 'Value-of-Solar Tariff' (VOST) (Phung, 2011[123]; Rábago, 2013[124]) which was first developed by the municipal electric utility Austin Energy[125].

The Value-of-Solar Tariff is based on the premise that electricity produced via distributed solar should be valued for the savings it incurred in transmission and

[119] Alasadi, S. and Abdullah, M. (2018) Comparative Analysis between Net and Gross Metering for Residential PV System. In *2018 IEEE 7th International Conference on Power and Energy (PECon)* (pp. 434-439). IEEE.
[120] Poullikkas, A., Kourtis, G., and Hadjipaschalis, I. (2013) A review of net metering mechanism for electricity renewable energy sources. *International Journal of Energy & Environment*, 4(6).
[121] Castillo-Cagigal, M., Caamano-Martín, E., Matallanas, E., Masa-Bote, D., Gutiérrez, A., Monasterio-Huelin, F., and Jiménez-Leube, J. (2011) PV self-consumption optimization with storage and Active DSM for the residential sector. *Solar Energy*, 85(9), 2338-2348.
[122] Motlagh, O., Grozev, G., and Foliente, G. (2015) Impacts of feed-in tariff and metering types on electricity consumption efficiency in Australia. In 21st International Congress on Modelling and Simulation, Gold Coast, Australia.
[123] Phung T., Riu I., Kaufman N., Kessler L., Amodio M., and De Silva G. (2017) The Effect of Austin Energy’s Value -of-Solar -Tariff on Solar Installation Rates. Berkeley Lab Electricity Markets and Policy Group (EMP)
[124] Rábago, K. (2013) The ‘Value Of Solar’ Rate: Designing An Improved Residential Solar Tariff. Solar Industry. February 2013.
[125] Austin Energy (2019) Value of Solar rate, Austin Energy.

distribution costs and the fuel cost of the central plant as well as the avoided environmental impacts (Brown and Sappington, 2017)[126]. However, since the deployment of smart meters with the capability of measuring the import and export of electricity separately, several countries traditionally using Gross Metering have introduced the Feed-in Tariff approach. For example, France opened up in 2017 the possibility for owners of solar rooftop to auto consume their generated solar energy and sell the excess to the grid, using the net metering dual-reading system (French Republic, 2017)[127].

Motlag *et al*.[128] (2015) analysed the impact of Feed-in Tariffs and metering systems on electricity consumption efficiency and found that customers on Net Metering with dual reading are likely to try to shift their consumption to when their rooftop solar was generating the most electricity, resulting in reduced demand on the grid. Moreover, while Net Metering reduces bills by saving electricity import, it is less sensitive to the value of the Feed-in Tariff offered than the value of solar electricity offered in Gross Metering. Consequently, the latter suffered a considerable decline when the subsidy supporting solar electricity plummeted or stopped.

Moreover, since there is no direct use of the solar generated electricity in the Gross Metering system, prosumers are not incentivised to spread their panels between the East and West portions of the roof to match their consumption profile better. Similarly, they are not encouraged to invest in domestic (behind-the-meter) energy storage as they cannot charge it with their solar energy system.

3.2.3 Benefits of this customer owned distributed solar archetype

For the embedded network operator

At the beginning of the millennium, when the presence of solar panels on the roofs of houses or businesses was still nascent, the consensus was that such generating assets distributed across the network, and located close to the load, would benefit the electricity network overall. In 2007, Lopes *et al*. (2007)[129] identified and listed a set of

---

[126] Brown, D. P. and Sappington, D. (2017) Designing compensation for distributed solar generation: Is net metering ever optimal. *Energy Journal*, *38*(3), 1-32.

[127] French Republic (2017) Order of May 9th, 2017 regarding buyback scheme for PV electricity- Arrêté du 9 mai 2017 fixant les conditions d'achat de l'électricité produite par les installations implantées sur bâtiment utilisant l'énergie solaire photovoltaïque. Republique Francaise.

[128] Motlagh, O., Grozev, G., and Foliente, G. (2015) Impacts of feed-in tariff and metering types on electricity consumption efficiency in Australia. In 21st International Congress on Modelling and Simulation, Gold Coast, Australia.

[129] Lopes, J., Hatziargyriou, N., Mutale, J., Djapic, P., and Jenkins, N. (2007) Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. *Electric Power Systems Research*, 77(9), 1189-1203.

drivers for the growth of distributed generation, including network-specific drivers such as avoidance of the construction of new transmission lines or augmentation of the capacity of existing lines given distributed generation can be located close to the load. Other drivers suggested included the improvement of power quality and reliability if network users were allowed to island their premises and use their distributed generation during network outages.

In addition, because these generators are distributed on the network, a localised event would not affect all the generating capacity at once like it would if affecting a centralised power plant, thus providing a drive for resilience. Seven years later and a higher penetration of solar on the grid, Perez-Arriaga and Bharatkumar (2014)[130] confirmed that these benefits for the utility were still valid, for example when the load profile can be largely met using local solar generation this can reduce congestion and defer investment in network augmentation.

Tongsopit (2016)[131] also pointed out that when customers are investing in rooftop solar they are taking the capital risk instead of the utility. In the context of a commercial and industrial precinct that is under pressure to add onsite generation to avoid inevitable expensive upgrades of its connection to the main grid, and under pressure to reduce its carbon footprint, this participation in the capital risk by the customers is not insignificant.

For the energy customers

Ruester *et al*. (2013)[132] noted that energy customers are no longer "simple consumers" and with the democratisation of rooftop solar on the public grid, they are increasingly looking to gain control of their energy supply and reduce their energy bills. This archetype gives them the benefit of the freedom of choice to invest in a cleaner and cheaper energy source.

---

[130] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

[131] Tongsopit, S., Moungchareon, S., Aksornkij, A., and Potisat, T. (2016) Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. *Energy Policy*, 95, 447-457.

[132] Ruester, S., Schwenen, S., Batlle, C., and Pérez-Arriaga, I. (2014) From distribution networks to smart distribution systems: Rethinking the regulation of European electricity DSOs. *Utilities Policy*, 31, 229-237.

Based on research on the stability of the energy supply with grid-connected distributed solar energy systems, Shang (2019)[133] mentioned that behind-the-meter generation allowed for an occasional increase of the onsite consumption greater than the capacity of the connection to the grid. Parra *et al*. (2017)[134] also mentioned that behind-the-meter resources are capable of decoupling the maximum import power from the actual demand of the customer.

In the context of the EEN of a commercial and industrial precinct, this additional capacity could benefit energy customers needing an occasional increase in demand without having to sink large sums in the augmentation of the capacity of their connection to the network. For example, a tenant who has installed rooftop solar could, in the middle of the day, charge several electric vehicles with superchargers for a total load higher than the capacity of its connection to the EEN, as long as the charging is modulated according to the solar energy provided by the PV system (Duan *et al*., 2019)[135].

3.2.4 The unconstrained spread of rooftop solar increases the complexity and cost of the network

Pérez-Arriaga and Bharatkumar (2014)[136] suggested there are a number of positive impacts of distributed generation on the network. However, the potentially negative impacts that distributed generation may have on networks that are not properly prepared is poorly understood (Davison, 2017)[137]. Collins and Ward (2015)[138] warned that a high level of distributed generation could require substantial additional infrastructure investment to maintain reliability and power quality across an extended grid. Indeed, the uptake of residential rooftop solar typically does not prompt users to

[133] Shang, B. (2019) Effects of Distributed Photovoltaic Power Generation on Stability of Electrical Voltage System. *Nonlinear Optics, Quantum Optics: Concepts in Modern Optics*, 50(4).
[134] Parra, D., Norman, S., Walker, G., and Gillott, M. (2017) Optimum community energy storage for renewable energy and demand load management. *Applied Energy*, 200, 358-369.
[135] Duan, C., Tao, H., Wang, C., Chen, J., Zhao, X., and Zhou, X. (2019) An Electric Vehicle Battery Modular Balancing System Based on Solar Energy Harvesting. In 2019 IEEE Transportation Electrification Conference and Expo (ITEC) pp. 1-7. IEEE.
[136] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.
[137] Davison, M., Summers T., and Townsend, C. (2017) A review of the distributed generation landscape, key limitations of traditional microgrid concept and possible solution using an enhanced microgrid architecture. IEEE Southern Power Electronics Conference (SPEC), Puerto Varas, pp. 1-6.
[138] Collins, L. and Ward, J. (2015) Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity. *Renewable Energy*, 81, 464-471.

change their behaviour and shift load away from peak periods to the time of day their solar is generating most[139].

Collins and Ward[140] talk about the "hosting capacity" of a distribution network which is defined by the technical capacity of the network to host local generation. More precisely, Watson *et al*. (2016)[141] talked about 'overvoltage' and 'overcurrent' on the distribution network resulting from high penetration of distributed generation without the utility having control over it, or appropriately managing its uptake. Overvoltage and overcurrent happen when the energy supply on sections of the network by distributed generation is higher than the local consumption, triggering reverse power flows.

Variable onsite generation on distribution networks can also put some strain on the "tap changer" of transformers if not properly managed. A transformer is a piece of equipment that modifies the characteristics of the electricity on a network to adapt it to the needs of a second network. On distribution networks, transformers typically reduce voltage from medium voltage (typically 11kV) to low voltage (typically 450V). A tap changer is a mechanism in transformers that regulates the output of the transformer, so when the load increases on the lower network, voltage wants to drop, but it is compensated by the tap changer to maintain the nominal voltage.

Similarly, when the load on the network decreases, the tap changer reduces the output of the transformer to avoid a voltage spike. On a traditional network (with no distributed generation), the diversity of loads makes for a smooth change in total load seen by the tap changer. As the penetration of variable onsite generation such as rooftop solar increases, the variability of demand increases too, and the tap changer of the transformers are working harder than designed, causing rapid wear and tear (Ranamuka *et al*., 2016)[142].

---

[139] However, when considering C&I precincts exclusively, PV would reduce the peak demand as it typically happens around midday and is more important in summer, both conditions when PV is covering the load.

[140] Collins, L. and Ward, J. (2015) Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity. *Renewable Energy*, 81, 464-471.

[141] Watson, J. D., Watson, N. R., Santos-Martin, D., Wood, A. R., Lemon, S., and Miller, A. J. (2016) Impact of solar photovoltaics on the low-voltage distribution network in New Zealand. *IET Generation, Transmission & Distribution*, 10(1), 1-9.

[142] Ranamuka, D., Agalgaonkar, A., Muttaqi, K., and Alam, M. (2016) Mitigating Tap Changer Limit Cycles in Modern Electricity Networks Embedded with Local Generation Units. *IEEE Transactions on Industry Applications*, 52(1), 455-465.

One solution is to smooth the variations of the output of the variable distributed generation, for example, with an utility-scale and utility-financed energy storage system (Western Power, 2019)[143]. Either way, the introduction of a variable source of energy on distribution networks increases the complexity of managing the balance between supply and demand and often requires increased operational and capital investment as Figure 14 shows.

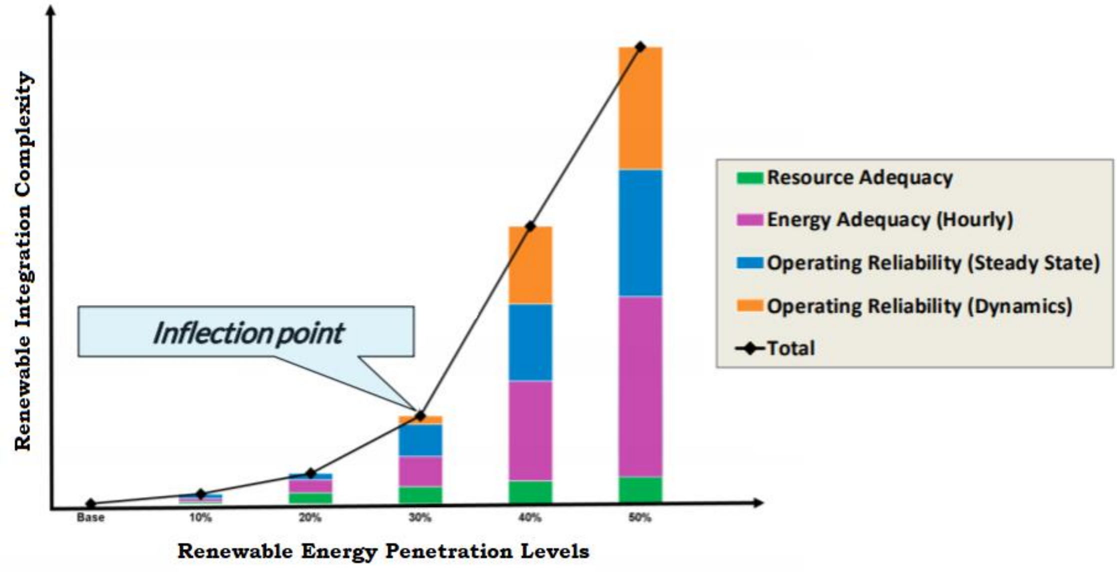

Figure 14: Complexity to integrate renewable energy on networks beyond 30 percent penetration levels

Source: Midcontinent Independent System Operator (MISO), 2019[144]

Moreover, the results from this Renewable Integration Impact Assessment show that from 30 percent penetration level (indicated by the 'inflection point' in the Figure above), the integration of renewables on the network requires extensive control and smoothing (and consequent capital and operational expenditures).

The owners of rooftop solar are not made aware of this consequence, nor are they typically held responsible for the impact, as there are no mechanisms in place to inform them of the contribution, positive or negative, their system has on the network. In the Australian National Electricity Market, this situation was created in 2007 with the introduction of Clause 6.1.4 in the *National Electricity (Economic Regulation of*

[143] Western Power (2019) Community batteries delivering big benefits. Western Power.
[144] MISO (2019) Renewable Integration Impact Assessment – Third workshop, November 14th-15th, 2019. Midcontinent Independent System Operator.

Distribution Services) Amendment Rules 2007 (AEMC, 2008)[145]. Clause 6.1.4 forbids distribution network service providers from charging users for exporting energy to the network, to ensure that network operators do not 'double-dip' by charging generators as well as consumers for transmission and distribution costs (Byrne and Parmenter, 2018)[146]. This clause applied to all prosumers, large and small (e.g. commercial and residential rooftop solar) and was motivated by the fact that distributed generation would likely support the distribution network, delay network upgrades, and thus reduce network charges for all users (Byrne and Parmenter, 2018).

However, in 2007, the energy regulator underestimated how rapid and sustained the uptake of residential rooftop solar would be, along with its impact on the distribution network and the consequent cost. One of these impacts is reverse flow of energy that happens on some discreet sections of the network when the total volume of energy exported by consumers exceeds the total volume imported. Another impact comes from how quickly solar generators change their output compared to other generators using a rotating piece of equipment such as a turbine (gas, coal, hydro) or a flywheel (gas, diesel). The latter are called synchronous generators while solar installations are called asynchronous generators.

The consequence of an increasing proportion of asynchronous generation on the network is a much more dynamic grid with respect to load and voltage (voltage spikes and high reverse energy flows) (Lopes *et al*., 2007[147]; Davison, 2017[148]; Bell and Gill, 2018[149]). Utilities are attempting to manage this dynamic electricity supply by reinforcing key parts of the grid, such as the transformers in substations (Byrne and Parmenter, 2018). Unfortunately, This reinforcement of the network involves an increase in investment in assets, which in turn increases the rates and customer bills (The Electric Power Research Institute, 2014)[150].

---

145 AEMC (2008) National Electricity (Economic Regulation of Distribution Services) - Amendment Rules 2007. Australian Electricity Market Commission, Sydney.

146 Byrne, M. and Parmenter, L. (2018) Cross about subsidies: the equity implications of rooftop solar in Australia. Renew & Total Environment Centre.

147 Lopes, J. P., Hatziargyriou, N., Mutale, J., Djapic, P., and Jenkins, N. (2007) Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. *Electric power systems research*, 77(9), 1189-1203

148 Davison, M., Summers T. and Townsend, C. (2017) A review of the distributed generation landscape, key limitations of traditional microgrid concept and possible solution using an enhanced microgrid architecture. *IEEE Southern Power Electronics Conference (SPEC)*, Puerto Varas, pp. 1-6.

149 Bell, K., and Gill, S. (2018) Delivering a highly distributed electricity system: Technical, regulatory and policy challenges. *Energy policy*, 113, 765-777.

150 EPRI (2014) The Integrated grid: Realizing the Full Value of Central and Distributed Energy Resources. Electric Power Research Institute

Consequently, the utility in charge of the network is forced to invest in controls, communication and bi-directional switchgear to fulfil its obligation of safe and reliable electricity supply, which in turn increases the regulated asset base and therefore the annual required revenue from the rates. However, this time, the number of customers does not grow, and their energy demand actually drops (because their demand is partially covered by rooftop solar), leading eventually to an increase in the bills. For example, since 2017 the South Australian public grid experienced an increase in over-voltage-related issues and, in some areas of very high penetration, the reverse energy flow (from rooftop solar) exceeded the thermal capacity of transformers, signalling the network was reaching its hosting capacity.

Consequently, South Australian Power Networks announced it would invest $37 million in new capital expenditure to adapt the network and expected a consequent $2 million increase in annual operating expenditure (SAPN, 2019)[151]. Similarly, Ausgrid announced it would spend $39 million to adapt the grid and accommodate the growing reverse flow generated by variable onsite energy generation (Ausgrid, 2018)[152]. The point here is that in the traditional approach used by the utility, network users connecting behind-the-meter generation are not made aware nor responsible for the impact of their rooftop solar on the network and the consequent cost, nor are utilities properly preparing for an increase in behind-the-meter generation.

3.2.5 Tariff structure not reflective of the contribution of customers to the cost of supplying energy

Ortega *et al*. (2008)[153] explained that when the electric power sector was vertically integrated, the leading electricity tariff objective was to recover the cost of the entire supply chain without assessing the cost of each component separately. Then, the liberalisation of the sector split the supply chain in order to introduce competition, typically for the generation and retail activities. However, they observed that regulators allocated the revenue of the distribution network among generators and consumers in the same way as it was before the liberalisation process. Indeed, the cost of a distribution network is driven by 'critical peak' periods (Simshauser, 2016)[154].

[151] SAPN (2020) 2020-2025 draft plan. South Australia Power Networks.
[152] Ausgrid (2018) Network Innovation Capex Program Cost Benefit Analysis Summary. Ausgrid.
[153] Ortega, M. P. R., Pérez-Arriaga, J. I., Abbad, J. R., and González, J. P. (2008) Distribution network tariffs: A closed question?. Energy Policy, 36(5), 1712-1725.
[154] Simshauser, P. (2016) Distribution network prices and solar PV: Resolving rate instability and wealth transfers through demand tariffs. Energy Economics, 54, 108-122.

Perez-Arriaga and Bharatkumar (2014)[155] added that with the growing integration of distributed generation on the network, more and more users are likely to become prosumers, alternating between importers and exporters of electricity, making it difficult to isolate the costs and benefits attributable to load and distributed generation. They added that the increasing number of prosumers is making the categories of tariffs obsolete since consumers could no longer be grouped in classes of users with *a priori* similar energy consumption patterns. Finally, they noted that the tariffs did not evolve with the users transitioning from passive end-user to active prosumers and that they are not reflective of how each network user contributes to the costs incurred by the network utility.

3.2.6 Impact on the cost of the network

The previous chapter explained that the standard billing system of the electricity sector is to remunerate the distribution utility partly with the sale of energy, which is now decreasing partly due to consumers covering a portion of their need with their own generators. Section 3.2.4 explained how customer-owned distributed solar was increasing the complexity of the network and forcing the utility to increase operational expenditures (OPEX) and capital expenditures (CAPEX) to maintain quality and reliability of the energy supply. Additionally, Section 3.2.5 mentioned that those network costs were not allocated to network users according to how they contribute to those costs, meaning that all consumers are paying for costs induced by a fraction of them. Therefore, this section looks at the collective consequence of these three issues on the electricity bills and draws a key lesson. Table 3 and Figure 15 below show that, in Australia, the network costs represent a significant part of a residential energy bill.

Table 3: Cost component proportion of retail electricity price in 2016-17

	National weighted average	SE QLD	NSW	ACT	VIC	SA	TAS	NT	WA
Network	48.40%	47.20%	52.70%	41.10%	45.10%	41.80%	53.70%	53.00%	48.70%
Wholesale	35.50%	35.80%	34.50%	30.00%	34.20%	40.60%	28.10%	57.10%	40.10%
Environmental policy	7.10%	14.20%	6.00%	11.80%	5.90%	8.80%	5.60%	3.60%	3.30%

Source: Data from AEMC market review advice on residential electricity price trends

[155] Pérez-Arriaga, I., and Bharatkumar, A. (2014). A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

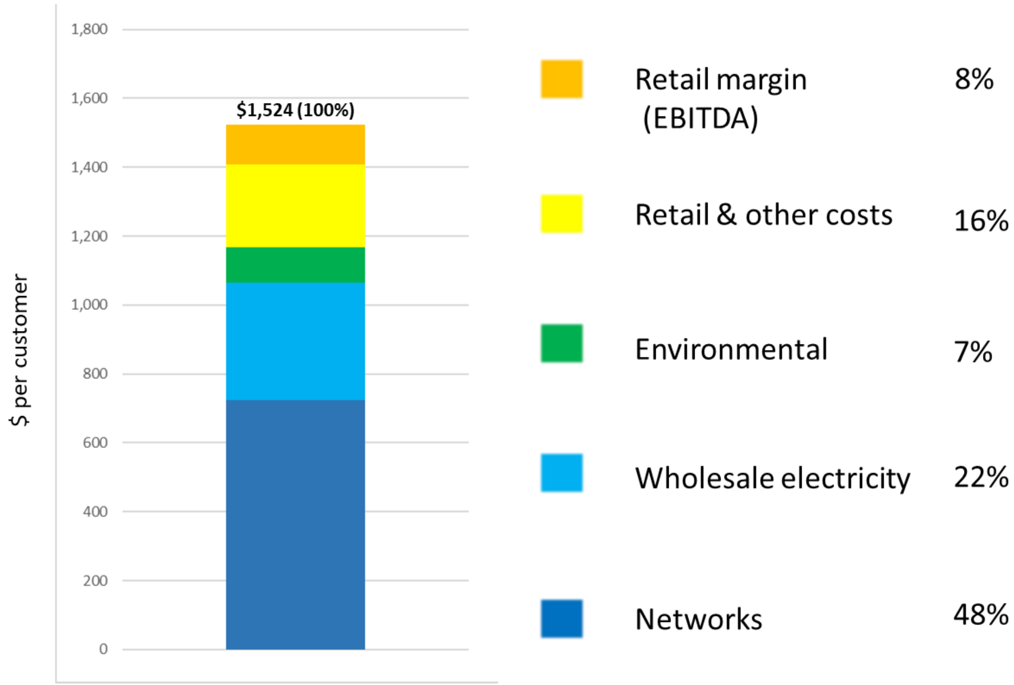

Figure 15: Components of an average residential customer bill across the NEM (excluding Tasmania) (2015/16, $ per customer,) excluding GST
Source: Data from ACCC, 2017[156]

The key lesson here is, if one of the objectives of the utility is to deliver an affordable energy supply to its customers, then low network costs must be a priority. If energy customers see solar as a means to reduce their electricity bills by reducing their energy import, the utility must drive the transition to solar in a way that helps reduce network costs. At first, this statement may appear to suggest that the interest in solar of the customers is not the same as the interests of the utility, but this is not entirely true. Indeed, if network costs make the major part of the customers' electricity bills, then managing the transition to solar in a way that helps reduce network costs will eventually impact electricity bills positively and benefit the customers.

3.2.7 Not an equitable business model

Financial equity

As customers pay for the use of the network partly through the energy portion of their electricity bill, the ones with rooftop solar pay less for the network as their solar panels reduce their average electricity import and, in the Australian context thanks to Clause 6.1.4 of the *National Electricity Amendment Rules 2007*, customers with rooftop solar

[156] ACCC (2017) Retail Electricity Pricing Inquiry Report – Preliminary Report. Australian Competition and Consumer Commission, Fig. 2.1 p32

do not yet have to pay to use the network to export electricity. Consequently, the way customers pay for the cost associated with providing electricity to them (network costs) does not reflect how they are using it, and customers who do not have rooftop solar (such as occupants in buildings with a shared roof or simply customers who cannot afford it) are contributing more towards network cost, leading to financial inequity between customers. This situation is called a "cross-subsidy" (ATA, 2018[157]; Byrne and Parmenter, 2018)[158] and is also applicable to energy customers on a private network in commercial and industrial precincts. This section will not dwell on other cross-subsidies experienced by residential customers on the public grid as it is not the focus of this research.

Social equity

Another case of inequity among customers may happen under the traditional utility approach (customer-owned distributed solar) when the total capacity of distributed generation installed on a portion of the network reaches the hosting capacity (the physical threshold at which the penetration of solar starts to affect network and system stability negatively), forcing the utility to impose restrictions to protect the network and the energy supply. One of these restrictions is to prohibit the installation of additional rooftop solar. This is the case in China where new approvals for rooftop solar are restricted by the government in zones reaching saturation, or in Hawaii where the utility had to limit or pause rooftop solar programs (Hess, 2016)[159].

On the Western Australian electricity network (the South West Interconnected System, or 'SWIS'), for now, it is only the case for generators above 10 kW that are required to lodge a connection request to be assessed by the public network utility (which is Western Power) who decides whether to authorise energy export depending on the state of saturation of the section of the network the customer is connecting to. Limiting the installation of customer rooftop solar is required when new requests exceed the maximum capacity, and approval is given on a first-come-best-dressed basis that opens up the potential for social inequity between energy customers on the network. Indeed, customers allowed to install rooftop solar could be seen as receiving privileges

[157] ATA (2018) Sharing the Load: Understanding Consumer Outcomes of Network Tariff Reform. Tariffs Project II prepared for Energy Consumers Australia, Alternative Technology Association.
[158] Byrne, M. and Parmenter, L. (2018) Cross about subsidies: the equity implications of rooftop solar in Australia. Discussion Paper. Renew and Total Environment Centre.
[159] Hess, D. (2016) The politics of niche-regime conflicts: distributed solar energy in the United States. *Environmental Innovation and Societal Transitions,* 19, 42-50.

compared to new entrants whose request to install solar is refused on the grounds of network capacity.

3.3 Archetype 2: Customer-owned centralised solar

According to Prehoda *et al*. (2019)[160], "*Community solar involves the installation of a solar electricity system that is built in one central location with the costs and benefits distributed across voluntary investors who choose to subscribe and receive credits based on the generated energy*.". Though Prehoda *et al*. described the existence of several variations of community solar business, ownership and governance models, in the context of an embedded network the variation of models selected for consideration in this thesis was where the centralised solar energy system is financed by voluntary energy customers on the embedded electricity network and built in compliance with the guidelines set by the embedded network operator.

In principle, the electricity produced by the solar energy system would offset, with a time reference, the consumption of its investors in proportion to their share in the investment. Therefore, if the embedded network operator is the only retailer of electricity on the embedded network, then the solar energy system is operated by the embedded network operator who reconciles, periodically, the consumption of each customer with the electricity generated by their share of the community system.

According to Yovanoff (2018)[161], one of the most significant value of a centralised community solar system, compared to individual rooftop solar installations, is to offer the benefits to customers for who it would be financially difficult or physically impossible to install a solar energy system because their roofs are not suitable. In the context of a commercial and industrial precinct, these customers could be the tenants in large shared buildings (such as shops in airport terminals or tenants renting a floor in an office building) with no direct access to a roof to install solar panels. Seyfang *et al*. (2013)[162] added that this wider access helps raise energy awareness and incentivises those who invested in the system to consider when they consume electricity during the day in relation to the generation of electricity by the community system.

[160] Prehoda, E., Winkler, R., and Schelly, C. (2019) Putting research to action: Integrating collaborative governance and community-engaged research for community solar. *Social Sciences*, *8*(1), 11.
[161] Yovanoff, D. (2018) Community-Owned Solar Power and Micro grids for New York State.
[162] Seyfang, G., Park, J., and Smith, A. (2013) A thousand flowers blooming? An examination of community energy in the UK, *Energy Policy*, 61, pp. 977–989.

3.4 Archetype 3: Third party-owned distributed solar

The third-party ownership model is also referred to in the literature as a "non-ownership" model. According to Agrawal *et al.* (2019)[163], non-ownership models consist of an independent company specialised in solar power (such as an installer of PV systems) who installs solar panels at a customer's site with no upfront cost to the customer who simply purchases electricity generated from the panels. However, the ownership of the installation is retained by the solar power company.

They also explained that there are two types of non-ownership business models: Firstly, a Solar Lease (SL) with a fixed monthly payment that contributes to the cost of capital and installation and a return on capital for the installer; and secondly a solar power purchase agreement (PPA) where the monthly payment is based on how much electricity is produced by solar panels. Tongsopit *et al.* (2016)[164] pointed out that PPA payments are usually lower than the retail electricity rate but can grow at an escalation rate.

This model of ownership does not affect the embedded network operator other than if the customer would invest in rooftop solar themselves. Therefore, weak points of this archetype have already been raised in Section 3.2. From the customer perspective, decoupling the solar energy from the physical installation is offering solar energy as a service and not as a product (Overholm, 2015)[165]. This model provides an attractive alternative for customers thanks to the absence of capital investment and the risk tied to the ownership of such a system (Davidson *et al*., 2015)[166].

3.5 Archetype 4: Third party-owned centralised solar

In this archetype, the centralised solar system is most likely installed on land or on top of a structure owned by the precinct owner. Two scenarios are possible:

1. If the embedded network operator does not retail electricity on the network (i.e. is only a distribution network operator), then the third party who invests in the solar

[163] Agrawal, V., Toktay, L. B., & Yücel, Ş. (2019). Non-Ownership Business Models for Solar Energy. *Georgetown McDonough School of Business Research Paper*, (3375372), 19-08.
[164] Tongsopit, S., Moungchareon, S., Aksornkij, A., and Potisat, T. (2016) Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. *Energy Policy*, 95, 447-457.
[165] Overholm, H. (2015) Spreading the rooftop revolution: What policies enable solar-as-a-service?. *Energy Policy*, *84*, 69-79.
[166] Davidson, C., Steinberg, D., and Margolis, R. (2015) Exploring the market for third-party-owned residential photovoltaic systems: insights from lease and power-purchase agreement contract structures and costs in California. *Environmental Research Letters*, 10(2), 024006.

system would pay a fee to the precinct owner for the place occupied by the solar system. The owner of the solar system would also pay a fee to the distribution network operator to access its network. Finally, the solar system owner would have to sell electricity to a registered electricity retailer (unless the solar system owner is a registered electricity retailer).

2. On the other hand, if the embedded network operator is an energy retailer on the EEN, then the business model would be a Power Purchase Agreement (PPA). This model is standard among commercial precinct such as airports, as indicated in Table 4.

Table 4: Example of ownership of solar systems on airport precincts

Airport location		PV capacity	Storage capacity	Ownership	Possibility to Feed-in to public grid[(a)]	Centralised
Australia	Adelaide	1.28MW	0	Airport	?	Yes
	Karratha	1MW	Smoothing	PPA	?	Yes
	Alice Spring	560kW	0	PPA	?	Yes
	Brisbane	6MW	0	Airport	?	No[(b)]
	Darwin	4MW	0	Airport	?	Yes
	Kingscote	50kW	In EVs	Airport	yes	Yes
	Longreach	99kW	0	?	?	Yes
USA	Denver	10MW	0	PPA	?	Yes
	Indianapolis	20MW	0	PPA	yes	Yes
	Fresno	2.4MW	0	PPA	Net metering	Yes
	Phoenix	5.4MW	0	PPA	?	Yes
Malaysia	Kuala Lumpur	19MW	0	PPA	FIT	Yes
India	Cochin	12MW	0	Airport	Net metering	Yes

Source: Hebert *et al*., 2016[167]

Notes
(a) A question mark was used when export to the grid was not mentioned, but it usually means no export is possible.
(b) Solar array on six buildings (owned by the airport) and spread over the entire precinct.
(c) This line applies only to the maintenance hangar of the Brantford airport.

The challenge of this archetype is for the third-party to find and maintain the right price point for the electricity it produces (Tongsopit *et al*., 2016) [168], as if it is:

[167] Hebert, L., Hayes, R., and Hargroves, K. (2016) Current State Assessment of Other Airports Around the World Installing Solar, Overview of the Situation of the Perth Airport Embedded Electricity Network and its Regulatory Context, Sustainable Built Environment National Research Centre (SBEnrc), Australia.
[168] Tongsopit, S., Moungchareon, S., Aksornkij, A., and Potisat, T. (2016). Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. *Energy Policy*, *95*, 447-457.

- Too high, then the embedded network operator (or the independent retailer) will likely have access to a better rate on the public grid. This is the case for embedded utilities which are aggregating a large number of consumers and are able to negotiate competitive rates, or

- Too low, where the embedded network operator could reconsider investing in the solar energy system.

From the perspective of the energy customers, this archetype could provide cheaper electricity during the day if the retailer (the embedded network operator or an independent retailer) decided to pass some or all of the savings to the customers, which is expected if under pressure by the competition. Therefore, the research concludes that the opportunity for solar to be introduced on a commercial and industrial precinct via a 'Third party-owned centralised solar system' is likely to happen only if the embedded network operator does not have an energy retail function or has no appetite or capability to invest in such a system.

3.6 Archetype 5: Utility-owned centralised solar

This archetype is widely used on commercial and industrial precincts. Table 4 shows that five out of the thirteen airport precincts considered had solar PV installations that were owned by the precinct owner (the embedded utility), and the vast majority were centralised. The research also identified a few examples of non-airport precincts:

- The Tonsley district is located 10 kilometres south of Adelaide’s central business district in South Australia. In 2010, the Government of South Australia purchased the 61-hectare site that had been built and used for car manufacturing by Chrysler and then Mitsubishi since the sixties, to establish a smart technology mixed-use precinct for industry, education, retail and residential living.[169] Part of its vision is showcasing South Australia as a great place to do business, including having utilities (electricity, gas and water) managed by Enwave energy (the embedded network operator) who owns the embedded network and will expand it as the site is developed. Enwave will also own and operate 6 MW of solar panels[170] that will be fitted on the roof of

[169] Tonsley (2020) Masterplan. Tonsley Innovation District.
[170] Renewal SA (2020a) Tonsley Project, Renewal SA

the Main Assembly Building (MAB), a vast building centrally located that used to host the car assembly lines, as well as a series of batteries.[171] Enwave does not plan to let tenants (in their own building) install rooftop solar to use that energy directly.[172]

– Brisbane Technology Park is a 33-hectare precinct located 16km south of Brisbane's Central Business District (Queensland). It is fitted with an embedded network, and the landowner has installed 1 MW of solar panels over the roof of 6 buildings.[173] The solar array is owned and operated by the embedded network operator, a business unit of the landowner.

The embedded utilities of these commercial and industrial precincts do not have to give the same freedom to their energy customers (to install rooftop solar) that is given by the public utilities to their customers (particularly, its residential customers). Instead, many embedded utilities prefer to keep the original hierarchical model of the electric utility before rooftop PV was introduced, when electricity was flowing only in a single direction, from the generators to the end-users (Kundur *et al*., 1994)[174]. Alternatively, in the case of an EEN, from the connection to the public grid to the embedded customers. Not only this approach maintains the traditional monopoly business model, but it also keeps customers totally dependent on the embedded utility for their energy needs.

Effectively, in this model of utility-owned centralised solar, the solar panels are connected in front of the customer meters, and solar electricity is sold to the energy customers on the embedded network at the same price as the electricity imported from the grid is sold to them. This model allows the embedded network operator to stay in control of the generation and the retail of energy on the precinct. This approach is used by embedded utilities to avoid the troubles met by the public utilities with the uptake of customer-owned behind-the-meter distributed generation as detailed in Section 3.2. Even issues around equity are avoided with this archetype as all the tenants are treated

[171] Essential Services Commission of SA (2018) Enwave application form for the issue of an Electricity Generation Licence, Essential Services Commission of SA.
[172] Renewal SA (2020b) Renewable solar energy Tonsley tenants. Renewal SA
[173] Gemenergy (2020) Recent projects, Brisbane technology park solar, Gemenergy
[174] Kundur, P., Balu, N., and Lauby, M. (1994) Power system stability and control (Vol. 7). New York: McGraw-Hill.

the same and none are allowed to install solar PV panels and enjoy their own electricity production.

However, this absence of customer-owned and distributed generation also means the embedded network operator does not benefit from associated advantages. The following sub-sections detail these missed advantages and focus on those advantages that apply to an embedded network where the energy from the main grid is considered a “centralised generation” and the connection to the grid the “transmission infrastructure”.

3.6.1 Imbalance of interests between utility and customers

Socially, customers would be offered the benefit of cleaner energy supply but refused the opportunity to participate, and benefit further, from their energy generation. They would not be allowed to take the investment risk and access the rewards of lower electricity costs. With this model, the balance of interests is biased towards the embedded network operator who entrenches itself in its monopolistic position, not making the precinct particularly attractive to new tenants with an appetite for an active role in energy generation.

3.6.2 Embedded network operator takes the capital risk

With this model, the embedded network operator takes on the capital risk alone by financing the solar system, whereas in the ‘customer-owned’ model these assets are financed by the customers. As risk is tied to the payback time of the investment, for the embedded network operator, this payback time is the result, on the one hand, of the avoided-cost of electricity not imported from the grid and the reduced network charges to the public grid, and on the other hand, by the price the embedded network operator charges electricity to its customers at, and the volume the latter consume.

A future reduction in any of these four components would reduce the return on investment (ROI) and lengthen the payback time, and thus have a direct impact on the embedded network operator’s revenues. There is no sign, in Australia at least, that grid electricity price and network charges will likely decrease under their current value, but the retail tariff on the EEN and the volume of energy delivered to the customers could.

For example, in a regulatory context where there is no electricity retail competition, the embedded network operator can use its monopolistic position to retail electricity at the highest price (the regulated tariffs). However, if (but more likely when) full retail contestability (FRC) is introduced, then the embedded network operator would have to reduce its retail tariff to remain competitive, decreasing the ROI of the solar system and lengthening its payback time.

Similarly, tenants on the precinct could implement energy efficiency programs and reduce their electricity demands. Worse, the embedded network operator could lose customers, either to the competition or simply because they have moved out of the precinct to find a location that will allow them to own solar; and see the volume of energy retailed to customers decrease. The embedded network operator taking the capital risk by financing the solar system is another weak point that makes this model not optimum.

3.6.3 Solar penetration limited by the economic value perceived by the embedded network operator

With the 'Utility-owned centralised solar' archetype, the embedded network operator takes on the capital risk alone and, therefore, would be expected to prioritise tangible outcomes that benefit its business directly. In some cases, this could mean limiting the amount of solar energy generation to target the quickest return on investment and avoid the issues created by a higher level of penetration (as shown previously in Section 3.2.4 with Figure 14).

Moreover, large precincts that import a significant volume of electricity from the grid can negotiate wholesale price for grid electricity making the levelised cost of energy (the 'LCOE') from onsite solar uncompetitive with electricity from the grid. In this case, the embedded network operator may look to other economic value that can be created by solar systems rather than just cheaper energy. For example the reduction of peak demand charges, avoidance of penalties for exceeding the contracted maximum demand, or delaying capital expenditures necessary to augment the capacity of the embedded network and the connection to the grid (e.g. that typically happens when the precinct welcomes additional tenants and the electrical load grows).

In a situation where the network charges are unbundled from the energy charges, the network costs mentioned above can be passed on to the network users and would not impact the network revenues of the embedded operator. Hence the financial motivation to avoid or delay these costs is stronger when the traditional tariff structure is used, where network costs are partially recovered through the sale of energy. In this situation, these network costs would reduce the embedded operator's profit (by increasing expenses without increasing energy sales) and investing in onsite electricity generation would make little economic sense.

Therefore, in this archetype, the amount of solar capacity is driven by a balance between savings (mostly avoided-network costs and demand related charges) and the complexity of the management of the energy supply, both concerning just the embedded network operator. Consequently, this approach is deemed to be suboptimal because the transition to solar could only be partial and the opportunity to significantly reduce associated carbon emissions, supporting the nation's effort as described in the Paris Agreement (United Nations, 2015)[175], would be largely missed.

3.6.4 Investment in solar motivated by the green image of the embedded network operator

Section 3.6.3 made the point the economic motivation for an embedded network operator to introduce their own solar on the precinct could be weak if the latter has access to competitively priced grid energy. It is even weaker when onsite solar is compared to alternative onsite generation solutions, particularly if the priority is to save network costs as described previously. For example, with the current price of gas in Western Australia gas turbines could appear to be a cheaper alternative to rooftop solar (Oakley Greenwood, 2018)[176]. Indeed, their LCOE is similar to commercial rooftop solar, and as they can run whenever they are needed ('on demand'), they can cost less than solar systems and energy storage combined (Lazard, 2016)[177].

If this archetype is used then it suggests that the financial aspect is not the primary driver for an embedded network operator to introduce solar, but rather that it is driven by the intention to satisfy 'green' corporate targets of their own business and their customers and to be seen taking an appropriate position regarding climate change.

3.6.5 Lack of incentive for collaboration leads to missed opportunities

In this model, customers remain totally dependent on the embedded network operator for their energy supply. Dependent on its network and, if there is no retail competition,

[175] United Nations (2015) Paris agreement. United Nations.
[176] Oakley Greenwood (2018) Gas Price Trends Review 2017, Commonwealth of Australia 2017.
[177] Lazard (2016) Lazard's Levelized Cost of Energy Analysis – Version 10.0. Table 1: Unsubsidized Levelized Cost of Energy Comparison, Lazard.

locked into its tariffs. Therefore, energy customers are considered passive with no incentive to change their behaviour for the benefit of themselves or the network besides the short-term rewards induced by variable tariffs (e.g. Time-of-Use prices). Also, customers have few reasons to engage with the embedded network operator and participate in the decisions about the infrastructure that will, eventually, impact their energy bill. Conversely, the embedded network operator does not see the point in engaging with them before making these decisions.

This is the situation that was explained for the public utility in Section 2.3.6, where energy regulators make choices for the welfare of customers without involving them in the decision process, leading to unnecessary targets being misaligned with the customers' priorities (and their disposition for trade-offs). This model applied to a private network has potentially similar consequences, therefore, this model is deemed not optimum.

3.7 Archetype 6: Utility-owned distributed solar

There is little published academic literature on this archetype, likely as regulated natural monopoly companies (such as vertically integrated electric utilities) are usually forbidden to enter competitive markets because regulated utilities often have access to lower-cost capital, large customer bases, and market risk protections that are not available to non-utility companies, giving them an unfair advantage (Rule, 2015)[178]. However, a few utilities have implemented this solution successfully such as the Arizona Public Service and ALG.

3.7.1 The case of Arizona Public Service

In 2014, the Arizona Public Service (APS) proposed to enter the residential rooftop market by offering to lease the roof space of 1,500 households for a $30 credit on their monthly electricity bills. This compensation was calculated to be more important than what customers would get in savings from owning their own solar system or through a Power Purchase Agreement (PPA) with a third party. On the utility side, the program called “AZ Sun”, expected to bring multiple benefits to APS (Randazzo, 2014[179]; Rule, 2015[180]) with the following considerations:

[178] Rule, T. A. (2015) Unnatural Monopolies: Why utilities Don't Belong in Rooftop Solar Markets. *Idaho Law Review*.
[179] Randazzo, R. (2014) AZCentral News
[180] Rule, T. A. (2015) Unnatural Monopolies: Why utilities Don't Belong in Rooftop Solar Markets. Idaho Law Review.

- The total cost for APS, over the 20 years contract, of 1,500 distributed generators would be equivalent to a solar farm that had been originally planned.

- The program would contribute to APS meeting its renewable energy objectives.

- Targeting low-income households in the process would contribute to APS' Corporate Social Responsibility (CSR) action plan.

- APS could experiment with facing solar panels to the west to generate more electricity on hot summer afternoons when the network needs the energy most.

- APS could experiment with equipment that regulates voltage across the system when penetration of solar energy reached the hosting capacity of particular portions of the network.

Though the initial objective was to meet the renewable energy goals and improve public image rather than to seek a direct economic return, this operation would in fact:

- Earn APS a return on the corresponding capital investment (thanks to the cost recovery of regulated assets) unlike if customers would install solar systems themselves.

- Protect APS' revenue since participant customers would continue to purchase their electricity from APS at the regulated tariff (which would most likely increase in the future), and protect its monopolistic position.

This model is very similar to the one presented in Section 3.6 (that of the 'Utility-owned centralised solar' archetype) and would have the same weaknesses for the customers as for the utility.

3.7.2 The case of the Australian utility AGL

The Australian utility AGL has designed a new business model for its utility-owned distributed solar program. AGL's rooftop solar program was in the form of a Solar Power Purchase Agreement (PPA) for residential customers, a first for a major electricity retailer in Australia (Parkinson, 2015a)[181]. AGL realised that with the reduction in the price of solar installations and the emergence of PPA offerings on the market, if consumers did not get their rooftop solar from AGL they would get it themselves sooner or later, or get it through a PPA with a third party. Nevertheless, selling energy to its customers at a lower price than the energy it traditionally retailed via the network seemed counter-productive for an energy retailer, but the way AGL planned its PPAs had other benefits to compensate this loss, namely:

- AGL offered PPAs to consumers even if they were not AGL customers. In this case, AGL acquired a partial retail contract with new customers, giving AGL a lead to complete the acquisition of these customers in the future (by convincing them to switch to AGL for the rest of their electricity needs).

- AGL PPAs have a duration of seven to twelve years, meaning AGL would secure these consumers in its portfolio (even when they did not source their standard retail contract with AGL) for an extended period.

- AGL PPAs include a monitoring service during the life of the arrangement, justified for maintenance purposes, providing access to the valuable raw solar energy generation data (not only excess energy exported to the grid) for seven to twelve years.

This model could be applied to an EEN in case retail competition is introduced on the precinct (or for EENs in jurisdictions where retail competition is already present) to reinforce the retail position of the embedded network operator.

3.8 Selection of archetypes suitable for commercial and industrial precincts

As the research progressed, it was essential to identify the reasons why the existing archetypes were suitable or not to support a cost-effective, socially equitable and environment-friendly introduction of solar in the specific context of private commercial and industrial precincts. The five tables below summarise the pros and cons of the selected archetypes in the context of a private embedded network of an industrial precinct looking at introducing solar energy. Note that introduction of solar

[181] Parkinson, G. (2015a) AGL Energy becomes first big retailer to roll out solar PPA plan. In: Parkinson, G. (Ed.), RenewEconomy.

on the precinct is considered a common theme to all scenarios, so pros that are applicable to all such as "greening of the energy supply" or "delaying upgrades of the connection to the main grid" have not been included to allow more focused comparison.

Table 5: Pros and cons of applying Archetype 1: 'Customer-owned distributed solar'

	PROS	CONS
For The Embedded Network Operator	The ENO does not have to take the capital risk of investing in on-site low carbon electricity generation. Generation close to the load means optimisation of all portions of the EEN possible (and reduced network upgrades).	ENO's revenue from the sale of electricity drops along with part of its distribution revenue. Customers are not made aware or responsible for the impact of their rooftop solar on the network and the energy supply. The energy supply becomes more dynamic, ENO lacks control, cannot optimise network, keeps investing to reinforce the infrastructure.
For The Customers	Customers are allowed to gain some control of their energy supply and reduce their energy bills. Customers can occasionally increase their electricity demand without being limited by their connection to the EEN.	Network costs increase, so does customer electricity bills. Customers are denied the installation of rooftop solar when the network becomes saturated (first-come best-served inequity).

Table 6: Pros and cons of applying Archetype 2: ‘Customer-owned centralised solar’

	PROS	CONS
For The Embedded Network Operator	The ENO has some control (and visibility) over the on-site generation to ensure the quality of the supply. The ENO does not have to invest the capital and take the risk of sizing the system appropriately.	The ENO’s revenue from the sale of electricity drops along with part of its distribution revenue. The solar PV array is centralised meaning individual feeders cannot be optimised.
For The Customers	Customers are allowed to gain some control of their energy supply and reduce their energy bills.	Customers still limited in their demand (ie business activity) by their connection to the EEN.
For The Precinct*	Access to solar as it is the case “across the street” on the public grid makes the precinct attractive. Better equity as customers can participate in their energy supply to the limit of the overall hosting capacity of the EEN. Expected environmental outcomes from increased solar systems uptake that is linked to customers’ economic benefits.	

* The perspective “For the precinct” relates to the value added by this archetype to the real estate. This perspective is taken in comparison to a similar commercial and industrial precinct “across the street” using the traditional electric utility approach of customer-owned solar.

Table 7: Pros and cons of applying Archetype 3: ‘Utility-owned centralised solar’

	PROS	**CONS**
For The Embedded Network Operator	The ENO looks 'green' and 'socially' acceptable. The ENO keeps control of the on-site generation to better ensure the quality of the supply. The ENO can keep the same retail rates and possibly improve its margin. The ENO secures the cost of a part of its electricity supply as LCOES of solar panels is less volatile than the LCOES of grid electricity.	The ENO takes the risk to invest capital with no certainty that enough customers would buy the resulting electricity to recover the capital. Lack of customer engagement keeps the ENO from optimising the network to help keep network cost as low as possible. The solar array is centralised meaning individual feeders cannot be optimised.
For The Customers	None	Possible savings passed on to the customers by the ENO are limited compared to the ones expected if the customer would own the solar system. Customers are still limited in their demand and business activity by their connection to the EEN.
For The Precinct*	None	No democratisation of the participation in the supply of electricity as it is the case “across the street” on the public grid. Depending on customers’ appetite for participation in energy supply, this barrier could push customers to seek to locate in another precinct. Solar penetration most likely limited to ENO’s economic

		return meaning limited decarbonisation of the precinct.

* The perspective "For the precinct" relates to the value added by this archetype to the real estate. This perspective is taken in comparison to a similar commercial and industrial precinct "across the street" using the traditional electric utility approach of customer-owned solar.

Table 8: Pros and cons of applying Archetype 4: 'Utility-owned distributed solar'

	PROS	CONS
For The Embedded Network Operator	Generation close to the load means the potential for optimisation of portions of the EEN possible (reduced network upgrades). The ENO keeps control of the on-site generation to better ensure the quality of the supply.	The ENO's revenue from the sale of electricity drops along with part of its distribution revenue.
For The Customers	Customers gain some control over their energy supply and can reduce their energy bills. Customers can increase their electrical load and business activity without being limited by their connection to the EEN.	Customer still denied the freedom to invest in solar as they see fit. Customers are denied access to this PPA when the network becomes saturated (first-come best-served inequity). Network costs increase so does customer electricity bills.
For The Precinct*		Limited participation in the generation of electricity compared to "across the street" on the public grid. Depending on customers' appetite to invest in its own PV array, this barrier could push customers to seek another precinct to locate in.

* The perspective "For the precinct" relates to the value added by this archetype to the real estate. This perspective is taken in comparison to a similar commercial and industrial precinct "across the street" using the traditional electric utility approach of customer-owned solar.

**Only the AGL model was selected for this review.

Table 9: Pros and cons of the existing metering and tariff systems

	PROS	CONS
Existing regulated retail tariffs	Regulated tariffs with demand charge attempt to link customer contribution to network costs.	Regulated tariffs cover a part of network costs with volumetric energy-based charges. Tariffs, in general, do not reflect the contribution of the customer to the network costs. Customer classes do not account for behind-the-meter generation, nor its location.
Net Metering **(with single-reading meter)**	Simple meter means lower cost for the customers.	Network used by customers as a virtual battery without collecting a charge for this service. Cannot use tariffs to reflect the positive nor negative contribution of distributed generation.
Solar Feed-in tariff **(with dual-reading meter)**	The feed-in tariff can be designed to reflect the positive or negative contribution of the distributed generation to the energy supply. The feed-in tariff can be time-sensitive.	The ENO does not see true consumption and true generation. Auto-consumption reduces revenue for the network whereas the use of the service remains.
Gross metering	The ENO sees the true consumption and true generation. Revenue for the network is not affected by behind-the-meter generation.	Does not encourage consumption reduction and demand management (such as time of use optimisation).

Based on the findings of the research: if the cost of the network represents the most substantial portion of the customer bill, then the impact of the archetype on the network should be a top selection criterion. Since the management of the distribution network is the duty of the embedded network operator, this means that the selected archetype must provide the embedded operator with a degree of control of the solar system for network management, and ensure a balance between the interests of the customers and the network operator.

Also if the hypothesis of strong uptake of battery-operated Electric Vehicles (EVs) in the fleets of tenants on the commercial and industrial precincts is accepted, then the capacity of the archetype to enable such business activity should also be considered a top selection criterion. Among other things, this may influence the location of the solar system in consideration of the location of the load created by EV charging. Indeed, if customers are expected to charge their fleet of EVs on their premises, then archetypes with behind-the-meter solar installations are preferred, whereas if customers' EVs are expected to be charged in centralised locations (such as car parks), then archetypes with centralised solar systems may be preferable.

However, the possibility of an alternative source of onsite electricity generation for EV charging, such as fuel cells for electricity generation for example, could affect the business case for solar systems, however these are unlikely to be distributed and will require dedicated land rather than being located on existing structure as in solar PV. This uncertainty however means the archetype selected must offer flexibility in electricity generation options and that the sharing of the risks to invest in solar and the associated rewards (notably reduced bills) must be considered a top criterion for the selection of the archetype.

Therefore, the research ruled out archetypes that did not involve the energy customers in the long term, such as Archetype 4, 'Third-party owned centralised solar', and Archetype 5, 'Utility-owned centralised solar'. Also, from the perspective of this research, Archetype 3, 'Third-party owned distributed solar' was considered similar to Archetype 1, 'Customer-owned distributed solar' and therefore omitted in the rest of the research.

Consequently, the three possible archetypes selected to carry on the research for the cost-effective introduction of solar on the EEN of commercial and industrial precincts selected were:

1. Archetype 1: Customer-owned distributed solar,
2. Archetype 2: Customer-owned centralised solar (also known as Community-solar), and
3. Archetype 6: Utility-owned distributed solar (with a solar PPA).

3.9 Identification of weaknesses in the existing approach

So far, the research has identified five key weaknesses in the existing approach as described below with the first not directly linked to the introduction of solar but relevant to the performance of an embedded network operator introducing innovation on its network. The remaining four gaps are specific to the introduction of solar on an EEN assuming the application of Archetype 1, 'Customer-owned distributed solar'.

3.9.1 The lack of customer engagement

The previous chapter explained how, on a regulated grid, even with an energy regulator in the governance model, the balance of interests is not always respected, and customer engagement remains a challenge. This issue is even more present on private networks within commercial and industrial precincts as the governance model does not include an energy regulator, as shown in Figure 16.

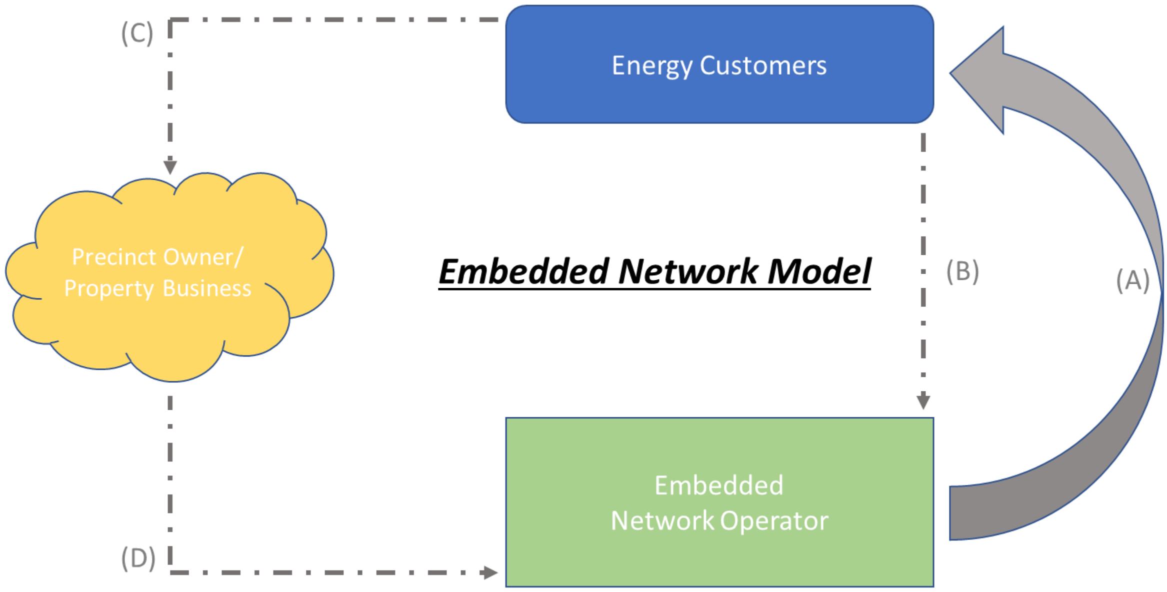

Figure 16: Simplistic representation of the governance model on an embedded electricity network

Where:

(A) The Embedded Network Operator delivers the service (network and energy).

(B) Customer feedback to the embedded network operator is possible but usually limited.

(C) The precinct owner receives indirect feedback from tenants through the popularity of its precinct (or lack of), or direct feedback when tenants are putting pressure on the property business, for example, to be allowed to install rooftop solar system.

(D) The precinct owner might then command the embedded network operator to come up with solutions to meet customers' expectations and support the property business.

With this governance model, it is even more challenging to ensure a balance of interests, indeed:

1. The embedded network operator would most likely adopt the same approach as the traditional utility, that is to seek to minimise risk and quickly recover costs through sales of electricity at the regulated rates, and

2. Just like the public utility, the embedded network operator would not be motivated to seek extra benefits for the customers beyond the minimum contracted services or seek to engage with them more than necessary. This explains why there is very little literature on the topic of embedded utilities engaging (or not) with their customers besides specific cases of innovative micro-grids where the utility is community-owned (typically some new residential embedded network or micro-grids).

Therefore, the challenge identified in Section 2.4 around how the balance of interest can be tailored to EENs and raises the question: "*How to ensure a balance of interests between the embedded network operator and the customers, and its corresponding customer engagement?"*

3.9.2 The bundling of network and consumption costs

A second weakness of the traditional model used by electric utilities is the business model where payments to cover network costs are bundled with other costs (such as energy generation**)** into the variable portion of the electricity bill, effectively collecting network revenues via the sale of energy (as explained in Section 2.2.4). Although this issue arose when customers started to implement energy efficiency programs to reduce energy consumption (but not necessarily their peak use), it was not a significant problem until the uptake of rooftop solar.

As such, it was with the uptake of rooftop solar that proved the traditional business model to be obsolete as utility's revenues eroded, whereas more costly distribution services were required (Section 2.3.4). This led to the realisation that the demand charges of some commercial tariffs were not found to be effective in resolving the issue. This raises the question: "*How to protect the revenue of the embedded network operator* [particularly for its distribution and power quality management duties] *when behind-the-meter solar systems reducing the sale of energy are introduced?*"

3.9.3 Customers are not made responsible for the pressure their solar system is putting on the network

As mentioned previously, when behind-the-meter generation is installed customers still use the network to access energy however it can result in more pressure on the network from exporting excess solar energy. However, since they are not charged for using the network for exporting energy, even when the network is saturated, they do not have an understanding of the impact of their system on the rest of the network, including the long term impact on network costs. This raises the question: "*How to make customers installing solar responsible and accountable for the pressure their solar system would put on the network?*"

3.9.4 Traditional approach create inequity in access to solar

As, Section 3.2.4 explained, network hosting capacity will reach its limit when solar energy penetration becomes high enough that it is not manageable for the network and this begins to affect the quality of energy supply as well as the integrity of network assets, such as transformers. When this limit is about to be reached, the operator is forced to prohibit additional behind-the-meter generation, which means taking from customers the right to participate in their energy supply as their direct neighbours in the precinct had the opportunity to do. This inequity of access to rooftop solar among customers raises the question: "*How to avoid inequity of access to solar among customers when penetration increases?*".

3.9.5 Introduction of solar limited by the capacity to manage the energy supply

The network operator could have difficulties ensuring the necessary quality of energy supply on the network when a high proportion of variable behind-the-meter generation is feeding it (as explained in Section 3.2.4). This issue is more related to the physical and technological aspects of renewable electricity than its financial and social aspects covered in the sections above. Therefore, it raises the question: "*How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of onsite variable electricity generation?*".

3.10 Summary of the chapter and contribution to thesis

The literature review of the different existing models to introducing solar on a network revealed a number of important weaknesses, some pertaining to core principles of the electric utility business model and some more specific to the introduction of solar on an embedded network. Even the most commonly used archetype used in Australia, the “utility-owned centralised solar”, showed it was a conservative, risk-advert approach following a traditional model of energy supply chain, missing out on critical social and environmental opportunities.

As this thesis aims to try to find an economically acceptable model that could enable precinct operators to capture associated economic, environmental and social benefits, this chapter allowed research into the overarching question, "*Are existing approaches capable of supporting the effective transition of an industrial precinct to solar energy?"* and confirm the calling for an alternative approach.

Finding solutions to the weaknesses that have been identified in relation to these existing models constitute a set of knowledge gaps in the academic literature. This thesis seeks to design a new and integrated approach for the introduction of solar on the EEN of a commercial and industrial precincts cost-effectively.

These weaknesses are summarised as the following set of questions:

1. “How to protect the revenue of the embedded network when behind-the-meter solar systems reducing the sale of energy are introduced?”

2. “How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of variable generation?”

3. “How to make customers installing solar responsible and accountable for the pressure their solar system would put on the network?”

4. “How to avoid inequity of access to solar among customers while penetration increases?”

5. “How to ensure a balance of interests between the embedded network operator and the customers, and the corresponding customer engagement?”

Chapter 4: Review and assessment of existing approaches to energy storage

This chapter is to complement Chapter 3 in the attempt to answer sub-question #1 Are the traditional theories and existing mainstream models capable of supporting the effective transition of an industrial precinct to solar energy?

Aim: Identify how energy storage can support the sustainable introduction of solar on the EEN of a commercial and industrial precinct.

Objective: Review academic literature on approaches to energy storage to support the introduction of solar on the network relevant to industrial precincts.

4.1 Introduction

The previous chapter looked at different approaches to introduce solar on the EEN of a commercial and industrial precinct without consideration of energy storage to allow focus and clarity. Nevertheless, the increasing level of penetration of variable energy generation (such as solar PV energy that generates a variable volume of electricity depending on the weather) on the grid creates challenges to the stability and reliability of the electricity system (Georgilakis, 2008)[182]. As demand on a network made up of a variety of loads is variable, supplying that network with variable sources of energy can make the balancing between demand and supply more difficult (Telaretti and Dusonchet 2016)[183].

Energy storage was cited on several occasions in the literature as a means to provide the necessary flexibility (Telaretti and Dusonchet 2016, Vassallo 2015[184]). Jia and Crabtree (2015)[185] pointed out that the current utility model predominantly varies supply to meet demand and energy storage would help shape and store energy from variable energy sources to make them behave in a manner similar to traditional dispatchable sources.

Vassallo (2015) explained that electricity networks are becoming more and more peaky, resulting in reduced utilisation of generating assets and Transmission and Distribution (T&D) infrastructure - the latter being a problem shared with embedded networks. He also explained that solar systems often replace thermal power generation which increases the difficulty for utility to maintain quality (voltage and frequency within tolerance). Indeed, thermal generators provide a high degree of mechanical inertia thanks to their rotating components, offering some "stiffness" to the network when demand varies rapidly.

In contrast, solar systems are inertia-less and, therefore, are not stabilising or hindering rapid changes in demand as thermal generations do. Energy storage can be used to help with the balance between demand and supply by charging and discharging

[182] Georgilakis, P. (2008) Technical challenges associated with the integration of wind power into power systems. *Renewable and Sustainable Energy Reviews*, *12*(3), 852-863.
[183] Telaretti, E., and Dusonchet, L. (2016) Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)* (pp. 1-6). IEEE.
[184] Vassallo, A. (2015) Applications of batteries for grid-scale energy storage. In *Advances in Batteries for Medium and Large-Scale Energy Storage* (pp. 587-607). Woodhead Publishing.
[185] Jia, J. and Crabtree, J. (2015) Driven by Demand: How energy gets its power. Cambridge: Cambridge University Press.

accordingly, often significantly quicker than thermal systems can vary their output. Vassallo concluded that energy storage could allow better utilisation of existing PV capacity and provide a deferral of network investments for some years. In the context of an EEN, the grid is used to ensure quality and stability of the electricity supply, but as onsite generation from solar systems grows, more stress would be put on the connection to the grid to regulate the variations and ensure stability.

A battery energy storage system (BESS) can add value to solar and to the network in different ways, and several technologies for storage of electricity are available, so a literature review of the likely performance considerations of these options is necessary. As the performance and suitability of each technology depend on the role expected from the BESS, this chapter starts by listing the different roles commonly given to energy storage systems (to support solar generation) before considering the different types of energy storage technologies. Once the roles and technology options have been covered, the chapter presents research findings from the literature on prevailing models of using a BESS and associated ownership models. Finally, the chapter discusses how the selected technologies and models of BESS could fill some of the gaps identified in the previous chapter.

4.2 Roles of an energy storage system on an embedded network

Akbari *et al*. (2018)[186] undertook a review of possible energy storage solutions to support solar systems and mentioned three main purposes:

1. To store excess solar PV electricity generated for later use when required, called *solar shifting (O'Connell et al., 2017)[187]*.

2. To assist electricity networks withstand peaks in demand allowing transmission and distribution grids to operate efficiently, called *peak shaving*.

3. To assist in smoothing out the variations in solar PV electricity generation and the consequent distortions in voltage, called *solar smoothing*.

[186] Akbari, H., Browne, M. C., Ortega, A., Huang, M. J., Hewitt, N. J., Norton, B., and McCormack, S. J. (2018) Efficient energy storage technologies for photovoltaic systems. *Solar Energy*, *192*, 144-168.
[187] O'Connell, A., Maitra, A., Smith, J., Jordan, B., and Cryer, C. (2017) Integrating photovoltaic and storage systems on distribution feeders. CIRED-Open Access Proceedings Journal, 2017(1), 1831-1835.

Based on a review of associated research the following seeks to define these roles further.

4.2.1 Solar shifting

Dufo-Lopez and Bernal-Agustin (2015)[188] explained that solar shifting involves charging the battery when electricity is inexpensive – for example during sunny hours of the day with energy from solar panels – and using it a few hours later when electricity from the grid is more expensive (on-peak tariff), through battery discharging. Charging with energy produced by PV systems during the day to use it when the sun is down is also called "*Solar Time Shifting*"[189]. Parra *et al*. (2017)[190] pointed out that load shifting is only economically sensible when the charging and discharging efficiency of the energy storage system is higher than the ratio between the off-peak and the on-peak retail prices of energy.

4.2.2 Peak shaving

Parra *et al*. (2017) described peak shaving as the use of stored energy to level-out the demand by charging the battery during low demand periods and discharging at peak demand periods to reduce the peak demand load. The research noted that peak demand could be considered at the customer level or at the (embedded) network level where the demand from all customers is aggregated. This difference will be covered in Section 4.4.4 on implantation and ownership models of energy storage systems.

Sardi *et al*. (2017)[191] pointed out that peak shaving could benefit the distribution utility (the network operator) who could delay augmentation of the capacity of components (system upgrade deferral). Moreover, peak shaving could also contribute directly to commercial gains. Indeed, Shi *et al*. (2018)[192] confirmed that peak shaving can be used to reduce the peak demand charge. Parra *et al*. (2017) covered the specific application of peak shaving by commercial and industrial customers, noting that for the ones who use high intensive electrical demand equipment, the demand charge could become

---

[188] Dufo-López, R., and Bernal-Agustín, J. (2015) Techno-economic analysis of grid-connected battery storage. *Energy Conversion and Management, 91*, 394-404.

[189] *Solar Time Shifting* described and considered in this research is slightly different from *energy arbitrage* where the battery is charged with electricity from the grid when it is inexpensive (off-peak tariff) and resold back to the grid when electricity is more expensive (on-peak tariff). Energy arbitrage is outside the scope of this research as not related to PV generation.

[190] Parra, D., Norman, S. A., Walker, G. S., and Gillott, M. (2017) Optimum community energy storage for renewable energy and demand load management. *Applied energy*, *200*, 358-369.

[191] Sardi, J., Mithulananthan, N., Gallagher, M., and Hung, D. (2017) Multiple community energy storage planning in distribution networks using a cost-benefit analysis. *Applied energy*, *190*, 453-463.

[192] Shi, Y., Xu, B., Wang, D., and Zhang, B. (2017) Using battery storage for peak shaving and frequency regulation: Joint optimization for superlinear gains. *IEEE Transactions on Power Systems*, *33*(3), 2882-2894.

economically more important than the variable portion of the bill. Parra et al (2017) also suggests that energy storage can be used to spread the electricity import, shave the peak demand and reduce associated charges. They also mentioned that in the case that the tariff involves a contracted maximum demand (CMD), the later could also be reduced using energy storage when the value of the maximum demand load can be forecast.

4.2.3 Solar smoothing

According to Thorbergsson *et al*. (2013)[193] the variability of renewable power output such as the one from solar PV systems, causes fluctuations in the balance between demand and supply that affect the voltage and the frequency of the electricity on the network. This explains why solar smoothing by energy storage systems is sometimes found in the literature under "Frequency regulation" and "Voltage regulation". Sasmal *et al*. (2016) [194] explained that when renewable energy penetration increases in a network the inherent variations may result in voltage instability of the energy supply, causing stress to the network and possibly having a detrimental effect on the connected loads. Jha *et al*. (2014)[195] described the process used by energy storage systems to regulate the fluctuations of voltage and frequency by charging in situations when going over a threshold and discharging when going under. Finally, Li *et al*. (2013)[196] warned that the difficulty in operating an energy storage system continuously for solar smoothing is to maintain the state of charge (SOC) within a specific range to prevent a forced shutdown of the system due to over-charge or over-discharge of the storage.

4.2.4 Summary of findings

The main difference between these three roles is the required rate of charge and discharge of the energy storage system. In the case of solar shifting, the storage system may charge over several hours from PV electricity and discharge over several hours when appropriate. Peak (demand) shaving requires the storage system to be able to discharge rapidly to cover a peak demand when it happens. Finally, solar smoothing

[193] Thorbergsson, E., Knap, V., Swierczynski, M., Stroe, D., and Teodorescu, R. (2013) Primary frequency regulation with Li-ion battery based energy storage system-evaluation and comparison of different control strategies. In Intelec 2013; 35th International Telecommunications Energy Conference, *Smart Power And Efficiency* (pp. 1-6).

[194] Sasmal, R. P., Sen, S., and Chakraborty, A. (2016) Solar photovoltaic output smoothing: Using battery energy storage system. In *2016 National Power Systems Conference (NPSC)* (pp. 1-5). IEEE.

[195] Jha, I. S., Sen, S., Tiwari, M., and Singh, M. K. (2014) Control strategy for Frequency Regulation using Battery Energy Storage with optimal utilization. In *2014 IEEE 6th India International Conference on Power Electronics (IICPE)* (pp. 1-4). IEEE.

[196] Li, X., Hui, D., and Lai, X. (2013) Battery energy storage station (BESS)-based smoothing control of photovoltaic (PV) and wind power generation fluctuations. *IEEE transactions on sustainable energy*, *4*(2), 464-473.

(voltage and frequency regulation) requires the storage system to charge and discharge as fast as the variation of the output of solar energy generation occurs, which is in the order of a fraction of a second (which is not possible for other backup options such as gas fired turbines).

Though these three roles are distinct and ideally batteries should be dedicated to just one role, it is often seen in the literature that an energy storage system delivers more savings when designed and used for more than one function (particularly peak shaving and PV smoothing) as both require a rather fast reaction from the storage system. In their study, Shi *et al*. (2018)[197] demonstrated that "*the saving from joint optimization* [for peak shaving and PV smoothing] *is often larger than the sum of the optimal savings when the battery is used for the two individual applications"*.

4.3 Overview of different technologies of energy storage available to support solar energy on an EEN

Electricity storage is a transformation process where electrical energy is converted into another form, stored then converted back to electricity when needed (Chen *et al*., 2009)[198]. Over the years since the first storage of electricity by Alessandro Volta (Hausman *et al*., 2008)[199], many different methods and processes have been developed to effectively store electrical energy for reuse. The U.S. Energy Storage Association (2020a) [200] divided the various approaches to energy storage into five main categories:

- Batteries (electrochemical storage solutions).
- Thermal (harnessing heat and cold to create energy on-demand or offset energy needs).
- Mechanical Storage (spinning a flywheel with an electric motor then switching the motor into generator mode that slows the flywheel and converts the energy back into electricity).

[197] Shi, Y., Xu, B., Wang, D., and Zhang, B. (2017) Using battery storage for peak shaving and frequency regulation: Joint optimization for superlinear gains. *IEEE Transactions on Power Systems*, 33(3), 2882-2894.
[198] Chen, H., Cong, T., Yang, W., Tan, T., Lia, Y., and Dinga, Y. (2009) Progress in electrical energy storage system: a critical review. *Prog Nat Sci* 19(3): 291–312.
[199] Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.
[200] Energy Storage Association (2020a) Technologies of Energy Storage, Energy Storage Association

– Hydrogen (using PV generated electricity to convert water into hydrogen via electrolysis for storage and later use to re-create electricity).

– Pumped Hydropower (pumping water into elevated storage reservoirs and using gravity to convert the energy back to electricity with turbines).

However, electrochemical storage, better known as battery storage, is the most common form of storage found in the literature for application with solar systems. Telaretti and Dusonchet (2016)[201] explained that this is due to its characteristics such as versatility, modularity, scalability and fast response time, and Fan *et al*. (2020)[202] added the benefit of a short construction cycle. Therefore, the research in this thesis has focused on battery storage technologies. A Battery Energy Storage System (BESS) is typically made of the three essential components (from Qian *et al*. 2010[203]):

1. A set of storage cells, where electricity is stored electrochemically.

2. An inverter, or bidirectional AC-DC converter, that works as the interface between the battery and the electricity network by transforming the DC electricity stored in the batteries into AC used on the network, and vice versa if the battery needs to be charged from the network.[204]

3. A battery management system that estimates the charge and health of each cell in the battery cell and applies active charge equalisation to balance the charge of all the cells in the pack.

As the intent here is to give an overview of commercially available technologies for energy storage that may be suitable for commercial and industrial precincts, the research has selected the four electrochemical technologies suggested by Sparacino *et al*. (2012)[205] and Telaretti and Dusonchet (2016)[206] as the most mature and commonly

---

[201] Telaretti, E. and Dusonchet, L. (2016) Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC) (pp. 1-6). IEEE.
[202] Fan, X., Liu, B., Liu, J., Ding, J., Han, X., Deng, Y., Lv, X., Xie, Y., Chen, B. and Hu, W. (2020) Battery Technologies for Grid-Level Large-Scale Electrical Energy Storage. Transaction of Tianjin University. 26, 92–103.
[203] Qian, H., Zhang, J., Lai, J. S., and Yu, W. (2010) A high-efficiency grid-tie battery energy storage system. *IEEE transactions on power electronics*, *26*(3), 886-896.
[204] However, since PV systems generate DC electricity, they can charge a battery with only a charge controller.
[205] Sparacino, A., Reed, G., Kerestes, R., Grainger, B., and Smith, Z. (2012) Survey of battery energy storage systems and modeling techniques. In 2012 IEEE Power and Energy Society General Meeting (pp. 1-8). IEEE.
[206] Telaretti, E. and Dusonchet, L. (2016) Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC) (pp. 1-6). IEEE.

used in stationary energy storage systems employed in the power sector, and particularly for working with solar PV generated electricity, namely: Lithium-ion batteries (Li-ion); Advanced lead-acid batteries (PbA); Sodium-Sulphur batteries (NaS); and flow batteries.

4.3.1 Lithium-ion batteries (li-ion)

Lithium-ion energy storage technology was invented by researcher M. S. Whittingham while working at Exxon Mobil Corporation in the 1970s (Whittingham, 1976)[207] and first commercialised by Sony and Asahi Kasei in 1991 (Sparacino *et al*., 2012). Since 2010, the global capacity of lithium-ion batteries for stationary energy storage applications has grown strongly, making it the type most used of all electrochemical storage systems since 2013 (Tsiropoulos *et al*. 2018)[208], as Figure 17 shows.

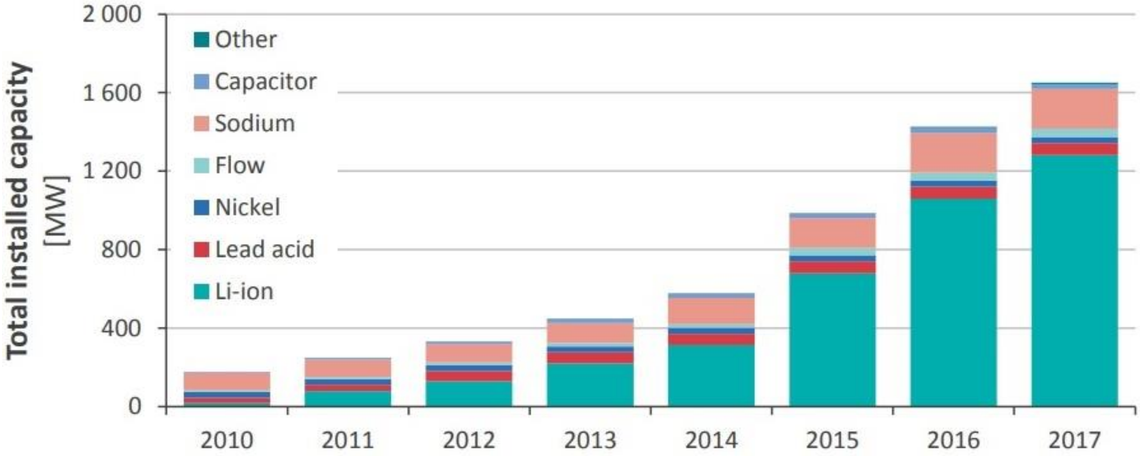

Figure 17: Global cumulative installed capacity of electrochemical storage systems 2010-2017

Source: Publications Office of the European Union, 2018[209]

Though Sparacino *et al*. (2012) mentioned that the cost of lithium-ion technology remains high due to its materials (many different rare metals involved), its price has plummeted in the last decade (see Figure 18 below) partly due to the global uptake of electric vehicles as they are using this technology for their batteries.

[207] Whittingham, M. (1976) Electrical energy storage and intercalation chemistry. *Science*, *192*(4244), 1126-1127.
[208] Tsiropoulos, I., Tarvydas, D., and Lebedeva, N. (2018) Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth. Publications Office of the European Union, Luxembourg.
[209] Tsiropoulos, I., Tarvydas, D., and Lebedeva, N. (2018) *Li-ion batteries for mobility and stationary storage applications* – Scenarios for costs and market growth, Publications Office of the European Union, Luxembourg.

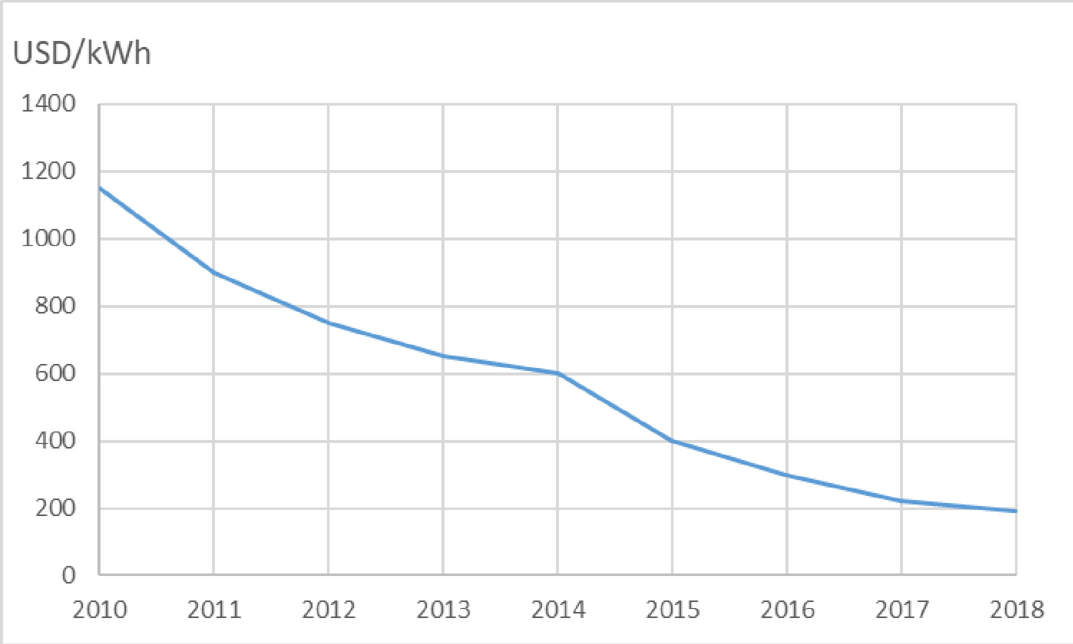

Figure 18: Evolution of the price of Lithium-ion batteries between 2010-2018

Source: Data from Bloomberg New Energy Finance[210]

Lithium-ion is the generic name given to a family of electrochemical energy storage systems using Lithium salt in their liquid electrolyte (the solution between the two electrodes) (Silberberg, 2006)[211]. However, if the anode (the negative electrode) is usually made of Carbon (or graphite), many different materials are used for the cathode, making for a high diversity of Lithium-ion-based batteries. Nevertheless, according to Qian *et al*. (2010)[212], the lithium iron phosphate cell ($LiFePO_4$) is the most common technology used for lithium-ion batteries designed to support solar PV systems. Tesla batteries are one of the exceptions as the company selected a lithium-nickel-cobalt-manganese configuration for both its electric cars and home energy storage systems. This variant of the Lithium-ion technology trades off cost and life expectancy[213] for better power density, understandable as it is to be used in vehicles (Ah/kg and Ah/l) (Nitta *et al*., 2015)[214].

[210] Bloomberg NEF (2018) *Ninth Battery Price Survey*. Bloomberg.

[211] Silberberg, M. (2006) *Chemistry: The Molecular Nature of Matter and Change*, 4th Ed. New York (NY): McGraw-Hill Education. p. 935.

[212] Qian, H., Zhang, J., Lai, J. S., and Yu, W. (2010) A high-efficiency grid-tie battery energy storage system. *IEEE transactions on power electronics*, *26*(3), 886-896.

[213] Measured as the expected number of equivalent full cycles (EFC) before maximum capacity is reduced to 70% of original capacity.

[214] Nitta, N., Wu, F., Lee, J. T., and Yushin, G. (2015) Li-ion battery materials: present and future. *Materials today*, *18*(5), 252-264.

Lithium-ion batteries have the capacity to charge and discharge quickly which is important in precinct level applications, and they have longer life span than older technologies such as lead-acid batteries. According to Parra *et al*.[215] (2017), lithium-ion batteries have a maximum charge and discharge rate of 3C (meaning it can charge or discharge in 1 hour at a rate that is three times its capacity) and a life expectancy of about 3,000 equivalent full cycles (EFC)[216]. Therefore, they recommended this technology for PV smoothing but, if economically sensible, this technology can also be used for peak shaving, and even solar shifting.

4.3.2 Advanced lead-acid batteries (PbA)

Sparacino *et al*. (2012)[217] explained that lead-acid technology is the most mature of the four described and has been used in batteries since the mid-1800s. It is also the most commercially mature utility-scale rechargeable battery technology, with over 35 years of industry usage (Jung *et al*. 1996)[218].

According to Parra *et al*. (2017), PbA batteries have a maximum charge rate of 0.2C and discharge rate of 0.4C (meaning it charges or discharges at a rate that is about ten times slower than lithium-ion batteries), which restricts its application to solar shifting. Moreover, the life expectancy of lead-acid batteries is about half of lithium-ion batteries (estimated to be 1,500 EFC) Parra *et al*. (2017),. The main benefit of this technology is its cost of ownership ($/kWh), which is about half the one of Li-ion (and the lowest of the four technologies covered in this chapter) (Ibrahim *et al*., 2012) [219]. However, with the reduction in the cost of Li-ion batteries in the last decade and a low charge and discharge rate, making it unsuitable for smoothing, this technology is now recognised as obsolete for network applications.

4.3.3 Sodium-Sulphur batteries (NaS)

The Sodium Sulphur battery was originally developed by the Ford Motor Company in the 1960s to power early-model electric cars (Sparacino *et al*., 2012)[220]. However, it

---

[215] Parra, D., Norman, S., Walker, G., and Gillott, M. (2017) Optimum community energy storage for renewable energy and demand load management. *Applied energy*, *200*, 358-369.
[216] EFC is an industry standard used to assess the useful life of a battery.
[217] Sparacino, A., Reed, G., Kerestes, R., Grainger, B., and Smith, Z. (2012) Survey of battery energy storage systems and modeling techniques. In 2012 IEEE Power and Energy Society General Meeting (pp. 1-8). IEEE.
[218] Jung, K. H., Kim, H., and Rho, D. (1996) Determination of the installation site and optimal capacity of the battery energy storage system for load leveling. *IEEE Transactions on Energy Conversion*, 11*(*1), 162-167
[219] Ibrahim, H., Beguenane, R., and Merabet, A. (2012) Technical and financial benefits of electrical energy storage. In 2012 IEEE Electrical Power and Energy Conference (pp. 86-91). IEEE.
[220] Sparacino, A., Reed, G., Kerestes, R., Grainger, B., and Smith, Z. (2012) Survey of battery energy storage systems and modeling techniques. In *2012 IEEE Power and Energy Society General Meeting* (pp. 1-8). IEEE.

was in 1992 that the first NaS battery system test facility was established in Japan in order to evaluate its performance for large power demand applications (Liao *et al*.[221] (2016). Commercial applications for utilities only appeared in the mid-2000 (Aneke and Wang, 2016) [222]. Tamyurek *et al*. (2003)[223], Wen (2006)[224], Aneke and Wang (2016) and Liao *et al*. (2016) all suggested that NaS batteries exhibit high power and high energy density (three times that of traditional Lead-acid batteries and almost twice that of Lithium-ion batteries), a long life cycle, low material costs and a high efficiency of approximately 85 percent.

NaS batteries have been used successfully since the mid-2000 by electricity distribution utilities for a wide variety of applications including peak shaving, renewable integration and power quality management (Wen, 2006), particularly thanks to their capability to provide a prompt and precise response (Aneke and Wang, 2016). However, Sparacino *et al*. (2012) and Aneke and Wang (2016) noted they have a high operating temperature (between 300 and 360°C) which leads to the (hot) metallic sodium being a high operational hazard as it is combustible if exposed to air and water (moisture). This presents a near insurmountable risk for precinct applications.

4.3.4 Flow Batteries

Unlike other battery technologies mentioned above, in a flow battery, the electricity is not stored in a battery cell but in separate tanks. Then, to charge or discharge the battery, the liquid in the two tanks are made to flow through a reactor stack and exchange electrons through a membrane without mixing. The Vanadium Redox (VR) battery and the Polysulfide-Bromine (PSB) battery are the most common types of flow battery (Telaretti and Dusonchet 2016)[225]. More recently, Zinc-Bromine (Zn/BR) batteries have seen increased development efforts and application to utility, community, and residential scales (U.S. Energy Storage Association (2020) [226].

[221] Liao, Q., Sun, B., Liu, Y., Sun, J., and Zhou, G. (2016) A techno-economic analysis on NaS battery energy storage system supporting peak shaving. *International Journal of Energy Research*, *40*(2), 241-247.
[222] Aneke, M., and Wang, M. (2016) Energy storage technologies and real life applications–A state of the art review. *Applied Energy*, 179, 350-377.
[223] Tamyurek, B., Nichols, D., and Demirci, O. (2003) The NAS battery: a multifunction energy storage system. In 2003 IEEE Power Engineering Society General Meeting (Vol. 4, pp. 1991-1996). IEEE.
[224] Wen, Z. (2006) Study on energy storage technology of sodium sulfur battery and its application in power system. In 2006 International Conference on Power System Technology (pp. 1-4). IEEE.
[225] Telaretti, E. and Dusonchet, L. (2016) Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC) (pp. 1-6). IEEE.
[226] Energy Storage Association (2020b) Zinc-Bromine (Znbr) Flow Batteries, Energy Storage Association.

In 2002, Lotspeich (2002)[227] ran a comparative assessment of Flow batteries and indicated that while VR batteries had a higher system net efficiency (70-85% vs 55-75% for PSB) and was suitable for smaller power output such as 250kW (5MW for PSB), PSB had a lower cost of ownership (for both $/kWh and $/kW), longer service life and safer components (VRB solutions are contained in sulphuric acid, at a similar pH as that found in a lead-acid battery). Lotspeich added that a cold start-up could take 10 minutes and are both more commonly used for slow charge and discharge rate applications (such as solar shifting) than fast rates (such as PV smoothing).

Moreover, their electrochemical reaction is reversible and non-destructive, meaning it is capable of 100 percent discharge (Sparacino *et al*., 2012)[228]. Finally, Fisher *et al*. (2019)[229] undertook a techno-economic comparison of various battery types in the behind-the-meter commercial and industrial market and concluded that Flow batteries at a 4 hour duration are less economical than shorter duration Lithium-ion or Lead-Acid batteries.

4.3.5 Summary of Findings

The findings of the literature review found that each of the technologies could be competitive depending on the service expected and the capacity required. However, Lead-Acid technology has been deemed obsolete for network applications, and Flow batteries are restricted to slow charging and discharging application such as solar shifting, which is not the identified priority for EENs introducing solar energy. To the contrary, Lithium-ion and Sodium-Sulphur batteries are capable of covering each of the three roles mentioned in Section 4.2.

Regarding usage, Sodium-Sulphur batteries seem to be limited to utility applications rather than behind-the-meter applications due to the significantly high operational hazard. Therefore, the Lithium-ion technology appears to be the most versatile option and has been selected for the purpose of this thesis as the technology of choice. This

[227] Lotspeich, C. (2002) A comparative assessment of flow battery technologies. In Proceedings of the electrical energy storage systems applications and technologies international conference (EESAT2002).
[228] Sparacino, A., Reed, G., Kerestes, R., Grainger, B. and Smith, Z. T. (2012) Survey of battery energy storage systems and modeling techniques. In *2012 IEEE Power and Energy Society General Meeting* (pp. 1-8). IEEE.
[229] Fisher, M., Apt, J., and Whitacre, J. F. (2019) Can flow batteries scale in the behind-the-meter commercial and industrial market? A techno-economic comparison of storage technologies in California. *Journal of Power Sources*, *420*, 1-8.

choice is both reinforced and further motivated by the clear widespread acceptance of this technology globally, as was shown in Figure 17.

4.4 Battery configuration and ownership models

For the sake of clarity and consistency, this part uses the same logic of physical location and connection to the embedded network for batteries that was used for solar systems in the previous chapter. Thus, the term 'distributed' assumes small battery energy storage systems (BESS) located behind-the-meter, while 'centralised' assumes a network-scale BESS connected directly to the network. Moreover, it is considered in this chapter that the primary purpose of a 'Distributed BESS' is to serve customers' interests first, while the primary purpose of a 'Centralised BESS' is to serve the utility's interests first. However, in both cases, customers and utility could benefit from each model of configuration of a BESS, depending on the control.

4.4.1 Distributed energy storage

Customer-owned

Darghouth *et al*. (2019)[230] looked at the economics of behind-the-meter energy storage for commercial customers in relation to rate design in the US and found that the technology could yield significant savings in demand charges (thanks to peak shaving) but also savings on the energy portion of the bill (thanks to load shifting). Interestingly, they also noted that energy savings scale more-or-less linearly with storage duration, whereas demand charge savings face diminishing returns at scale, meaning that the sizing of the energy storage intended to reduce demand charges must be precisely tailored to the customer's peak demand.

However, Schreiber *et al*. (2013)[231] noted that the participation of customer-owned behind-the-meter storage in the quality and reliability of the energy supply induced losses in self-sufficiency (stored energy used for the benefit of the grid and not to offset the customer's load) and must, therefore, be compensated by adequate tariffs in order to happen. This means that a customer with a solar + battery system (that creates power

[230] Darghouth, N., Barbose, G., and Mills, A. (2019) Implications of Rate Design for the Customer-Economics of Behind-the-Meter Storage. *Lawrence Berkeley National Laboratory*.
[231] Schreiber, M., and Hochloff, P. (2013) Capacity-dependent tariffs and residential energy management for photovoltaic storage systems. In *2013 IEEE power and energy society general meeting* (pp. 1-5). IEEE.

fluctuations in the network) could not be required to smooth these fluctuations before it affects the network unless compensated for this “work”.

The studies mentioned above assumed the behind-the-meter BESS was financed directly by the customer who then recovers the investment gradually via savings on the energy bills. However, just like solar systems, a BESS can be leased. For example, Ilieva and Rajasekharan (2018)[232] called “storage for free” the business model proposed by Stem, a US company, which offers its commercial customers fixed repayments for its BESS that are guaranteed to be lower than the customer’s cost savings.

Customer-financed but utility controlled

The second model is the one used by Horizon Power, a vertically integrated public electric utility serving regional Western Australia. Simpson (2017)[233] explained that some portions of the network served by Horizon experienced a rapid and early rate of distributed solar generation adoption, such as the town of Carnarvon, and that Horizon responded by placing a moratorium on systems in 2011. The solution later chosen to tolerate more distributed solar systems to be connected was to require customers to include a generation control system when they connect photovoltaic panels to the electricity network, such as behind-the-meter energy storage for smoothing (Horizon Power, 2019[234]). Vassallo (2015)[235] explained that these “generation management” systems help remove variability in the required output of the power station during periods of lost and recovered output from the PV panels in times of cloud cover.

Applied to the context of the EEN of a commercial and industrial precinct introducing solar, this solution would mean that customers installing behind-the-meter solar and battery systems would be made responsible for the impact their system has on the network. This appears to be the most equitable solution since the alleviation of the impact is financed by the customer creating the impact (principle of 'impactor pays') rather than being contributed to by the other customers. However, if the principle of the impactor pays is welcome, the fact that the energy storage system is located behind-

[232] Ilieva, I., and Rajasekharan, J. (2018) Energy storage as a trigger for business model innovation in the energy sector. In *2018 IEEE International Energy Conference (ENERGYCON)*(pp. 1-6). IEEE.
[233] Simpson, G. (2017) Network operators and the transition to decentralised electricity: An Australian socio-technical case study. *Energy Policy*, *110*, 422-433.
[234] Horizon Power (2019) Solar technical requirements. Horizon Power.
[235] Vassallo, A. M. (2015) Applications of batteries for grid-scale energy storage. In *Advances in Batteries for Medium and Large-Scale Energy Storage* (pp. 587-607). Woodhead Publishing.

the-meter denies benefits for the precinct associated with an economy of scale and from achieving other duties that could be technically beneficial for the utility while still providing financial compensation for the customer.

Utility-owned

Behind-the-meter also means outside of the utility's inherent jurisdiction, so it was expected that examples of utility-owned behind-the-meter energy storage systems would be as rare as examples of utility-owned behind-the-meter solar systems. As anticipated, a review the literature did not find mention of such models, but did identify an application that could inform how a utility could use a behind-the-meter BESS for its interests, namely the case of Sonnen. Sonnen is a German company active in Europe, USA and Australia, who offer behind-the-meter energy storage technology that is charged using solar power (and on-grid electricity in specific markets) and uses grid prices and weather forecast to optimise the use of energy via an energy management software.

Ilieva and Rajasekharan (2018)[236] explained the company is capable of linking the home-battery systems it sold to its customers (tens of thousands of them) to make a virtual power plant (VPP) and use them to balance the network when there is a surge in demand (peak shaving). Sonnen gets paid by the market-operator for doing so, then rewards customers who opted into the program for the grid services their home battery provided. Sonnen[237] also reported another model called SonnenFlat where customers get a comfortable annual energy credit that they can use at any time of the day or night in exchange of letting Sonnen manage their battery to occasionally stabilise the grid, either by discharging the batteries during peak periods or, charge the batteries when the network gets saturated with solar or wind energy. In the context of the EEN of a commercial and industrial precinct, the embedded network operator could run such a program when needed while letting the customers enjoy their storage for their own use the rest of the time.

[236] Ilieva, I., and Rajasekharan, J. (2018) Energy storage as a trigger for business model innovation in the energy sector. In *2018 IEEE International Energy Conference (ENERGYCON)*(pp. 1-6). IEEE.
[237] Sonnen (2020) sonnenCommunity. Sonnengroup

4.4.2 Centralised energy storage

Zeh *et al*. (2014)[238] ran a comparative study between distributed behind-the-meter BESSs and a centralised BESS of the same overall capacity on a same portion of a network. They found that the primary advantage of a centralised BESS was the possibility to be positioned where it supports the quality of the energy supply best. Figure 19 and Figure 20 below show how voltage stability is better achieved with a well-placed centralised BESS than with a series of distributed BESSs.

The colours in the figures show how voltage changes from its nominal value (in green) to yellow, which shows a small acceptable voltage rise due to an unbalance between load and PV generation (and export to the grid), to red which shows a voltage rise outside the tolerance zone, with possibly damaging effects on customers appliances. As can be seen in Figure 20, a centralised BESS connected at the end of a node can absorb excess PV energy and stabilise the voltage on that node.

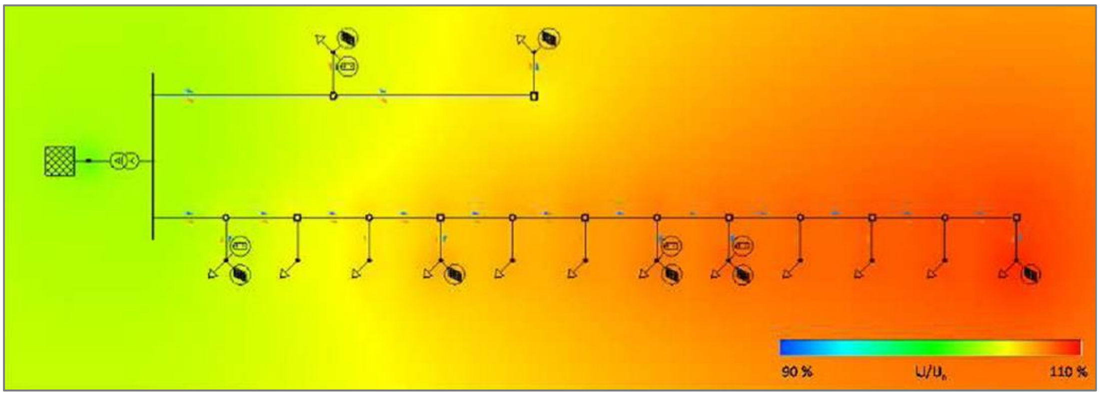

Figure 19: Isosurface of the voltage profile on a distribution network with 14 loads, 7 PV systems, and 4 behind-the-meter BESSs

Source: Zeh *et al*., 2014

[238] Zeh, A., Rau, M., and Witzmann, R. (2014) Comparison of decentralised and centralised grid-compatible battery storage systems in distribution grids with high PV penetration. *Progress in photovoltaics: research and applications*, *24*(4), 496-506.

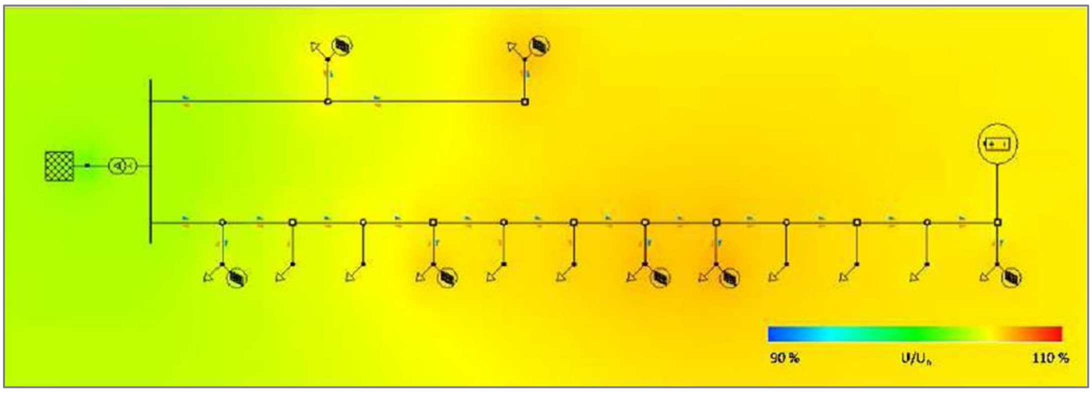

Figure 20: Isosurface of the voltage profile on a distribution network with 14 loads, 7 PV systems, and a centralised BESS

Source: Zeh *et al*., 2014

Therefore, in addition to the economy of scale made possible with a large centralised BESS compared to a series of small behind-the-meter BESSs, the overall benefits for both the utility and the customers could be more significant with a centralised BESS than with a series of distributed BESSs.

Utility-owned

Battery based energy storage systems have been used by distribution utilities since the early eighties to shave peak demand and protect distribution substations (EPRI, 1983[239], 1984[240], Jung *et al*., 1996[241]) and as a way to deal with the variability of renewable resources from the early nineties (Bolduc *et al*., 1993[242], Lachs and Sutanto, 1995[243]). As explained in Section 3.2.4 "*The unconstrained spread of DER increases the complexity and cost of the network*" and Section 3.2.7 "*Not an equitable business model*" if the utility is forced to invest in a BESS to alleviate the impact of customer's solar systems. In the traditional utility business model this capital cost would be recovered via the electricity bills of all the customers, including the ones who did not install solar systems.

[239] EPRI (1983) Utility Battery Operations and Application, EM-2946-SR. Resources. Electric Power Research Institute.
[240] EPRI (1984) Battery Energy Storage Test Facility, EM-2995. Resources. Electric Power Research Institute.
[241] Jung, K. H., Kim, H., and Rho, D. (1996) Determination of the installation site and optimal capacity of the battery energy storage system for load leveling. *IEEE Transactions on Energy Conversion*, *11*(1), 162-167.
[242] Bolduc, P., Lehmicke, D., and Smith, J. (1993) Performance of a grid-connected PV system with energy storage. In Conference Record of the Twenty Third IEEE Photovoltaic Specialists Conference-1993, pp. 1159-1162. IEEE.
[243] Lachs, W. R., and Sutanto, D. (1995) Application of battery energy storage in power systems. In Proceedings of 1995 International Conference on Power Electronics and Drive Systems. *PEDS 95* (pp. 700-705). IEEE.

Building on the work of Tant *et al*. (2013)[244] on the cost for the utilities to run a BESS for voltage regulation and peak demand reduction in a residential distribution network with high PV penetration, Poulios *et al*. (2015)[245] found that the distribution utility would have to bear considerable costs if all the technical constraint violations (mostly induced by behind-the-meter solar systems) are addressed exclusively by the network BESS. Whereas on the other hand, applying some low curtailment levels would reduce the required battery capacity significantly.

Moreover, in the context of the embedded network operator of a commercial and industrial precinct who purchases electricity at a very competitive rate ($/kWh), no commercial gain would be expected from using this network BESS for load shifting (Parra *et al*. 2017)[246], as explained in Section 4.2.1. Consequently, a centralised BESS financed by the embedded operator would not be profitable to the operator nor the PV customers and be indirectly paid by all energy customers.

Customer-owned

Zeh *et al*. (2014) also compared the financial implications for the customers between customer-owned distributed BESSs and customer-owned centralised BESS, considering two losses:

a. The losses of feed-in if and when the solar system would have to be curtailed once the BESS (distributed or centralised) is fully charged and the network hosting capacity is reached, called 'throttling losses', and

b. The losses of PV energy consumed by the PV customer (directly from the PV and after-hours from the BESS), called 'self-sufficiency losses'.

They concluded that in comparison to distributed storages, the losses incurred by the centralised storage with the same charging power and capacity as the sum of all distributed storages could be halved.

[244] Tant, J., Geth, F., Six, D., Tant, P., and Driesen, J. (2012) Multiobjective battery storage to improve PV integration in residential distribution grids. *IEEE Transactions on Sustainable Energy*, *4*(1), 182-191.
[245] Poulios, V., Vrettos, E., Kienzle, F., Kaffe, E., Luternauer, H., and Andersson, G. (2015) Optimal placement and sizing of battery storage to increase the PV hosting capacity of low voltage grids. In *International ETG Congress 2015; Die Energiewende-Blueprints for the new energy age* (pp. 1-8). VDE.
[246] Parra, D., Norman, S. A., Walker, G. S., and Gillott, M. (2017) Optimum community energy storage for renewable energy and demand load management. *Applied Energy*, *200*, 358-369.

4.4.3 Summary of findings

From the different approaches described above, it appears that a customer-owned centralised BESS with operator control would provide the best balance of benefits for the customers (economy of scale) and the utility (PV smoothing to protect the embedded circuit, the connection to the grid, and the quality of the supply on the EEN, and potentially peak shaving to limit network charges and defer augmentation of the connection to the grid). Having the smoothing asset financed by the PV customers also offers the most equitable solution. Indeed, if customers installing solar systems would be required to participate in the centralised BESS, with a minimum number of shares corresponding to the amount of customer-owned solar system to smooth, this would be more equitable for other customers on the network not installing PV.

4.5 Contribution of energy storage to the introduction of solar on an EEN

The findings from the literature review on energy storage contribute to informing some of the gaps identified in previously, such as:

Gap #2: "*How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of variable generation?*"

A centralised BESS controlled by the embedded network operator could help stabilise the grid and maintain the quality of the energy supply even in the occurrence of high penetration of onsite variable generation (rooftop solar).

Gap #3: "*How to make customers installing solar responsible and accountable for the pressure their solar system would put on the network?*"

One answer to this question is to make mandatory for customers installing a solar system to buy shares in the community-BESS in the proportion of the capacity of PV they install on their roof. This minimum storage capacity would be used to smooth the variation of their solar systems.

Gap #4: "*How to avoid inequity of access to solar among customers while penetration increases?*"

The previous chapter explained that inequity of access to solar among customers happens when the network (or a portion of it) gets saturated in distributed generation, and the embedded network operator is forced to prohibit any additional solar systems to protect the infrastructure and ensure the quality of the energy supply. A community-BESS could help increase the hosting capacity of the network so a larger number of customers could install solar and participate in the reduction of their energy bills.

4.6 Summary of Chapter and Contribution to Thesis

The review of literature for this thesis has made clear that energy storage could be a beneficial addition to the introduction of solar on the EEN, for the customers and even more for the embedded network operator. The three roles expected from an energy storage system have been identified as solar shifting, peak shaving, and solar smoothing, with the first one being most beneficial for the customers, the last one most beneficial for the utility, and the second beneficial for both. Solar smoothing was identified as the priority role for energy storage to play. An energy storage system using electrochemical technology (battery) was selected, and within it, the Lithium-ion chemistry found to be most common, mature and best capable of providing solar smoothing (and possibly the other roles if needed).

Centralised energy storage showed more advantages than distributed storage such as commercial gains and technical improvement of the network as a whole. Based on the literature it is concluded that it is better when a customer installing solar systems contributes financially to the energy storage system, rather than letting the utility finance it alone and recover its cost via energy bills. Specifically a community-owned and utility-controlled centralised Lithium-ion battery designed primarily for grid stabilisation (solar smoothing), with the possibly of being scaled up should be used for peak shaving, is the most suitable option for an EEN to transition to solar energy. Nevertheless, to add some of the benefits of the distributed energy storage model, the EEN could be equipped with several network-scale energy storage systems that are connected to the network in strategic locations (and feeders) to support more efficiently all the nodes of the embedded network.

Chapter 5: Review and Assessment of Potential Solutions

Sub-question #2 What suggested models, systems and theories could help fill in the identified gaps and support the long-term and cost-effective transition of an industrial precinct to solar energy?

Aim: Look for solutions to document the identified gaps in order to put together an integrated approach to support the transition of an industrial precinct to solar energy.

Objective: Literature review of suggested and conceptual models and solutions from the electricity sector and models and theories from other sectors that could contribute to the knowledge gaps.

5.1 Introduction

A number of different approaches (archetypes) to introducing solar systems on an electricity network that where identified in the academic literature were presented in Chapter 3. These approaches were considered within the context of the Embedded Electricity Network (EEN) of a commercial and industrial precinct. The chapter concluded that the archetype of 'Customer-owned distributed solar' was most beneficial overall.

However, the chapter also raised several issues, identified in the research as gaps, that remained when using the traditional utility model to introduce solar in this manner. These gaps were:

- *Gap 1: Revenue Protection* - “How to protect the revenue of the embedded network operator when behind-the-meter solar systems that reduce the sale of energy are introduced?”

- *Gap 2: Network Optimisation* - “How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of solar PV generation?”

- *Gap 3: Customer Accountability* - “How to make customers installing solar responsible and accountable for the pressure their system would put on the network?”

- *Gap 4: Customer Inequity* - “How to avoid inequity of access to solar among customers while penetration increases?”

- *Gap 5: Balance of Interest* - “How to ensure a balance of interests between the embedded network operator and the customers, and the corresponding customer engagement?”

Chapter 4 then complimented these findings and investigated the use of energy storage to support the introduction of solar systems on an EEN and concluded that:

- Having a battery for smoothing purposes is a must to manage high levels of solar PV penetration (partly filling Gap 2).

- Having the customers who install solar participate in the cost of this battery could incentivise them to manage the pressure their own solar system would put on the network (partly filling Gap 3) and

- Using energy storage to increase the hosting capacity of the network would allow more customers to access solar (partly filling Gap 4).

In this chapter findings are presented from the academic literature to identify what scholars have suggested to fill these gaps. The chapter also looks at what industry is proposing and expands the literature review to academic fields outside the electricity sector to gather theories and models that could provide additional guidance as to how to fill the gaps. This chapter aims to identify and select for further investigation a set of theories and industry practices that help build an integrated approach specific to the introduction of solar PV on EENs of commercial and industrial precincts.

Though the scope of an embedded network operator considered in this research covers all portions of the supply chain (i.e. vertically integrated utility), the research selected to focus the literature review on the distribution portion. This choice was motivated by two factors. The first was that network costs had been identified as the major component of the cost of electricity supply (see Section 3.3.2.6) and the weak link of the supply chain when distributed energy resource, such as rooftop solar systems, is introduced in the energy system.

Secondly, because distribution services are a natural monopoly on EENs and it is the primary role of the embedded network operator, unlike energy retail that can easily be opened to competition. In some parts of Australia, like in Western Australia, energy retail can also be a monopoly on EENs, but it is a legislated monopoly that can be broken by a rule change that would allow retail competition to be introduced on private networks. This has been the case in the states of Victoria, New South Wales, and South Australia in 2017 with the Power of Choice reform[247].

Thirdly, though the proposed solutions and examples from the industry defy easy grouping, this research suggested a categorisation that organises them according to the aspect of the traditional approach they would disrupt the most: Economic,

[247] AEMO (2017) Power of Choice. Guide to Embedded Networks. Australian Energy Market Operator.

organisational or social. They are presented below with an adaptation to the context of this research to inform which gap they would fill and how.

5.2 Solutions suggesting changing the economic aspect of the existing model

5.2.1 Overview

As Pérez-Arriaga and Bharatkumar (2014)[248] mentioned, when utilities were vertically integrated, the distribution of revenue between the different sections of the supply chain was not critical, and the objective was to ensure that the cost of the overall supply chain was covered by the payments from customers. The latter deregulation of the electricity sector that led to the splitting up of the supply chain (see Section 2.3.1) made the network utility an entity independent from generation and retail while keeping very restricted relations with the customers. This changed the economics of the entire system with the incentive now to ensure profitability of each part rather than as a whole.

When energy efficiency started eroding the revenue of the utility and, later, rooftop solar disrupted the entire energy sector financially, technologically and socially, many scholars and industry experts around the world suggested network utilities should find a new business model (York and Kushler, 2011[249]; Lehr, 2013[250]; Brown *et al*. 2014[251]; Burger and Luke, 2017[252]; Tayal and Rauland, 2017[253]; Cross-call *et al*., 2018[254]). Embedded utilities on private electricity networks are typically covering both distribution and retail of energy, and possibly some onsite generation. However, with or without retail competition, embedded utilities could suffer the same revenue erosion issue as the utilities on the public grid have experienced and, hence should also seek new business models to remain economically viable.

[248] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.
[249] York, D., and Kushler, M. (2011) The Old Model Isn't Working: Creating the Energy utility for the 21st Century. White paper. American Council for an Energy Efficient Economy.
[250] Lehr, R. (2013) New Utility Business Models: Utility and Regulatory Models for the Modern Era, The Electricity Journal, 26 (8), 35-53.
[251] Brown, M. A., Staver, B., Smith, A. M., and Sibley, J. (2014) Business Models for utilities of the Future: Emerging Trends in the Southeast. School of Public Policy, Georgia Institute of Technology.
[252] Burger, S. P., and Luke, M. (2017) Business models for distributed energy resources: A review and empirical analysis. *Energy Policy*, *109*, 230-248.
[253] Tayal, D., and Rauland, V. (2017) Future business models for Western Australian electricity utilities. *Sustainable Energy Technologies and Assessments*, *19*, 59-69.
[254] Cross-Call, D., Gold, R., Goldenberg, C., Guccione, L. and O'Boyle, M. (2018) Navigating Utility Business Model Reform: A Practical Guide to Regulatory Design. Rocky Mountain Institute, Snowmass, Colorado.

This section presents findings from a review of literature on solutions proposed to dissociate the revenue of the network utility from the sale of energy, referred to as 'Decoupling' by Rochlin (2016)[255]. The following part focuses on solutions for new tariff structures and the following one focuses on new ratemaking models.

5.2.2 New tariff structures

Discussion around better tariff structures is not new (Throgmorton, 1996)[256] and the erosion of the revenue of the network utility from falling energy consumption (e.g. due to energy efficiency) has been well discussed (Ortega *et al*. 2008[257]; Grace, 2014[258]; (Blansfield and Jones, 2014[259]; Beaufils and Pineau, 2018[260]). More recently though, the uptake of residential rooftop solar has caused significant disruption to the public electricity distribution system, changing it from a network of passive consumers to a system of both active and passive users with diverse consumption and generation behaviours (Pérez-Arriaga and Bharatkumar, 2014)[261]. With 'network costs' the principal cost covered by energy bills of customers (Section 3.2.6), the solution to keeping energy supply affordable while embracing distributed generation seemed to lay in the reduction, or at least the stabilisation, of the cost of the network.

Appropriate electricity tariffs are recognised to be capable of influencing consumption behaviour, triggering demand response, and improving distributed generation management, with limited impact on the network (Strbac and Mutale, 2005)[262]. For example, such outcomes where found as part of a tariff change by the US Federal Energy Regulatory Commission as part of a review of wholesale electricity pricing models across the utilities of the country beginning in 2014 (FERC, 2014)[263]. Therefore, the literature was investigated for suggested tariff structures related to

[255] Rochlin, C. (2016) Distributed renewable resources and the utility business model. *Electricity Journal, 29*(1), 7-12.
[256] Throgmorton, J. A. (1996) Planning as persuasive storytelling: The rhetorical construction of Chicago's electric future: University of Chicago Press.
[257] Ortega, M. P. R., Pérez-Arriaga, J. I., Abbad, J. R., and González, J. P. (2008) Distribution network tariffs: A closed question?. *Energy Policy*, *36*(5), 1712-1725.
[258] Grace, W. (2014) Exploring the death spiral – a system dynamics model of the south west interconnected system. Australian: Urban Design Research Centre (AUDRC).
[259] Blansfield, J. and Jones, K. (2014) Industry Response to Revenue Erosion from Solar PVs (Chapt 14). Distributed generation and its implications for the utility industry. Academic Press. Edited by Sioshansi, F. P.
[260] Beaufils, T., and Pineau, P. O. (2018) Structures tarifaires et spirale de la mort: État des lieux des pratiques de tarification dans la distribution d'électricité résidentielle. CIRANO, Centre interuniversitaire de recherche en analyse des organisations.
[261] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.
[262] Strbac, G., and Mutale, J. (2005) Framework and methodology for pricing of distribution networks with distributed generation. Cent. Distrib. Gener. Sustain. Electr. Energy.
[263] FERC (2014) Price Formation in Energy and Ancillary Services Markets Operated by Regional Transmission Organizations and Independent System Operators, Federal Energy Regulatory Commission.

electricity distribution infrastructure that better reflected how customers are using the network, as importer or exporter of electricity, and ensure they pay for their corresponding use and burden on the network.

Inspiration from the road network

Like public electricity networks, road networks are large, investment heavy, and long-lasting infrastructure that seek to serve the public. Jia and Crabtree (2015)[264] use the analogy of the response to the situation of the public road network in the USA to inform responses to issues in the public electricity network (that also could be applied to other regions of the world such as Australia and Europe). Interestingly, just like the electricity network, the road network is often financed based on energy use, in the form of taxation on fuel used by road vehicles (in addition to revenue from vehicle registration and licensing fees).

Just like for the electricity network, if energy use is decreasing but the need for, and use of, the infrastructure remains the same, if not increasing, there is a discrepancy between revenue and expenses and the utility struggles financially. For the road network, it is the case of the road vehicles becoming more fuel-efficient (due to stricter fuel efficiency standard) that is causing the revenue erosion. Jia and Crabtree cited a report from the American Congressional Budget Office that mentioned that between 2004 and 2014, the expenses have exceeded the revenues by more than USD52 billion[265]. This situation is likely to be further exacerbated as road users eliminate the purchase of fuel by switching to electric vehicles.

Moreover, because cars are more fuel-efficient (and comfortable), they noted that people are driving farther, thus using the network more. They also pointed out that, like electricity networks, roads have significant ongoing maintenance needs and limited options for generating revenue; and that the length and size (referring to the cost) of a portion of a network is not proportional to its amount of users (e.g. Washington State-managed roads account for only 8.3 percent of the total mileage of roads in that state but make over 43 percent of the daily use (Jai and Crabtree, 2015)). A parallel can be easily drawn with long and costly transmission systems bringing electricity to a few users in remote areas (particularly the case in Australia). On that

[264] Jia, J., and Crabtree, J. (2015) *Driven by Demand: How Energy Gets its Power*. Cambridge: Cambridge University.
[265] Jia, J., and Crabtree, J. (2015) *Driven by Demand: How Energy Gets its Power*. Cambridge: Cambridge University.

note, Jai and Crabtree stated that "*Robust transportation networks like roadways are unsung heroes of thriving economies*", and the same can be said of the energy networks such as electricity grids.

Consequently, Jai and Crabtree (2015) noted that the solution commonly used around the world is the introduction of road user charges such as a road toll (also applicable to bridges and tunnels). Tolls can be applied at fixed points in the road network to charge passing vehicles[266] either at a fixed rate or a rate reflective of the time of day (rush hour), and/or size (weight and length) of the vehicle. This approach can encourage drivers to shift their travels to periods with less traffic to reduce congestion, while also generating additional revenue and charge more the vehicles that are putting more stress on the infrastructure (road wear) or justifying the structural augmentation of the load-bearing property of a bridge.

Translated to the electricity sector, the principle of road user toll would see electricity customers charged for their energy demand (effectively the miles travelled) which is varied depending on the time of the day depending on the network peak demand (effectively network congestion) leading to infrastructure "wear" and augmentation need. Moreover, just as a toll system for roads is very localised, so there is a direct relation between payment collection and the portion of the road that is used, the electricity tariff would account for the specific context of the portion of the network the users are connected to.

Flexible pricing of network charges

The literature review revealed frequent advocacy for the generalisation of a demand charge in electricity tariffs, meaning that all network users (including residential) are not only charged for their energy consumption but also for their peak demand (Simshauser, 2016[267]; Wood and Hemphill, 2016[268]; ATA, 2018[269]). However, as most commercial tariffs already have a demand charge, the idea had to be pushed further because, traditionally, the demand charge is calculated based on the peak demand of

[266] Although fixed location tolls is a limited solution and is likely to soon be replaced by real-time location-based 'tolls' in response to the shift to electric vehicles.
[267] Simshauser, P. (2016) Distribution network prices and solar PV: Resolving rate instability and wealth transfers through demand tariffs. *Energy Economics*, *54*, 108-122.
[268] Wood, L. and Hemphill, R. (2016) Recovery of utility fixed costs: utility, consumer, environmental and economist perspectives. Lawrence Berkeley National Laboratory. Future Electric Utility Regulation, Report 5.
[269] ATA (2018) Sharing the load: Understanding consumer outcomes of network tariff reform. Tariffs Project II prepared for Energy Consumers Australia, Alternative Technology Association.

each customer, independently of when the network peak period occurs. This charge is therefore relevant to recover the cost of infrastructure directly related to the use of the network by the individual customer, such as the line transformer that sits between the feeder of that customer and the rest of the distribution system. However, capacity-related costs incurred by the network utility at system scale (such as the connection of the EEN to the main grid) are mostly associated with the peak demand of the system, not the individual customer's peak demand. Indeed, some customers do not have their peak demand at the same time as the majority of customers on the network and, therefore, do not contribute the same to the system peak demand. Lazar and Gonzalez (2015)[270] argued that traditional demand charges "*track cost causation very poorly*" and that it would be more relevant to charge customers for their demand during the distribution system's peak demand rather than during their individual peak demand.

To this, Bell and Forster (2017)[271] suggested adding a time component (Time-of-Use or ToU) to the peak demand charge, to make it more reflective of network congestion and the contribution, positive or negative, of behind-the-meter distributed generation to this situation. A contribution that could induce the need to reinforce the network infrastructure, trigger investment and thus increase its cost. Bell and Forster argued that a Time-of-Use demand charge would incentivise customers to change their consumption behaviour (such as Demand-Side Management (DSM) strategies for industrial customers), make better use of their onsite generation and promote the uptake of energy storage.

In the candidate's opinion, Pérez-Arriaga and Bharatkumar are the ones proposing the most advanced and innovative approach to allocate network costs to customers according to how each of their activity contributes to the total system costs incurred by the network operator (see below).

Network charges reflective of cost causality

The approach by Pérez-Arriaga and Bharatkumar (2014)[272] is based on the principle of cost causality and uses the "*distribution network use of system (DNUoS) charges*"

[270] Lazar, J. and Gonzalez, W. (2015) Smart Rate Design for a Smart Future. Montpelier, VT: Regulatory Assistance Project.
[271] Bell, W. P., and Foster, J. (2017) Using solar PV feed-in tariff policy history to inform a sustainable flexible pricing regime to enhance the diffusion of energy storage and electric vehicles. *Journal of Bioeconomics*, *19*(1), 127-145.
[272] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

introduced a few years earlier by Pollitt and Bialek (2007).[273] The latter identified the need for more locational pricing within the network to drive the uptake of renewable distributed energy resources where they are most needed (Pollitt and Bialek, 2007). In relation to distributed energy resources such as the rooftop solar systems, Pérez-Arriaga and Bharatkumar assured that "*Well-designed DNUoS charges can enable more efficient use of the distribution system by, for example, incentivizing efficient location or siting of distributed energy resources and optimal operation in response to distribution system conditions.*".

Their approach requires the use of two sources of data: The first is a model of the network containing the costs and the various factors that influence these costs, called the 'cost drivers', which is referred to as the 'Reference Network Model' or RNM. The second data set relates to the hourly profile of each customer on the network, for both the import and export of electricity, using advanced metering systems. The combination of the RNM and the customer profiles can provide clarity on how customers' electricity activities are impacting the cost of the network.

In short, the approach is to tailor the demand charge to each customer depending on how their peak demand contributes to the cost of the wider system. There are a number of advantages to this approach, namely:

- The first advantage of this method is that it no longer relies on grouping customers into classes from their assumed consumption patterns but instead considers customers individually, and therefore helps to fill Gap 2.
- The second advantage is that network charges are not directly related to actual energy consumption (Gap 1) but how and when customers are using the network and how this contributes to the cost of the network (Gap 3).
- Linking the network charges to how users are using the service provides an equitable system (Tayal and Evers, 2018)[274] and ensures the charges are agnostic

[273] Pollitt, M. G., and Bialek, J. (2007) Electricity Network Investment and Regulation for a Low Carbon Future.University of Cambridge.
[274] Tayal, D. and Evers, U. (2018) Consumer preferences and electricity pricing reform in Western Australia. *utilities policy*, Elsevier, vol. 54(C), pp. 115-124.

to the activity happening behind the meter like the presence of rooftop solar or other distributed energy resources, such as electric vehicle chargers.

- Because the proposed DNUoS are temporal and locational, they could help customers select better the capacity of rooftop solar that matches both their needs (cover their load and save on bills) and contributes positively to the network depending on where they are on the network (Gap 2) in a win-win situation (Gap 5).

- Once the rooftop solar is installed, the utility could help the customer make the best use of it (behaviour change when possible, such as shifting loads like programming EVs to charge when the sun is shining) or investing in a BESS (or in more shares (storage capacity) of the Shared BESS) for peak shaving and load shifting.

This approach proposed by Pérez-Arriaga and Bharatkumar is particularly suited to private networks as they are less constrained by the barriers facing public network operators such as an energy regulator supporting policies of socialisation of electricity costs, the multi-jurisdictional nature of some networks, or the significant cost and complexity associated with the necessary deployment of advanced meters on a large public grid. As this approach would foster the optimisation of the utilisation of the network and lead to the reduction, or at least the stabilisation in time, of the network costs, it should also reduce the electricity bills of customers.

The research considered this approach to be directly applicable to commercial and industrial precincts as it is and strongly capable of filling Gaps 1, 2 and 3.

5.2.3 New ratemaking models for the network utility

Modifying the utility business model, and particularly how it earns its revenue, is also related to ratemaking. One of the major proposals for the improvement of ratemaking found in the literature is the introduction of performance-based incentives in the revenue model of distribution utilities, contributing to the decoupling of a part of the revenue from the sale of energy and participating in the optimisation of infrastructure investments. The research found the work of Roman *et al*. (1999)[275] to be one of the

[275] Roman, J.,Gomez, T.,Munoz, A., and Peco, J. (1999) Regulation of distribution network business. IEEE Transactions on Power Delivery, 14(2), 662–669.

first to suggest such an evolution of the regulating framework, with the introduction of notions such as efficiency of the capital expenditure and operating expenditure as well as the quality of services delivered by the network operator.

Cossent and Gomez (2013)[276] explained that the idea to introduce a performance-based incentive came from the observation that, with the traditional model, energy regulators were not able to assess how much effort the utility put into optimising its operations and managing the asset base, which they called "*information asymmetry*". The latter could give an opportunity for utilities to argue they did their best but are facing high costs (higher than they really do), leading to an increase in the remuneration thanks to the cost-recovery business model. To inform new options for ratemaking a set of fours case studies have been investigated as presented below.

The New York Reforming the Energy Vision Model (NY REV)

In April 2014, the New York Public Service Commission presented a vision to reform the regulated network utility (Zibelmen, 2016)[277]. The customer-oriented regulatory reform aimed to change the utility business model and practices to ensure that both planning and integration of distributed energy resources from third-party providers was a central focus, and utility companies were incentivised to consider distributed solutions as an alternative to traditional centralised generation or investment in network solutions (Bade, 2016)[278].

Bade (2016) explained that the implementation of the reform was organised into two stages: the first stage focused on the transition of network utilities into 'Distribution Service Platforms'; and the second stage focused on the reform of ratemaking and rate design. The objective of the second stage was to decouple utility revenues from the sale of energy to make utility companies less sensitive to higher distributed energy resource penetrations. To do so, the regulator envisioned moving utilities away from traditional cost-of-service ratemaking and towards performance-based rates and giving them earning incentives that prompted them to invest in distributed energy resources

[276] Cossent, R. and Gomez, T. (2013) Implementing incentive compatible menus of contracts to regulate electricity distribution investments. utilities Policy, 27, 28–38.
[277] Zibelmen, A. (2016) REVing Up the Energy Vision in New York: Seizing the Opportunity to Create a Cleaner, More Resilient, and Affordable Energy System. IEEE Power and Energy Magazine, 14(3), 18-24.
[278] Bade, G. (2016) REV in 2016: The year that could transform utility business models in New York. UtilityDive.com.

rather than more traditional, capital-intensive grid projects, such as building new transmission lines, substations or centralised generation.

Bade (2016) went on by explaining that instead of relying on fixed charges to cover grid costs, the regulator preferred demand charges that provide a better revenue collection method because they coincide with peak usage on the grid that can be managed by the end-user through demand response, efficiency, or distributed generation and storage. Covering the grid costs with demand charge would effectively provide an added incentive for the deployment of these resources. The aim of the overall reform was to give the utilities taking the role of a Distribution Service Platform (DSP) the opportunity to make a higher return than with the capital-based rate-of-return if it met the Performance-Based Ratemaking (PBR) goals. At the same time, the overall energy system cost to customers would be lower with increased services (Mitchell, 2016)[279]. Figure 21 below is an example of how the earnings could be distributed over time.

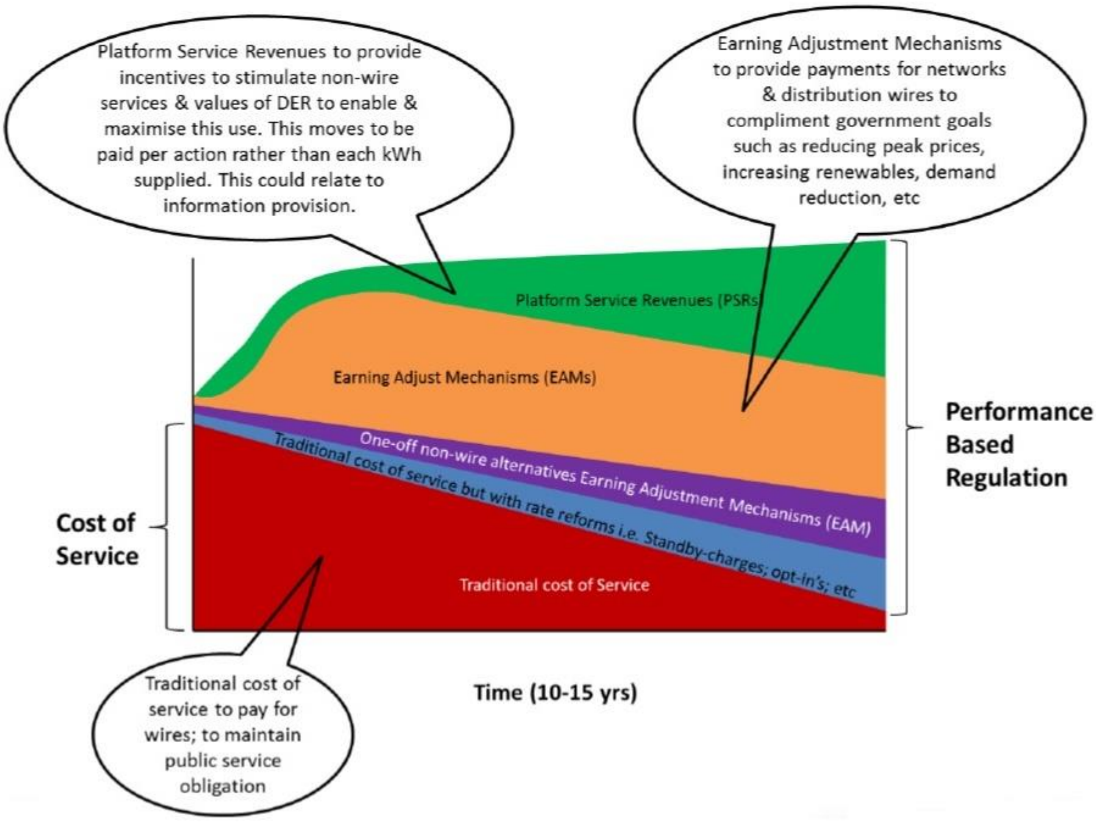

Figure 21: Source of utility revenue in the New York Reforming the Energy Vision
Source: Mitchell, C. (2017)[280]

[279] Mitchell, C. (2016b) DSP slidepack - Updated Dec. 2017. iGov Advisory Group, University of Exeter
[280] Mitchell, C. (2017) Bringing It Together. iGov Advisory Group, University of Exeter.

Among the different sources of revenue presented in Figure 21, the Platform Service Revenues (PSRs, in green) are of particular interest to this research as they could be adapted to embedded operators taking the role of DSP. The revenues would come from service subscriptions or scheduling fees from energy customers or third parties wanting to use the network to optimise their distributed energy resources (solar, battery or demand response) or aggregate them. However, to attract payments, these services would have to be optional and add value to customers or third parties beyond traditional distribution and electricity supply services (Cross-Call *et al*., 2018)[281].

The UK RIIO Model

The United Kingdom first introduced an 'Innovation Quality Incentive' for capital expenditure allowances in the 2005-2010 regulatory period (Crouch, 2006)[282] which was then extended to other costs in the following period (Cossent and Gomez, 2013)[283]. This experience informed a review of regulation for energy networks (OFGEM, 2010)[284] which led to the introduction of the UK's 'Revenue = Incentives + Innovation + Outputs' model, referred to as the RIIO. The RIIO was first implemented on transmission networks in 2013 and on distribution networks in 2015.

The model is a performance-based approach with main incentives intended to reward utilities for improvements in the delivery of services to customers and, in turn, provide an incentive for innovation (Frame *et al*., 2018)[285]. According to Mitchell (2016) [286] who compared the NY REV and the RIIO models, the latter was "*designed to encourage network companies to: put stakeholders at the heart of their decision-making process; invest efficiently to ensure continued safe and reliable services; innovate to reduce network costs for current and future consumers; play a full role in delivering a low carbon economy and wider environmental objectives*".

The business model was designed so that companies implementing innovative projects to deliver energy to end-consumers would share the risk and the rewards of the

---

[281] Cross-Call, D., Gold, R., Goldenberg, C., Guccione, L. and O'Boyle, M. (2018) Navigating Utility Business Model Reform: A Practical Guide to Regulatory Design. Rocky Mountain Institute (RMI), Snowmass, Colorado.
[282] Crouch, M. (2006) Investment under RPI-X: practical experience with an incentive compatible approach in the GB electricity distribution sector. *Utilities Politics*. 14(4), 240.
[283] Cossent, R. and Gomez, T. (2013) Implementing incentive compatible menus of contracts to regulate electricity distribution investments. *Utilities Policy*, 27, 28–38.
[284] Ofgem (2010) RIIO - a new way to regulate energy networks. Facts Sheet 93. Office of Gas and Electricity Markets (UK)
[285] Frame, D., Hannon, M., Bell, K., and McArthur, S. (2018) Innovation in regulated electricity distribution networks: A review of the effectiveness of Great Britain's Low Carbon Networks Fund. *Energy Policy*, 118, 121-132.
[286] Mitchell, C. (2016a) Transformational Regulation – comparing the NY REV and RIIO. iGov Team, University of Exeter.

outcome. Moreover, utilities earned a return on a portion of the total expenditures both capital and operating expenditures (AEEI, 2018)[287], which reduced the incentive to invest in large-scale capital projects. For example, if a distribution network operator delivered a project with expenses below the approved budget, the savings would be shared between ratepayers and the utility. These savings represented an extra revenue for the utility but also meant network costs remained low, which would benefit the customers in the long term, a win-win situation. However, the system also worked the other way, making the distribution system operator accountable if going over budget by reducing its regulated revenue (OFGEM, 2010)[288].

The Australian Better Regulation Model

A similar approach was used in the Eastern and Southern States of Australia, on the National Electricity Market (NEM). In 2008, the States of Victoria and South Australia introduced financial mechanisms in the regulation to encourage energy networks to deliver efficiency and improvements to customers. Performance-based incentives were then adopted by the Australian Energy Regulator (AER) in 2013 for the whole of the National Electricity Market. They became part of the AER's 'Better Regulation' program, a reform for energy markets to be more consumer-focused (AER, 2014)[289]. The regulation reform, inspired by the UK's RIIO, was breaking away from the cost recovery model used since the inception of the public utility, that involved looking back at past costs and adjusting the rates to ensure the revenue corresponding to these costs, as explained earlier.

The Better Regulation reform package was made up of two schemes (ENA, 2019)[290], namely:

1. The Efficiency Benefit Sharing Scheme (EBSS) which provided a short-term financial benefit to network businesses if they could deliver operating expenditure efficiencies beyond those forecasted and approved by the AER. The EBSS allowed network providers to retain the reward for any underspend, or receive a penalty for any overspend for six years, regardless of which year within the regulatory period

[287] AEEI (2018) Utility earnings in a service-oriented world. San Francisco, CA: Advanced Energy Economy Institute.
[288] Ofgem, (2010) RIIO - a new way to regulate energy networks. Office of Gas and Electricity Markets (UK).
[289] AER (2014) Overview of the Better Regulation reform package. Australian Energy Regulator.
[290] ENA (2019) Rewarding Performance: How customers benefit from incentive-based regulation. Energy Networks Australia.

the under or over-spend occurred. After that period the gains (if any) would be passed on to the customers.

2. The Service Target Performance Incentive Scheme (STPIS) which provided networks with a short-term financial reward if they would beat reliability targets for customers set by the AER. The STPIS was applied to unplanned outages, so it excluded planned outages for scheduled maintenance and upgrades, and extreme weather events like cyclones (however did not include storms). The STPIS incentivised electricity networks to maintain and improve service performance by rewarding them with a percentage of allowed revenue when performance improved or penalising when service performance declined.

The French TURPE Model

In 2014, the French energy regulator, the CRE (Commission de Régulation de l'Electricité) introduced a performance parameter interventions, wait-time to be connected, or wait-time for resolution of complaints.

The TURPE (Tarifs d'Utilisation des Réseaux Publics de l'Electricité) is the regulated tariff for the utilisation of the public electricity network in France. The French electricity tariff system differs from the Australian tariffs as it involves a fixed demand charge (even for residential customers). This fixed charge corresponded to a maximum demand initially enforced by a breaker rated at the contracted maximum demand, now progressively replaced by advanced meters. However, as in Australia, it also involves the volume of energy delivered, so the network utility suffered similarly from revenue erosion due to reduced energy consumption, first from energy efficiency programs, then by behind-the-meter solar when France authorised the auto-consumption of its electricity in 2017 (Lienhart 2018[291] and Denoyel 2018[292]) (see Section 0 for details on the recent switch from gross metering to net metering in France).

Nevertheless, the fourth generation of the TURPE (TURPE 4) for the 2014-2017 period, saw the introduction of what is referred to as a bonus-malus system, or a bonus-penalty system, to incentivise the network utility to make the most of the investments

[291] Lienhart, J. B. (2018) Les impacts de l'autoconsommation d'électricité photovoltaïque sur les coûts de développement et d'exploitation du réseau. ENPC - École des Ponts ParisTech.
[292] Denoyel, L. M. (2018) L'autoconsommation collective : perspectives réglementaires, sociétales et économiques : D'un système linéaire et centralisé à un système diffus et localement organisé : mutation du système électrique vers la décentralisation et la pluralisation des acteurs. ENPC - École des Ponts ParisTech.

used to calculate its revenue base (RTE, 2012)[293]. Some of the performance criteria were related to customer satisfaction that was measured, for example, by planned interventions on-time, wait-time to be connected, or wait-time for resolution of complaints.

5.2.4 Summary of Findings

Each of the four models outlined above propose alternatives to the traditional energy-consumption based revenue approach, which allow some degree of decoupling of the remuneration generated from the system from the direct sale of energy. However, most of the models do so by introducing a performance-based revenue that requires an energy regulator to set and assess the performance criteria, which does not apply to private networks that self-regulate performance and investment decisions since they are commercial entities and not public services.

These solutions, although informative, are therefore not directly applicable to EENs and do not completely fill the gaps identified. However, they provide valuable insights for a commercial entity that wants to attract premium tenants by offering an energy supply and network services with performance above standard. Nevertheless, the Platform Service Revenues approach proposed in the NY REV could be the exception if there is added value to the platform services provided by the embedded utility, and customers are ready to pay for them. In this case, this model could help fill Gap 1.

5.3 Solutions suggesting changing the organisational aspect of existing model

5.3.1 Spectrum of new roles for the utility

In its 2018 report "*Reimagining the Utility*"[294], the Rocky Mountain Institute (RMI) argued that for the electricity sector to achieve a zero-carbon grid, electric utility roles and functions must shift. Indeed, the utility had historically performed the agreed-upon roles of forecasting, planning, and building network infrastructure, but expectations for utility functions were shifting, particularly for the distribution system. Nevertheless, a report from the Lawrence Berkley National Laboratory on new roles for utilities and third-party providers (Blansfield *et al*., 2017)[295] warned that if

[293] Herz, O. (2012) Tarificatoin des reseaux – TURPE 4. Salon clients.
[294] Cross-Call, D., Gold, R., Guccione, L., Henchen, M., and Lacy, V. (2018) Reimagining the Utility: Evolving the Functions and Business Model of utilities to Achieve a Low-Carbon Grid. Rocky Mountain Institute, Snowmass, Colorado.
[295] Blansfield, J., Wood, L., Katofsky, R., Stafford, B., Waggoner, D., and Schwartz, L. (2017) Value-Added Electricity Services: New Roles for utilities and Third-Party Providers. Lawrence Berkeley National Laboratories.

customers were now expecting utilities to deliver additional attributes (such as flexibility, greater customer control or environmental sustainability), the utility still had to maintain the core attributes.

The study from Berkley Lab called 'basic services' the services the utility was obligated to provide (or expected, in the case of a private utility or embedded electricity network operator), and called 'value-added services' the services corresponding to the aforementioned additional attributes, proposed to customers voluntarily who then became 'participants' and accepted to pay possible extra cost. This volunteer approach meant the cost of these services were not shared by all the customers (only the participants), and the services would generate additional revenue for the service provider. The term '*service provider*' is used here instead of utility because, as the Berkley Lab report mentioned, some of these value-added services could be provided by third parties. In this case, the utility would integrate, for the customers, value-adding services provided by third parties into the network without competing with them.

Therefore, the new roles for the utility would gravitate around the notion of additional attributes and value-added services, depending on who is providing the services, such as services delivered by the operator, and services organised by the operator but delivered by a contractor. The RMI (2018) suggested that this shift could be towards two extremes as shown in Figure 22, namely: when the utility provides value-added services (or invests in new types of assets such as distributed energy resources) then it would expand its current monopoly; but if instead, the utility withdrew from services except distribution of electricity it would let competitive third-parties propose value-added services, and the role of the utility would be to integrate the services smoothly. At the latter end of the spectrum, the utility would act as a platform provider, an integrator, of the third-party services, encouraging innovation. Similar conceptual models were proposed earlier by Fox-Penner that were called the "energy service utility" and the utility as "smart integrator"[296].

[296] Fox-Penner, P. (2014) Smart Power: Climate Change, the Smart Grid, and the Future of Electric utilities. Island Press.

Figure 22: Spectrum of utility models

Source: RMI, 2018[297]

Models towards the first extreme, the expanded monopoly services approach, are easier to achieve as they only require the utility to add new services to its existing offer, with several successful examples in the USA, such as the Fort Collins Utilities in Colorado and Green Mountain Power in Vermont (see sections 5.3.3 below respectively for more details on these models). In contrast, models towards the other extreme, the transformed platform operator approach, face a substantial challenge to change given the inertia of the traditional utility business model (where a vast majority of utility earnings derives from return on regulated, centralised assets). Finally, RMI warned that utilities should not, in practice, occupy either of these theoretical extremes but rather find the right hybrid model for their context. The following sections present examples of such hybrid models, with one close to each end of the spectrum.

5.3.2 The embedded network operator as "Platform Operator" of resources and services

When a network operator takes the role of a platform operator, it partners with contractors who offer services the operator does not have in-house. By connecting these service providers to network users, the operator can negotiate some form of fee or revenue share. Just like Uber earns a fee per booking (in addition to a fee per km driven), a platform operator is another business model for the utility to decouple its revenue from the sale of energy (University of Texas, 2017)[298].

In the NY REV, regulated utilities in New York are given a hybrid role. The utilities are still in charge of network operations and reliability planning, as per their previous

[297] Cross-Call, D., Gold, R., Guccione, L., Henchen, M., and Lacy, V. (2018) Reimagining the Utility: Evolving the Functions and Business Model of utilities to Achieve a Low-Carbon Grid. Rocky Mountain Institute, Snowmass, Colorado.

[298] University of Texas (2017) A Comparison of New Electric Utility Business Models. Policy Research Project Report #191 Energy Institute, the University of Texas at Austin.

monopoly, but they also take on the role of facilitating the integration of distributed energy resources across the network. This role has been called Distribution System Platform (DSP), "*akin to an air traffic controller that coordinates and facilitates the deployment of various distributed energy resources on the grid."* (Bade, 2016)[299].

As part of this approach the notable changes and new functions would be:

- A DSP is the opposite of a traditional network utility whose key incentive is the capital-based rate of return.

- The role of a DSP is primarily driven through performance-based regulation, linked to desired outcomes.

- A DSP is a market facilitator, not a 'do-er'; thus, it is incentivised to increase third-party entrants and driven by increased system efficiency.

It is important to note that ownership of generation assets or participation in retail markets by the DSP would be the exception rather than the rule. A DSP can own distributed energy resources only if it has tried to procure them and the market has not produced affordable choices. Also, it may make sense for a DSP to own some energy storage to improve grid functioning (e.g. smoothing) or some distributed energy resources when they would benefit low-income residents who cannot afford them, or for demonstration projects (Roberts, 2015)[300].

The role of a distribution system platform is best taken by the utility (and the embedded network operator) when the latter is only in charge of the distribution network with no energy retail business. Indeed, the platform operator must be unbiased to providers proposing services to the customers as its role is to "*...smoothly integrate innovative energy services and solutions onto the existing grid, allowing them to compete on equal footing with electricity from centralised power plants*." (Stein, 2014)[301]. Along with being able to compete on equal footing with energy imported from the main grid and on-sold by the retailer in the case of an embedded network.

[299] Bade, G. (2016) REV in 2016: The year that could transform utility business models in New York. UtilityDive.com.
[300] Roberts, D. (2015) New York's revolutionary plan to remake its power utilities. Vox.com.
[301] Stein, E. (2014) Utility 2.0: New York State Envisions New Platform Giving Equal Priority to Clean Energy Solutions, Published October 15, 2014.

This model would allow the utility to take roles where remuneration is not energy-based, hence decoupling revenue from the direct sale of electricity (Gap 1). The model could also improve the optimisation of the network and quality of the supply by setting targets to third-party actors and thus transferring the liability onto them theoretically (Gap 2). Since the platform operator earns revenue when third parties provide value-added services to customers and not based on the sale of a volume of electricity, it is possible this model also contribute to Gap 5.

5.3.3 The embedded network operator as "Distributed Resource Finance Aggregator"

In the 'Distributed Resource Finance Aggregator' model suggested by the Rocky Mountain Institute (Newcomb *et al*., 2013)[302] the utility would take the role of aggregator of customers to negotiate bulk prices for energy services (such as energy efficiency audits and retrofits, purchase of rooftop solar, installing energy management systems). The model suggests the utility is remunerated on the one hand by a commission on sales of services, and on the other by a fixed rate specific to customers installing distributed energy resources to ensure the distribution costs are recovered even if that customer becomes a net-zero importer of energy (Newcomb *et al*., 2013).

When the City of Fort Collins in Colorado, USA, set its 2030 greenhouse gas reduction goals, Fort Collins Utilities (in charge of distribution and retail of electricity) proposed to offer a bundled package of integrated utility services. The Rocky Mountain Institute (RMI, 2014)[303] presented and assessed the innovative business model. The report by RMI recommended that Fort Collins Utilities adopted a hybrid approach that maintained utility relationship with the customers, leveraged utility price, scale, and speed, while at the same time allowed more market innovation and customer choice. The new roles recommended to be taken by the utilities were to promote and administer the implementation of demand reduction programs to reduce peak loads (improvement of the energy efficiency of customers' houses and businesses) and distributed generation (installation of behind-the-meter rooftop solar).

Fully integrating these functions allowed the utility to design and control the business model that ensured the revenue loss from the reduced sale of energy would be

[302] Newcomb, J., Lacy, V., and Hansen, L. (2013) New Business Models for the Distribution Edge. Rocky Mountain Institute.
[303] Mandel, J., Campbell, M., et al. (2014) Integrated Utility Services: A New Business Model for Fort Collins Utilities. *Rocky Mountain Institute.*

compensated by the billing of these new services (called "utility margin replacement"). The result was also a win-win situation for the customers who benefited from low-interest rate loans to finance building energy efficiency improvements and rooftop solar thanks to the economy of scale of the operation managed by Fort Collins Utilities. The co-benefit was healthier, cheaper to run and more comfortable buildings.

The "utility margin replacement" presented in this model would fill Gap 1 (protect the utility revenue) and, with the reduction in peak load on the distribution network and more control from the utility, participate in documenting Gap 2.

5.3.4 Utility to partner with new entrants to cover new roles

Read (2009)[304] suggested that, for utilities to innovate in value creation, they should seek complementary partnerships to go beyond exploring opportunities and act as "*co-creators of opportunities*". Helm (2016)[305] also proposed partnerships between large utilities with low flexibility, with smaller more agile and local utilities; and cited the example of German utility incumbents partnering with local partner utilities to market and apply demand response solutions. Hamwi and Lizarralde (2017)[306] suggested embedded utilities should partner with ICT providers and smart device vendors to modernise the embedded network, increase hosting capacity and reliability, and improving the efficiency of energy balancing, and ultimately improve the stability of the electricity supply and lower electricity bills for customers.[307]

Tayal and Rauland (2017)[308] studied the situation of utilities (including incumbent energy retailers, network operators and generators) struggling in a transforming energy sector and noted that they "*will have to adapt and compete with new services and products, or face increasing redundancy in the market*". Instead of utilities taking new roles, they suggested they partner with new entrants to leverage their new products and services rather than developing these new products and services in-house, thus combining their traditional expertise and customer relationships with innovative offers from their partners. Tayal and Rauland noted that developing these innovative

[304] Read, S., Song, M., Smit, W., (2009) A meta-analytic review of effectuation and venture performance. Journal of Business Venture. 24(6),573–587.
[305] Helm T. (2016) Asset transformation and the challenges to servitize a utility business model. Energy Policy 91:98–112.
[306] Hamwi, M., and Lizarralde, I. (2017) A review of business models towards service-oriented electricity systems. *Procedia CIRP*, *64*, 109-114.
[307] This is obviously a valuable part of any future distributed utility but would not be pursued in any further detail in this thesis.
[308] Tayal, D., and Rauland, V. (2017) Future business models for Western Australian electricity utilities. *Sustainable Energy Technologies and Assessments*, *19*, 59-69.

partnerships with third parties could allow utilities to better deal with regulatory constraints that would limit them otherwise. This practice would also provide incumbents with low-risk access to innovation capabilities (Boscherini *et al.*, 2011)[309]. Tayal and Rauland (2017) adapted the work from previous researchers to depict an example of such an innovative partnership, as shown in Figure 23.

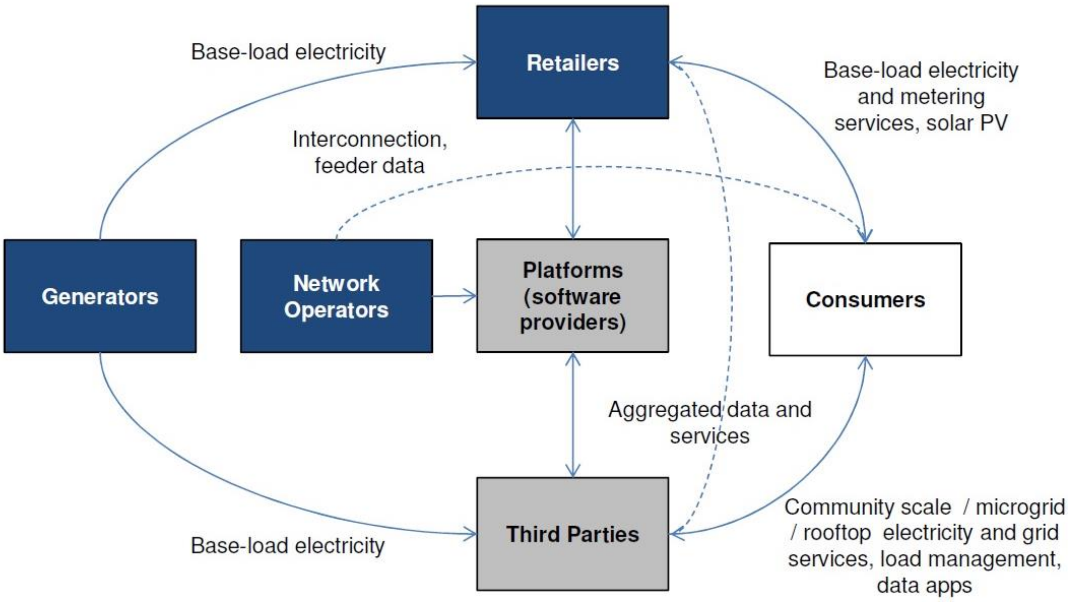

Figure 23: A future scenario of market participant relationships

Source: Tayal and Rauland, 2017[310]

In the context of private EENs where the embedded utility is vertically integrated and possibly less prone to competition, the partnerships could be integrated within the business of the utility rather than outsourced, keeping a single front office for the customers and avoiding other risks involved with contracting innovation-related services to outside parties.

5.3.5 How these new roles could help document the identified gaps

Building on from the RMI (Cross-Call *et al.*, 2018)[311] the research used the spectrum that was proposed and expanded it to identify roles that the embedded network operator of commercial and industrial precincts could take, as presented in Figure 24.

[309] Boscherini, L., Chiaroni, D., and Frattini, F. (2011) Escaping the incumbent's curse: the adoption of renewable energies in Italy. In *The XXII ISPIM Conference. "Sustainability in Innovation: Innovation Management Challenges"* (pp. 1-22).
[310] Tayal, D., and Rauland, V. (2017). Future business models for Western Australian electricity utilities. *Sustainable Energy Technologies and Assessments, 19*, 59-69.
[311] Cross-Call, D., Gold, R., Guccione, L., Henchen, M., and Lacy, V. (2018) Reimagining the Utility: Evolving the Functions and Business Model of utilities to Achieve a Low-Carbon Grid. Rocky Mountain Institute, Snowmass, Colorado.

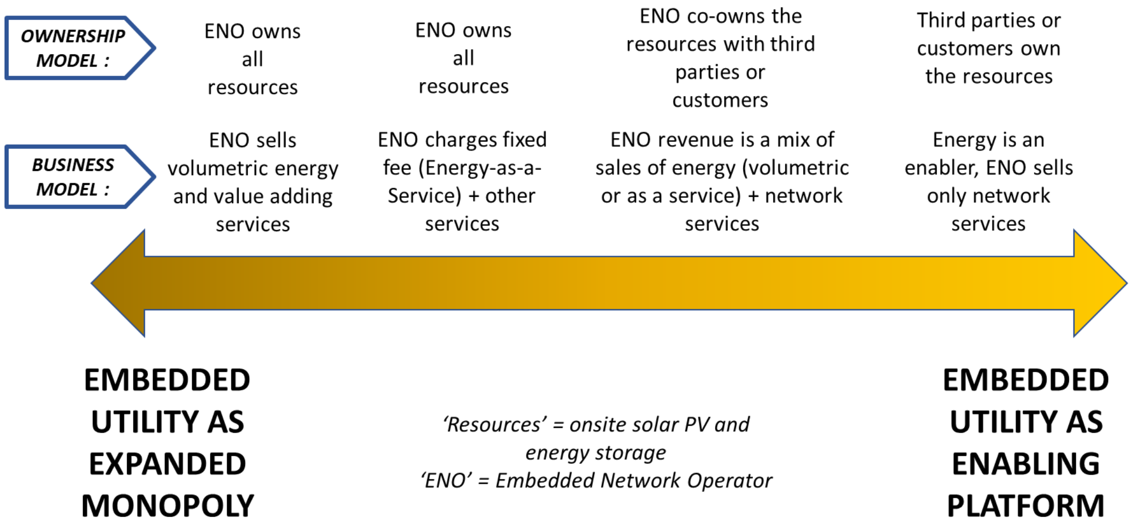

Figure 24: Spectrum of roles for the embedded network operator

Source: Informed by Cross-Call *et al.*, 2018

On the left side of the spectrum, the embedded utility (the embedded network operator) owns all assets and although it introduces a few value-adding services, such as peak demand management, it remains fragile to the evolution of network use by customers and certainly to the introduction of competition for the retail of electricity. The energy supply then transitions from a product, sold in volume (in kWh), to a service, represented in the middle of the spectrum by degrees of co-ownership by customers and third parties with a gradual sharing of the risk and the reward, and a more management-focused role for the operator. Finally, on the right of the spectrum, the embedded operator withdraws from ownership of energy assets (but not the network itself) and concentrates on its Distribution System Operator (DSO) role (where it has a monopolistic position). In this role the embedded operator builds up its capabilities to orchestrate the "embedded market", and in the process decoupling revenue from the direct sale of energy.

According to these examples, taking new functions in its role of distribution system operator could help the embedded utility decouple either partially (Fort Collins Utilities' example) or totally (NY REV and the *Distribution Service Platform*) its revenue from the sale of energy (Gap 1). These new functions also give the opportunity for the operator to engage with the customers on topics related to the distribution network, and how to optimise it and reduce or contain its cost (Gap 2). Since these value-added services are customer-focused and the network operator is rewarded for (its contribution to) adding extra value to customers, these new roles could contribute to filling Gap 5.

5.4 Solutions suggesting changing the social aspect of the existing model

In this section, the 'social aspect' of the existing model is assumed to consider the users of the network in the form of individual energy customers or the pool of energy customers on the precinct. This section gathers suggestions and examples related to possible new forms of collaboration between the utility and its customers, often by giving customers a new role.

Feedback from, and interaction with, energy customers has always been the role of the retailing department of vertically integrated utilities or the independent retailers. The conventional distribution network paradigm was one of “fit and forgot” (Pérez-Arriaga and Bharatkumar, 2014)[312] and Section 2.2.3.5, explained in detail how utilities are struggling to engage with network users. The following sub-sections explore how the retail and distribution roles of the utility could further engage with customers.

5.4.1 Engage with customers to better manage the energy mix

Shannon (2016)[313] claimed the alarming ‘Death Spiral’ from rooftop solar (and battery) uptake might be only a distraction to a real growth opportunity for utilities if customers are “*brought to the market*” and stopped being treated as passive end-users. Like with many other scholars, the business model Shannon suggested requires the customer charges to be unbundled, so the real cost of energy generation, transmission, distribution, and other services are made transparent to the customers. However, what makes Shannon’s model unique is the proposition to base the new business model on the following three principles in order to support customer choice:

1. Customers control their energy supply,
2. Utilities build infrastructure to be responsive to customer preferences, and
3. Utility risk is tied to customer preferences.

[312] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

[313] Shannon, R. S. (2016) Bringing the customer to the market: A new utility business model. *The Electricity Journal*, *29*(5), 15-18

Under this model customers would be given a choice to select where their energy comes from, setting a portion of their energy supply to each energy source available on the network, and their associated unit cost.

Shannon explained that this feedback would give a signal to utilities and the energy regulator about which infrastructure to invest in to satisfy customer expectations (i.e. the market demand). Because customer preference may change over time, programs that rely on consumer preferences are inherently riskier than traditional utility investments. To mitigate this risk or lessen their exposure, Shannon proposed two solutions: one is to get customers to subscribe into multi-year contracts like it is the case for private TV services, internet and mobile phones; and the other one is to require a minimum purchase from existing assets to avoid having to write them off too early.

Applied to an embedded network receiving a large portion of its energy from the grid that is complemented by onsite solar, the application of Shannon's model would be limited. However, it could inform the embedded network operator about the customers' appetite for more low-carbon forms of energy generation and thus their support for utility-scale (centralised on the embedded network) low-carbon onsite generation. Alternatively, adapted to network solutions, this model could inform the customers of the utility investment options and their relative cost (and impact on the customers' bills), though it would be difficult to translate clearly and simply the trade-offs and the long-term impacts (such as the impact on customers' bills) to customers. Nevertheless, this mode of communication with the customers could support the operator effectively if it takes the role of the platform operator, as suggested in Section 5.3.2.

This innovative approach translates best the role of the embedded network operator as a platform provider who enables businesses to carry on their activities with the highest level of predictability of future energy costs. This is likely to be a valuable feature for business managers of energy-intensive businesses, such as storage and logistics businesses, especially when their vehicle fleets begin to switch to EVs.

5.4.2 Engage with customers to better manage reliability

Regarding distribution functions, Shannon (2016) suggested that energy customers with behind-the-meter storage might not value network-provided reliability in the same way. For example, they could opt for their grid-based electricity to be 100 percent renewable and rely on their battery to cover periods of intermittency. Hence the necessity to give more choice to customers to control their energy supply and to better understand their expected degree of reliability if the utility is to invest wisely in energy mix, balancing, quality control and backup systems. This may be particularly the case on a private network where reliability standards are not necessarily set by an energy regulator but are part of a commercial contract between the embedded network operator and the customers.

This is echoed by energy expert Alan Pears in an Australian context (Pears, 2018)[314] who attributes the narrow-sighted approach that led the decision-makers (the heads of utilities on the Australian NEM, backed by the energy regulator) to over-build the network to "*keep the light on at all cost*". Pears suggested that sharing the effort between in-front-of-the-meter and behind-the-meter (i.e. between utility and customers) is a better way to mitigate the risk. Moreover, he warned that not only it is better, but it is happening, and soon it will likely be acceptable to have brown-outs and black-outs on the grid with consumers relying on their own behind-the-meter energy storage to avoid disruption in exchange for having grid-supplied electricity at a reasonable price the rest of the time.

Similarly, Jia and Crabtree (2015)[315] covered in length the topic of "*resilience as a core value"* of utility networks in general and electricity networks in particular. They noted that most of today's critical infrastructure in developed countries is interconnected with neighbouring countries and regions to provide reliable and nearly continuous access to electricity. However, this interdependence also means that significant disruption to one electricity grid can consequently cost significantly in damage and lost output across the entire interconnected system. They suggested further that increasing the diversity of resources and technology across a grid would help create resilience. More specifically, in Chapter 14 of their book, they noted that service providers are responsible for the risk of non-delivery of electricity. Nevertheless, that resilience could come from the end-users who could be rewarded for maintaining their independence (temporarily) and for drawing or injecting power into the grid "reliably".

[314] Pears, A. (2018) Risky Business? ReNew magazine #149.
[315] Jia, J. and Crabtree, J. (2015) *Driven by Demand: How Energy Gets its Power*. Cambridge: Cambridge University.

As a caveat, the above opinions might seem to suggest the best option is to push customers to acquire behind the meter energy storage so they can, in addition of solar systems, disconnect from the network. However, it is mostly not the case, and the underlying suggestion is to increase customer engagement and increase customer-utility collaboration to share the efforts towards a more reliable but also affordable and cleaner electricity supply or more simply, to convince customers to support the utility to invest in the modernisation of the (embedded) network. This is based on the experience in Perth where in some suburbs over 30 percent of householders have PV, but the owners use the grid to share their excess electricity in order to make money and thus are happy to be part of a resilient grid (Green and Newman, 2017)[316].

5.4.3 Engage with the customers to better manage peak demand

Managing peak demand, both from a supply (generation) perspective and a distribution (network) perspective, has been a challenge managed by the utility alone while the customers were considered (and were behaving as) passive users. With the uptake of energy efficiency and demand-side management followed by customer-owned generation and the growing presence of customer-owned storage, utilities and third parties are now being called to come up with business models involving the customers in solving the growing utility challenge of managing peak demand efficiently.

In 2017, Enel, a large power utility with a global presence, created Enel X to gather services not related to the sale of commodities and, thanks to this autonomy, enabled the research and implementation of new business models and the development of innovative solutions (Enel, 2018)[317]. One of Enel X's businesses is called 'e-industries' and within this area, a service tailored to large energy customers to help them reduce their peak demand charges (annual peak demand charge as well as any penalties for exceeding their Contracted Maximum Demand (CMD)). Enel X assists customers so they manage their consumption more efficiently during network peak demand events (that effects the annually-averaged peak demand charge) as well as when they are at risk of exceeding their CMD, as explained in the infographic of Figure 25.

[316] Green, J. and Newman, P. (2017) Citizen Utilities: The Emerging Power Paradigm, *Energy Policy*, 105: 283-293
[317] Enel (2018) Cities of tomorrow – Circular cities. Enel.

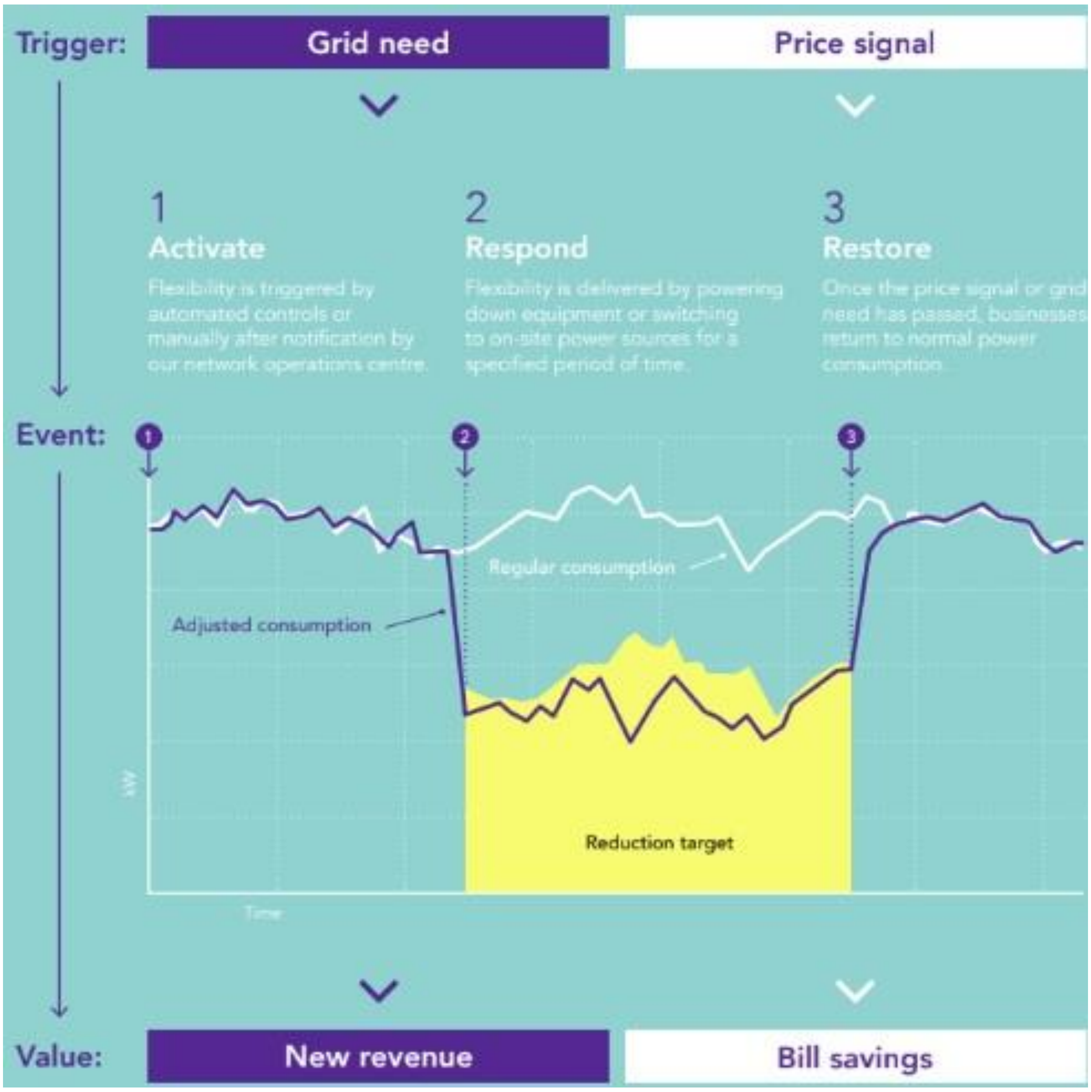

Figure 25: Power flexibility services provided by Enel X

Source: Enel X[318]

In Enel X’s business model, the savings are shared (to an undisclosed proportion) between the customer and Enel X based on a shadow bill that estimates the potential demand charges that could have occurred without Enel X’s intervention. The embedded network operator could collaborate similarly with its customers, using the same business model or offering its service for free as it would benefit from its customers better managing their demand by reducing or deferring significant network upgrades.

AGL, the oldest Australian utility, engaged with their customers to better manage peak demand using a different approach. The utility proposed a customer-owned household

[318] Enel X (2019) About Enel X brochure - Power flexibility. Enel

battery storage solution (AGL, 2015a)[319] where participating customers were offered a selected battery storage system at a heavily discounted price in exchange for signing up to a long-term contract with AGL (Parkinson, 2018)[320]. As part of this offer, each residential battery is controlled centrally through a 'cloud-connected intelligent control system', enabling the distributed storage units to be aggregated into a virtual power plant (VPP), allowing AGL to enter the capacity market (Tayal, 2017)[321] while supporting the grid and rewarding the customers (AGL, 2015b)[322]. Moreover, AGL gets a co-benefit in access to battery usage data (Parkinson, 2015b)[323]. This model could be applied to an EEN as peak demand reduction would directly benefit the embedded network operator thanks to reduced or deferred network augmentation investments.

5.4.4 Skipping the energy customer to deal directly with the load

Sioshansi (2012)[324] also supported the idea that "*the consumer as a passive agent at the receiving end of the industry's long value chain is an outdated notion*". However, he noted that the portion of customers reacting to price signals (e.g. time-of-use tariffs inviting customers to reduce their energy use during peak demand periods or shift it to the off-peak period) are yet a minority. He, therefore, noted it would be a revolution when price signals are passed directly to smart devices and appliances, influencing time of use and bypassing the consumer altogether. Similarly, Harper-Slaboszewicz (2012)[325] suggested pushing this concept by skipping the human interface thanks to automation following a ''set-and-forget'' principle and letting appliances and equipment communicate directly with the market operator for price signals.

5.4.5 Summary of findings

The models suggested by the academic literature and the ones implemented in industry that were selected in this section support the notion of increased collaboration between the utility and the customers to achieve win-win outcomes. Therefore, they provide inspiration to achieve the balance of interests mentioned in Gap 5. Some of the models

[319] AGL (2015a) AGL is First Major Retailer to Launch Battery Storage. AGL.
[320] Parkinson, G. (2018) AGL switches to Tesla and LG Chem for virtual power plant In: Parkinson, G. (Ed.), RenewEconomy.
[321] Tayal, D. (2017) Leveraging innovation for electricity utilities. *The Electricity Journal*, *30*(3), 23-29.
[322]AGL (2015b) Help build a battery-powered future, AGL.
[323] Parkinson, G. (2015b) AGL offering 7.2kWh battery storage at under $10,000 In: Parkinson, G. (Ed.), RenewEconomy.
[324] Sioshansi, F. P. (2012) Why the Time Has Arrived to Rethink the Electric Business Model. *The Electricity Journal*, 25(7), 65-74.
[325] Harper-Slaboszewicz, P., McGregor, T., and Sunderhauf, S. (2012) Customer View of Smart Grid—Set and Forget? In *Smart Grid* (pp. 371-395): Elsevier.

of collaboration presented in this section contribute to a better management of the energy supply and optimisation of network utilisation, thus contributing to Gap 2. Finally, some literature also suggested the utility could provide this collaboration as a remunerable service, thus potentially providing a decoupling of revenue from the sale of energy (mentioned in Gap 1), though this point is better covered in the next section.

5.5 The Product-Service System theory for the embedded network operator

The Distribution System Platform theorised by the RMI (and under implementation by the NY REV), the financial aggregator and project manager role taken by the Fort Collins Utilities, the Enel X and AGL offering, all provide examples of suggested or implemented business models that inform solutions for the utility to transition from selling a just product (energy) to selling a number of services. The Product-Service System theory, or PSS, can help better understand why the models mentioned previously can deliver better value to the customer and increase (or protect) profit for the service provider (the utility). The Product-Service System theory is presented in a section of its own because it supports economic, organisational and social changes to the existing utility model, and therefore, runs across the topics covered in the previous sections.

5.5.1 Introduction to the concept

According to Boken *et al*. (2014)[326], a PSS is a business model where the customer's needs are satisfied by the delivery of a service, or a set of services, rather than through the sale of a particular product. With more nuance, Goedkoop *et al*. (1999)[327] defined the term product-service system as "*a marketable set of products and services capable of jointly fulfilling a user's need. The product/service ratio in this set can vary, either in terms of function fulfilment or economic value*". Building on the concept of a 'product/service ratio', Tukker (2004)[328] talked about a continuum where the content of the offering would span from '*mainly product'* through to '*mainly service'*, and

[326] Bocken, N. M., Short, S. W., Rana, P., and Evans, S. (2014) A literature and practice review to develop sustainable business model archetypes. *Journal of cleaner production*, *65*, 42-56.
[327] Goedkoop M., van Halen C., te Riele H., Rommens, P. (1999) Product service systems, ecological and economic basis. PriceWaterhouseCoopers N.V. / Pi!MC, Storrm C.S. and Pre consultants.
[328] Tukker, A. (2004) Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business strategy and the environment*, *13*(4), 246-260.

proposed three main categories and eight subcategories of Product-Service System models represented in Figure 26.

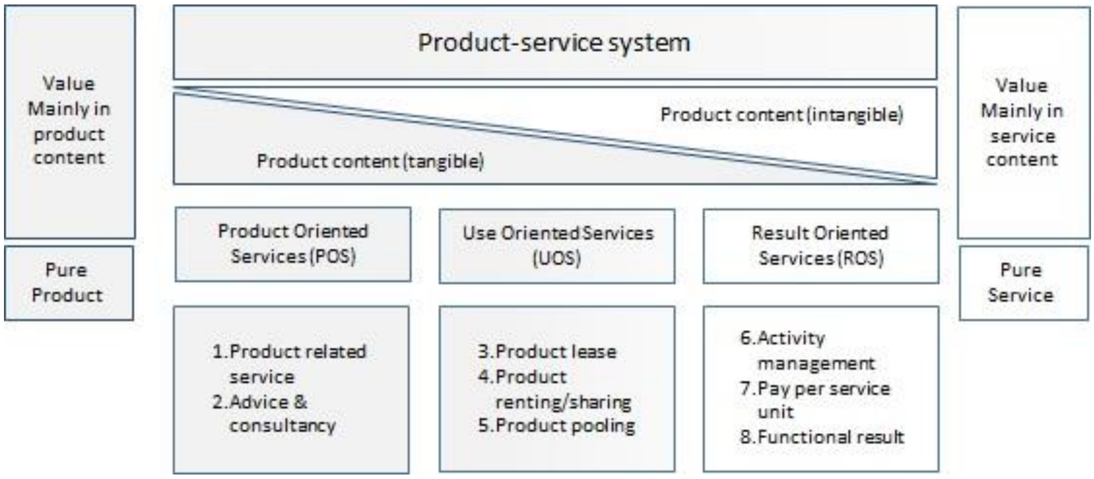

Figure 26: Main and subcategories of PSS

Source: Tukker 2004

The main categories are:

1. *Product-Oriented Services* (POS) that involves the sale of a product with additional services offered with it;

2. *Use-Oriented services* (UOS) where the ownership remains with the provider and is made available as a service to the customer; and

3. *Result-Oriented Services* (ROS) where provider and customer agree on a result with no pre-determined product involved.

The latter is the type used in the NY REV that has the objective to decouple utility revenues from the sale of energy by phasing-out of the 'Cost-Of-Service' model and replacing it with 'Performance-Based Remuneration' and 'Platform Service Revenues', as shown in Figure 21). The approach then has, as the means the opportunity to manage third-party-owned energy resources (including customer-owned distributed energy resources) to provide a result rather than investing in capital-intensive infrastructure. The model used by the Fort Collins Utilities, however, is more a Product-Oriented Service where the utility's primary activity and source of income remains the distribution and retail of electricity, but where additional services whose remuneration is not related to the sale of the "product", that of electricity, are offered to the customers.

Mont (2002)[329] explained that business models based on the PSS approach draw their success primarily from two components: from 'internal efficiency', that allows the service provider to make a profit without increasing the total price for the customer; and from an 'internal synergy' that allows the service provider to offer, at no additional cost, additional services valuable to the customer, hence creating a better value proposition. For example, as in the case of Crown Uniforms and Linen Services[330], a company in the business of selling work uniforms (dresses, pants, shorts and shirts). The company noticed its clients need was not to purchase uniforms for their workers but to ensure their workers have clean and fresh attire, for brand reputation, employee retention and, when the uniform is part of the Personal Protection Equipment (PPE), for safety reasons. That company decided to change its business model to propose these special apparels as a service to its clients rather than selling them new ones repeatedly. To make a case, the yearly service fee had to be more competitive for the clients compared to buying new uniforms for its employees and replacing them at the end of their life.

The service provider (Crown Uniforms and Linen Services) leveraged its knowledge in work clothes manufacturing, its experience in how they were worn and how best to maintain them to develop new designs and select better materials that were more resistant to wear when used but also when washed. The additional cost was compensated by the longer life of the clothes. The materials were also selected to be easier to wash and quicker to dry to gain in washing efficiency (washing time, water, energy). The service provider also worked on the washing and drying process, carefully choosing the equipment and the detergent, again to minimise time, water and energy and consequently reduce operating costs. These internal efficiencies reduced the life-cycle cost of the apparels allowing the service provider to make a profit without increasing the total cost for the customer. Moreover, the service provider offered free delivery, an additional service valuable to the customer that did not add cost to the service provider since the dirty clothes had to be picked up regardless, hence increasing the value proposition by leveraging internal synergy.

Mont (2002) also explained that when a customer acquires a product, it is to provide a service, and sometimes more than one service. In most cases, the product is an enabler

[329] Mont, O. K. (2002) Clarifying the concept of product–service system. *Journal of Cleaner Production*, *10*(3), 237-245.
[330] Crown Uniform (2019) Uniforms and Apparel – The Crown process, Crown Uniform.

of business or lifestyle, but not the primary concern. Mont observed that the customer is not able or knowledgeable enough to use the product to its full capacity all the time and extract all its value, including other services it can fulfil. However, this maximum efficiency can be achieved by a firm specialised in the use of this product, knowledgeable of all its resources across the items life cycle and with the ability to use the same product for other customers or other purposes. Once the supplier realises it can provide a service and not just a product, then it would sell the customer just the service it needs and not the whole product, consequently decoupling the economic transaction from the sale of the product. Moreover, the sale becomes an on-going engagement with the customer and not a one-time event.

On-demand transport is another example of a PSS Model. In the case of a taxi ride, the customer’s need is not to own or even to drive a car but to get somewhere. The alternative to taking a taxi is for the customer to buy a car and to drive it to go where he/she needs to be at that moment. However for the majority of the time the product remains under-utilised, and at the end of the year, the cost per ride or cost per kilometre is higher than if that customer would have used on-demand transport. Therefore, the solution is to propose the car as a service and have the customer pay only for his/her rides or kilometres transported. The price of just that ride is a lot higher than the cost of the same ride with the customer’s car, but the customer wins because he/she pays only for what is used. The driver also wins because his/her asset reaches a high utilisation rate and therefore a higher Return-on-Investment.

An example from the tyre industry

In the early 2000s, Michelin, a dominant player in the tyre industry, was facing increasing competition from Asian tyre manufacturers and was concerned that transport companies may be attracted by the lower initial investment offered by the competition (up to 38 percent cheaper in some cases). The concern was that even if customers understood that a lesser quality tire would have longer term issues such as premature failure, increased wearing and fuel consumption, they may still opt for the cheaper upfront option. Indeed, tyre-related breakdowns had become the most frequent reason for commercial vehicle stoppage since truck engine reliability had increased dramatically. Moreover, fuel cost was, after staff cost, the second most important operating cost of a road transport company (Renault *et al*., 2010) [331].

It was also the decade of raising awareness on climate change, and road transport companies were feeling the pressure from the community and associated government politics to reduce their emissions. With the most expensive tyres on the market, the Michelin sales team had to justify constantly their premium price by emphasising the exceptional longevity, robustness and lower fuel consumption, but this was true only when the tyres were fitted and maintained correctly, which was not always the case. Moreover, the unique capacity of Michelin's tyres to be re-grooved and re-treaded, extending the life of the tyre up to 2.5 times, was rarely fully achieved due to lack of experience and expertise in the service shops. The Michelin executive team concluded that to make sure clients would experience the full potential of Michelin's tyres, Michelin would have to take over the maintenance of its products. Michelin already had a long and profitable experience selling their expertise to end-users, but this was a new business model altogether, shifting from just selling products (tyres) to selling a service (the ability to get the most out of the tires).

The new business model called Michelin Fleet Solutions (MFS) was to provide customers with the tires they needed for their fleet and charge a monthly fee based on the number of kilometres driven by each vehicle. With this model, Michelin's profitability relied on its expertise in the maintenance and fitting of their tyres to optimise their use, keeping them in service as long as possible. It also helped Michelin differentiate itself from the competition that had a business model based on selling tires that was enhanced by tires wearing out and requiring replacement sooner. The clients saw many advantages, the two major ones being a peace of mind that tires were being managed and the performance responsibility was not on them, and the tyre-related costs where now variable costs directly linked to vehicle use.

The Michelin's PSS story informs this research of important elements in the switch from selling a commodity to selling a service. The analysis of the situation identified that Michelin's clients needed to perceive more value and receive more from this service than peace of mind and monthly scheduling of tyre-related costs. On the other

[331] Renault C., Dalsace F. and Ulaga, W. (2010) Michelin Fleet Solutions: From selling tires to selling kilometers. HEC Paris, Case Study no. 510-103-1.

hand, the business model had a few weak points from which two are relevant to the topic of this thesis:

1. The profitability depended on the optimisation of the life of the tyres which depended on the expertise of independent service providers not always capable, or sometimes willing, to achieve Michelin's expectations. In the case of an EEN, it means that not only the energy customer would expect the embedded network operator to put its expertise to work to increase the penetration of renewables (and let the customer install as much solar as needed) but also reduce the running cost of the EEN and reduce the end cost of electricity supply.

2. There was a trend in truck drivers to loosen their driving habits when they knew they were not responsible for the longevity of the tyres. In the case of energy-as-a-service, a change in the behaviour of customers regarding their energy consumption could happen if they feel they no longer need to worry about climate change as they are using renewables, or may not need to reduce consumption as energy is cheaper.

Michelin solved both problems by using sensors to monitor vehicle and tyres' data to extract strategic information valuable for the optimisation of the tyre (for Michelin's benefit), more fuel-efficient driving (for the client's benefit) and to anticipate tyre maintenance (for the benefit of both) (Norwell 2014)[332]. With the promise of a better fuel economy, the client changed from seeing tyres as a necessary product they have to purchase to seeing them as a way to improve their business bottom line. Applied to energy on an EEN, this means the embedded network operator would have to improve its monitoring capabilities, possibly even monitoring behind the meter activity, to offer the best service to its customers while optimising the network and its cost.

From the telecommunication industry

The telecommunication industry underwent disruptive changes in the nineties with the deregulation of the industry and the development of the internet and mobile telephony. The tariffs of mobile telephony were first similar to the landline service with an important fixed charge and a small variable charge for calls. With the democratisation

332 Norwell, I. (2014) Case Review: Michelin. Transport Engineer Magazine, Institute of Road Transport Engineers, UK.

of mobile phones and the introduction of smartphones that used more and more data, mobile plans evolved, providers would charge customers for every minute called, every text, and the fixed charge became the smaller portion of the bill.

Today, as the adoption of mobile devices is widespread and involves many other uses than just having conversations, operators have developed plans (tariffs) with one fixed fee that corresponds to a bundle of services the customer needs, or wants, and is ready to pay for. In that bundle, texts and calls are unlimited (so, they appear like free to the customer) and data is following this trend (and soon it would also be unlimited data across all plans). This last trend in plans complete the transition of the business model of mobile telephony from the sale of a commodity (minutes, texts and Gigabytes) to the sale of a service (connectivity). Further, the transition process brought in many new actors across the telecommunication industry however the incumbent actors did not see their revenue shrink. Instead, the total size of the pie grew, about four times between 1992 and 2015.[333]

From the water industry

For decades, the agricultural lands on the foothills of the Alps in the South of France had a straightforward but efficient business model where the farmers would only pay a yearly charge to use water from the distribution network. The charge depended on the size of the pipe feeding the customer, which did not have to be very large since it was feeding a large reservoir continuously on the customer’s land. Aggregated, the charges were paying for the maintenance of the distribution network (cleaning of small-scale canals and sealing of cracked concrete pipes), and the simple yearly billing (non-metered supply means no meter to read). The charge could have been used to recover the initial cost of the network, but it was not necessary as it had long been fully paid for.

Water, the commodity, was free because there was no cost involved in producing it (no desalination or pumping), sanitising it (snow melt water was suitable for agricultural purposes) or pressuring it (the gravity-fed network did not need pumps). The size of the pipe connecting the customer to the network represented the 'pressure' applied to the network as the larger the pipe the more water was needed in the network,

[333] Lande, J. (1994) Telecommunications Industry Revenue: TRS Fund Worksheet Data. Federal Communications Commission; March 1994; Radiant Insights, Inc. (2016) U.S. Telecom Market Size to Reach $1.3 Trillion by 2020, Radiant Insights, Inc. March 30, 2016.

which would trigger network augmentation to ensure every customer on the network had water. The tariff depended on the size of the pipe and was made to discourage customers from requesting large pipes but instead, encourage them to invest in a large water tank, so they had the necessary volume of water available to water the crops at the end of warm days. This storage would buffer the peak demand that happened once or twice a day when farmers were watering their crops. Also, the yearly fee was low enough that customers had no interest in looking for ways to go “off-grid” such as collecting and storing rainwater or pumping from a bore.

In this example, water is proposed as a service and not a commodity. The network delivered a commodity with some constraints (no pressure and low volume), but the participation from the customer (investment in the water tank, its maintenance and management of its demand in relation to its storage capacity) is rewarded by the very low cost of supply (and commodity). The participation of the customers also allowed a better sharing of the resource among other users by the smoothing of their demand which in turns kept the cost of the network low. Finally, the utility was encouraged to maintain the network to the minimum standard necessary to deliver the service and had no incentive to over-invest in the infrastructure and was not affected if customers reduce their water consumption as their revenue was decoupled from the sale of the commodity.

This example informs the thesis on how a commodity can be supplied as a service in a win-win outcome if the efforts and rewards are shared between the utility and the customers. Applied to the EEN of an industrial precinct, the situation could look like the following: Customers’ peak demand would be limited like the pipe in the example, so that the EEN peak demand stays under the threshold of network augmentation and expensive grid connection upgrades. In turn, this limited maximum demand rewards the customers with a low yearly connection charge. To satisfy loads that require punctually higher demand than the “pipe”, customers would rely on behind-the-meter energy storage similar to the water tank of the example.

5.5.2 The PSS applied in the energy sector

The research for this thesis include a review of publications mentioning a change in business model in the energy sector towards a shift from selling a product to selling a service. The most notable topic found was the shift from selling electricity to selling a service that mets the needs of the customer, called Energy-as-a-Service (EaaS) (Langel, 2004)[334] or Power-As-A-Service (PAAS) (Enel, 2018) [335]. Just like it was explained in the previous sections, a PSS requires the supplier to get close to the clients, understand their needs more than their '*wants*' and provide the services that satisfy the needs rather than the product that satisfies the wants. As Amory Lovins, co-founder, chief scientist and chairman emeritus of the Rocky Mountain Institute (RMI), nicely put it: "*People don't want raw kilowatt-hours […] they want hot showers, cold beer, comfort, mobility, illumination […]*"[336].

However, the electric utility has historically and by nature not been fit to offer services. *Historically* because, as explained in Section 4, it has never needed to be customer-centred, and *by nature*, because its business is capital dominant, both for expenditures and revenues, based on tangible assets with long amortisation periods resulting in a minimum-risk minimum-change culture (Helm, 2016) [337]. On the other hand, service-oriented business models depend more on intangible assets which can restrict traditional utilities when seeking to develop these services (Hamwi and Lizarralde, 2017)[338]. Helm (2016) summarised the barriers for utilities to transition to, or at least introduce some level of service-based business model, in the diagram pictured in Figure 27. The figure shows, on the second row on the left, that intangible assets such as the know-how are only complimentary (circled in red) and the most important infrastructure attribute of the utility business model (BM in the table) are tangible assets such as the poles and wires. In opposition, for service-oriented business models (the last row on the right in the table), intangible assets are central (circled in blue).

[334] Langel, C. (2004) Energy as a Service. Published in BWK: das Energie-Fachmagazin 56(3):9-9. Springer-VDI Verlag, Dusseldorf.
[335] Enel (2018) Cities of tomorrow – Circular cities. Enel.
[336] Ward, L. (2007) Amory Lovins: Solving the Energy Crisis, Popular Mechanics, 01 October 2007.
[337] Helm T. (2016) Asset transformation and the challenges to servitize a utility business model. Energy Policy 91:98–112.
[338] Hamwi, M., and Lizarralde, I. (2017) A review of business models towards service-oriented electricity systems. *Procedia CIRP*, *64*, 109-114.

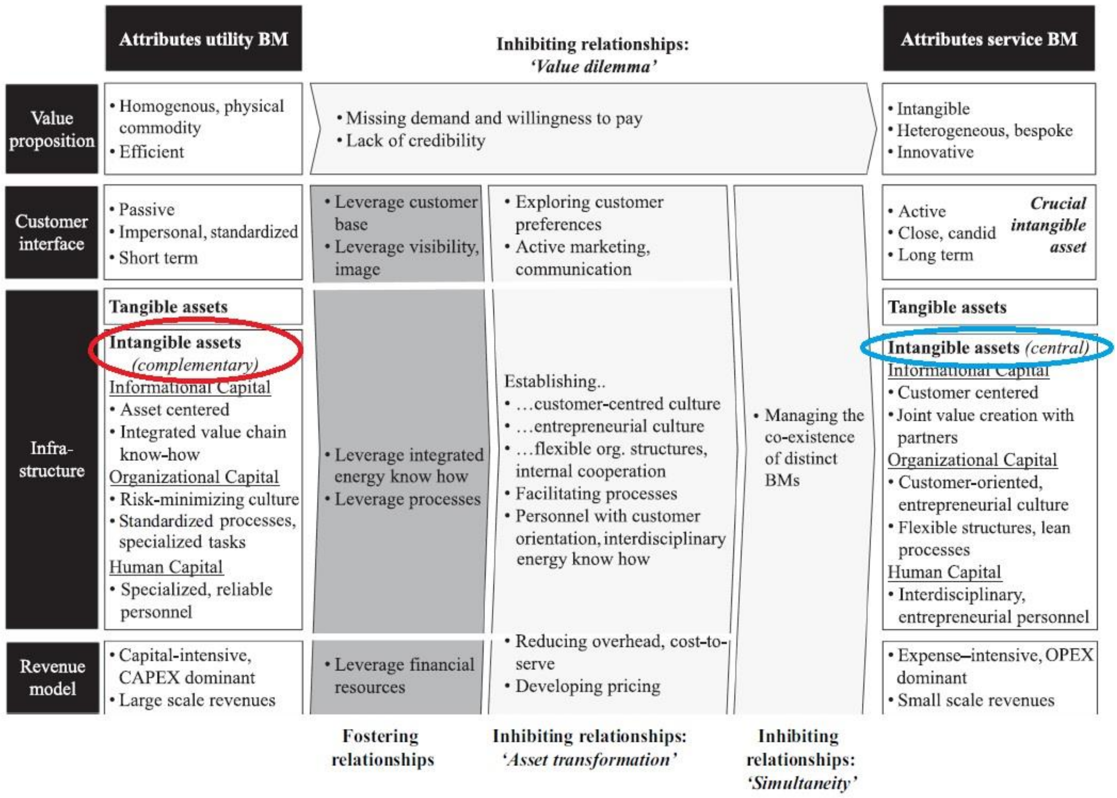

Figure 27: Attributes of the utility BM vs a Service BM

Source: Helm, 2016

The network operator on an EEN is very similar to the public utility considered by Helm in that there is limited engagement with the customers and the focus is on running a business centred on tangible assets rather than intangible assets.

For the purpose of this thesis the embedded network operator is considered to cover both distribution and energy retail roles, and in order to study the application of the PSS to EENs it was necessary to split the section into examples and suggestions from the literature for the retail of energy, and another sub-section for the distribution role. It was also important to split these two functions as the retail of energy concerns the sale of a commodity (electricity) by units and can therefore directly apply the PSS theory in what is called Energy-as-a-Service (EaaS). On the contrary, the distribution operator does not sell a product but a service, so it is more difficult to apply the PSS theory to its business model.

The PSS theory applied to the retail role of the utility

Many papers and reports cover business models where third-party providers optimise the affordability of energy supply for the customers, though it is often to the detriment of the retailer's revenues. Indeed, in these models, the service provider helps the customer reduce its bills, and as the service fees are less than the savings, it creates a win-win-lose situation for the customer, the provider and the retailer respectively. Since this research aims at proposing solutions to introduce solar in a way that would benefit both the customers and the embedded network operator, models presented below have been selected on the basis that the embedded network operator could be that service provider (without a third party) and the outcome is a win-win for the customer and the embedded network operator.

Solar energy as a service: Power Purchase Agreement offered by a retailer

Solar Power Purchase Agreements (PPAs) are typically the case where a third party invests in a solar system for a host customer and sells the energy to the latter at an agreed fixed price lower than the retail price (Wainstein and Bumpus, 2016)[339]. The customer saves on the energy bill, and the investor receives an income from the sale of energy as well as any tax credits and other incentives generated from the system. Therefore, a solar PPA turns a behind-the-meter solar installation from a product into a service, lifting in the process the main barrier encountered by business customers to install solar: the high upfront capital (Frantzis *et al*., 2008)[340]. In this equation, both the third party and the host customer benefit from the operation to the detriment, however, of the energy retailer who sells less energy (and consequently to the detriment of the network operator whose revenues are partly based on the volume of energy delivered and is still responsible for the network despite the reduced demand from the customer).

Energy storage and EV charging as a service

A similar example can be found with Green Mountain Power (GMP), the electric utility of Vermont, who proposed to their residential customers energy storage as a service by providing a Lithium-ion battery for an on-bill fee for ten years after which the ownership of the battery transferred to the customer (Cross-Call *et al*., 2018)[341]. The upfront and ongoing losses incurred by the utility (upfront for the acquisition of the battery and ongoing for the loss in the sale of energy) were compensated by the

[339] Wainstein, M. E., and Bumpus, A. G. (2016). Business models as drivers of the low carbon power system transition: a multi-level perspective. *Journal of Cleaner Production, 126*, 572-585.
[340] Frantzis, L., Graham, S., Katofsky, R., Sawyer, H., (2008) Photovoltaics Business Models. National Renewable Energy Laboratory, Burlington.
[341] Cross-Call, D., Gold, R., Goldenberg, C., Guccione, L. and O'Boyle, M. (2018) Navigating Utility Business Model Reform: A Practical Guide to Regulatory Design. Rocky Mountain Institute, Snowmass, Colorado.

reduction or deferral of network investments thanks to the use of these batteries by the utility as a virtual power plant to reduce peak demand, referred to as 'shared access' (Gold *et al.*, 2017)[342].

GMP also proposed another win-win deal to their customers by offering EV charging as a service to residential customers. The program offered a level 2 EV charger and unlimited off-peak charging plan for a fixed monthly fee (though charging during system on-peak period, which happens only five to ten times a month, incurred a disproportionately high electricity charge (Cross-Call *et al.*, 2018). Not only would the utility benefit from encouraging EV charging loads to occur during the off-peak period (thanks to the aggressive tariff), but as the provided chargers were grid-interactive, once connected to the vehicle the timing of EV charging could be centrally managed by GMP for even more flexibility and balancing of the electricity supply on the network to lower system costs. Additionally, unlike the home battery program, encouraging the uptake of EV charging meant shifting energy consumption from fossil fuel to electricity and consequently shifting the revenues from the petrol companies to the electric utility. This is one of the rare cases where the utility can support decarbonisation, decrease its customer bills and increase the sale of electricity simultaneously (assuming electricity is low carbon).

The PSS for the distribution utility

Business models using a Product Service System (PSS) to deliver better value or bring more profit that involves the distribution utility exclusively (with no retail function) are rare to find, mainly for the following reasons:

1. The distribution role of the utility is already service-based (transport of electricity, management of the quality of the electricity supply, management of existing and new connections, the balance between supply and demand) and does not involve the sale of any product. Whereas a distinctive attribute of service business models is their structure developed around a commodity product such as units of energy (Helm, 2016)[343]. The value proposition is,

[342] Gold, R., Guccione, L. and Henchen, M. (2017) Customer-Centric Energy System Transformation: A Case Study of the Opportunity with Green Mountain Power. Rocky Mountain Institute, Colorado.
[343] Helm T. (2016) Asset transformation and the challenges to servitize a utility business model. Energy Policy 91:98–112.

therefore, already at the extreme end of the continuum proposed by Tukker in Figure 26, called “Pure service”.

2. Secondly, the distribution role has a natural monopolistic position due to its capital-intensive and geographically dependent infrastructure. This means its service has no competition or alternative service that could serve as a reference to the customers, while it is a necessary condition for a PSS-inspired model to be more competitive than the traditional model (Mont, 2002)[344].

The models proposed previously in this chapter that involve the distribution role exclusively and the decoupling of its revenue from the sale of energy (as a PSS model would) are not alternative models to switching from the sale of a commodity to the sale of a service, but rather alternative service models where the cost of service is not based on the quantity of product delivered (energy) but is rather based on subscription or pay-per-use. Therefore, the research concludes there is no academic suggestion or example in the industry of the application of the PSS exclusive to the distribution role of the utility.

The foundational principle of the Product Service System theory, being the shift from selling a product to selling a service, is a prime model to decouple the revenues of embedded electricity utilities from the sale of energy which contributes to filling Gap 1. The examples covered in this section could help the embedded utility best optimise the distribution network and best manage the quality of the energy supply, hence helping fill Gap 2. Finally, service models covered in this section support the collaboration between the utility and the customers for a win-win situation, and as one of the principles of this theory is the provider earns revenue when value is added to the customer, then it contributes to fill Gap 5.

5.6 Synthesis

The review of literature on suggested and implemented solutions, in the form of innovative tariffs, roles, and business models, showed that globally scholars and industry experts have been working towards the transformation of the electric utility as it transitions inevitably towards becoming distributed, customer involved, and low-carbon. The solutions identified and selected in this research fill most of the gaps

[344] Mont, O. K. (2002). Clarifying the concept of product–service system. *Journal of cleaner production*, *10*(3), 237-245.

described in the previous chapters, with potential for adaptation and implementation on an EEN. As some solutions fill more than one gap, and gaps can be inter-related, Table 10 presents the findings of this chapter.

Table 10: Summary of suggested models and the gaps they could fill

Solution or Strategy	Gap filled	Comment on inter-relation	Comment on applicability to EENs
Distribution Network Use of System (DNUoS) charge (i.e. network users are charged in relation to how their demand impacts the cost of the network)	1, 2 and 3	This is a powerful solution that tackles the three gaps head-on.	It is easier to implement on a small network with limited intervention from regulation.
New role for the ENO: extended monopoly (i.e. the ENO keeps all its functions (distribution, retail, …) and proposes or subcontracts additional services)	2 and possibly 1	With the ENO keeping a traditional role, the additional functions would have a limited impact on its revenue stream and protection against retail competition.	This is the less disruptive way for an ENO to modernise its services, particularly if it partners with third parties to access their innovative products and services
New role for the ENO: platform operator (i.e. The ENO disengages from all functions except distribution, and coordinates third parties who are providing other services to its network users)	1 and 2, and most likely 5	A more significant decoupling from energy retail contributes to covering Gap 1. Having a more neutral position and being service-based and customer-focused would help fill Gap 5.	This disruptive shift away from traditional generation asset ownership fits precincts under development better. In any case, it has to be integrated into the corporate strategy and drive the governance and investment decisions.
New role for the customer and network operator engages with customers to	2 and 5 and possibly 1	Reaching out to customers and their distributed energy resources would give more means to the	It is difficult for any utility that is constrained to have the long-term views defined by the life of its assets to engage and

collaborate towards a more efficient EEN		ENO to better manage the supply. Engaging with customers also means being more transparent, which should foster a balance of interests (Gap 5). The examples given being mostly service-based, this category of solutions could contribute to decoupling of revenue from the sale of energy (Gap 1)	collaborate with customers who have the short-term view to reduce energy bills. The suggestions and examples identified in the research are not holistic and disruptive enough of the traditional utility/customer relationship to support significant customer engagement and a balance of interest between the ENO and customers.
Service-based business models	1 and 2 and most likely 5	This category of solutions is interconnected with the ENO and the customers taking new roles and interacting more.	Just like the utilities on the public grid, embedded operators are asset-centred. Thus service-based models would not be easy to introduce. Partnering with, or subcontracting third parties to access their innovative services and models could be the way.

The review of literature identified satisfactory solutions to fill the most 'technical' Gaps, that of Gap 2 and in some part Gap 4, and as much efforts is being put into modernisation of grids (and embedded networks) into smart grids (outside the scope of this research), these two gaps should find even more solutions. The review identified solutions to the more 'economic' gaps, that of Gaps 1 and 3, however, significant transformations would have to take place on the EEN to fill these gaps completely, including the utility and the customers taking new roles and setting up the new relationship between the two consequent to these new roles.

Predominantly for Gap 1, the shift towards service-based models based on the PSS theory would help fill this gap, but it would require a significant transformation of the energy business, from its role and its relation with customers, its economic model and the governance that frames the energy supply on the precinct. Finally, though the research found examples that would support customer engagement by the utility and collaboration between the two parties for the ‘greater good’ of the precinct, the research findings suggest that no satisfactory solution has been found at this point that fills the lack of balance of interest that is needed to support the sustainable introduction of solar and battery on the EEN.

5.7 Summary of Chapter and Contribution to Thesis

The need for a reform of the utility business model is not new and has produced a vast amount of work from researchers and industry experts around the globe, for the last decade and more. It is now getting to the point of maturity where a few governments (through their electric utility and public service regulatory commissions) are making a move and deeply reforming their regulated utilities (their business models and objectives) to cater for the critical technical, environmental and social changes the electricity sector is undergoing. Examples of these changes are the increase in new entrants (including the customers becoming prosumers), the uptake of distributed energy resources, decarbonisation of the supply, democratisation of customer participation in the supply, and the digitisation and increasing importance of data and telecommunications in the management of the energy supply. The New York *Reforming the Energy Vision* (NY REV) is the best example that it is happening at scale.

The NY REV is a very inspiring reform, but it is not directly transferable to EENs of industrial precincts because of its scale and the fact they are privately run for commercial purposes and not supervised by a regulator and a regulated rate of return. Similarly, other solutions identified in the research do not fully fill the gaps identified earlier and particularly the balance of interests. Therefore, the next chapter looks for the lessons learned from a case study on an existing industrial and commercial EENs in order to attempt to propose solutions that fill these gaps and support the sustainable introduction of solar and battery on the EEN.

Chapter 6: Case Study: The Perth Airport Industrial Precinct

Sub-question #4: What are the lessons learnt from simulated scenarios of the introduction of solar on an existing commercial and industrial precinct fitted with an electricity embedded network?

Aim: Learn critical knowledge missing in the literature about the impact of introducing solar on a commercial and industrial precinct.

Objective: Conduct a thorough assessment of the energy business on an existing commercial and industrial precinct and simulate a variety of scenarios for the introduction of solar on its electricity embedded network to gain new knowledge unlikely to be in literature and progress towards the proposition of a new approach for industry precincts.

6.1 Introduction to Case Study

The previous chapters presented findings from academic and industry literature that would help define the most appropriate approach and model to introduce solar energy on commercial and industrial precincts cost-effectively. Following this research a few key questions remained, namely:

1. What is the financial impact on the embedded network operator of the different models to introduce solar (and battery), and
2. What is the most appropriate model to enable a balance of interests between the parties.

Moreover, the literature did not reveal a dominant and clear business model for the introduction of solar on commercial and industrial precincts. Therefore, to progress towards closing the knowledge gaps and the definition of an appropriate model, a new case study needed to be developed with industry partners to test aspects of energy related business models in industry precincts. The case study needed an existing precinct fitted with a private Electricity Embedded Network (EEN), big enough to have several customers and an embedded network operator. The industrial precinct needed to have: a large enough scale of operation to inform the research; have direct participation of the precinct owner, the embedded network operator and the energy customers; along with the potential for collaboration with industry experts to ensure consideration of latest and best practices.

The author was selected to be the Lead Researcher for Curtin University in a project led by the Sustainable Built Environment National Research Centre (SBEnrc) and working with Perth Airport Pty Ltd (precinct owner) and energy sector specialist Balance Utility Solutions. The research project focused on identifying the most appropriate ways to incorporate solar energy on the precinct. Therefore, except for customer participation[345], this research project had all the necessary ingredients for a pertinent case study to support this research and offer a unique opportunity to test some of the suggested solutions to introduce solar on a commercial and industrial precinct cost-effectively.

[345] The prospect of introducing solar on the precinct was a sensitive topic amongst customers (see reasons why further down this chapter) and the precinct owner preferred this project did not involve customers.

Initially, the project scope was to study the introduction of renewable energy on the precinct starting with a greenfield site in the northern area of the existing Perth Airport Industrial Precinct (PAIP). The PAIP is fitted with a private embedded electricity network and managed by the Perth Airport Pty. Ltd. (PAPL). With this initial scope, the project promised to contribute to informing the thesis on the following questions:

- What different models are best to introduce solar on an industry precinct that would make sense for this particular context?
- How do these models compare financially, from the perspective of the energy customers and the embedded network operator?
- What is the cost of solar electricity, and how does it compare to the cost of electricity imported from the main grid?
- What are the co-benefits for the precinct owner associated with introducing renewable energy on the precinct?
- Are there particular new loads or load profiles expected in commercial and industrial precincts that could significantly impact the strategy to transition to solar PV?

However, in the first phase of the three-year study, the initial research findings created interest in broadening the research scope from PAPL. Hence the project shifted from a focus on 'Introducing renewable energy to green the environment of a new part of the precinct' to considering the 'Cost-effective long-term transition of the entire estate to solar energy', with sub-targets to offer a win-win situation for the embedded network operator and the customers, so it supports the property business with best-in-class energy supply. This expanded scope for the research project provided the opportunity to investigate aspects of greater relevance to the thesis, such as to inform the following questions:

- What are the Strengths, Weaknesses, Opportunities and Threats (SWOT) of the energy business on an established commercial and industrial precinct, and how would onsite renewable energy affect these?

- Which model offers the best balance of the interests between the embedded network operator and the customers?
- How could the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN with the introduction of a high penetration of solar energy? (contributing to Gap 2)
- How could customers installing solar systems be responsible and accountable for the pressure their system would put on the network? (contributing to Gap 3)
- How could inequity of access to solar PV among customers be avoided while levels of installation is increasing? (contributing to Gap 4)

The following sections describe the context of the Perth Airport Industrial Precent and its energy business, the methodology used to investigate the performance of different models, and the interpretation of the results relevant to the thesis research questions.

6.2 Overview of the Perth Airport Industrial Precinct

Perth Airport Pty Ltd (PAPL) is a privately listed company, and the rightful lessee of the Australian Commonwealth land[346] hosting Perth's main airport and the commercial and industrial area around it, called the Perth Airport Industrial Precinct (PAIP). PAPL is made up of several profit centres, also called business units:

- The aero business unit oversees all activities linked to air transport, from landing planes to moving passengers, luggage and freight in and out of the Terminals.
- The property business unit oversees the commercial management of the PAPL estate and particularly the leasing of the land and a portfolio of buildings on it.
- The infrastructure business unit oversees infrastructure on the precinct, including infrastructure for the aero activities (such as the runways and the Terminals), the civil infrastructure such as roads and car parks, and the utilities including the embedded electricity network (EEN) as part of the energy business.

[346] The Commonwealth ownership gives it much simpler planning powers for business than land managed under WA State Government powers, making the precinct more attractive for commercial and industry users.

The PAPL estate is of significant size with over 2,100 hectares (5,200 acres) of land close to the centre of Perth's main light industrial area, and just 10 km from the Central Business District. PAPL's property business is responsible for property management and facilities management, maintaining approximately 40 investment buildings, managing over 300 leases within its property portfolio, and managing more than 120 property tenants.[347]

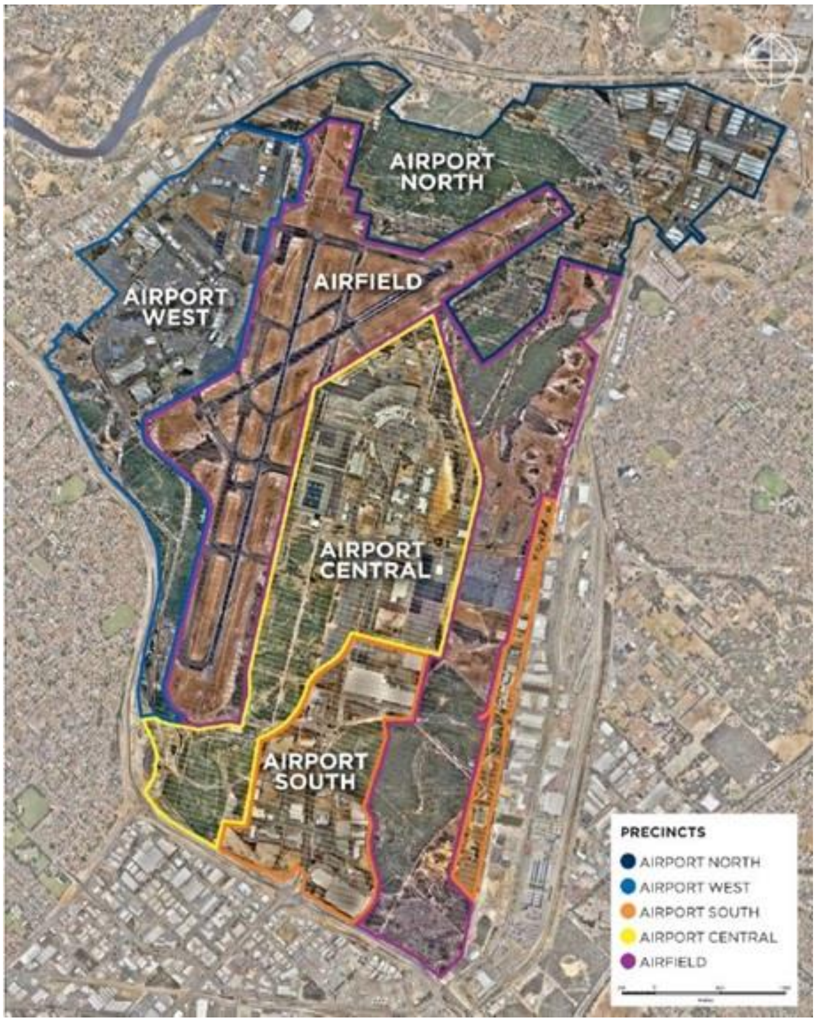

Figure 28: Satellite view of the Perth Airport Industrial Precinct
Source: With permission from Perth Airport Pty Ltd

The general downturn of the Western Australian economy from 2013 had somewhat slowed the arrival of new tenants and delayed expected developments on the precinct. There was plenty of vacant land on the estate to expand development and welcome more non-residential tenants. Therefore, one of the principal focuses of the corporate

[347] Perth Airport (2020) Home – Property. Perth Airport Pty Ltd.

strategy was to reinforce the property business (PAPL, 2018)[348]. A satellite view of the PAIP with the different sub-precincts is shown in Figure 28, where the 'Airport North' precinct is the greenfield site described earlier as the initial focus of the SBEnrc research project.

From an energy perspective, the PAIP is similar in many aspects to many other industrial precincts in Australia and around the world in that it is fitted with a privately owned and operated electricity network connected to the public grid. As such PAPL has roles and duties similar to a vertically integrated electric utility as it:

- Supplies electricity to its tenants (by importing electricity from the public grid, complemented by two small onsite tri-generation units) and ensures the quality of the supply.
- Distributes electricity around the embedded electricity network (owning, operating, maintaining and expanding the EEN).
- Retails electricity to its tenants.

To present the context of the PAIP from the energy business perspective in a more detailed and structured manner, and to analyse the introduction of renewable electricity on the precinct from a corporate strategy point of view, the research undertook a SWOT analysis.

6.3 SWOT analysis from the energy business perspective

The idea that a good corporate strategy means ensuring a fit between the opportunities and threats (external factors) and the strengths and weaknesses (internal qualities or characteristics) of a company comes from the works of K. R. Andrews in the nineteen sixties and seventies (Andrews, 1971).[349] In the early eighties, Weihrich (1982)[350] stated organisations should use a rational approach toward anticipating, responding to, and even altering the future environment in order to remain effective. He called the collection of strengths and weaknesses of the company and the opportunities and the threats offered by the environment a "*tool for situational analysis*". He explained that

[348] Perth Airport (2018) Annual report 2017-18, Perth Airport Pty Ltd.
[349] Andrews, K. (1971) *The Concept* of *Corporate Strategy*, Irwin, Homewood, IL.
[350] Weihrich, H. (1982) The TOWS matrix—A tool for situational analysis. *Long range planning*, *15*(2), 54-66.

a SWOT matrix (the result of a SWOT analysis) served to compare the environmental threats and opportunities with a company's weaknesses and especially its strengths to support strategic planning. This approach was supported by Hill and Westbrook (1997)[351] who also mentioned that a SWOT analysis was one of the most popular approaches to improve a corporate strategy but warned that, unlike the analysis, the output of a SWOT matrix was too rarely exploited for strategy purposes.

Therefore, the SWOT analysis was selected as the methodology to study the external factors of the PAIP and its internal qualities and characteristics in regard to the strategic planning of the introduction of solar on its EEN. The findings will be summarised in a matrix at the end of the section to present key learnings to inform the thesis.

6.3.1 Strengths

The corporate structure of PAPL

The corporate structure on the PAIP is the type where the same entity (PAPL) is the landowner (and property developer), the embedded network operator (distribution of electricity) and the energy retailer (electricity imported from the grid and on-charged to energy customers). Moreover PAPL is also the largest energy consumer. Other industrial precincts such as the Brisbane Technology Park[352] have a similar structure with the landowner also being responsible for the distribution network and retail of electricity.[353] In contrast, precincts such as the Peel Industrial Area in Western Australia[354] or the Tonsley District in South Australia,[355] have an independent contractor as the embedded network operator (in charge of distribution and retail of electricity). The corporate structure on the PAIP was deemed a strength for the energy business as the corporate vision and goals could be shared among business units and thus synergies between them would not only be possible but also driven by a common interest (the success of the overall organisation).

[351] Hill, T. and Westbrook, R. (1997) SWOT analysis: it's time for a product recall. *Long range planning*, *30*(1), 46-52.
[352] Business & Technology Precincts (2020) BTP - Brisbane Technology Park
[353] AER (2020) Electricity distribution and retail exemption awarded to APN Funds Management Limited for Brisbane Technology Park. Australian Energy Regulator
[354] Government of Western Australia (2019) Ground-breaking microgrid to power jobs in the Peel. Media statements.
[355] Enwave (2020) Tonsley Innovation District, Enwave.

The size of PAPL's energy business

With several hundred energy customers and a peak demand of over 25 MW,[356] PAPL is well placed to take advantage of economies of scale. Such a size could be a burden to trigger change, with pressure from customers to change, but once a change has been decided, the size would become a strength. This scale also confers PAPL a competitive advantage when dealing with external partners such as the energy retailer to the precinct with which PAPL was able to negotiate bulk rates. Also, the precinct is a large enough customer on the Western Australian electricity network to use its "weight" to participate in the energy market when the regulation would make it possible.

The typology of PAPL customers

Energy customers on the EEN are of all sizes and energy profiles, but they are all businesses, no residential customers. Perez-Arriaga and Bharatkumar (2014)[357] mentioned that a distinguishing feature of commercial and industrial energy customers was the availability of detailed profiles of electricity consumption thanks to meters collecting peak demand within a billing period. On the other hand, residential customers are a unique type of energy consumer with decision-making processes not always driven by economic value (Breadsell *et al.*, 2019)[358]. The vast amount of research dedicated to residential energy customers compared to non-residential customers was a sign of that complexity.

Another advantage of having businesses as energy customers was the typical daytime operation which translates into an energy profile with a peak demand that corresponds closely to the electricity generation profile for solar PV panels, as shown in Figure 29 and Figure 30.

---

[356] Government of Western Australia (2019) Response to Position Paper on Reforms to the Reserve Capacity Mechanism, Government of Western Australia.

[357] Pérez-Arriaga, I. and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. *MIT Center for Energy and Environmental Policy Research*.

[358] Breadsell, J., Byrne, J., and Morrison, G. (2019) Household energy and water practices change post-occupancy in an Australian low-carbon development. *Sustainability, 11*(20), 5559.

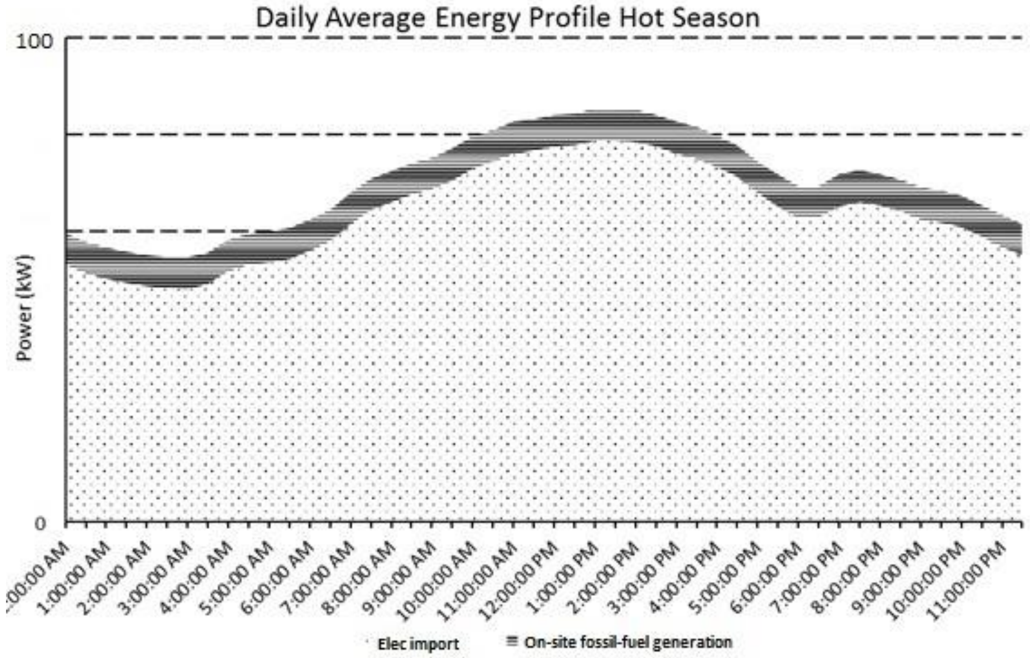

Figure 29: Daily average energy profile of the PAIP during the hot season

Source: Hebert *et al.*, 2017[359]

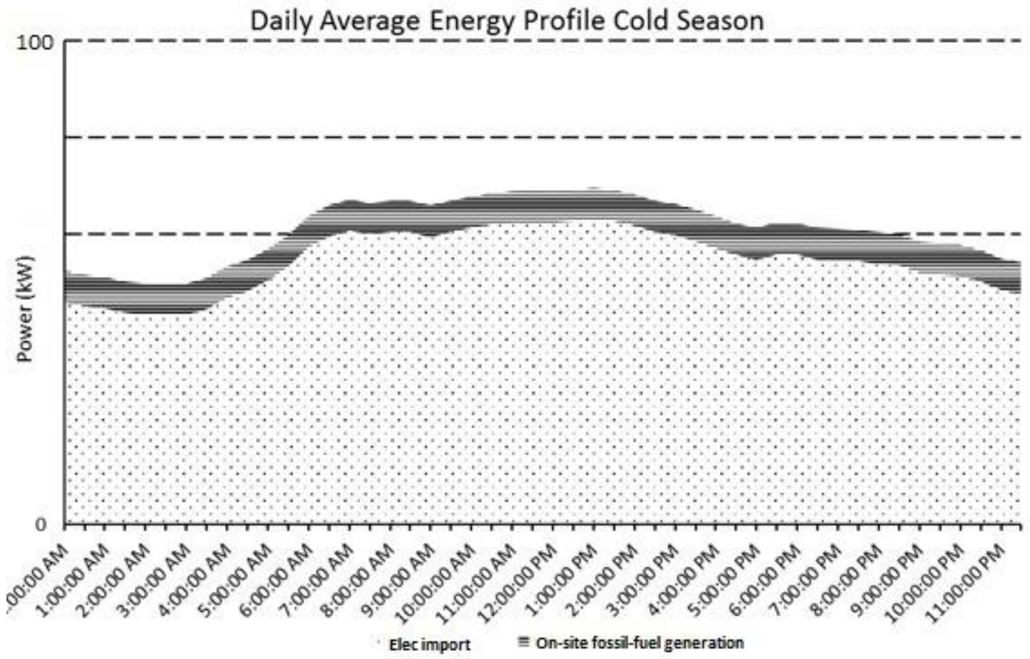

Figure 30: Daily average energy profile of the PAIP during the cold season

Source: Hebert *et al.*, 2017

[359] Hebert, L., Hayes, R., and Hargroves, K. (2017) *Review of Onsite Energy Options and Study of the Energy Demand on the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

These profiles are well covered by on-site generation of electricity from solar PV panels and gives the technology a good chance to be economically sensible as it eliminates a large part of the energy storage requirement while also generating electricity during some of the peak demand times. Panels could also be oriented towards the east and the west to spread the production and meet the load profile even better. Therefore, having to deal only with businesses as energy customers appeared as a strength.

Availability of a greenfield development site

As shown in the satellite view of Figure 28, a large portion of the Airport North precinct had not yet been developed. Hence given there were no buildings or communications or electricity networks installed this was a great opportunity for PAPL to design the optimum conditions to introduce solar from inception and reap the savings from the start rather than having to wait for avoided costs in delayed network capacity augmentation. Though it appeared like an opportunity, the analysis has classified it as a strength as it was part of PAPL internal capabilities (yet untapped).

Abundance of space for solar panels

Being an industrial precinct and an airport, the PAIP has many warehouses, hangars, factories and Terminals, all with large “unused” roofs. Additionally, the PAIP had a significant stock of land that could not be developed because the lots were too close to the airstrips to erect buildings due to noise levels and aero regulations. Ground-mounted solar panels could then be installed on these lots giving them new commercial value. Availability of roof space and land was a strength for the precinct to transition to solar energy.

The strategic location

The precinct is a prime location for businesses with easy access for workers and visitors due to multiple freeways and a passenger train line (under development at the time of writing). The location is also particularly strategic for logistic and distribution businesses thanks to the proximity of the international airport but also due to freeways and a freight rail line which put other industrial areas in Perth, the commercial port and the heavy industry area in close reach. PAPL corporate strategy intended to leverage this competitive advantage to attract premium new tenants to its precinct. The link of this strength to the energy business will be revealed in the section on opportunities.

6.3.2 Weaknesses

Cost of connection to the grid

The connection between the EEN and the public grid is via a substation with capacity expandable only in large and costly steps. This weakness was not specific to the PAIP, but a constraint for any EEN with an ambition to grow its customer base and thus increase the electrical load in excess of the installed capacity to import electricity. Due to the non-linear nature of this type of asset, when a capacity limit is forecast to be reached, the upgrade to the next step up is often a multi-million-dollar investment that must be provisioned at least two years ahead of the upgrade (the case of the PAIP) as shown by the grey area in Figure 31.

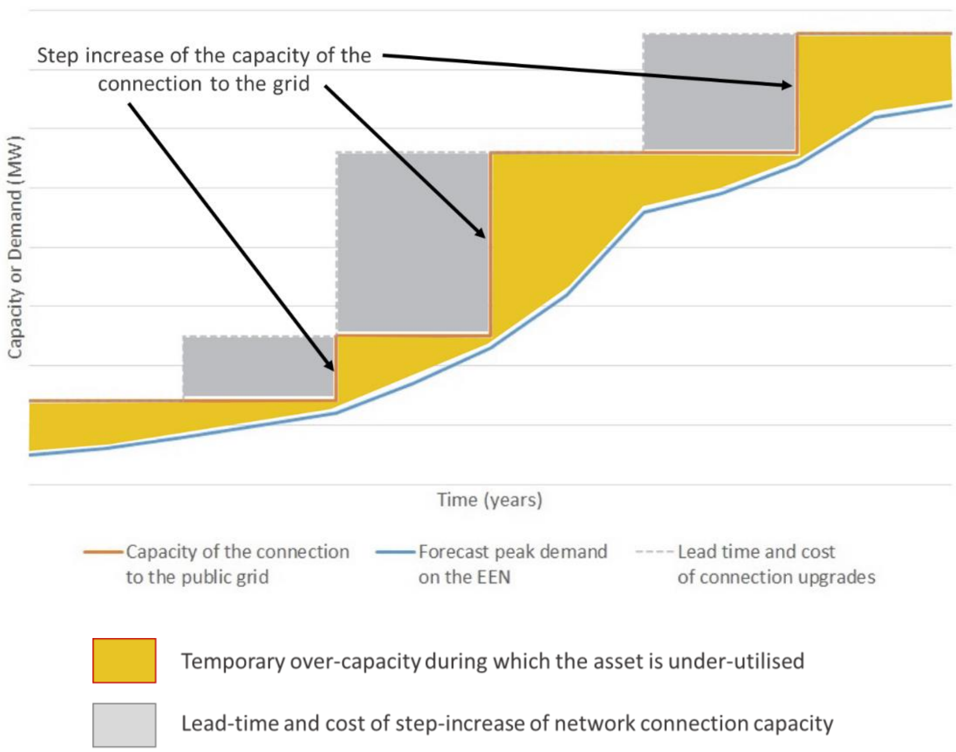

Figure 31: Expected load growth on the PAIP and necessary augmentation of the grid connection capacity[360]

Source: Data provided by Perth Airport Pty Ltd

[360] MW scale has been withheld due to confidentiality

Moreover, because any single upgrade was a significant step up in capacity, the new capacity would be higher than the necessary capacity of the moment (temporary over-capacity). Therefore, the asset would be under-utilised until the electrical load grew to catch up the installed maximum capacity (e.g. more tenants connect to the EEN) as shown by the yellow area in

Figure 31. During this period, the embedded network operator must bear the financial burden of an investment that cannot be recovered by the lack of users, the typical dilemma of utilities, as explained in Chapter 2.

The forecast maximum demand (the bottom blue line) was estimated according to PAPL's Master Plan to expand the Terminals and existing precincts and develop the Airport North precinct. The maximum grid connection capacity (the top red line) shows the resulting augmentation of the connection to the grid required to ensure this demand is met, with the largest step involving a multi-million-dollar project to install a third transformer and double the capacity of the substation. This graph does not show the necessary augmentation of the portion of the public network that feeds into the PAIP and it is anticipated that this would also be a multi-million-dollar project PAPL would be required to contribute to financially.

Implications of uptake of onsite energy generation

Like many embedded network operators, PAPL is responsible for the quality of the energy supply on the precinct and its reliability. However, with almost all of the energy supplied by the public grid, the quality of the energy supply (voltage and frequency regulation) was effectively a default outcome of the public grid operation. Nevertheless, if the amount of embedded generation were to increase within the precinct, the capability of the public grid to control and ensure power quality and reliability would reduce somewhat, and part of the responsibility would shift to PAPL.

Hence with the introduction of variable generation on the EEN of the precinct PAPL would be expected to manage a more dynamic energy supply with a more complex balance of supply and demand, and control a more technically complex infrastructure (which may include energy storage, telecommunication infrastructure, digitalisation and data management). Consequently, the introduction of solar would force PAPL to transition from the traditional role of Distribution Network Operator (DNO) to the more evolved role of Distribution System Operator (DSO) (Apostolopoulou *et al*., 2016)[361]. Therefore, PAPL as the embedded network operator would be forced to take on new functions (meaning more staff and more in-house skills) and manage new network assets, a transformation typically difficult for an established energy business.

The typology of PAPL customers

The counter-part of serving exclusively commercial and industrial customers is the typical reduction of activities during weekends and public holidays. In the case of the PAIP, during these periods of low activity the base load consumption would consist of businesses operating seven days a week, cold rooms, and other continuous activities such as the aero business and the space conditioning of Terminals. However, weekends were displaying a significant drop in energy consumption, as shown in

Figure 32 and Figure 33.

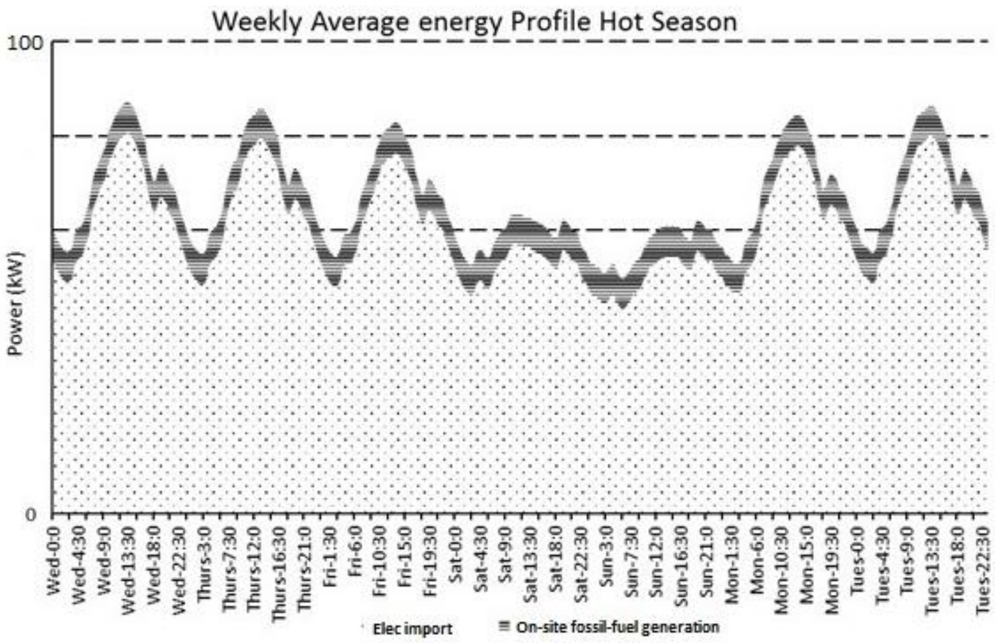

Figure 32: Weekly average energy profile of the PAIP during the hot season

Source: Hebert *et al.*, 2017[362]

[361] Apostolopoulou, D., Bahramirad, S., and Khodaei, A. (2016) The interface of power: Moving toward distribution system operators. IEEE Power and Energy Magazine, 14(3), 46-51.

[362] Hebert, L., Hayes, R., and Hargroves, K. (2017) *Review of Onsite Energy Options and Study of the Energy Demand on the Perth Airport Industrial Precinct*, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

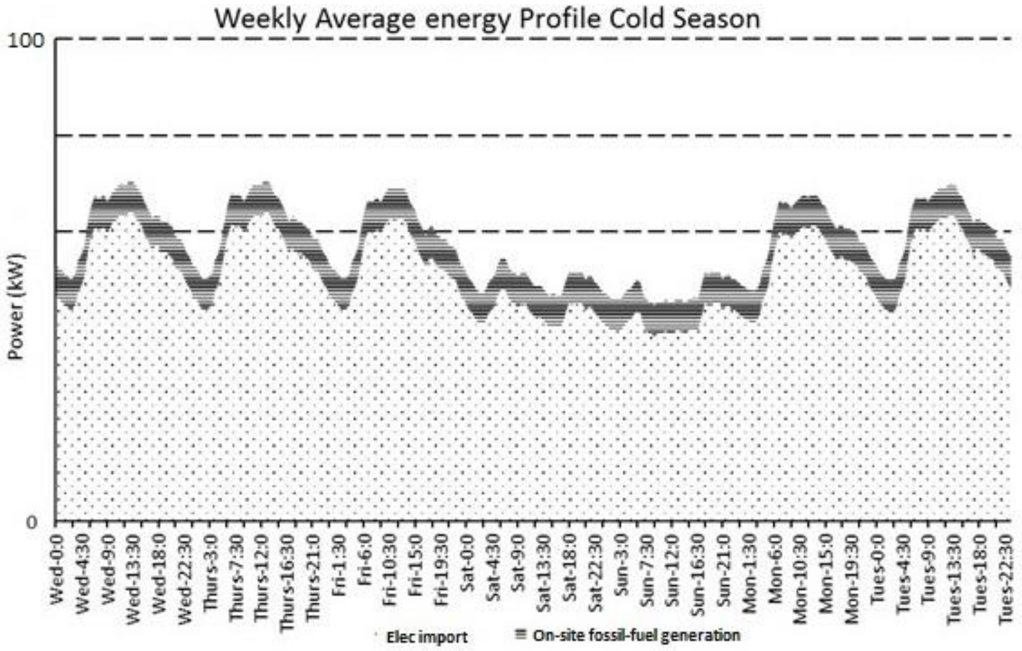

Figure 33: Weekly average energy profile of the PAIP during the cold season

Source: Hebert *et al.*, 2017

As the sun is typically shining the same on weekends as on weekdays, the smaller weekend peak demand became the benchmark for assessing the hosting capacity of the EEN (effectively the system's base load) and the penetration limit of solar energy without the use of energy storage. This average weekly energy profile with lower peak demand during weekends and public holidays constituted a weakness for the introduction of non-dispatchable generation such as solar panels on the EEN.

A comfortable regulatory situation

At the time of writing, PAPL's energy business was enjoying a monopoly situation since energy retail competition was not yet regulated in Western Australia as it is in the eastern states of Australia.[363] This situation allowed PAPL's energy business to purchase electricity at a bulk price and to resell it to its captive customers at the published tariffs, making in the process, most of the margin of the energy business. This situation could be seen as a strength as it made the energy business a rather simple, risk-free and profitable operation. However, the research findings suggest this situation is in fact a weakness as this comfortable situation made PAPL reluctant to move away from the business-as-usual approach as it seemed to present a risky

[363] States and Territories in Australia, besides WA and the Northern Territory, have connected their electricity networks and operate under the National Energy Market and National Energy Rules. WA has two public electricity networks, but neither is connected to the national network (a thousand kilometres away) and thus have been able to operate independently.

endeavour, and presented a difficult strategic decision without full understanding of the ramifications, in large part the impetus for the research project. In effect, this "numbing" situation presented a barrier to the introduction of solar energy on the precinct, despite early glimpses of associated benefits.

Lagging behind other similar precincts on solar energy

In the 2018 Annual Report, PAPL's CEO reaffirmed PAPL's "*commitment to operating in a sustainable manner and incorporating sustainability into all aspects of its business*", including reducing its carbon emissions. Among other efforts, in 2018 PAPL achieved level 1 "*Mapping*" certification under the Airports Council International (ACI) Airport Carbon Accreditation scheme and was working towards Level 2 "Carbon Reduction". However, with no renewable energy onsite and electricity imported from the main grid bearing a high carbon intensity (0.72kgCO_2e/kWh)[364], the quest for significant carbon reductions seemed a tough challenge. A desktop review of what was happening in airports around the world from an energy provision perspective was conducted for the Project Team (See Chapter 3 Table 4). This review found that a number of Australian airports had already installed solar systems, as shown in Table 11.

Table 11: Summary of Australian airports with a significant PV array

Airport location		PV capacity
Australia	Adelaide	1.28 MW
	Alice Spring	560 kW
	Brisbane	6 MW
	Darwin	4 MW
	Karratha	1 MW
	Kingscote	50 kW
	Longreach	99 kW

Source: Hebert *et al.*, 2016[365]

[364] Department of Industry, Science, Energy and Resources (2018b) National Greenhouse and Energy Reporting Technical Guidelines 2017-18. Australian Government.

[365] Hebert, L., Hayes, R., and Hargroves, K. (2016) Current State Assessment of Other Airports Around the World Installing Solar, Overview of the Situation of the Perth Airport Embedded Electricity Network and its Regulatory Context, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Therefore, the absence of onsite renewable energy on the Perth Airport industrial precinct was added to the list of weaknesses.

No allowance for solar for current tenants

The desire to reduce energy cost, spurred on by the rapid uptake of rooftop solar in the Australian residential sector, motivated energy customers of the PAIP to show genuine interest in generating their own electricity onsite, especially if it could also reduce greenhouse gas emission associated with electricity consumption. However, in the absence of a strategy to effectively introduce solar on the precinct, PAPL had been turning down requests from tenants to install solar systems behind their meter (i.e. on their roofs). Consequently, existing customers were increasingly putting pressure on PAPL to have access to onsite renewable energy, and rooftop solar had become more often a non-negotiable condition for prospective tenants. The lack of solution offered by PAPL constituted a weakness, but as it meant that PAPL could or was losing tenants, this last point was also categorised as a Threat.

6.3.3 Opportunities

Regulatory situation around retail competition

The absence of retail competition was also an opportunity for PAPL to test innovative business models and solutions without the risk to lose unsatisfied customers to the competition.

Focus on attracting new tenants to the precinct

Exploring alternative solutions in situations where the status quo faces limited threats or planned expenditures is very challenging. However, with PAPL's ambition to expand development and attract new businesses to the precinct, a business-as-usual scenario would see the infrastructure division being allocated a significant budget to adapt the network to accommodate the new growth. Having such a reference scenario with a substantial budget was an opportunity to explore a wide range of scenarios – such as introducing solar energy and battery storage – with similar levelised costs. The growth was also going to mean extra costs associated with the upgrade of the connection to the public grid , thus for PAPL that meant millions of dollars would have to be spent regardless of whether they chose to stay with a business as usual approach or go for an innovative onsite energy option. They only had to choose the wisest way to spend these millions.

Likely increase in demand from electric vehicle charging

Electric vehicles (EVs) are expected to grow at a slow pace in Australia but to catch up with the global trend by 2036, as shown in Figure 35.

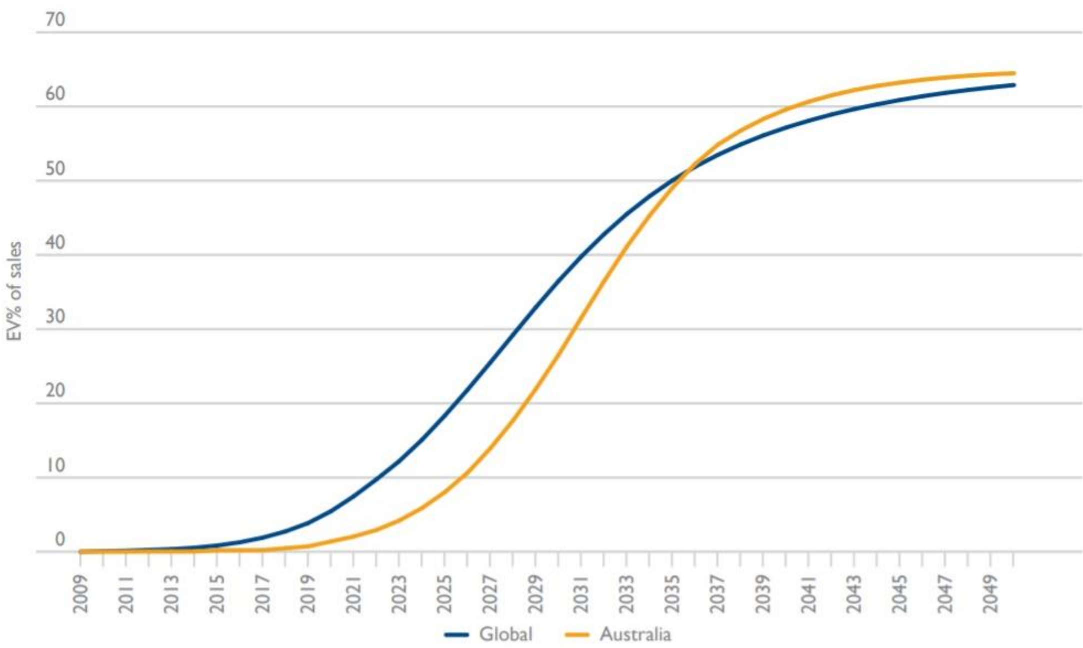

Figure 34: Global and Australian predicted EV sales

Source: Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2019[366]

Furthermore, the Australian Electric Vehicle Council (AEVC, 2019)[367] expect commercial fleets to be driving the transition to EVs in Australia, with the Australian Financial Review (2018)[368] estimating that corporate and government fleets may make up just over half of annual sales. On commercial and industrial precincts, particularly the ones which are logistics hubs, such as the Perth Airport Industrial Precinct, these fleets will include both local delivery vehicles (up to nine-ton delivery trucks) that cover short-distance trips to planned destinations, and captive vehicles in warehouses (such as forklifts and towing tugs) often currently running on liquefied gas (LPG).

Vehicles specific to the Perth airport, such as taxis, rideshare vehicles, and visitors parking in short-term car parks, could receive a quick charge, while travellers leaving

[366] BITRE (2019) Electric Vehicle Uptake: Modelling a Global Phenomenon. Report 151. Department of Infrastructure, Transport, Cities and Regional Development, Bureau of Infrastructure, Transport and Regional Economics, Australian Government.

[367] AEVC (2019) State of Electric Vehicles. Australian Electric Vehicle Council.

[368] AFR (2018) *Car fleets are big business in Australia*, Australian Financial Review.

their EVs in the long-term car parks could expect their battery full on their return. Airport buses, shuttles and baggage trucks could also switch to EVs requiring charging rather than refuelling. In addition, workers on the precinct may want to charge their personal EV while at work.

In June 2018 the Australian Logistics Council (ALC) formed an Electric Vehicles Working Group to consider the impact that EVs could have on the movement of freight.[369] Australia Post proposed to spend sixty million dollars on electric vehicles over a three year period,[370] and Woolworths has been testing an electric refrigerated delivery truck. During a 2019 interview for the magazine Power Torque,[371] Paul Graham, Chief Supply Chain Officer for Woolworths, said: "*Woolworths is actively investing in safe and sustainable transport, and we see electric vehicle technology playing an important part in our future fleet strategy.*". Ben Newton, Head of Transport Development for Woolworths and a member of the ALC EV Working Group added "*Electric vehicles are coming, and we need to learn how they are going to impact a retail supply chain operation*". Interestingly, the article author Ed Higginson further added "*If charging stations can be coupled to solar energy at depots, the cost of fuelling suddenly becomes very attractive. Just as importantly, it's a solution that has minimal impact to the environment*.".

It is clear that the expected uptake of commercial EVs that require charging on the precinct will be a great opportunity to vary the load and assist in the balance of demand and supply when the supply is variable (i.e. from solar PV), provisioning that PAPL has developed an organised and operator-controlled EV charging strategy. This uptake of EV charging on the precinct could also be an opportunity for PAPL to attract premium logistics and distribution businesses if it can offer an energy supply situation adapted to EV charging.

Uptake of battery-operated electric planes

In the farther, but not so distant future, it is expected to see some form of electric air transport either by use of hybrid systems or a complete switch to electric planes. Already, small planes (two to four seats) are successfully flying with electric motors

[369] ALC (2020) Australian Logistics Council – Electric Vehicles Working Group -About us. Australian Logistics Council.
[370] ALC (2019) Quote from Australia Post General manager of road and air networks James Dixon at the 2019 ALC forum. Australian Logistics Council.
[371] Higginson, E. (2019) Woolworths take the lead towards a greener future. Power Torque Magazine.

powered by batteries, and the technology is being applied to small commercial aircraft. For instance Patel (2019)[372] presented details of a fleet of commercial six-passenger aircraft flying over 12 routes in the Pacific Northwest that had been converted to battery-operated electric motors. In April 2019, Whitehead and Kane[373] suggested that "*By 2022, nine-seat planes could be doing short-haul (500-1,000km) flights. Before 2030, small-to-medium 150-seat planes could be flying up to 500 kilometres.*". In June the same year, start-up company Eviation presented a fully functional nine-seater commercial plane capable of flying a thousand kilometres on a single battery charge at the Paris Airshow, which is expected to be certified by 2023 (Kennedy, 2020)[374]. Hence following shortly after the transition to electric commercial road vehicles is the transition to greater, and even fully, electrified aeroplanes which presents an opportunity for PAPL to promote its aero services with an energy supply adapted to the charging of such aircraft.

6.3.4 Threats

Regulatory situation around energy retail competition

Apart from providing temporal opportunities, the delay in the introduction of retail competition on embedded networks in Western Australia is a growing threat. For example, mid-2019 the Australian Energy Market Commission (AEMC) called for a change to the rules an provided the Council of Australian Governments (COAG) Energy Council a comprehensive package of detailed advice on laws, rules and regulations to protect consumers and improve choice in embedded networks.[375] Part of this rule change would mean that energy customers on the PAIP would be able to step around PAPL and choose the electricity retailer of their choice, called 'Full Retail Contestability' (FRC). Even though PAPL would still receive a revenue for the use of its network, the introduction of retail competition would bring the following changes and consequences to PAPL energy business, listed in order of likelihood:

1. PAPL would have to rethink its tariffs to propose distribution charges as close as possible to the cost to supply electricity, with the risk that not all capital

[372] Patel, P. (2019) First Passenger Electric Aircraft to Take Off Soon. Spectrum IEEE, Institute of Electrical and Electronics Engineers.
[373] Whitehead, J. and Kane, M. (2019) Get set for take-off in electric aircraft, the next transport disruption. The Conversation.
[374] Kenneddy, T. (2020) We Could All Be Flying in Electric Planes Sooner Than You Think. Vice.
[375] AEMC (2019) Updating Regulatory Frameworks For Embedded Networks - Final Report Australian Energy Market Commission 20 June 2019.

expenditures and operating expenditures would be recovered, which is an issue common to utilities that are not vertically integrated (Ortega *et al*., 2008)[376].

2. If the introduction of retail competition in Western Australia follows the rules of the National Energy Market, then PAPL would have to align its retail prices of electricity to shadow the best offer on the market (AER, 2018)[377], thus putting downward pressure on its retail margins.

3. With a portion of energy customers choosing the competition, PAPL would find itself serving a smaller number of energy customers, reducing its ability to bulk purchase energy from its own retailer, losing bargaining power. Moreover, the retailer selling energy to PAPL may also be a competitor for the retail of electricity to the tenants on the precinct.

4. A smaller number of energy customers would also translate into fewer opportunities for economies of scale, for example for systems that rely on the control of bulk energy flow or for programs that rely on a critical level of demand in order to work (e.g. tariff driven) or a diversity of energy consumption profiles.

5. Power of choice (of energy retailer) given to customers would mean PAPL would have less flexibility to introduce innovative solutions that may scare off customers to competing energy retailers or trigger them to negotiate for compensations.

Prospective tenants lost as cannot install own solar system

As explained in Section 6.3.2, rooftop solar has become more often a non-negotiable condition for prospective tenants (which aligns to informal feedback from the PAPL property development team). Consequently, Perth Airport property may have been losing tenants and stands to lose more based on this restriction, so this is considered a Threat.

Unanticipated uptake of battery-operated electric vehicles

The expected uptake of EVs on the precinct could be a threat if this new type of energy demand was not anticipated and accommodated. Indeed, during the project, it was

[376] Ortega, M. P. R., Pérez-Arriaga, J. I., Abbad, J. R., and González, J. P. (2008) Distribution network tariffs: A closed question?. *Energy Policy*, *36*(5), 1712-1725.
[377] AER (2016) Retail Exempt Selling Guideline. Version 5, March 2018. Australian Energy Regulator. Annexe A-2 Condition 7 p37.

identified that PAPL tenants such as a shopping centre were already offering charging stations for EVs, meaning that if deploying charging points was not part of PAPL's energy strategy, it would happen regardless, but not in an organised manner that would deliver maximised benefits to the EEN and its users. The distribution of typical arrival times of commercial vehicles shown in Figure 35 shows an early peak that will not correspond with peak solar generation which may cause issues on the EEN, not to mention the contribution to the actual EEN peak later in the day.

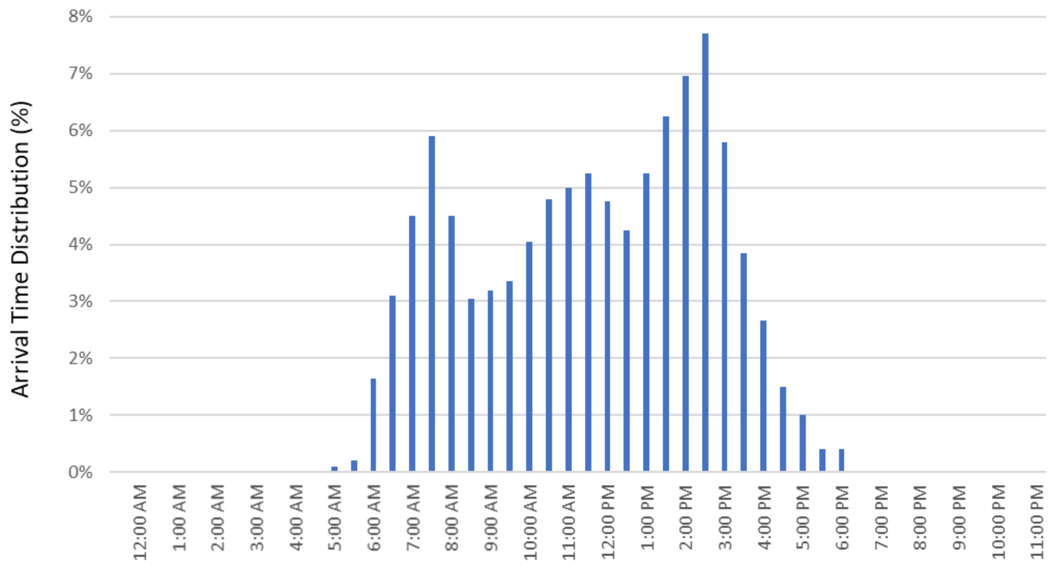

Figure 35: Charging start time for commercial vehicles

Source: Data from Parliament of Victoria[378], 2018

Without proper planning and economic and governance mechanisms in place, the uptake of EVs could translate into a concentration of charging demand at the wrong times of the day that would trigger the need for avoidable network augmentation, while the network is underutilised the rest of the time, and inevitably an increase in network charges for all customers. Therefore, the uptake of EVs charging following this possible scenario was deemed a threat to PAPL.

6.3.5 Synthesis of the SWOT analysis findings

The findings of the SWOT analysis have been coded and are summarised in Table 12.

[378] Parliament of Victoria (2018) Inquiry into electric vehicles. Legislative Council, Economy and Infrastructure Committee

Table 12: Summary of the SWOT analysis

STRENGTHS	WEAKNESSES
S1 Corporate structure. **S2** PAPL is a large customer on the public grid, giving it negotiating power on wholesale price. **S3** Typology of energy customers. **S4** Greenfield of Airport North. **S5** Available space for PV panels. **S6** Strategic location in Metro Perth.	**W1** Costs associated with physical connection to the public grid. **W2** Embedded operator forced to change to take on the new role of DSO. **W3** A comfortable situation. **W4** Lagging behind other Airports on uptake of solar energy. **W5** Lack of option for customers to install rooftop solar.
OPPORTUNITIES	**THREATS**
O1 Current regulation of retail competition beneficial. **O2** Expected arrival of new tenants on the precinct means energy business would need to evolve in any case. **O3** Uptake of EVs in commercial and industrial customers likely.	**T1** Introduction of retail competition in the near future with precedent from other States. **T2** Prospective tenants lost to the competition when retail competition open up. **T3** *Ad Hoc*, uncontrolled EV charging.

Rowe *et al*. (1994)[379] proposed a SWOT Matrix with typologies of decisions to characterise the results from a SWOT analysis, as shown in Figure 36.

[379] Rowe, W., Dickel, D., Mann, R., Mockler; R. (1994) "Strategic Management: a methodological approach". 4th Edition. Addison-Wesley. Reading, Massachusset USA

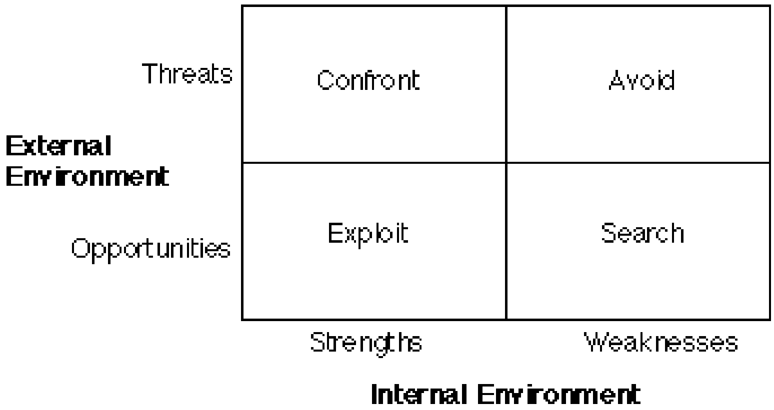

Figure 36: Diagram showing the type of decisions issued from a SWOT analysis
Source: Rowe *et al*, 1994

However, the objective of the SWOT analysis was not to develop a corporate strategy to improve the business of a company, but to identify the drivers, enablers, opportunities and barriers of the introduction of solar PV and battery storage on the PAIP. Therefore, the matrix proposed by Rowe *et al*. (1994) was adapted to this purpose in Table 13, to extract the takeaways.

Table 13: Drivers, enablers, opportunities and barriers of a corporate strategy of introducing solar and battery on the precinct

STRENGTHS	WEAKNESSES
S1 PV could attract premium tenants and boost the property business. **S2** PV and battery could allow PAPL to enter the energy market. **S3** PV generation is well suited for the energy profile of its typical customer. **S4** PV and battery could shape the distribution infrastructure of Airport North to make it more attractive.	**W1** Onsite supply by PV and battery could reduce costs related to connection upgrade to the public grid. **W2** If done right, the transition could open up to new, non-energy related revenues by delivering new services to the customers. **W3** The new situation may again present a comfortable position.

S5 Put the roofs and other appropriate underused spaces to work. **S6** Centrally located means more opportunity for delivery EVs made competitive due to PV and battery.	**W4** PV and battery could participate significantly in the reduction of carbon emissions. **W5** Make Perth Airport tenants happy by having a PV and battery solution for them.
OPPORTUNITIES	**THREATS**
O1 No retail competition means PAPL has time to test, refine and expand the chosen solar PV and battery storage option. **O2** Investment in solar PV and battery storage solution could be an equivalent cost to the business-as-usual scenario, involving upgrading the connection to the grid and reinforcing the distribution network. **O3** PV and battery could support the uptake of EVs in commercial and industrial customers.	**T1** Establishment of strategic solar PV and battery storage could provide early mover advantages when retail competition is introduced. **T2** Premium tenants secured thanks to an attractive energy supply (clean, affordable, flexible). **T3** Solar PV and battery and the corresponding tariffs could help influence EV charging profiles.

Further to Table 13, W3, that of PAPL being in a "*comfortable situation*" already, was not directly affected by the introduction of solar PV and battery storage, although it may present the only viable 'comfortable position' once retail competition and demand from tenants for solar grows to unmanageable levels. Overall, there are many occurrences where solar PV and battery storage reinforce the strengths, reduce the weaknesses, exploit the opportunities, and better prepare the precinct to face its threats; hence presenting a strong case to integrate the introduction of solar PV and battery storage into the corporate strategy of the PAIP.

More importantly, the SWOT analysis revealed a characteristic specific to EENs compared to the public grid in that the energy business could be used as an enabler to the success of other business units such as the property business, answering the question "*What are the co-benefits for the landowner to introduce renewable energy on its precinct?*", a research question as part of the SBEnrc Research Project with PAPL. Following this analysis, the PAPL executive team also saw the opportunity to increase land value with cost-effective, environmentally friendly and business-enabling energy supply.

It may be the case that developing an energy solution that offers tenants a superior energy supply than on the public grid or other embedded networks, might attract premium tenants and support the growth of the property business.

6.4 Modelling and simulation methodology used

6.4.1 The energy business analysis model used

Introduction to the Balance Energy Network Optimiser model

The industry partner of the research project, Balance Utility Solutions ('Balance'), has extensive knowledge and a long experience working on projects involving various (renewable) energy and storage solutions, both on microgrids and interconnected networks. Balance have created a model, 'The Balance Energy Network Optimiser', to model the economic impacts of various scenarios involving a range of energy generation and storage options and business strategies around infrastructure funding and revenue. This model uses data on the cost, energy generation performance, and energy efficiency levels of various supply-side generation options in order to simulate and compare the financial and environmental outcomes of different scenarios. The model was used by Balance as part of the SBEnrc research project and the findings have been used to inform this thesis.

The model was informed by historical information provided by PAPL such as energy consumption levels, distribution amounts for the different tariffs, and data on purchase and resale tariffs. Other information provided by PAPL informed the likely future conditions on the precinct, such as the expected increase in energy consumption (as a result of the planned development of the sub-precincts and construction of new terminals) and the level of investment required to upgrade the grid that fed the Perth Airport Industrial Precinct according to anticipated growth of the electrical load over time. Other data sourced by Balance or found in industry reports was used to better inform the model of other variables impacting the electricity system. The timeframe for the scenarios was set to 10 years as this was agreed to be an acceptable balance between long-term decision support and confidence in the associated assumptions.

The logic of the model

Applied to the PAIP, the logic of the model is as follows:

1. Data representing 'energy in' and 'energy out' of the EEN was compiled to represent the conditions on the precinct at the start of the SBEnrc research project (i.e. no solar energy and some onsite tri-generation units):

    a. The 'energy in' was represented by half-hour data of energy imported from the public grid and the energy generated onsite by the tri-generation units.

    b. The 'energy out' was represented by the amount of energy sold to customers on the precinct and the energy used by PAPL’s operations (e.g. terminals, runways, sewage pumps, street lighting). However, in the absence of energy meters on some of PAPL’s assets, a precise break-down energy consumption was not available nor were estimates of network losses within the precinct. Therefore, the energy consumed by PAPL’s operations was assumed to be the difference between the total 'energy in' and the energy sold to customers.

2. Algorithms were used based on published tariffs and formulas to calculate a baseline:

    a. From the 'energy in' data, the volume of energy use and the related environmental, network and capacity fees and charges were calculated. The algorithms used were verified by comparing the results of a simulation of the current situation with actual bills. Following verification the simulation of various scenarios with different levels of 'energy in' allowed the calculation of not only the energy cost variation but also the assorted charges.

    b. The 'energy out' data and the distribution of energy customers among the different tariffs permitted the estimation of the average demand from each energy customer and their related cost, and consequently the related revenues for the energy business. The total amount of energy sold to customers that was estimated was verified by comparing with the energy sales data provided by PAPL for a known period. This approach allowed the model to simulate scenarios of future growth with different variations in the number and type of energy customers, as well as the size of PAPL's operations. The model calculated the resulting variations in the amount of electricity purchased by various types of customers (in kWh) and the overall demand (in kW), and the associated revenue both from electricity sales and demand charges. This level of detail was critical to simulate different scenarios of the introduction of solar (i.e. centralised or distributed), different uptake and penetration levels across the precinct, different battery capacities, and the impact of these transition scenarios on the average cost of electricity supply per tariff category and average revenue for the energy business.

3. Once the baseline was validated, scenarios could be defined and simulated for comparison with the following functionality:

   a. If a new embedded generation source was simulated, the energy import from the grid was adjusted accordingly and the financial implications were recalculated. The latter would consider expenses relating to the investment, the type of financing, the fuel cost (if any), maintenance and operation costs, and also the recalculated energy charges. This simulation considered downtime for maintenance, time of generation in relation to on/off-peak periods, and daily and seasonal variations for solar generation.

b. If new developments were to be simulated on the precinct, this would involve new tenants connecting to the embedded electricity network. Depending on the tariff, the amount of energy sold to customers would then be recalculated as well as the cost for PAPL related to the increase in 'energy in'. When the precinct peak demand reached a threshold, the capital expenditure related to the necessary capacity increase on both the PAPL side of the connection to the grid, and the grid side (estimated by PAPL), would be added, with the appropriate lead times, to the cash flow estimations.

c. A number of other variables could also be adjusted to investigate the sensitivity of scenarios, such as: the price of grid electricity; the market value of the Federal environmental charges for large generators emitting greenhouse gas emissions, called 'Large-scale Generation Certificates' (LGC); the expected internal rate of return set by PAPL for investments; and the associated discount rate.

This process of simulation aimed to identify relative benefits and drawbacks of different types of onsite energy integration and business strategies and, in doing so, informed the course of action as part of the corporate strategy (that of shifting from the current strong economic benefit for PAPL that was likely to be threatened to a win-win situation for PAPL and the energy customers, as explained in the introduction).

Outputs and limitations of the model

The outputs of the model include the following economic and environmental dimensions:

Net Present Value

The 'Net Present Value' (NPV) was calculated by discounting the annual after-tax cash flows at the specified discount rate of 10 percent. The incremental cash flow analysis (meaning the change in cash inflows and outflows that are specifically attributed to the project/investment decision) was calculated based on the formula below:

$$\text{Incremental Cash Flows} = \text{Change in Cash Inflows} - \text{Change in Cash Outflows} - \text{Taxes}$$
$$\text{With Taxes} = (\Delta\text{Inflows} - \Delta\text{Outflows} - \text{Depreciation Tax Shield}) \times \text{Tax Rate}$$

As part of the calculation the following assumptions were made:

- Only include items which comprise cash.
- Only include items that change if the project was undertaken.
- Cash inflows are deemed increases in revenue, cost savings, residual value (salvage value), and decreases in working capital.
- Cash outflows are deemed initial capital cost, opportunity cost, subsequent investment, outlays, and increases in operational costs and working capital.
- Exclusions from the cash flow include sunk costs (costs that have already been incurred).

Net Present Cost

The 'Net Present Cost' (NPC) for PAPL customers was calculated using the same method as the NPV described above. However, it took into account expenses such as the energy bills for energy imported from the EEN and, when applicable, the capital expenditure in rooftop solar, and the cost of energy storage.

Profit and Loss Statement

The annual energy operation profit and loss statement for PAPL after tax.

Levelised Cost of Energy

The 'Levelised Cost of Energy' (LCOE) is the discounted cost per kWh of electricity generated for the life of the evaluation period (but does not consider revenue offsets).

Levelised Cost of Energy Supply

The 'Levelised Cost of Energy Supply' (LCOES) is the discounted cost per kWh of electricity used by the customers for the life of the evaluation period (includes the cost of electricity imported from the EEN and the LCOE of the customer-financed assets).

The algebraic equations of the indicators presented above are detailed in Appendix 1, p252.

Greenhouse Gas Emissions Reduction

The greenhouse gas (GHG) emissions reduction is the difference between the scenarios' greenhouse gas emissions and the reference scenario's emissions, in tons of CO_2e per year. The resulting model provided a generalised profit impact study for the PAPL energy business and helped identify the costs and benefits of each option for PAPL and the customers. However, many technological, regulatory and even social limitations were not or could not be adequately modelled.

The algorithms behind the model

The model extracts key indicators from complex simulations using a suite of algorithms, namely:

1. Using half-hour energy import data and half-hour energy generation data as a reference, an algorithm calculated the change in energy and peak demand when the number and type of customers changed (such as from tenants on new developments, expansions to terminals, and the uptake of electric vehicles and the consequent charging load).

2. An algorithm was used to estimate the impact of onsite generation, including the variable generation from renewable energy solutions and, when selected, the impact of energy storage.

3. Based on the results from the algorithms mentioned above, a third algorithm estimated the corresponding demand and capacity charges for the customers and the costs and revenue for the PAPL energy business.

6.4.2 Modelling and simulation approach

General assumptions, base case and reference scenarios

A set of base assumptions were defined that were common to all scenarios, including externalities such as: the price of electricity imported from the grid;[380] the formula to calculate the network charges; the market value of the large generation certificates (LGCs); financial rates; along with internal factors, such as the expected growth of the

[380] Even if a high penetration of renewable onsite would most likely mean a reduction in energy import and consequently a reduction in the purchasing power that allowed PAPL to negotiate very competitive prices.

electrical load on the precinct, and the cost of each step to augment the connection to the main grid.

A base case scenario was then defined that would serve as a reference for the other scenarios. In the reference scenario, PAPL would maintain a conservative Business-as-Usual (BaU) strategy, meaning that it would not introduce solar energy on the precinct, but instead invest capital in augmenting the connection to the grid to follow the growth of the precinct (and the electrical load), while increasing payments in energy imports and network charges. If the 'Cost Recovery' theory (outlined in Section 2.2.3) were to be applied to this network investment, the energy bills would increase for energy customers. However, since PAPL was already using the published tariff (i.e. the highest tariff found on the adjacent public grid) any increase in the network charges above this threshold would have been very poorly received by the customers. Therefore, any capital expenditure would either be recovered through an increase of the leases (reducing the attractiveness of the precinct) or not be recovered and directly taken off the margin of the energy business (reducing the profitability of the energy business).

The modelling also sought to investigate the implications of discounting the retail energy price compared with a reduction in the volume of electricity sold due to customers installing rooftop solar. The project team modelled a number of scenarios, involving different combinations of the configuration of solar systems (centralised or distributed), ownership (customers or operator financed), solar PV uptake (total installed capacity on the precinct) and battery capacity, with the following three standing to contribute directly to answering the research questions of this thesis, namely:

a) A scenario representing the most common method of introduction of solar energy on the public grid, namely 'Customer-owned solar and no battery' (assuming distributed solar systems rather than centralised),

b) A scenario representing the most common method of introduction of solar on commercial and industrial precincts, namely 'Operator-owned solar and battery' (with centralised solar PV and a centralised battery), and

c) A scenario representing a likely balance of interests between PAPL and its energy customers, namely 'Customer-owned solar and shared battery' (with distributed solar systems and centralised battery).

Scenario A: Customer-owned solar and no Battery

This scenario was selected to represent the situation most commonly found on the public grid, where businesses invest in rooftop solar to contribute to their daily load (noting that there are no Feed-in Tariffs for businesses in Western Australia) but are not required to invest in any form of energy storage to smooth their generation and mitigate impacts on the network. Therefore, this scenario was modelled without energy storage. Moreover, without energy storage the capacity of solar systems installed on the EEN was limited to the hosting capacity of the embedded network which was defined by the lowest average peak demand during the hot season (where solar energy generation is at full capacity), which was found to be 14 MW during weekends, compared with a maximum peak demand of 25 MW during weekdays.

From the energy profile data available for the precinct, the energy profile for a virtual customer was extrapolated to show how the electricity import of a customer changes when rooftop solar is installed and used to cover a part of the load (Figure 37 and Figure 38).

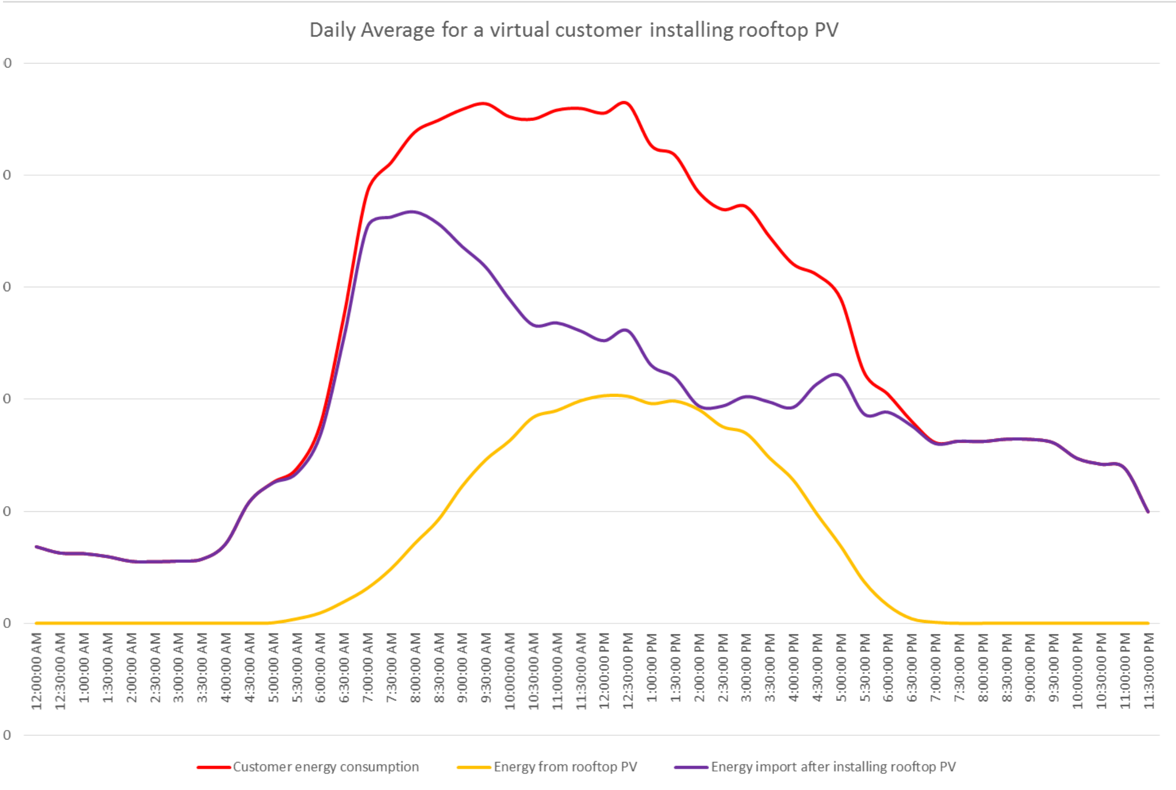

Figure 37: Decomposition of daily average for a virtual customer installing rooftop PV

The red line on top represents the customer energy consumption profile (daily average over a year), which corresponds to the customer's energy import before rooftop solar is installed, thus the volume of energy retailed by PAPL.

In yellow, the energy profile of a rooftop solar installation (daily average over a year), typically sized to cover the load and limit uneconomic excess (no Fit on energy export). In purple, the difference between energy consumption and solar energy which corresponds to the energy imported once rooftop solar is installed (thus the new volume of energy retailed by PAPL).

As per the graph below, the yellow area represents the volume of energy covered by rooftop PV, which is a 100% retail loss for PAPL, and the area in purple, the new volume of energy retailed by PAPL after rooftop solar in installed.

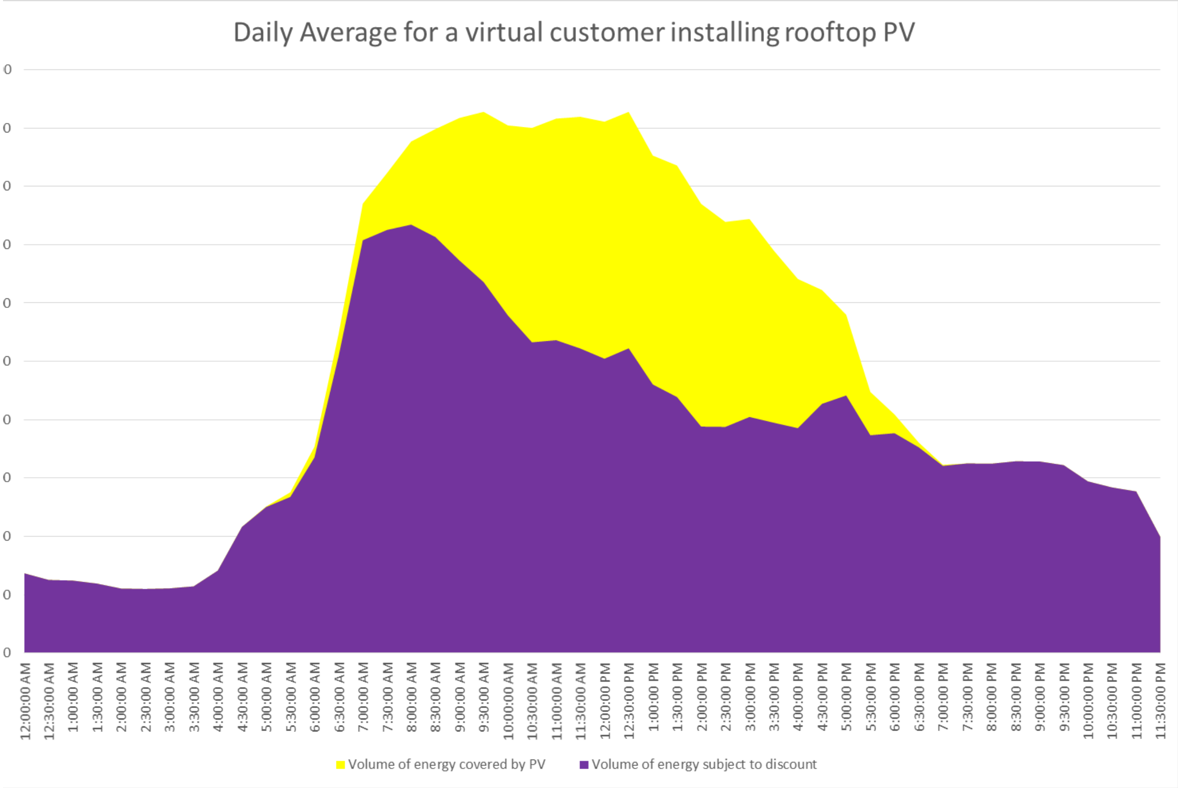

Figure 38: Daily average load covered by solar for a virtual customer

However, the loss in revenue induced by the rooftop solar (in yellow) is partly compensated by a reduction in import from the Grid, thus a reduction for PAPL in energy cost and Demand charges.

Scenario B: Operator-owned (centralised) solar and battery

A number of industrial precincts fitted with an EEN that have introduced solar have applied a model where tenants do not own the solar system, and the array is centralised, as **Table 14** shows. In this case, the PV array is typically owned by the embedded network operator, and when energy storage is installed, it is also centralised and operated by the operator.

Table 14: Examples of how solar has been introduced on some non-residential precincts

Airport location		PV capacity	Storage capacity	Ownership	Centralised
Australia	Adelaide	1.28MW	0	Airport	Yes
	Karratha	1MW	Smoothing	PPA	Yes
	Alice Spring	560kW	0	PPA	Yes
	Darwin	4MW	0	Airport	Yes
	Kingscote	50kW	EVs	Airport	Yes
	Longreach	99kW	0	Airport	Yes
USA	Denver	10MW	0	PPA	Yes
	Indianapolis	20MW	0	PPA	Yes
	Fresno	2.4MW	0	PPA	Yes
	Phenix	5.4MW	0	PPA	Yes
Malaysia	Kuala Lumpur	19MW	0	PPA	Yes
India	Cochin	12MW	0	Airport	Yes

Precinct location		PV capacity	Storage capacity	Ownership	Centralised
South Australia	Tonsley	2.4MW	(Planned)	Embedded Utility	Yes
Western Australia	Peel	1MW	0	Embedded Utility	yes
Queensland	Brisbane	1MW	0	Embedded Utility	Yes

PPA = Power Purchase Agreement.

In this scenario, the PV array would be owned and operated by PAPL and was therefore assumed to be installed on the roof of PAPL-owned buildings and carports. The embedded network would also be fitted with a large-scale Battery Energy Storage System (BESS), owned and operated by PAPL, to smooth the fluctuations of solar energy generation and increase the hosting capacity. The amount of smoothing necessary would be relative to the sensitivity of the EEN, but in the absence of this information, the scenario assumed a 12 minutes smoothing capacity,[381] corresponding to energy storage capable of replacing the total solar energy generation in 12 minutes.

[381] The smoothing time used on Horizon Power's network for customers with rooftop PV was used as reference.

The use of the BESS for load shifting was not simulated as the very competitive price of electricity from the grid did not make this role for the BESS economically viable.

Scenario C: Customer-owned (distributed) solar and shared (centralised) battery

In this scenario, energy customers would be permitted to invest in rooftop solar to contribute to their demand but would be required to participate in the financing of a shared battery to mitigate any impacts on the network by smoothing fluctuations in solar generation and increasing the hosting capacity. The option of using behind-the-meter storage was compared to the use of a network scale shared central battery system (like the one shown in Figure 39) that would be financed by customers and managed by PAPL.

Figure 39: Example of a containerised network-scale battery storage system
Source: Balance Utility Solutions

The option of a network scale shared battery system was selected as although batteries installed on customers' premises (i.e. behind the meter) are closer to the load and can better mitigate local impacts on the network, they come with the risk of a lack of conformity, and limited potential for PAPL to control the battery in order to achieve network optimisation. Moreover, they would most likely be less cost-effective than a shared battery system that would benefit from economies of scale and would also better support modularity and scalability.

Another significant advantage of utility-scale BESS is that the system can be designed and built to be modular and scalable. Therefore, they can be built and upscaled largely “just in time” and avoid the classic utilisation pattern of many network assets such as transformers, and substations which tend to be underutilised early in their life and then gradually become capacity-constrained before the next major upgrade investment is triggered.

This modular approach would also allow customers in the future to buy more hosting capacity if they wish to increase their solar array. They would also be able to buy more storage capacity to acquire peak shaving and/or load shifting capability. In this case, the customer’s part of the shared storage would be virtually charged up with the customer’s excess PV energy exported to the network, and the equivalent volume of energy would be subtracted from the customer’s metered consumption during the on-peak period. This simple accounting method has the benefit of working with existing energy meters without the need for a more advanced tracking system. Therefore, for the long-term network optimisation and increased performance of the whole precinct, the archetype of a ‘*Customer-owned distributed solar and shared battery*’ was selected as the preference for the PAPL research. Moreover, the capacity of the BESS in this model is set to correspond to the level of storage required to meet the technical standard set for smoothing the customer installed solar systems, like in the ‘O*perator-owned solar and battery’* archetype.

The business model used for the BESS in this ‘*Customer-owned distributed solar and shared battery*’ archetype assumes that customers installing rooftop solar would be charged a fixed fee by PAPL, on their electricity bill, for providing this bundled solar hosting capacity service. This charge would be set to repay the capital from the purchase of the BESS, the operating costs of the system, and a return on capital for PAPL. Also, the charge would be relative to the share of storage capacity allocated to smooth the PV systems installed by the customer. Other uses of the BESS such as peak shaving and load shifting were not modelled in this study because the level of detail of data available did not allow the construction of a robust models to produce reliable results. Therefore, the BESS was financially represented as a loss in the simulations since smoothing had no direct economic benefit (only long-term savings on the network).

Estimation of the average PV capacity installed on the precinct

To best compare the different scenarios of the introduction of solar PV, three potential levels of uptake of rooftop solar generation on the EEN were defined as SMALL, MEDIUM and LARGE. With the assumption that PAPL energy business would not offer a Feed-in Tariff for the excess electricity generated by the solar panels, the installed solar PV capacity was considered to be covering the customers' load during sunny hours

As a result, the three levels of uptake of rooftop solar and the penetration compared to the average lowest peak demand and the absolute peak demand are set out in Table 15.

Table 15: Summary of the installed PV capacity corresponding to the three levels of PV uptake and related percentage of penetration

PV Uptake	PV capacity in MW	Penetration (lowest peak)	Penetration (highest peak)
Small	9.8	70%	39%
Medium	12.6	90%	50%
Large	15.3	109%	61%

Note: Considering the lowest average peak demand of 14MW (weekends) and an absolute highest of 25MW

In the case of the 'Operator-owned solar and battery' archetype, the level of "uptake" relates to the risk-appetite of the embedded operator to invest in a solar system.

Solar system and battery costs

Based on average prices provided by Balance Utility Solutions at the time, rooftop solar was considered to cost $1,600/kW when customers were paying for it separately (as part of 'Customer-owned solar, no battery' and 'Customer-owned solar and shared battery models) and $1,300/kW for the 'Operator-owned solar and battery' model thanks to economies of scale (a more competitive price for an aggregated bulk purchase and installation on fewer locations). Depreciation was set to occur linearly over a 10 year period in each of the three cases. Balance Utility Solutions estimated the cost of batteries for smoothing at a rate of $1,650/kWh.[382] The assets were depreciated over ten years in both cases and, in the 'Customer-owned solar and shared battery' archetype, the cost was charged to customers at a rate of one-tenth of its value every year for ten years plus a 10 percent service fee to account for immobilisation of capital and the service associated with monitoring and maintaining the asset. The resulting capacities and costs are shown in Table 16.

Table 16: Summary of capacities and costs for the scenarios modelled

	MODELS:	*Base model*		*Customer-owned PV & no battery*		*Utility-owned PV & battery*		*Customer-owned PV & community battery*	
		MW or MWh	**$m**	**MW or MWh**	**$m**	**MW or MWh**	**$m**	**MW or MWh**	**$m**
Small uptake	**PV**	0	(Cost to upgrade the connection to the Grid)	9.8	15.7	9.8	12.7	9.8	15.7
	Storage	0		0.0	0.0	1.0	1.5	1.0	1.5
Medium uptake	**PV**	0		12.6	20.2	12.6	16.4	12.6	20.2
	Storage	0		0.0	0.0	1.3	1.9	1.3	1.9
Large uptake	**PV**	0		N/A	0.0	15.3	19.9	15.3	24.5
	Storage	0		0.0	0.0	1.5	2.3	1.5	2.3

Since PAPL could not export energy to the main grid (as per the public grid operator Western Power) and could reach a low peak demand of 14MW over weekends, it would be difficult to manage a high penetration of variable onsite generation without the help of a smoothing battery. Thus, the LARGE uptake of PV was deemed not feasible in the 'Customer-owned solar and no battery' was not modelled. The MEDIUM level was not recommended but modelled for information. Effectively, with this archetype PAPL would have to turn down all requests for new rooftop solar installations once the penetration level came close to the hosting capacity, thus creating inequality among customers, possibly causing dissatisfaction and reduced attraction for potential new tenants, along with a missed opportunity to significantly reduce the greenhouse gas emissions of the precinct.

[382] These BESS will be “power batteries” with fast discharge capacity, instead of the “energy batteries” used for load shifting, hence the premium price.

6.5 Results and interpretation of the different models to introduce solar

As the objective of the case study was to identify which archetype was most appropriate in the case of PAPL (as a proxy for other similar precincts) to provide a balance between the financial benefit for the customers (cost savings) and the financial losses for the energy business (reduced profit), the two criteria used to assess options were the Net-Present-Cost (NPC) for the customers, and the Net-Present-Value (NPV) for the embedded network operator. The latter were calculated over a ten-year period and used to assess the performance of each model in each scenario. For confidentiality reasons, raw results could not be shared in this thesis, so results are either presented without scale or relative to a reference (percentages).

6.5.1 Presentation of Results

The results of the modelling have been summarised in Table 17 and Table 18 with interpretation provided below.

Table 17: Changes in customer cost (NPC) and operator value (NPV) relative to the NPC and NPV of the reference scenario

Scenario #	Model	PV uptake	Customers NPC	Operator NPV
1	BaU	0	Reference NPC	Reference NPV
2	Customer-owned PV & no Battery	Small	-9.5%	-5.2%
3		Medium	-11.6%	-7.6%
4	Operator-owned PV & Battery	Small	0.0%	1.2%
5		Medium	0.0%	1.0%
6		Large	0.0%	0.9%
7	Customer-owned PV & shared Battery	Small	-8.9%	-5.1%
8		Medium	-10.9%	-7.4%
9		Large	-12.7%	-9.4%

Representing changes in NPC and NPV in relation to the NPC and NPV of the reference scenario was selected as it identifies the expected trend for each model without revealing commercial in confidence information. This method is interesting to assess separately what customers could expect to save and what the embedded operator could expect to earn or loose for each option.

6.5.2 Interpretation of Results

Customer-owned solar and no battery

As indicated in Table 17, this archetype would offer customers an average of ten per cent savings over the ten years of the study compared to the reference scenario. The archetype would penalise the embedded network operator with a loss of profit of six per cent on average due to the reduction in the volume of electricity retailed to customers. However, this loss was considered acceptable when considering non-financial benefits, including greenhouse gas emissions reductions and increased competitiveness of the precinct. The profit reduction was kept low due to the following financial benefits for the operator:

- The operator would not have to invest in onsite generation (as the customers would make this investment),
- The capital expenditure for the connection augmentation would be reduced or at least deferred,
- Grid charges paid by the operator to the main grid would be reduced, and
- The operator would receive customers' excess solar for free (if no Feed-in Tariff is offered) and could sell to non-PV customers (or use in its own operations).

Operator-owned solar and battery

The NPV of the scenarios where the embedded network operator invests in solar and a battery system is expected to be almost the same as the reference scenario where millions are spent throughout the ten-year period to upgrade the connection to the main grid. This is because the capital expenditure to install solar and a battery system is supported by the operator and not recovered through sales as it competes with the low price of the electricity imported from the main grid. The latter explains why, in this particular situation, solar PV (and battery) is not a competitive alternative to grid import for the operator. Consequently, investing in onsite solar and energy storage would not enable the operator to offer any discounts to the customers who would then see no economic value in this transition to renewables (Table 17 and Table 18 show no change in NPC between this archetype and the reference model with no solar energy).

Customer-owned solar and shared battery

This model shows very similar financial benefits for the customers (NPC) as the 'Customer-owned solar and no battery' model. The slight decrease in cost savings is due to customer participation in the community battery charged as “hosting capacity services” by the operator. The embedded network operator sees a slight corresponding increase in NPV due to the small return on investment for immobilising capital for the centralised battery system.

6.5.3 Summary of Findings

The approach used assessed the impact of each option on the customers (NPC) and the embedded operator (NPV) separately. However, the dollar value of the reference cost for the customers (NPC) is close to three times more than the dollar value of the energy business for the embedded operator (NPV). Therefore, in dollar value, the potential savings for the customers are much larger than Table 17 shows. The results in Table 17 were a necessary first step to show the trends, but the research proposes another method that reveals the range of the dollar value of each scenario by using the same reference for both the customers and the operator: this time the NPV of the reference scenario was selected as the common reference for both the customers and the embedded operator, in Table 18.

Table 18: Customer cost (NPC) and operator value (NPV) changes relative to the NPV of the reference scenario

Scenario #	Model	PV uptake	Customers NPC	Operator NPV
1	BaU	0	281% of the reference NPV	Reference NPV
2	Customer-owned PV & no Battery	Small	-27%	-5.2%
3		Medium	-33%	-7.6%
4	Operator-owned PV & Battery	Small	0%	1.2%
5		Medium	0%	1.0%
6		Large	0%	0.9%
7	Customer-owned PV & shared Battery	Small	-25%	-5.1%
8		Medium	-31%	-7.4%
9		Large	-36%	-9.4%

With this method, it is easier to appreciate how some of the scenarios are benefiting the customers significantly without affecting the energy business too much. To better visualise the financial results, the scenarios modelled were plotted on a chart using their dollar value (scale removed from the chart for confidentiality).

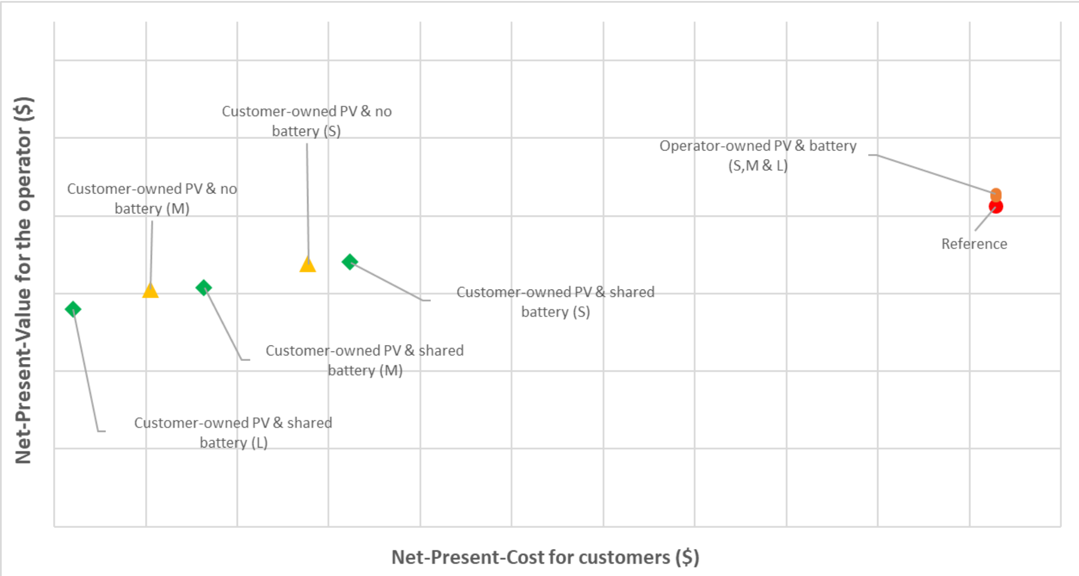

Figure 40: Chart of scenarios plotted according to their dollar value NPC and NPV

The ratios displayed in Table 18 can be visualised in this chart. For example, the expected benefits for the customers (NPC reduction) for the SMALL 'Customer-owned and shared battery' scenario are about five times more important than the corresponding losses for the operator, as shown in Figure 41 with customer cost savings represented in green and operator losses in red.

Figure 41: Chart showing benefits to customers outweigh losses of operator

6.5.4 Recommendation for introducing solar on the Perth Airport industrial precinct

The 'Operator-owned solar and shared battery' archetype, mimicking the models typically used by embedded network operators who invest alone in energy assets to keep them under control, does not deliver significant value in the context of the Perth Airport (low wholesale energy price from the grid and high capital expenses related to augmentation threatening the growth of the precinct). The increase in NPV is marginal compared to the risk taken to invest alone in solar and battery, and the solution does not bring direct financial benefits to the customers.

In contrast, the scenarios where customers invest in rooftop solar seem to deliver significant savings to customers for relatively low losses for the embedded network operator. The relatively low loss for the operator is due to the co-benefits introducing onsite solar energy brings to the embedded network operator, such as deferred expenditures in connection augmentation or reduced (public) grid charges, even if the reduction in the volume of energy sold erodes the margins significantly. Therefore, introducing solar energy on the precinct with installations financed by the customers is a win-win-win situation for the customers, the embedded network operator, and the precinct owner who benefits from a reduction in greenhouse gas emissions and a more attractive precinct for a limited financial effort from its energy business. The latter provides an answer to the question "*What are the co-benefits for the landowner to introduce renewable energy on its precinct?*".

The advantage of adding a customer-financed shared battery does not appear in these simulations as they are not financial but have been discussed earlier in this chapter.

6.6 Impact of tariff discounts

As explained in Section 6.3.4, there is a key lesson to learn from the effect of retail tariff discounts that could be imposed on the energy business if retail competition would be introduced.

Table 19, the impact for the customers and the embedded network operator for the average retail tariff discounts observed on the contestable market. The impact on the net present cost (NPC) to customers and the net present value (NPV) for the operator for a large uptake of customer-owned solar has been added for comparison.

Table 19: Impact of tariff reduction and comparison with introduction of customer-owned solar and shared battery

Discounted tariffs	Archetype	PV uptake	Customers NPC	Operator NPV
No	No Solar	0	Reference	Reference
Yes	No Solar	0	-12.0%	-18.8%
No	C-O PV & S. Batt	Large	-12.7%	-9.4%

The conservative retail tariff discounts simulated (second line in the table above) could offer 12 percent reduction of the total cost of energy over ten years for the customers, but this would also result in a loss of nearly 19 percent for the embedded network operator. In comparison, letting customers invest in rooftop solar and participate in a shared battery for smoothing (third line in the table) would bring slightly more savings to the customers, but would half the revenue loss for the operator. Therefore, these findings confirm that, compared to a loss in revenue from discounted electricity tariffs, the loss of revenue from reduced volume of energy sales due to customers install their own rooftop solar is partly compensated by co-benefits for the embedded network operator. These co-benefits, such as deferred expenditures in connection augmentation or reduced (public) grid charges, do not exist when electricity retail tariffs are discounted.

This simulation brings a complement of answer to the question "*What are the co-benefits for the landowner to introduce solar energy on its precinct?*".

6.7 Summary of Chapter and Contribution to Thesis

In summary, the following results have been presented in Chapter 6:

1. As expected, the simulations verified that investing in solar PV and battery storage is not interesting economically for an embedded network operator who imports electricity from the grid at a competitive price and then on-sells to captive customers. This option is still allowed and hence widely used by embedded networks because it does not disrupt the traditional utility business model, making offering onsite energy generation to customers an expensive option.

2. The simulations also suggest that letting customers invest in their own rooftop solar and consume this electricity to reduce energy bills does not actually have the anticipated financial impact commonly assumed. In the situation of Perth Airport, a loss in net present value of only 9 per cent could translate into a reduction of close to 13 per cent savings for the customers (See Table 17) — which amounts to a 35 percent reduction in dollar value of the customer energy cost (See Table 18) — and can be viewed as an efficient 'transfer of wealth', with customer satisfaction and an increase in precinct competitiveness gained in the process.

3. The simulations found that even a conservative reduction in the energy retail tariffs would have a marked impact on the revenue of the embedded network operator (See Table 19). Moreover, such change would not have the same wealth transfer effect or other non-financial co-benefits that are observed in the customer-owned rooftop solar approach.

4. Hence, the simulations suggest that the introduction of retail competition is a greater threat than allowing the introduction of customer-owned rooftop solar, with the latter potentially reducing the likelihood of energy retail competition targeting the precinct if (but more likely when) this is allowed by a change in the regulation.

The results suggest that sharing the risks and the efforts with the customers by allowing them to install solar PV and contributing to the financing of a shared battery for smoothing could lead to a win-win situation for both the customers and the embedded network operator. The findings contribute to documenting the following Gaps:

- Gap 2 "*How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of solar generation*": The shared network energy storage appears as the most appropriate solution to provide the smoothing necessary to reduce the pressure solar generation puts on the network and help maintain the quality of the supply.

- Gap 3 "*How to make customers installing solar responsible and accountable for the pressure their solar system would put on the network*": Having only the customers installing rooftop solar participate in the share battery, proportional to the capacity of PV installed, is not only equitable but also reminds customers that they are part of a system and their decisions regarding electricity supply can affect others on the system.

The transition to electric mobility of commercial fleets and passenger vehicles was identified as being either a threat or an opportunity for an embedded operator depending if the uptake is anticipated and planned for. This highlights an important further research area related to the study of the interaction between the distribution network and the batteries of electric vehicles that are connected to it, which is outside the scope of this thesis. However, it cannot be ignored in the transition to onsite energy generation on commercial and industrial precincts and is a critical factor when considering both the economics of the transition and the associated limitations such as the hosting capacity.

The results and lessons learned from the case study on the Perth Airport Industrial Precinct with the SBEnrc were instrumental to informing the thesis and shed light on the specific challenges and opportunities that a commercial and industrial precinct is likely to face when considering a strategy to introduce solar energy. Given the shift to onsite energy generation is a recent focus for industrial precincts these findings provided invaluable insights not available in the current literature. This has allowed the thesis to combine these findings with the findings of the literature review to create a new approach for commercial and industrial precincts to transition cost-effectively to solar, the 'Industrial Village Energy Approach', as presented in the next chapter.

Chapter 7: Introducing The Industrial Village Energy Approach and its Components

Proposed answer to the main research question: How can an industrial precinct, fitted with an embedded electricity network, transition to cost-effective long-term on-site solar energy generation?

Aim: Proposition of an Industrial Village Energy approach.

Objective: Detail the rationale, the considerations and the targeted outcomes of each of the central elements of the proposed approach to a cost-effective and long-term transition to solar energy by industrial precincts.

6.8 Introduction

In Chapter 5 the findings from a selection of innovative models from the electricity industry and solutions and theories from other industries were considered that could close the gaps identified in existing models. The case study in Chapter 6 then revealed valuable insights and confirmed the financial benefits of a collaborative approach between the embedded network operator and energy customers from the introduction of solar on industrial precincts. This chapter proposes a new approach to underpin a cost-effective and long-term transition to solar of industrial precincts and presents the rationale, considerations and targeted outcomes of each of its element as well as how they work together.

6.9 The proposed approach

6.9.1 Overview

The proposed approach is collaborative in essence as it involves both the embedded network operator and the customers and aims for mutual long-term benefits. The approach involves the transparent sharing of risks and rewards between the parties and is driven by achieving an acceptable balance of interests. The approach consist of three elements, namely: new roles for the parties, a governance model inspired by the traditional governance model found in a village, and new agreements between parties. A plan to implement this approach will also need three ‘satellite’ components namely: stakeholder engagement, integration and review and reporting. Figure 42 illustrates the process to implement the proposed approach with the Boxes 2, 3 and 4 (in dark orange) representing the central elements of the approach whereas the Boxes 1, 5 and 6 represent the implementation support components.

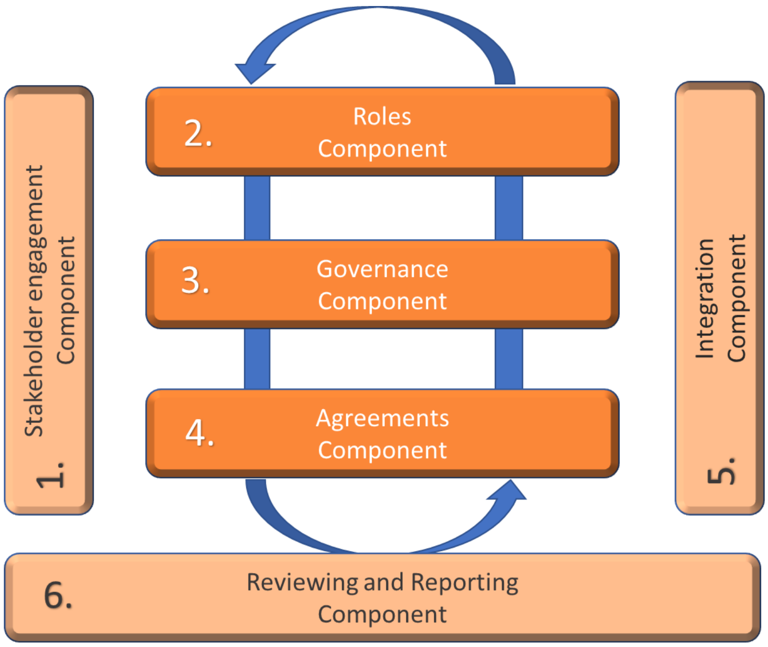

Figure 42: Scaffolding of the Industrial Village Energy Approach

As can be seen in Figure 42, stakeholder engagement (Box 1) is the first step of the process. This component focuses on ensuring the approach, the principles of balance of interest and sharing risks, efforts and rewards are well understood and adopted by the stakeholders who are (but not limited to) the embedded network operator, the energy customers, the precinct owner. It is also the step where the process may be adapted to the context if necessary (e.g. degree of freedom from the energy regulator or the presence of retail competition on the precinct).

The elements in Boxes 2 to 4 are central to the approach and complement each other, and in practice they may need to be implemented over a number of iterations. This iteration process is represented by the integration component (Box 5) which seeks to achieve an acceptable balance of interests between the embedded network operator and the customers, and as such is fundamental to the success of the approach. The last component (Box 6) then focuses on performance review of the implementation of the approach to both validate intended outcomes and provide guidance for future iterations of the previous components as part of a process of continual improvement.

The three satellite components (Boxes 1, 5 and 6) are not be explored in more details in this thesis as they are only necessary for the implementation of the approach and can use mainstream project management standards.

6.9.2 Element 1: Redefine Roles and functions

New role for the embedded network operator

<u>Rationale</u>

As explained in 'Section 3.2.4: The unconstrained spread of distributed energy resources increases the complexity and cost of the network', depending to the approach taken the uptake of rooftop solar could either reduce load congestion on the network or, put new pressure and increase its complexity. In addition to being responsible for system security and reliability, utilities are now being looked to in order to ensure the system is flexible enough to accommodate new types of loads such as EV charging and variable distributed generation such as rooftop solar, all while providing the level of service that customers expect (Tayal, 2017)[383]. Therefore, if the use of the network is changing and customer expectations for this service are also changing, the role of the network utility will need to also change and this will involve taking on new roles.

<u>Considerations for implementation</u>

As Section 5.3.1 explained, and is shown in Figure 22 (represented as Figure 43 for ease of reference) the embedded network operator could expand its traditional monopoly position, on one end of the spectrum or, on the other end, divest from non-network specific duties and take up the new role of a 'Distribution System Platform Operator' (Cross-call *et al*., 2018)[384].

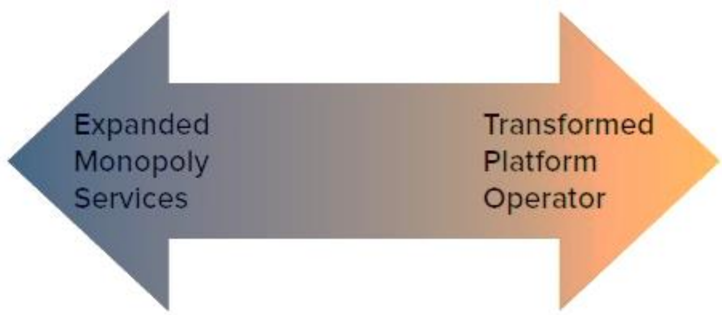

Figure 43: Spectrum of utility models

Source: Rocky Mountain Institute (RMI, 2018)

[383] Tayal, D. (2017) Leveraging innovation for electricity utilities. *The Electricity Journal*, *30*(3), 23-29.

[384] Cross-Call, D., Gold, R., Guccione, L., Henchen, M., and Lacy, V. (2018) Reimagining the Utility: Evolving the Functions and Business Model of utilities to Achieve a Low-Carbon Grid. Rocky Mountain Institute, Snowmass, Colorado.

The shift towards the role of a Distribution System Platform Operator would come with disruption, while the shift toward expanded monopoly allows retaining most of the existing (and traditional) operations and ownership of assets (at least until regulatory conditions change). Hence the choice is context-dependent and there is no one clear preferred approach for all EENs of commercial and industrial precincts. However, it is possible to give some indications as to how to weigh up the options depending on the context, and most notably the current, or expected, position of the embedded network operator (ENO).

If the current (or expected) position of the ENO is not to keep or develop energy generation assets or associated retail operations, then it is recommended that the ENO shift toward the role of a Transformed Platform Operator. This will allow the embedded network operator to reinforce its central role on the precinct, supervise and monitor use of the network, and develop a revenue independent from the sale of energy. This shift is also a robust strategy to prepare for the introduction of retail competition. Indeed, as mentioned in a report by Lawrence Berkeley National Laboratories (Blansfield *et al*., 2017)[385], customers should be allowed to access services that can be provided by external entities rather than the ENO competed with them. Such an approach would likely foster efficiency in the system, while services driven by longer-term goals and customer benefit may be better served by the embedded network operator. If instead the embedded network operator is vertically integrated and does not feel the threats mentioned above, expanding its services to add value to customers and decouple its revenue from the sale of energy is likely to be a sound approach.

<u>Targeted outcome</u>

The distribution network is bound to remain the centrepiece of the electricity system and a natural monopoly driven by customer satisfaction when other parts of the supply chain are profit-driven and could be outsourced. To strengthen the position of the embedded network operator, its role would shift from a simple Distribution 'Network' Operator (DNO), focused on the distribution asset to a more complex Distribution

[385] Blansfield, J., Wood, L., Katofsky, R., Stafford, B., Waggoner, D., and Schwartz, L. (2017) Value-Added Electricity Services: New Roles for utilities and Third-Party Providers. Lawrence Berkeley National Laboratories.

'System' Operator (DSO) managing an array of services that provide value to customers, as shown in Figure 44 below.

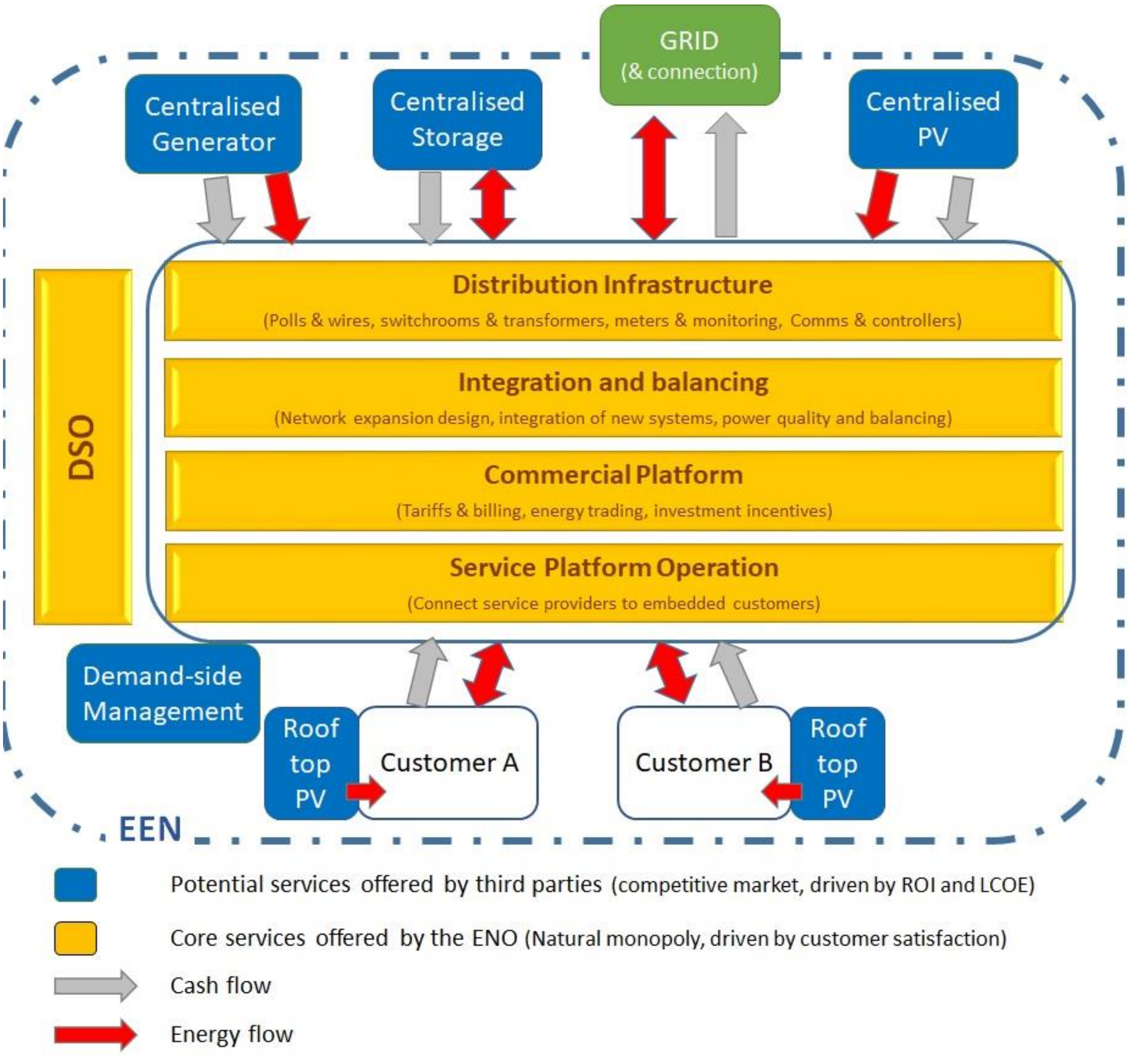

Figure 44: New roles for the Distribution System Operator (DSO) in a transforming electricity system

In Figure 44 the blue boxes represent the services that could be provided by the embedded network operator if it were fully vertically integrated, or if not, that could be opened to third parties with the creation of a competitive market. To the contrary, the yellow boxes represent functions that are typically covered by the DSO. The top two yellow boxes, that of 'Distribution Infrastructure' and 'Integration and Balancing', are a legacy of the traditional monopoly position. The bottom two yellow boxes, that of 'Commercial Platform' and 'Service Platform Operation', are opportunities for the DSO to optimise the network and extract new revenue.

In any case, these new services provide the opportunity for the embedded network operator to diversify its revenue beyond the sale of energy. The red arrows show that each of the energy flows pass through the network (except rooftop solar that is used to meet customer demand first), and the grey arrows show the payments for the use of the network and related services (with only one grey arrow leaving the DSO to pay for the use of the main grid)[386]. Achieving these energy and cash flows would see the role of the embedded network operator evolving from just being the gatekeeper of access to electricity, to a service provider with multiple revenue streams and engaged customers.

New role for the customers

Rationale

Numerous residential customers on the public grid have now shifted from passive end-users to active participants and prosumers. Seeing this and the associated benefits, business customers in commercial and industrial precincts have the same appetite to invest in rooftop solar. These customers have a similar expectation to participate in their electricity supply, while reducing energy costs (ideally using clean energy) and possibly add some flexibility to meet their energy demands. However, taking a closer look it is clear that investing in behind-the-meter energy generation is somewhat limited given network costs typically make up a substantial portion of electricity bills. Hence, participating in network optimisation rather than in reducing the delivery of energy is more likely to deliver the significant reduction in energy bills .

Therefore, while customers are keen to become active energy producers, the findings of the research for this thesis suggests that in-fact they need to become active network users. This can be achieved in two complementary stages:

- Stage 1: Ongoing participation in network optimisation.
- Stage 2: Participation in the decision-making process of the long-term planning of network augmentation.

[386] Payments for energy are not represented in this diagram, only payments for network related charges (Distribution service charges, smoothing charges and demand charges).

Considerations for implementation

There are a number of considerations for Stage 1 (ongoing participation) in order for customers to adopt an active role, namely: : network users need an understanding of how overall electricity demand has an impact on network costs, and more specifically how their behaviour could impact the portion of the network they are connected to and how it can be reduced; direct feedback – ideally live – on the state of the network in order to make rapid educated decisions; and a direct reward for adopting the preferred behaviour. These considerations will be covered in the next sections (e.g. new governance, new network tariffs). When considering Stage 2 it is essential to identify the period of the tenant leases or at least the longer plans of tenants on the precinct. Given network assets (poles, wires, transformers, substations) are stranded, capital intensive and rarely modular, they usually require long-term planning and long-term action plans. Therefore, how tenants are likely to participate must be considered if their role is to include participation in the optimisation of the network.

Targeted outcome

The targeted outcome is a better sharing of the risks, efforts and rewards between the embedded network operator and the tenants/customers to create acceptable mutual benefits for the parties. The primary win for the customers being the reduction in electricity bills thanks to reduced network charges.

6.9.3 Element 2: Create New Governance Structure

Rationale

The presence of an energy regulator in the governance of Public Utilities is typically justified, among other reasons, by the size of the network and the number of customers it serves and the need to ensure appropriate conditions. However, such a system is unlikely to be fit for small networks where the balance of interests between customers and embedded utility cannot be solved by adding some kind of third party regulator. This led to the investigation of how the balance of interests are managed in small communities with the research to support the thesis approaching the problem of governance of the energy system in commercial and industrial precincts from the perspective of a village.

The concept of a village typically involves some form of community that is gathered in the same geographic area that shares interests, infrastructure and local resources, while fostering collaboration between villagers, managed by local rules. Hence for the purpose of this thesis a commercial and industrial precinct is proposed to be considered as an "Industrial Village", and further that the focus of the village in this instance is on energy, where commercial success is the shared interest, the embedded electricity network is the shared infrastructure, and energy is the shared resource. Every consumer, prosumer and energy producer connected to the industrial village's electricity network is considered a member of the village and the village is governed by specific rules. The success of a village relies on reaching and maintaining an appropriate balance of interest between the villagers, who want to succeed individually (the families in the village who are concerned about their wellbeing), and the body which governs the village (such as the Mayor and the elected council) who want the village to succeed as a whole, placing the interest of the village first, including the financial health of the village's government.

Considerations for implementation

The proposed Industrial Village Energy Approach is based on the following principles:

1. The purpose of a focus on energy in an Industrial Village is to create and share a set of efficient, effective and affordable energy resources which benefit the individuals within the village and the village as a whole.

2. The energy related infrastructure and the rules of the Industrial Village enable the members of the village to thrive individually (i.e. providing reliable, affordable and unconstrained energy supply for tenants to run their business), including having the opportunity to invest in on-site energy solutions.

3. The members of the village are inter-connected and interdependent (meaning that their behaviour and choices will impact other members) given the shared energy system.

4. The Industrial Village is governed by a body whose priority is for the village to be an attractive place (to do business) and facilitates Principles 1, 2 and 3 while protecting the financial position of the village government (and service provider). Under this structure the embedded network operator takes on a role similar to the 'Mayor' of the village, while also being the village public works department.

Typically, embedded electricity networks of commercial and industrial precincts have most of the physical attributes described above (such as tenants gathered in a defined geographic area, sharing the same distribution network), with two new critical areas necessary to apply the approach on a traditional precinct;

1) The mission of the energy business (and its operational arm, the embedded network operator) needs to change from aiming to increase its bottom line, to looking after the interests of the precinct as a whole, including its tenants. This change is likely to be enacted at the precinct's corporate level to ensure consistency across all business units (energy, property, others).

2) As the village concept relies on the sharing of risks and rewards, the precinct should adopt a governance model similar to a traditional village, with shared decisions made at council meetings where the embedded network operator meets with its energy customers (or customer representatives for larger precincts). These meetings are also an occasion to update the expectations of tenants and discuss present issues and opportunities along with potential trade-offs.

Targeted outcome

Such a governance model aims to create the necessary environment for the embedded network operator and customers to meet, communicate, and collaborate towards preferred mutually beneficial goals while sharing risks, efforts and rewards. On the one hand, the outcome can be a genuine opportunity for customer participation that reduces frustration along with electricity bills. On the other, it provides a strong platform for the embedded network operator to stay abreast of the level of customer satisfaction, work with customers to optimisation of the network (lowering expenditure and increased profits), and make the precinct more attractive to current and future tenants.

6.9.4 Element 3: Agree on New Financial Agreements

New network tariffs

Rationale

At the heart of the financial struggle for energy utilities around the globe is the traditional cost recovery model that bases a portion of the network operator revenues on the volumetric sale of energy. However, as explained in previous chapters, the expenditure that needs to be recovered by the utility, and particularly the Distribution Network Operator (DNO), is not directly proportional to the volume of energy sold, but rather it is proportional to the local and system-wide peak energy demand. Along with this complication the traditional model that has been in place for decades has been disrupted first by efforts to improve energy efficiency, followed by the rapid uptake of distributed generation in the form of rooftop solar, and as previously explained this has led to the identification of a gap in the literature around "How to protect the revenue of the embedded network operator when behind-the-meter solar systems are introduced".

The suggestion to redesign demand charges to reflect the use of the network was identified in Chapter 5 as a solution. Furthermore making customers responsible for the pressure they put on the network was posed as a solution to the gap in the literature around "How to make customers installing solar systems responsible and accountable for the pressure they put on the network". The need to propose new agreements between the customers and the embedded network operator also responds to concerns described in Section 6.9.2, as, along with the operator, customer risks and efforts must be rewarded accordingly.

Considerations for implementation

The long-term reduction in network costs that would eventually allow the reduction, or at least stabilisation of electricity bills, is one of the rewards customers can expect as part of the new approach. Delivering such outcomes require that customers efforts are reward, for instance in the form of new embedded network charges. Professor Pérez-Arriaga has been working on this topic for over a decade, first with Ortega *et al*. in 2008[387], then developing, with master's student Bharatkumar, the concept of "*distribution network use of system (DNUoS) charges*" in 2014 based on applying the cost causality principle to the area of network charges (Pérez-Arriaga and Bharatkumar, 2014)[388]. The concept of DNUoS is particularly well fitted to private electricity networks that are smaller and often simpler systems than the public grid and also (partially) free from restrictions from associated regulations.

[387] Ortega, M. P. R., Pérez-Arriaga, J. I., Abbad, J. R., and González, J. P. (2008) Distribution network tariffs: A closed question?. *Energy Policy*, *36*(5), 1712-1725.

[388] Pérez-Arriaga, I., and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

However, studies such as the one conducted by the Australian Energy Market Commission (AEMC, 2012)[389] suggest that behaviour change does not happen as a direct result of a change in tariff price. The AEMC research report concluded that *"convenience, awareness and understanding will also determine consumption behaviour*. This means that when utilities introduce innovative pricing tariffs, they also need to ensure their customers understand their value in the context of the whole electricity network (Ratinen, 2014)[390]. The service provided by Enel X, as outlined in Section 5.4.3, highlights the need to assist energy customers to change behaviours even when the price signals are clear and the savings easily achievable. Therefore, new tariff structures and process cannot just be rolled out to customers. The embedded network operator must take care to ensure its customers understand their purpose and value, which requires the operator engaging with them, a task that the proposed village governance structure should facilitate.

Targeted outcome

New cost-reflective network charges have three objectives:

1. Ensure that adequate revenues are received to compensate for the pressure caused by customer energy generation and usage patterns on the network,

2. Decouple the revenue of the embedded network operator from the sale of energy, and

3. Incentivise (reward) customers to change their consumption behaviour or invest in behind-the-meter solutions to reduce their pressure on the network and the consequent cost incurred.

On this last point, it was identified that, on the Australian public grid, better managing customer demand and generation using new tariffs could save over sixteen billion dollars in network augmentation by 2050 (Ratinen and Lund, 2014)[391].

[389] AEMC (2012) Power of Choice Review - giving Consumers Options in the Way They Use Electricity. Australian Electricity Market Commission, Sydney.

[390] Ratinen M., Lund P.D. (2014) Growth strategies of incumbent utilities as contextually embedded: Examples from Denmark, Germany, Finland and Spain, Technology in Society 38 (2014) 81–92.

[391] Graham, P. and Brinsmead, T. (2017) Minimising customer bill increases in a decarbonising and decentralising electricity system. CSIRO at IAEE Conference Singapore.

Financial participation in the shared battery

Rationale

The introduction of solar systems on the precinct that are installed by tenants behind the meter on the roof of buildings would likely lower their electricity bills. However, given the fluctuating nature of solar energy, these system could also negatively impact the quality of the supply of electricity on the network unless the generation is smoothed (See Section 4.2.3). The mainstream solutions adopted by public utilities when the penetration of solar energy reaches a point where grid stability is likely to be impacted is the rejection of applications for new solar energy installations (See Section 3.2.7) or, if new installations are to be added, the investment by the network operator in a network battery (See Section 3.2.4). Both solutions create inequity between energy customers who have solar systems and those who do not (either by being blocked from adding solar as they are too late or by having to contribute to the cost of a battery to respond to other people solar panels), thus a better alternative is needed. This alternative is for a shared battery financed by customers installing solar systems and controlled by the utility to support grid stability.

Considerations for implementation

Customers installing rooftop solar would be charged a fixed fee by the embedded network operator, on their electricity bill, for being provided a bundled solar hosting capacity service. Revenue from this charge would be used to contribute to repaying the capital expense of the Battery Energy Storage System (BESS), the operating costs of the system, and a return on capital. A first consideration is the length of the lease of the tenants installing solar systems, as the investment in a BESS is a long-term (e.g. 10 years) commitment for the embedded network operator. The embedded network operator must therefore take the financial risk that a new tenant would agree to take over the existing installed solar system and the corresponding agreement for the solar hosting capacity service. A second consideration would be how this agreement could be extended to other optional services offered by the energy storage, such as load shifting and peak shaving for the customers, however these items are not covered in this thesis.

Targeted outcome

Ultimately, the targeted outcome is to maintain a stable, affordable and equitable electricity supply on the precinct while providing energy customers the opportunity to install rooftop solar systems. More specifically, the shared battery would provide smoothing of the fluctuating supply of energy generated by customers' solar systems, thus contributing to grid stability; customers installing solar systems sharing a network-scale battery instead of a multitude of small behind-the-meter batteries would contribute to its affordability thanks to the economy of scale; and the financing of the hosting services (the battery system and its maintenance and operation) provided only by customers that install solar systems would contribute to equity.

6.10 Synthesis of the proposed approach

The suggested approach is made up of three elements that propose an alternative to the traditional model and work together and complement each other. As previously mentioned, the aim of the energy business shifts from a focus on increasing sales of electricity to cultivating ways to receive revenue from a range of network related opportunities. This is a major shift for a commercial entity, and it not only requires executive management to understand the short term implications but to also recognise the longer term benefits. Communicating this new approach to customers that offers them a share of the risks, efforts, and rewards may also be a challenge, hence the selection of 'stakeholder engagement' as the first step in the approach, with the logic summarised in Figure 42.

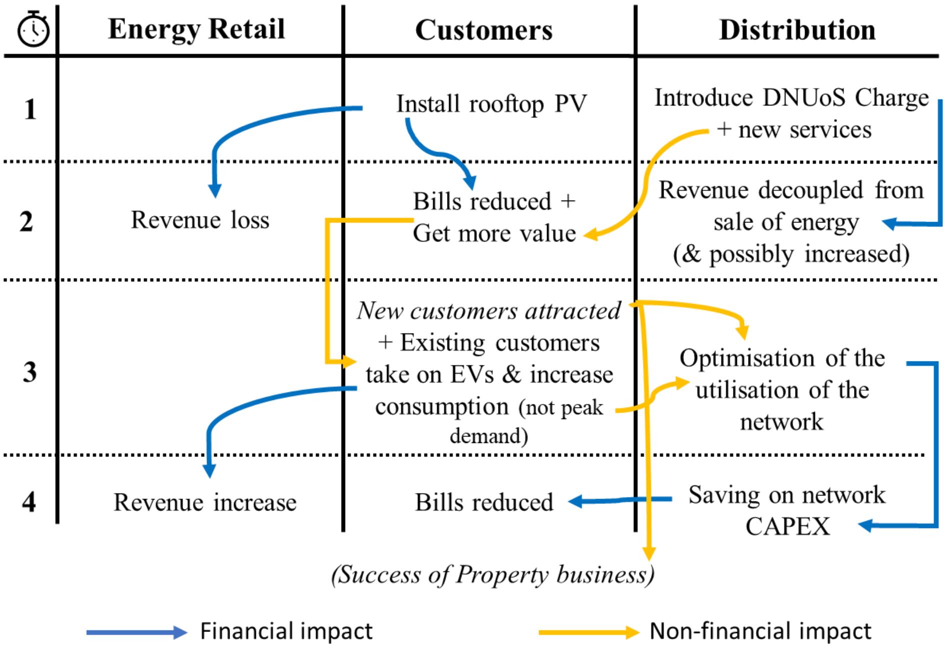

Figure 45: Logic of Industrial Village Energy Approach shared long-term co-benefits

As can be seen in Figure 45, letting customers install rooftop solar while introducing new network charges can lead to mutual benefits for the customers, the embedded operator and the precinct owner. The elements of the proposed approach could be integrated by the precinct owner and its embedded network operator to build a new business model that would support the successful transition of the precinct to solar energy. Building on from the work of Tayal and Rauland (2017)[392] to evaluate the attributes of potential future business models for Western Australian electricity utilities as shown in Table 20, Table 21 adapts the findings to embedded network operators.

[392] Tayal, D. and Rauland, V. (2017) Future business models for Western Australian electricity utilities. *Sustainable Energy Technologies and Assessments*, *19*, 59-69.

Table 20: Drivers and Key Characteristics of Future Utility Business Models

External Factors	Technological Innovation	Climate Change and Resource Scarcity	Urbanisation and Demographic changes	Economic Shifts
Sectoral Changes	Increased Competition and New Entrants	Cost Pressures and Price Rises	Consumer Behaviour and Demand Preferences	Government Policy and Regulation
Required Characteristics	Customer Focus	Community Engagement	R&D incubator of Innovative technologies	Regulatory and Policy Engagement
		Participation in Distributed Generation Markets	Transform to Energy Service Provision	

Future Utility Business Models

Source: Tayal and Rauland (2017)

Table 21: Drivers and Key Characteristics of Future ENO Business Models

External Factors	Technological Innovation (1)	Community and Peer Pressure to Act against Climate Change and Resource Scarcity	Competition from other C&I precincts	Government Policy and Regulation
Sectoral Changes	Energy Retail Competition & New Service Providers on the Precinct	EEN Augmentation (CAPEX) and Increasing Main Grid Network Charges (OPEX)	New Types of Load (1) and Change in Demand Preferences	Embedded Customers Seeking Energy Democratisation (e.g. Install Rooftop PV)
Required Characteristics	**Sharing of Efforts, Risks and Rewards**	**Collaboration and Transparency**	**Customer Focus**	**Decoupling of Revenue from the Sale of Energy**
Proposed Solutions	- Customers Allowed to Install Rooftop PV - Customers with PV Participate in Financing a Smoothing BESS - New Tariffs Rewarding Behaviours Favourable to All	- New Governance Framework - Customer Engagement Process - Embedded Network Operator Re-centred on its Distribution role	- Customer Engagement Process - Utility Proposes Value-Adding Services - ENO Enable Customers' Business Activities (1)	- New Network Tariffs - Embedded Network Operator Re-centred on its Distribution Role - ENO Proposes Value Adding Services

(1) In general, and uptake of electric mobility on the precinct in particular

Future Embedded Network Operator Business Models

Source: Adapted from Tayal and Rauland (2017)

6.11 Summary of Chapter and Contribution to Thesis

This chapter presented a set of elements that form the proposed 'Industrial Village Energy Approach' intended to achieve a cost-effective and collaborative transition to solar energy on commercial and industrial precincts. The Chapter presented findings to contribute to filling a number of the identified research gaps, including a new governance structure inspired by the traditional organisation of a 'village'. This provides an approach to harnessing on-site solar energy collaboratively on commercial and industrial precincts, that embedded network operators can adapt to their specific context — such as their degree of freedom from the energy regulator or the presence of retail competition on the precinct.

The proposed approach would also help modernise the way electricity is managed by embedded network operators and have a positive impact on its customers. Just like Jia and Crabtree[393] (2015) noted that "*Energy's central role in society means that modernization within the sector will have downstream effects on virtually every aspects of life*", modernising the electricity business on the precinct will have downstream (positive) effects on the businesses on that precinct. This supports the rationale that the well prepared and managed introduction of solar energy on commercial and industrial precincts will make them better places to do business, attract premium tenants and consequently improve the property business on the precinct.

[393] Jia, J., and Crabtree, J. (2015) *Driven by Demand: How Energy Gets its Power*. Cambridge: Cambridge University

Chapter 8: Conclusions and Further Research

7.1 Conclusions

7.1.1 Significance and Originality

In the latter stages of the PhD research, the candidate observed growing interest from precinct owners, embedded network operators in accelerating the transition of industrial and commercial precincts to onsite solar energy generation, and state governments and public utility in harnessing cost-effectively and collaboratively distributed energy generation and storage. The growing awareness of the challenges of increasing penetration of distributed solar energy and the related interest to manage it so threats become opportunities are particularly observable in Western Australia. Indeed, its public network is both one of the most isolated and one with a highest penetration of distributed energy resources. It is therefore at the forefront of the challenges associated with the transition to distributed solar energy.

The growing interest in managing this challenge better has been observed by the candidate when in April 2019 the Western Australian Parliament published a report on 'Implications of a distributed energy future' highlighting the strategic role of micro-grids and embedded networks in the transition to a system of renewable energy for the State (Parliament of Western Australia, 2019)[394]. Further, on 20 May 2019, the Western Australian Government established the Energy Transformation Taskforce to deliver the Western Australian Government's Energy Transformation Strategy.[395] The 'Distributed Energy Resources Roadmap' was then proposed in December 2019 and officially published in April 2020 highlighted that "the rise of *distributed energy resources is driving innovation in customer offerings and services*" and "*will require appropriate policy, technical, market and regulatory settings*".[396]

One of the first decisions as part of the implementation of the roadmap was the state-wide deployment of 'community power banks' (CEC, 2020)[397]. The choice of utility-scale and utility-controlled community battery energy storage systems (the

[394] Parliament of Western Australia (2019) Implications of a distributed energy future. Parliament of Western Australia, Legislative Assembly, Economics and Industry Standing Committee. Report 5

[395] Government of Western Australia (2019) The Energy Transformation Taskforce. Government of Western Australia.

[396] Government of Western Australia (2020) Distributed Energy Resources Roadmap. Energy Transformation Taskforce, Government of Western Australia.

[397] CEC (2020) WA leads with neighbourly solar energy plan. Media Release, 04 April 2020, Clean Energy Council.

‘community power banks’) is similar to the option proposed in this thesis, as opposed to other states in Australia who are supporting behind-the-meter customer-owned options such as residential battery rebates in Victoria and South Australia.

More specifically on embedded electricity networks, in early 2020, another industrial precinct owner in Perth reached out to the SBEnrc in order to learn more about the research undertaken with the Perth Airport as well as to enquire about the findings of this PhD research, and expressed interest in introducing cost-effective long-term onsite solar energy generation on its embedded network.

As government and industry sectors seek to reduce energy costs, secure revenues from energy distribution, and reduce associated pollution, this thesis provides highlights of an approach that could support such a transition to onsite solar energy generation and storage. Indeed, by participating in a localised contextual study, the research expanded beyond the current body of knowledge to analyse issues and barriers involved in such a transition. As such, the research proposes an approach that would be relevant to embedded network operators and precinct owners globally.

The originality of this research, besides the case study of the Perth Airport Industrial Precinct and the proposed Industrial Village Energy Approach, is the consideration of a large number of archetype models for the introduction of solar energy on a network. Previous research like the one conducted by Huijben and Verbong (2013)[398] mentioned in Chapter 3 have explored a portion of these archetypes (ownership models, centralised or distributed) but the candidate did not find a study that would cover the 6 archetypes covered in this thesis.

[398] Huijben, J. C., and Verbong, G. P. (2013) Breakthrough without subsidies? PV business model experiments in the Netherlands. *Energy Policy*, *56*, 362-370.

7.1.2 Research findings

This thesis was undertaken to inform a response to the primary research question, '*How can an industrial precinct, fitted with an embedded electricity network, transition to cost-effective long-term onsite solar energy generation?*'. The literature review investigated the history of electricity, the birth and establishment of electric utilities, cost recovery theory, and ratemaking process, in order to develop an understanding of how to make the business model of electric utilities less vulnerable to disruption. Recent disruptions to the energy sector and associated systems have come from customers seeking to consume less energy (change in trend in demand growth) and become actors in the production of their energy with rooftop solar systems. As a consequence, customers are effectively inverting the flow of energy and revenue. Therefore, the traditional model used for public utilities to introduce solar on the network, namely the "distributed customer-owned solar and no battery" archetype, is not capable of providing a balance of interests as part of a cost-effective long-term transition to solar energy.

After coming to this conclusion, the research to inform this thesis investigated other mainstream models used to introduce solar energy on the public electricity grid with a focus on identifying options suited to embedded electricity networks of commercial and industrial precincts. The models investigated revealed a number of emerging issues and barriers to be addressed rather than presenting a viable alternative model, which led to the conclusion that a model capable of supporting a cost-effective and long-term transition to solar energy suited to the conditions on a commercial industrial precincts had not been developed in the literature.

At this point, the list of issues and barriers gathered from the investigation of existing models and theories highlighted a set of key knowledge gaps, namely:

1. "How to protect the revenue of the embedded network when behind-the-meter solar systems reducing the sale of energy are introduced?"

2. "How to help the embedded network operator optimise the distribution network and best manage the quality of the energy supply on the EEN, particularly with the introduction of high penetration of variable generation?"

3. “How to make customers installing solar responsible and accountable for the pressure their solar system would put on the network?”

4. “How to avoid inequity of access to solar among customers while penetration increases?”

5. “How to ensure a balance of interests between the embedded network operator and the customers, and the corresponding customer engagement?”

These gaps then formed the criteria for the design of a new model that could successfully support a cost-effective long-term transition to solar energy on commercial and industrial precincts with embedded electricity networks. Furthermore, based on the findings of the literature review it was identified that an energy storage solution may be needed to support such a transition. Further research led to the conclusion that ‘smoothing’ the variability of rooftop solar electricity generation was the most critical function required from energy storage, with Lithium-Ion technology likely to be the most flexible and best fit for purpose technology. Following the modelling of a set of scenarios it was then concluded that a shared network-scale Battery Energy Storage System (BESS) that was financed by customers who installed rooftop solar and controlled by the embedded network operator for the greater good of the precinct was the option that made most business sense, contributing to filling Gaps 2 and 4.

After coming to these conclusions, the literature was reviewed in order to find innovative solutions, both from the electricity sector and other sectors, that stood to address the knowledge gaps. Based on the findings and on the outcomes of the Perth Airport Industrial Precinct case study, the following recommendations are made.

New roles for the network operator

The embedded network operator should take new roles and offer new network services which add value to customers while creating new ongoing revenue streams. Considering solar energy does not require a fuel but is a variable form of generation, the transition to solar energy is likely to reduce the cost of electricity on the one hand, while increasing the need for stability control on the network on the other.

In addition, energy retail competition is — or would be once introduced — a pressure on the energy retail business of an embedded network operator, whereas owning the embedded distribution infrastructure ensures a monopoly over network services. Therefore, the embedded network operator should adopt a strategy that relies less on energy retail and increasingly more on the development of new network services and related revenues streams, such as services based on the Product-Service Theory as discussed in the thesis. This solution to reinforce the position of the embedded network operator around its core asset and develop new network services will contribute to filling Gap 1.

Redesign of Network Charge

Network charges on commercial and industrial precinct embedded electricity networks should be re-designed based on the principle of cost-causality in order to reflect the positive and negative impacts on costs experienced by each user on the network. This solution would have the intention to make customers accountable for the pressure they apply on the embedded electricity network by their solar system, and help them select the appropriate behind-the-meter energy solution that supports – or at least has a lessor impact on – the network and other users.

These network tariffs would also reward customers who make an effort to adapt their consumption behaviour to relieve pressure on the network, such as reducing load during times of peak demand across the precinct. At the precinct scale, the redesign of network charges would increase the utilisation rate of the embedded electricity network. This would help the embedded network operator to optimise the use of the network and, in the long term, defer and reduce capital and operational expenditures related to network augmentation and operation. Underpinned by an appropriate governance structure (see below) such efforts from the community of network users would also seek to reduce network costs, with part of the savings passed on to customer bills over the longer term. This solution to re-design the network charges will contribute to filling Gaps 2 and 3.

New methods of customer engagement

The embedded network operator should engage with customers in new ways. For most of the twentieth century, energy customers have been passive end-users caring only for "*the light to turn on when they flipped the switch*" and electric utilities had little to no engagement with customers. This situation has been changing slowly in the last few decades with customers first becoming aware of the environmental impact of electricity generation and developing an appetite to make a difference by seeking to reduce energy consumption through energy efficiency improvements and demand management.

The situation then evolved with consumers seeking to have a choice in the source of energy and to become prosumers by installing rooftop solar systems, largely on residential homes. Hence the necessity to engage with customers has been a growing requirement, especially for distribution service providers (the core role of embedded network operators). Indeed, customer relations has typically been the role of the retailer who sends the bills and collects payments for services provided along the supply chain (Retailer, Distribution, Transmission, Generators and Market Operator). Hence for a successful transition to solar energy to occur the embedded network operator must collaborate in new ways with its network users.

Accordingly, embedded network operators need to learn and develop skills to engage more with the network users. This recommendation to engage more with network users to collaborate and share risks and rewards in the transition to solar energy will contribute to filling Gap 5 primarily along with Gaps 2 and 3.

***

Collectively, the findings of the research helped to develop a new approach that stands to successfully support a cost-effective transition to solar energy on commercial and industrial precincts with embedded electricity networks. It is noted that little guidance and lessons learned were found in the literature relating to commercial and industrial precincts that had transitioned to solar - presenting the opportunity for an original contribute to the academic field. Key to informing the development of an appropriate approach in this thesis was to compliment the research findings by developing a new demand driven research case study to test some of the proposed hypotheses about industry precinct business models drawn from the literature and created by the researcher. As a result the conclusion of the thesis is that the ‘customer-owned (distributed) solar and shared (centralised) battery storage’ archetype was the most appropriate option to offer mutual benefits for both the embedded network operator and customers, along with providing benefits to the precinct property business.

In addition, the thesis concludes that the application of the above recommendations requires the relationship between the embedded network operator and customers to be organised using new governance structures. The proposed governance structure was inspired by models typical of 'villages' where resources are shared by members of the village, and the village is governed by a Mayor who makes decisions for the greater good of the village through consultation. This structure was adapted by considering a commercial and industrial precinct as effectively being a 'village', with energy customers being members of the village, the energy supply being the shared resource, and the embedded network operator acting as both the village Mayor and public works department. This proposed governance model will contribute to filling Gaps 4 and 5.

The recommendations and structures mentioned above form an original contribution to the academic research through the development of the ‘*Industrial Village Energy Approach’* which is the proposed answer to the research question ‘*How can an industrial precinct, fitted with an embedded electricity network, transition to cost-effective long-term onsite solar energy generation?*’.

However, further research is necessary.

7.2 Further research

This thesis has presented an 'Industrial Village Energy Approach' with three elements that can be used to develop strategies and business plans associated with the transition to increased onsite energy generation on commercial and industrial precincts. In addition to research into the practical implications of applying the elements and how to improve their implementation, further research could be done to build upon the findings and explore application of the proposed approach to other applications within commercial and industrial precincts, such as a 'Industrial Village Water Approach', or an 'Industrial Village Telecommunications Approach'.

7.2.1 Further investigation of implementation considerations

One of the key contributions of this thesis is the energy modelling and financial simulations undertaken as part of the case study of the Perth Airport Industrial Precinct that suggested the ‘customer-owned (distributed) solar and shared (centralised) battery system’ was the most appropriate model for both the customers and the embedded network operator. However, before selecting this option it is recommended to undertake further research into the implementation of associated governance and tariff structures to verify mutual benefits are achievable for both for the embedded network operator and the customers.

Similarly, the set of modelling and financial simulations realised would give better insights on the implementation of the approach if they could be complemented with more scenarios. For example, the consideration of a wider use of the shared battery, looking into the benefits for the embedded network operator (as additional network services) and the energy customers (as cost saving opportunities) of peak shaving and load shifting uses. Another example is the consideration of how electric vehicles likely to be plugged on the embedded network in the near future could integrate the 'Industrial Village Energy Approach' and be managed so it respects the principle of the balance of interest to the balance of interest. These complementary studies would explore scenarios of charging times and intensity, punctual and on-demand discharging into the embedded network (Vehicle to Grid), and the related tariff and business models that would fit into the 'Industrial Village Energy Approach' and support the balance of interest.

Further, the thesis argues that the proposed approach would make the precinct attractive to premium tenants and support the property business by guiding a cost-effective long-term transition to onsite solar energy generation. However, this was not tested, so an areas of future study could be to explore and verify the co-benefits of the approach for the property business of the precinct operator.

7.2.2 Application to other forms of embedded electricity networks

This thesis focused on commercial and industrial precincts fitted with an embedded electricity network and further research could be carried out to investigate the application and benefits of the approach to the following types of embedded networks:

- Other less industrial non-residential precincts such as university campuses, technology parks and shopping centres.
- Residential precincts fitted with an embedded electricity network, such as retirement villages and eco-villages.

7.2.3 Implications for the public grid

Building on the findings in the thesis further research could be undertaken to investigate how the proposed approach could inform public utilities on ways to integrate the growing number of customer-owned rooftop solar systems and new options to engage with energy customers better.

7.2.4 Application to other utilities

Another extension of this research could be the adaptation and application of the proposed approach to other utilities such as the water utility, particularly in areas where water resources are limited, where it could be a cost-effective and long-term solution for customers to invest in "behind the meter" rainwater tanks to cover part of their need, and even feed their excess rain water into the network when needed.

Chapter 9: Bibliography

ACCC (2017) Retail Electricity Pricing Inquiry Report – Preliminary Report. Australian Competition and Consumer Commission, Fig. 2.1 p32.

ALC (2019) Quote from Australia Post General manager of road and air networks James Dixon at the 2019 ALC forum. Australian Logistics Council.

ALC (2020) Australian Logistics Council – Electric Vehicles Working Group -About us. Australian Logistics Council.

Adams, W. (2006) The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006.

AEC (2016) Reforms to Reserve Capacity Mechanism: WA seeks to get the balance right. Australian Energy Council.

AEEI (2018) Utility earnings in a service-oriented world. San Francisco, CA: Advanced Energy Economy Institute.

AEMC (2008) National Electricity (Economic Regulation of Distribution Services) - Amendment Rules 2007. Australian Electricity Market Commission, Sydney.

AEMC (2012) Power of Choice Review - giving Consumers Options in the Way They Use Electricity. Australian Electricity Market Commission, Sydney.

AEMC (2017) Reliability Frameworks Review, Interim Report, 19 December 2017, Sydney. Australian Energy Market Commission.

AEMC (2019) Updating Regulatory Frameworks for Embedded Networks - Final Report Australian Energy Market Commission 20 June 2019.

AEMO (2017) Power of Choice. Guide to Embedded Networks. Australian Energy Market Operator.

AER (2014) Overview of the Better Regulation reform package. Australian Energy Regulator.

AER (2016) Retail Exempt Selling Guideline. Version 5, March 2018. Australian Energy Regulator. Annexe A-2 Condition 7 p37.

AER (2019) Annual electricity consumption - NEM, dataset. Australian Energy Regulator.

AER (2020) Electricity distribution and retail exemption awarded to APN Funds Management Limited for Brisbane Technology Park. Australian Energy Regulator.

AEVC (2019) State of Electric Vehicles. Australian Electric Vehicle Council.

AFR (2018) Car fleets are big business in Australia, Australian Financial Review.

AGL (2015a) AGL is First Major Retailer to Launch Battery Storage. AGL.

AGL (2015b) Help build a battery-powered future. AGL.

Agrawal, V., Toktay, L. B., & Yücel, Ş. (2019). Non-Ownership Business Models for Solar Energy. *Georgetown McDonough School of Business Research Paper*, (3375372), 19-08.

Akbari, H., Browne, M. C., Ortega, A., Huang, M. J., Hewitt, N. J., Norton, B., and McCormack, S. J. (2018) Efficient energy storage technologies for photovoltaic systems. Solar Energy, *192*, 144-168.

Alasadi, S. and Abdullah, M. (2018) Comparative Analysis between Net and Gross Metering for Residential PV System. In 2018 IEEE 7th International Conference on Power and Energy (PECon) (pp. 434-439). IEEE.

Alt, L. (2006) Energy utility Rate Setting, Lulu.com.

Andrews, K. (1971) The Concept of Corporate Strategy, Irwin, Homewood, IL.

Aneke, M., and Wang, M. (2016) Energy storage technologies and real life applications–A state of the art review. Applied Energy, 179, 350-377.

Apostolopoulou, D., Bahramirad, S., and Khodaei, A. (2016) The interface of power: Moving toward distribution system operators. IEEE Power and Energy Magazine, 14(3), 46-51.

Arnett, J., Schaffer, L., Rumberg, J., and Tolbert, R. (1984) Design, installation and performance of the ARCO Solar one-megawatt power plant. Proceedings of the Fifth International Conference, Athens, Greece. EC Photovoltaic Solar Energy Conference: 314.

ATA (2018) Sharing the Load: Understanding Consumer Outcomes of Network Tariff Reform. Tariffs Project II prepared for Energy Consumers Australia, Alternative Technology Association.

Ausgrid (2018) Network Innovation Capex Program Cost Benefit Analysis Summary. Ausgrid.

Austin Energy (2019) Value of Solar rate, Austin Energy.

Averch, H. and Johnson, L. (1962) Behavior of the Firm Under Regulatory Constraint. The American Economic Review, 52(5): pp. 1052-1069.

Bade, G. (2016) REV in 2016: The year that could transform utility business models in New York. UtilityDive.com.

Barraco, J. (2013) Distributed Energy and Net Metering: Adopting Rules to Promote a Bright Future. J. Land Use & Envtl. L., 29, 365.

Beaufils, T., and Pineau, P. O. (2018) Structures tarifaires et spirale de la mort: État des lieux des pratiques de tarification dans la distribution d'électricité résidentielle. CIRANO, Centre interuniversitaire de recherche en analyse des organisations.

Bell, K., and Gill, S. (2018) Delivering a highly distributed electricity system: Technical, regulatory and policy challenges. Energy policy, 113, 765-777.

Bell, W. P., and Foster, J. (2017) Using solar PV feed-in tariff policy history to inform a sustainable flexible pricing regime to enhance the diffusion of energy storage and electric vehicles. Journal of Bioeconomics, 19(1), 127-145.

BITRE (2019) Electric Vehicle Uptake: Modelling a Global Phenomenon. Report 151. Department of Infrastructure, Transport, Cities and Regional Development, Bureau of Infrastructure, Transport and Regional Economics, Australian Government.

Blansfield, J. and Jones, K. (2014) Industry Response to Revenue Erosion from Solar PVs (Chapt 14). Distributed generation and its implications for the utility industry. Academic Press. Edited by Sioshansi, F. P.

Blansfield, J., Wood, L., Katofsky, R., Stafford, B., Waggoner, D., and Schwartz, L. (2017) Value-Added Electricity Services: New Roles for utilities and Third-Party Providers. Lawrence Berkeley National Laboratories.

Bloomberg NEF (2018) Ninth Battery Price Survey. Bloomberg.

Bocken, N. M., Short, S. W., Rana, P., and Evans, S. (2014) A literature and practice review to develop sustainable business model archetypes. Journal of cleaner production, 65, 42-56.

Bolduc, P., Lehmicke, D., and Smith, J. (1993) Performance of a grid-connected PV system with energy storage. In Conference Record of the Twenty Third IEEE Photovoltaic Specialists Conference-1993, pp. 1159-1162. IEEE.

Bonbright, J., Danielsen, A., and Kamerschen, D. (1961) Principles of public utility rates. New York: Columbia University Press.

Boscherini, L., Chiaroni, D., and Frattini, F. (2011) Escaping the incumbent's curse: the adoption of renewable energies in Italy. In The XXII ISPIM Conference."Sustainability in Innovation: Innovation Management Challenges" (pp. 1-22).

Brady, F. (1996). Contribution on Australia: A dictionary on electricity. In *international conference on large high voltage electrical systems. Australia National Committee of CIGRE*.

Breadsell, J., Byrne, J., and Morrison, G. (2019) Household energy and water practices change post-occupancy in an Australian low-carbon development. Sustainability, 11(20), 5559.

Brown, D. P. and Sappington, D. (2017) Designing compensation for distributed solar generation: Is net metering ever optimal. Energy Journal, 38(3), 1-32.

Brown, M. A., Staver, B., Smith, A. M., and Sibley, J. (2014) Business Models for utilities of the Future: Emerging Trends in the Southeast. School of Public Policy, Georgia Institute of Technology.

Burger, S. P., and Luke, M. (2017) Business models for distributed energy resources: A review and empirical analysis. Energy Policy, 109, 230-248.

Business & Technology Precincts (2020) BTP - Brisbane Technology Park, Business & Technology Precincts.

Byrne, M. and Parmenter, L. (2018) Cross about subsidies: the equity implications of rooftop solar in Australia. Renew & Total Environment Centre.

Castaignede, L. (2018) “Airvore ou la face obscure des transports” Ecosociete, Montreal, Canada.

Castillo-Cagigal, M., Caamano-Martín, E., Matallanas, E., Masa-Bote, D., Gutiérrez, A., Monasterio-Huelin, F., and Jiménez-Leube, J. (2011) PV self-consumption optimization with storage and Active DSM for the residential sector. Solar Energy, 85(9), 2338-2348.

Catney, P., MacGregor, S., Dobson, A., Hall, S., Royston, S., Robinson, Z., and Ross, S. (2014) Big society, little justice? Community renewable energy and the politics of localism. Local Environment, 19(7), 715-730.

CEC (2020) WA leads with neighbourly solar energy plan. Media Release, 04 April 2020, Clean Energy Council.

Chen, H., Cong, T., Yang, W., Tan, T., Lia, Y., and Dinga, Y. (2009) Progress in electrical energy storage system: a critical review. Prog Nat Sci 19(3): 291–312.

Collins, L. and Ward, J. (2015) Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity. Renewable Energy, 81, 464-471.

Comello, S. and Reichelstein, S. (2017) Cost competitiveness of residential solar PV: The impact of net metering restrictions. Renewable and Sustainable Energy Reviews, 75, 46-57.

Cossent, R. and Gomez, T. (2013) Implementing incentive compatible menus of contracts to regulate electricity distribution investments. utilities Policy, 27, 28–38.

Cross-Call, D., Gold R., Goldenberg C., Guccione L., and O'Boyle M. (2018) Navigating utility Business Model Reform: A Practical Guide to Regulatory Design. Rocky Mountain Institute, Snowmass, Colorado.

Cross-Call, D., Gold, R., Guccione, L., Henchen, M., and Lacy, V. (2018) Reimagining the Utility: Evolving the Functions and Business Model of utilities to Achieve a Low-Carbon Grid. Rocky Mountain Institute.

Crouch, M. (2006) Investment under RPI-X: practical experience with an incentive compatible approach in the GB electricity distribution sector. Utilities Politics. 14(4), 240.

Crown Uniform (2019) Uniforms and Apparel – The Crown process, Crown Uniform.

CSIRO (2011) Climate Change. Science and Solutions for Australia. CSIRO Science and Solutions for Australia Series, CSIRO (eBook).

Dakin, M. (1963) Review of Principles of Public utility Rates. Journal of Legal Education. Vol. 15, No. 3 (1963), pp. 358-362

Daly, P. A., and Morrison, J. (2001) Understanding the potential benefits of distributed generation on power delivery systems. In 2001 Rural Electric Power Conference. Papers Presented at the 45th Annual Conference (Cat. No. 01CH37214) (pp. A2-1). IEEE.

Darghouth, N., Barbose, G., and Mills, A. (2019) Implications of Rate Design for the Customer-Economics of Behind-the-Meter Storage. Lawrence Berkeley National Laboratory.

Darghouth, N., Barbose, G., and Wiser, R. (2011) The impact of rate design and net metering on the bill savings from distributed PV for residential customers in California. Energy Policy, 39(9), 5243-5253.

Darghouth, N., Barbose, G., Wiser, R. (2010) The Economic Value of PV and Net Metering to Residential Customers in California. Lawrence Berkeley National Laboratory. American Solar Energy Society (ASES) National Solar Conference, Phoenix, AZ, May 17-22, 2010. SOLAR 2010 Conference Proceedings.

Davidson, C., Steinberg, D., and Margolis, R. (2015) Exploring the market for third-party-owned residential photovoltaic systems: insights from lease and power-purchase agreement contract structures and costs in California. Environmental Research Letters, 10(2), 024006.

Davison, M., Summers T. and Townsend, C. (2017) A review of the distributed generation landscape, key limitations of traditional microgrid concept and possible solution using an enhanced microgrid architecture. IEEE Southern Power Electronics Conference (SPEC), Puerto Varas, pp. 1-6.

De Santillana, G. (1965) Alessandro Volta. Scientific American, 212(1), 82-91.

Denoyel, L. M. (2018) L'autoconsommation collective : perspectives réglementaires, sociétales et économiques : D’un système linéaire et centralisé à un système diffus et localement organisé : mutation du système électrique vers la décentralisation et la pluralisation des acteurs. ENPC - École des Ponts ParisTech

Department of Agriculture, Water and the Environment (2018a) Quarterly Update of Australia’s National Greenhouse Gas Inventory: Department of the Environment and Energy September 2018. pps 7,12.

Department of Industry, Science, Energy and Resources (2018b) National Greenhouse and Energy Reporting Technical Guidelines 2017-18. Australian Government.

Dijkgraaf, E., van Dorp, T. P., and Maasland, E. (2018) On the effectiveness of feed-in tariffs in the development of solar photovoltaics. The Energy Journal, 39(1).

Duan, C., Tao, H., Wang, C., Chen, J., Zhao, X., and Zhou, X. (2019) An Electric Vehicle Battery Modular Balancing System Based on Solar Energy Harvesting. In 2019 IEEE Transportation Electrification Conference and Expo (ITEC) pp. 1-7. IEEE.

Dufo-López, R., and Bernal-Agustín, J. (2015) Techno-economic analysis of grid-connected battery storage. Energy Conversion and Management, 91, 394-404.

Egan, R. (2018) National survey report of PV power applications in Australia. Australian PV Institute

ENA (2019) Rewarding Performance: How customers benefit from incentive-based regulation. Energy Networks Australia.

Enel (2018) Cities of tomorrow – Circular cities. Enel.

Enel X (2019) About Enel X brochure - Power flexibility. Enel.

Energy Storage Association (2020a) Technologies of Energy Storage. Energy Storage Association.

Energy Storage Association (2020b) Zinc-Bromine (Znbr) Flow Batteries Energy Storage Association.

Enwave (2020) Tonsley Innovation District. Enwave.

EPRI (1983) Utility Battery Operations and Application, EM-2946-SR. Electric Power Research Institute.

EPRI (1984) Battery Energy Storage Test Facility, EM-2995. Electric Power Research Institute.

EPRI (2014) The Integrated grid: Realizing the Full Value of Central and Distributed Energy Resources. Electric Power Research Institute.

EPRI (2015) The Integrated grid: A Benefit-Cost Framework. Palo Alto, CA, USA. Electric Power Research Institute.

Essential Services Commission of SA (2018) Enwave application form for the issue of an Electricity Generation Licence. Essential Services Commission of SA.

European Environment Agency (2019) Atmospheric greenhouse gas concentrations. European Environment Agency.

Fan, X., Liu, B., Liu, J., Ding, J., Han, X., Deng, Y., Lv, X., Xie, Y., Chen, B. and Hu, W. (2020) Battery Technologies for Grid-Level Large-Scale Electrical Energy Storage. Transaction of Tianjin University. 26, 92–103.

Faruqui, A. and Lessem, N. (2014) Comments on Massachusetts Department of Utilities Notice, DPU 14-04, Investigation by the Department of Public Utilities into its own motion on Time Vary Rates. Technical report, The Brattle Group.

FERC (2014) Price Formation in Energy and Ancillary Services Markets Operated by Regional Transmission Organizations and Independent System Operators, Federal Energy Regulatory Commission.

Finkel, A., Moses, K., & Munro, C. (2017) Independent review into the future security of the national electricity market: blueprint for the future [Finkel review].

Fisher, M., Apt, J., and Whitacre, J. F. (2019) Can flow batteries scale in the behind-the-meter commercial and industrial market? A techno-economic comparison of storage technologies in California. Journal of Power Sources, 420, 1-8.

Ford, A. (1997) System dynamics and the electric power industry, System Dynamics Review, The Journal of the System Dynamics Society, 13(1), 57-85.

Fox-Penner, P. (2014) Smart Power: Climate Change, the Smart Grid, and the Future of Electric utilities. Island Press.

Frame, D., Hannon, M., Bell, K., and McArthur, S. (2018) Innovation in regulated electricity distribution networks: A review of the effectiveness of Great Britain's Low Carbon Networks Fund. Energy Policy, 118, 121-132.

Frantzis, L., Graham, S., Katofsky, R., Sawyer, H., (2008) Photovoltaics Business Models. National Renewable Energy Laboratory, Burlington.

French Republic (2017) Order of May 9th, 2017 regarding buyback scheme for PV electricity- Arrêté du 9 mai 2017 fixant les conditions d'achat de l'électricité produite par les installations implantées sur bâtiment utilisant l'énergie solaire photovoltaïque. Republique Francaise.

Garnett, S., Wintle, B., Lindenmayer, D., Woinarski, J., Maron, M. and Legge, S. (2020) Conservation scientists are grieving after the bushfires – but we must not give up. The Conversation.

Gemenergy (2020) Rcent projects, Brisbane technology park solar. Gemenergy.

Georgilakis, P. (2008) Technical challenges associated with the integration of wind power into power systems. Renewable and Sustainable Energy Reviews, 12(3), 852-863.

Glover, D., Overbye T. and Sarma, M. (2016) Power System Analysis & Design. 6th ed., Cengage Learning, Inc., Mason, OH, United States.

Goedkoop M., van Halen C., te Riele H., Rommens, P. (1999) Product service systems, ecological and economic basis. PriceWaterhouseCoopers N.V. / Pi!MC, Storrm C.S. and Pre consultants.

Gold, R., Guccione, L. and Henchen, M. (2017) Customer-Centric Energy System Transformation: A Case Study of the Opportunity with Green Mountain Power. Rocky Mountain Institute, Colorado.

Gormley Jr, W. (1983) The politics of public utility regulation, University of Pittsburgh Press.

Government of Western Australia (2019) Ground-breaking microgrid to power jobs in the Peel. Media statements.

Government of Western Australia (2019) Response to Position Paper on Reforms to the Reserve Capacity Mechanism. Government of Western Australia.

Government of Western Australia (2019) The Energy Transformation Taskforce. Government of Western Australia.

Government of Western Australia (2020) Distributed Energy Resources Roadmap. Energy Transformation Taskforce, Government of Western Australia.

Government of Western Australia, Department of Finance (2016) Final Report: Reforms to the Reserve Capacity Mechanism, 7 April 2016, p.3

Grace, W. (2014) Exploring the death spiral – a system dynamics model of the south west interconnected system. Australian: Urban Design Research Centre (AUDRC).

Graham, P. and Brinsmead, T. (2017) Minimising customer bill increases in a decarbonising and decentralising electricity system. CSIRO at IAEE Conference Singapore.

Green, J. and Newman, P. (2017) Citizen Utilities: The Emerging Power Paradigm, Energy Policy, 105: 283-293 .

Gui, E. M., and MacGill, I. (2018) Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. Energy Research & Social Science, 35, 94-107.

Hamwi, M., and Lizarralde, I. (2017) A review of business models towards service-oriented electricity systems. Procedia CIRP, 64, 109-114.

Hargadon, A., and Douglas, Y. (2001) When innovations meet institutions: Edison and the design of the electric light. Administrative Science Quarterly, 46(3), 476-501.

Harper-Slaboszewicz, P., McGregor, T., and Sunderhauf, S. (2012) Customer View of Smart Grid—Set and Forget? In Smart Grid (pp. 371-395): Elsevier.

Hausman W., Hertner P., and Wilkins M. (2008) Global Electrification: Multinational Enterprise and International Finance in the History of the Light and Power 1878-2007. New York, NY, USA. Cambridge University Press.

Hebert, L., Hayes, R., and Hargroves, K. (2016) Current State Assessment of Other Airports Around the World Installing Solar, Overview of the Situation of the Perth Airport Embedded Electricity Network and its Regulatory Context, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Hebert, L., Hayes, R., and Hargroves, K. (2017) Review of Onsite Energy Options and Study of the Energy Demand on the Perth Airport Industrial Precinct, Sustainable Built Environment National Research Centre (SBEnrc), Australia.

Helm T. (2016) Asset transformation and the challenges to servitize a utility business model. Energy Policy 91:98–112.

Herz, O. (2012) Tarificatoin des reseaux – TURPE 4. Salon clients. RTE.

Hess, D. (2016) The politics of niche-regime conflicts: distributed solar energy in the United States. Environmental Innovation and Societal Transitions, 19, 42-50.

Hess, D. (2018) Energy democracy and social movements: A multi-coalition perspective on the politics of sustainability transitions. Energy research & social science, 40, 177-189.

Higginson, E. (2019) Woolworths take the lead towards a greener future. Power Torque Magazine.

Hill, J. and Whitfled, A. (2015) The Big Disconnect. Background Briefing – ABC Radio National.

Hill, T. and Westbrook, R. (1997) SWOT analysis: it's time for a product recall. Long range planning, 30(1), 46-52.

Horizon Power (2019) Solar technical requirements. Horizon Power.

Huijben, J. C., and Verbong, G. P. (2013) Breakthrough without subsidies? PV business model experiments in the Netherlands. Energy Policy, 56, 362-370.

Trebing, H. M. (1985). America's Electric Utilities: Past, Present, and Future. *The Energy Journal*, *6*(3).

Ibrahim, H., Beguenane, R., and Merabet, A. (2012) Technical and financial benefits of electrical energy storage. In 2012 IEEE Electrical Power and Energy Conference (pp. 86-91). IEEE.

Ilieva, I., and Rajasekharan, J. (2018) Energy storage as a trigger for business model innovation in the energy sector. In 2018 IEEE International Energy Conference (ENERGYCON)(pp. 1-6). IEEE.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p 151.

IPCC (2018) Global warming of 1.5°C. [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Intergovernmental Panel on Climate Change.

Jha, I. S., Sen, S., Tiwari, M., and Singh, M. K. (2014) Control strategy for Frequency Regulation using Battery Energy Storage with optimal utilization. In 2014 IEEE 6th India International Conference on Power Electronics (IICPE) (pp. 1-4). IEEE.

Jia, J. and Crabtree, J. (2015) Driven by Demand: How energy gets its power. Cambridge: Cambridge University Press.

Jones, D., Braganza, K., and Tobin, S. (2020) Weather bureau says hottest, driest year on record led to extreme bushfire season, The Conversation.

Jung, K. H., Kim, H., and Rho, D. (1996) Determination of the installation site and optimal capacity of the battery energy storage system for load leveling. IEEE Transactions on Energy Conversion, 11(1), 162-167.

Kenneddy, T. (2020) We Could All Be Flying in Electric Planes Sooner Than You Think. Vice.

Kundur, P., Balu, N., and Lauby, M. (1994) Power system stability and control (Vol. 7). New York: McGraw-Hill.

Lachs, W. R., and Sutanto, D. (1995) Application of battery energy storage in power systems. In Proceedings of 1995 International Conference on Power Electronics and Drive Systems. PEDS 95 (pp. 700-705). IEEE.

Lande, J. (1994) Telecommunications Industry Revenue: TRS Fund Worksheet Data. Federal Communications Commission; March 1994; Radiant Insights, Inc. (2016) U.S. Telecom Market Size to Reach $1.3 Trillion by 2020, Radiant Insights, Inc. March 30, 2016.

Langel, C. (2004) Energy as a Service. Published in BWK: das Energie-Fachmagazin 56(3):9-9. Springer-VDI Verlag, Dusseldorf.

Lazar, J. and Gonzalez, W. (2015) Smart Rate Design for a Smart Future. Montpelier, VT: Regulatory Assistance Project.

Lazard (2016) Lazard’s Levelized Cost of Energy Analysis – Version 10.0. Table 1: Unsubsidized Levelized Cost of Energy Comparison, Lazard.

Lehr, R. (2013) New Utility Business Models: Utility and Regulatory Models for the Modern Era, The Electricity Journal, 26 (8), 35-53.

Li, X., Hui, D., and Lai, X. (2013) Battery energy storage station (BESS)-based smoothing control of photovoltaic (PV) and wind power generation fluctuations. IEEE transactions on sustainable energy, 4(2), 464-473.

Liao, Q., Sun, B., Liu, Y., Sun, J., and Zhou, G. (2016) A techno-economic analysis on NaS battery energy storage system supporting peak shaving. International Journal of Energy Research, 40(2), 241-247.

Lienhart, J. B. (2018) Les impacts de l'autoconsommation d'électricité photovoltaïque sur les coûts de développement et d'exploitation du réseau. ENPC - École des Ponts ParisTech.

Lopes, J. P., Hatziargyriou, N., Mutale, J., Djapic, P., and Jenkins, N. (2007) Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. Electric power systems research, 77(9), 1189-1203.

Lotspeich, C. (2002) A comparative assessment of flow battery technologies. In Proceedings of the electrical energy storage systems applications and technologies international conference (EESAT2002).

Mandel, J., Campbell, M., et al. (2014) Integrated Utility Services: A New Business Model for Fort Collins Utilities. Rocky Mountain Institute.

Manibog, F. (2004) Power for Development: A Review of the World Bank Group's Experience with Private Participation in the Electricity Sector, Washington, DC, World Bank.

McHenry, M. (2012) Are small-scale grid-connected photovoltaic systems a cost-effective policy for lowering electricity bills and reducing carbon emissions? A technical, economic, and carbon emission analysis. Energy Policy, 45, 64-72.

Meinel, A. and Meinel, M.(1977) Applied solar energy: an introduction. NASA STI/Recon Technical Report A, 77.

MISO (2019) Renewable Integration Impact Assessment – Third workshop, November 14th-15th, 2019. Midcontinent Independent System Operator.

Mitchell, C. (2016a) Transformational Regulation – comparing the NY REV and RIIO. iGov Team, University of Exeter.

Mitchell, C. (2016b) DSP slidepack - Updated Dec. 2017. iGov Advisory Group, University of Exeter.

Mitchell, C. (2017) Bringing It Together. iGov Advisory Group, University of Exeter.

Mont, O. K. (2002) Clarifying the concept of product–service system. Journal of Cleaner Production, 10(3), 237-245.

Moran, C. and Ball, C. (2018) Structuring Better Caps for Sustainability Incentive Programs. Idaho Law Review. 54: 177-211.

Moreno-Munoz, A., Bellido-Outeirino, F., Siano, P., and Gomez-Nieto, M. (2016) Mobile social media for smart grids customer engagement: Emerging trends and challenges. Renewable and Sustainable Energy Reviews, 53, 1611-1616.

Motlagh, O., Grozev, G., and Foliente, G. (2015) Impacts of feed-in tariff and metering types on electricity consumption efficiency in Australia. In 21st International Congress on Modelling and Simulation, Gold Coast, Australia.

Mountain, B. (2019) Ownership, regulation, and financial disparity: The case of electricity distribution in Australia. Utilities Policy, 60, 100938.

Newcomb, J., Lacy, V., and Hansen, L. (2013) New Business Models for the Distribution Edge. Rocky Mountain Institute.

Newman, P, Beatley T and Boyer H (2017) Resilient Cities: Overcoming Fossil Fuel Dependence, Island Press, Washington DC.

Newton, P. and Newman, P. (2015) Critical Connections: The Role of the Built Environment Sector in Delivering Green Cities and the Green Economy, Sustainability, 7, 9417-9443.

Nicholson, W. and Snyder, C. (2012) Microeconomic Theory: Basic Principles and Extensions (11 ed.). Mason, OH: South-Western. pp. 27-154.

Nitta, N., Wu, F., Lee, J. T., and Yushin, G. (2015) Li-ion battery materials: present and future. Materials today, 18(5), 252-264.

NOAA (2018) Trend in Atmospheric Carbon Dioxide, dataset. National Oceanic and Atmospheric Administration (USA).

Norwell, I. (2014) Case Review: Michelin. Transport Engineer Magazine, Institute of Road Transport Engineers, UK.

Oakley Greenwood (2018) Gas Price Trends Review 2017, Commonwealth of Australia 2017.

O'Connell, A., Maitra, A., Smith, J., Jordan, B., and Cryer, C. (2017) Integrating photovoltaic and storage systems on distribution feeders. CIRED-Open Access Proceedings Journal, 2017(1), 1831-1835.

Ofgem (2010) RIIO - a new way to regulate energy networks. Facts Sheet 93. Office of Gas and Electricity Markets (UK).

Ofgem, (2010) RIIO - a new way to regulate energy networks. Office of Gas and Electricity Markets (UK)

Ortega, M. P. R., Pérez-Arriaga, J. I., Abbad, J. R., and González, J. P. (2008) Distribution network tariffs: A closed question?. Energy Policy, 36(5), 1712-1725.

Overholm, H. (2015) Spreading the rooftop revolution: What policies enable solar-as-a-service?. Energy Policy, 84, 69-79.

Parkinson, G. (2015a) AGL Energy becomes first big retailer to roll out solar PPA plan. In: Parkinson, G. (Ed.), RenewEconomy.

Parkinson, G. (2015b) AGL offering 7.2kWh battery storage at under $10,000 In: Parkinson, G. (Ed.), RenewEconomy.

Parkinson, G. (2018) AGL switches to Tesla and LG Chem for virtual power plant In: Parkinson, G. (Ed.), RenewEconomy.

Parliament of Victoria (2018) Inquiry into electric vehicles. Legislative Council, Economy and Infrastructure Committee.

Parliament of Western Australia (2019) Implications of a distributed energy future. Parliament of Western Australia, Legislative Assembly, Economics and Industry Standing Committee. Report 5.

Parra, D., Norman, S. A., Walker, G. S., and Gillott, M. (2017) Optimum community energy storage for renewable energy and demand load management. Applied Energy, 200, 358-369.

Patel, P. (2019) First Passenger Electric Aircraft to Take Off Soon. Spectrum IEEE, Institute of Electrical and Electronics Engineers.

Pears, A. (2018) Risky Business? ReNew magazine #149.

Pérez-Arriaga, I. and Bharatkumar, A. (2014) A framework for redesigning distribution network use of system charges under high penetration of distributed energy resources: New principles for new problems. MIT Center for Energy and Environmental Policy Research.

Perth Airport (2018) Annual report 2017-18. Perth Airport Pty Ltd.

Perth Airport (2020) Home – Property. Perth Airport Pty Ltd.

Petersen, J. (2016) Energy concepts for self-supplying communities based on local and renewable energy sources: A case study from northern Germany. Sustainable Cities and Society, 26, 1-8.

Phillips, Jr., C. (1993) The Regulation of Public utilities: Theory and Practice (3rd ed.) Public Utilities Reports, INC., Arlington Va. USA.

Phung T., Riu I., Kaufman N., Kessler L., Amodio M., and De Silva G. (2017) The Effect of Austin Energy's Value -of- Solar -Tariff on Solar Installation Rates. Berkeley Lab Electricity Markets and Policy Group (EMP).

Pollitt, M. G., and Bialek, J. (2007) Electricity Network Investment and Regulation for a Low Carbon Future. University of Cambridge.

Poulios, V., Vrettos, E., Kienzle, F., Kaffe, E., Luternauer, H., and Andersson, G. (2015) Optimal placement and sizing of battery storage to increase the PV hosting capacity of low voltage grids. In International ETG Congress 2015; Die Energiewende-Blueprints for the new energy age (pp. 1-8). VDE.

Poullikkas, A., Kourtis, G., and Hadjipaschalis, I. (2013) A review of net metering mechanism for electricity renewable energy sources. International Journal of Energy & Environment, 4(6).

Prehoda, E., Winkler, R., and Schelly, C. (2019) Putting research to action: Integrating collaborative governance and community-engaged research for community solar. Social Sciences, 8(1), 11.

Qian, H., Zhang, J., Lai, J. S., and Yu, W. (2010) A high-efficiency grid-tie battery energy storage system. IEEE transactions on power electronics, 26(3), 886-896.

Rábago, K. (2013) The 'Value Of Solar' Rate: Designing An Improved Residential Solar Tariff. Solar Industry. February 2013.

Ranamuka, D., Agalgaonkar, A., Muttaqi, K., and Alam, M. (2015) Mitigating Tap Changer Limit Cycles in Modern Electricity Networks Embedded With Local Generation Units, IEEE Transactions on Industry Applications, 52(1), 455-465.

Randazzo, R. (2014) AZCentral News.

Ratinen M., Lund P.D. (2014) Growth strategies of incumbent utilities as contextually embedded: Examples from Denmark, Germany, Finland and Spain, Technology in Society 38 (2014) 81–92.

Rauter R., Jonker J., and Baumgartner R. (2017) Going one's own way: drivers in developing business models for sustainability, Journal of Cleaner Production, 140, Part 1, P144-154

Read, P. and Denniss, R. (2020) With costs approaching $100 billion, the fires are Australia’s costliest natural disaster. The Conversation.

Read, S., Song, M., Smit, W., (2009) A meta-analytic review of effectuation and venture performance. Journal of Business Venture. 24(6),573–587.

Renault C., Dalsace F. and Ulaga, W. (2010) Michelin Fleet Solutions: From selling tires to selling kilometers. HEC Paris, Case Study no. 510-103-1

Renewal SA (2020a) Tonsley Project. Renewalsa.

Renewal SA (2020b) Renewable solar energy Tonsley tenants. Renewalsa.

Ritchie, H. and Roser, M. (2017) CO_2 and Greenhouse Gas Emissions. OurWorldInData.org.

Roberts, D. (2015) New York's revolutionary plan to remake its power utilities. Vox.com.

Rochlin, C. (2016) Distributed renewable resources and the utility business model. Electricity Journal, 29(1), 7-12.

Roman, J.,Gomez, T.,Munoz, A., and Peco, J. (1999) Regulation of distribution network business. IEEE Transactions on Power Delivery, 14(2), 662–669.

Rowe, W., Dickel, D., Mann, R., Mockler; R. (1994) "Strategic Management: a methodological approach". 4th Edition. Addison-Wesley. Reading, Massachusset USA.

Ruester, S., Schwenen, S., Batlle, C., and Pérez-Arriaga, I. (2014) From distribution networks to smart distribution systems: Rethinking the regulation of European electricity DSOs. Utilities Policy, 31, 229-237.

Rule, T. A. (2015) Unnatural Monopolies: Why utilities Don't Belong in Rooftop Solar Markets. Idaho Law Review.

SAPN (2020) 2020-2025 draft plan. South Australia Power Networks.

Sardi, J., Mithulananthan, N., Gallagher, M., and Hung, D. (2017) Multiple community energy storage planning in distribution networks using a cost-benefit analysis. Applied energy, 190, 453-463.

Sasmal, R. P., Sen, S., and Chakraborty, A. (2016) Solar photovoltaic output smoothing: Using battery energy storage system. In 2016 National Power Systems Conference (NPSC) (pp. 1-5). IEEE.

Schreiber, M., and Hochloff, P. (2013) Capacity-dependent tariffs and residential energy management for photovoltaic storage systems. In 2013 IEEE power and energy society general meeting (pp. 1-5). IEEE.

Sewchurran, S. and Davidson, I. (2016) Drivers and Application of Small Scale DG on Municipal Distribution Networks in South Africa. In Proceedings of the 24th South African Universities Power Engineering Conference, pp. 105-114.

Seyfang, G., Park, J., and Smith, A. (2013) A thousand flowers blooming? An examination of community energy in the UK, Energy Policy, 61, pp. 977–989.

Shang, B. (2019) Effects of Distributed Photovoltaic Power Generation on Stability of Electrical Voltage System. Nonlinear Optics, Quantum Optics: Concepts in Modern Optics, 50(4).

Shannon, R. (2016) Bringing the customer to the market: A new utility business model, The Electricity Journal, 29(5): 15-18.

Shi, Y., Xu, B., Wang, D., and Zhang, B. (2017) Using battery storage for peak shaving and frequency regulation: Joint optimization for superlinear gains. IEEE Transactions on Power Systems, 33(3), 2882-2894.

Silberberg, M. (2006) Chemistry: The Molecular Nature of Matter and Change, 4th Ed. New York (NY): McGraw-Hill Education. p. 935.

Simpson, G. (2017) Network operators and the transition to decentralised electricity: An Australian socio-technical case study. Energy Policy, 110, 422-433.

Simshauser, P. (2016) Distribution network prices and solar PV: Resolving rate instability and wealth transfers through demand tariffs. Energy Economics, 54, 108-122.

Sioshansi, F. (2000) E-commerce and the Energy Sector: The Pioneers May Not Get It Right; The Procrastinators Are Likely to Become History. The Electricity Journal, 13(5): 42-49

Sioshansi, F. P. (2012) Why the Time Has Arrived to Rethink the Electric Business Model. The Electricity Journal, 25(7), 65-74.

Sonnen (2020) sonnenCommunity. Sonnengroup.

Sparacino, A., Reed, G., Kerestes, R., Grainger, B. and Smith, Z. T. (2012) Survey of battery energy storage systems and modeling techniques. In 2012 IEEE Power and Energy Society General Meeting (pp. 1-8). IEEE.

Stein, E. (2014) Utility 2.0: New York State Envisions New Platform Giving Equal Priority to Clean Energy Solutions, Published October 15, 2014.

Strbac, G., and Mutale, J. (2005) Framework and methodology for pricing of distribution networks with distributed generation. Cent. Distrib. Gener. Sustain. Electr. Energy.

Synergy (2020) Electricity plans for your business. Synergy.

Tamyurek, B., Nichols, D., and Demirci, O. (2003) The NAS battery: a multifunction energy storage system. In 2003 IEEE Power Engineering Society General Meeting (Vol. 4, pp. 1991-1996). IEEE.

Tant, J., Geth, F., Six, D., Tant, P., and Driesen, J. (2012) Multiobjective battery storage to improve PV integration in residential distribution grids. IEEE Transactions on Sustainable Energy, 4(1), 182-191.

Tayal, D. (2017) Leveraging innovation for electricity utilities. The Electricity Journal, 30(3), 23-29.

Tayal, D. and Evers, U. (2018) Consumer preferences and electricity pricing reform in Western Australia. utilities policy, Elsevier, vol. 54(C), pp. 115-124.

Tayal, D. and Rauland, V. (2017) Future business models for Western Australian electricity utilities. Sustainable Energy Technologies and Assessments, 19, 59-69.

Telaretti, E. and Dusonchet, L. (2016) Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC) (pp. 1-6). IEEE.

The Australian Geographic (2013) On this day Sydney gets electricity. The Australian Geographic.

The Smart Energy Consumer Collaborative (2019) Consumer Pulse and Market Segmentation Study. The Smart Energy Consumer Collaborative.

Thistlethwaite, M. (2012) The Senate Proof Committees – Electricity Prices Committee Report.

Thorbergsson, E., Knap, V., Swierczynski, M., Stroe, D., and Teodorescu, R. (2013) Primary frequency regulation with Li-ion battery based energy storage system-evaluation and comparison of different control strategies. In Intelec 2013; 35th International Telecommunications Energy Conference, Smart Power And Efficiency (pp. 1-6).

Throgmorton, J. (1996) Planning as persuasive storytelling: The rhetorical construction of Chicago's electric future: University of Chicago Press.

Throgmorton, J. and Fisher, P. (1993) Institutional change and electric power in the city of Chicago, Journal of Economic Issues 27(1): 117. P67

Tomain, J., Cudahy, J., Trotta, J., and Cudahy, R. (2004) Energy law in a nutshell. Energy Law Journal, 32: 631.

Tongsopit, S., Moungchareon, S., Aksornkij, A., and Potisat, T. (2016) Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. Energy Policy, 95, 447-457.

Tonsley (2020) Masterplan. Tonsley Innovation District.

Tsiropoulos, I., Tarvydas, D., and Lebedeva, N. (2018) Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth. Publications Office of the European Union, Luxembourg.

Tukker, A. (2004) Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment, 13(4), 246-260.

United Nations (2015) Paris agreement. United Nations.

University of Texas (2017) A Comparison of New Electric Utility Business Models. Policy Research Project Report #191 Energy Institute, the University of Texas at Austin.

Van Veelen, B. (2018) Negotiating energy democracy in practice: Governance processes in community energy projects. Environmental Politics, 27(4), 644-665.

Vassallo, A. (2015) Applications of batteries for grid-scale energy storage. In Advances in Batteries for Medium and Large-Scale Energy Storage (pp. 587-607). Woodhead Publishing.

Verbong, G., Beemsterboer, S., and Sengers, F. (2013) Smart grids or smart users? Involving users in developing a low carbon electricity economy. Energy Policy, 52, 117-125.

Wainstein, M. and Bumpus, A. (2016) Business models as drivers of the low carbon power system transition: a multi-level perspective. Journal of Cleaner Production, 126, 572-585.

Wan, Y. and Green, H. (1998) Current Experience with Net Metering Programs. Conference proceedings Windpower '98, Bakersfield, CA USA.

Ward, L. (2007) Amory Lovins: Solving the Energy Crisis, Popular Mechanics, 01 October 2007.

Watson, J. D., Watson, N. R., Santos-Martin, D., Wood, A. R., Lemon, S., and Miller, A. J. (2016) Impact of solar photovoltaics on the low-voltage distribution network in New Zealand. IET Generation, Transmission & Distribution, 10(1), 1-9.

Weihrich, H. (1982) The TOWS matrix—A tool for situational analysis. Long range planning, 15(2), 54-66.

Wen, Z. (2006) Study on energy storage technology of sodium sulfur battery and its application in power system. In 2006 International Conference on Power System Technology (pp. 1-4). IEEE.

Wenger, H., Schaefer, J., Rosenthal, A., Hammond, B., and Schlueter, L. (1991) Decline of the Carrisa Plains PV power plant. Photovoltaic Specialists Conference, Conference Record of the Twenty Second IEEE. IEEE.

Western Power (2019) Community batteries delivering big benefits. Western Power.

Whitehead, J. and Kane, M. (2019) Get set for take-off in electric aircraft, the next transport disruption. The Conversation.

Whittingham, M. (1976) Electrical energy storage and intercalation chemistry. Science, 192(4244), 1126-1127.

Wood, L. and Hemphill, R. (2016) Recovery of utility fixed costs: utility, consumer, environmental and economist perspectives. Lawrence Berkeley National Laboratory. Future Electric utility Regulation, Report 5.

Wood, T., Blowers, D., and Griffiths, K. (2018) Down to the wire: A sustainable electricity network for Australia. Grattan Institute.

World Bank (2018) World Development Indicators, World Bank.

York, D., and Kushler, M. (2011) The Old Model Isn't Working: Creating the Energy utility for the 21st Century. White paper. American Council for an Energy Efficient Economy.

Yovanoff, D. (2018) Community-Owned Solar Power and Micro grids for New York State. State University of New York at Buffalo.

Zeh, A., Rau, M., and Witzmann, R. (2014) Comparison of decentralised and centralised grid-compatible battery storage systems in distribution grids with high PV penetration. Progress in photovoltaics: research and applications, 24(4), 496-506.

Zibelmen, A. (2016) REVing Up the Energy Vision in New York: Seizing the Opportunity to Create a Cleaner, More Resilient, and Affordable Energy System. IEEE Power and Energy Magazine, 14(3), 18-24.

Zott, C., Amit, R., and Massa, L. (2011) The business model: recent developments and future research. Journal of Management, 37(4), 1019-1042.

Appendix 1

Details of the algebraic equations used in the case study financial model.

NPV

The financial model looks at the Net Present Value (NPV) of options (scenarios) which means that it calculates the cost and the revenue for each year of a defined period (typically 10 years) and adjusts each result to the value of dollars in year 1. This allows to not only create a common context to compare each scenario but also rewards early gains and late expenses, as it is the case in real life.

Equation 1: Net Present Value

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

Where:

R_t = the net cash difference (inflow-outflows) during a single period t

i = the discount rate or the return that could be earned in alternative investments

t = the number of time periods considered in the simulation

LCOE and LCOES

When only looking at the cost of energy from the provider perspective, a similar approach to NPV is the Levelised Cost Of Energy (LCOE). It looks at the cost of electrical energy produced over a period versus the sum of the costs involved over that same period. Like for NPV, this allows to create a common context to compare each option but also how initial investment and operating costs (such as fuel cost) influence the cost of energy over a certain period.

Equation 2: Levelised Cost of Energy[399]

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = Average lifetime levelised electricity generation cost

I_t = Investment expenditure in the year t

M_t = Operations and maintenance expenditure in the year t

F_t = Fuel expenditure in the year t

E_t = Electricity generation in the year t

r = Discount rate

n = Amortisation period

399 From BREE (2012). Australian Energy Technology Assessment 2012. Bureau of Resources and Energy Economics – Australian Government.

Appendix 2

Expected Greenhouse Gases (GHG) emissions embodied in the electricity imported from the Grid based on the energy consumption on the precinct.

Results of greenhouse gases (GHG) savings were not mentioned in the body of the thesis because at the time of writing, PAPL had only a commitment to investigate avenues to reducing its carbon emissions with no hard target. Moreover, there was no Carbon Tax or other regulation in place to incentivise or force a reduction of GHG in Australia.

However, the reduction of GHG with the proposed solution is notable and confirms the environmental aspect of sustainability is also covered with this approach.

1. The benchmark scenario

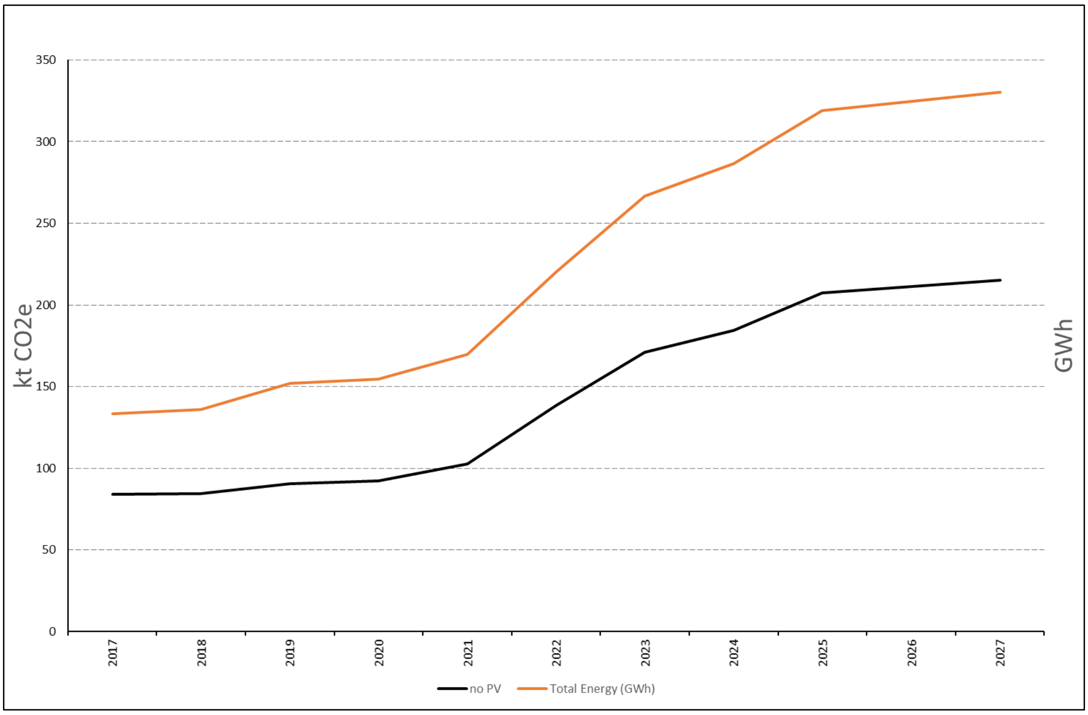

Figure 46: 10-year electricity consumption and consequent GHG emissions (benchmark scenario)

Figure 46 shows how the GHG emissions – from the carbon embodied in the electricity imported from the Grid (see **Figure 5** in the thesis) – increase with the growth of the energy consumption on the airport precinct as more energy customers settle and connect to its embedded electricity network (EEN). The increase in GHG emissions is not proportional to the energy consumption because it was assumed that in the future, the carbon intensity of the electricity on the Grid will be reduced thanks to ever growing proportion of renewables feeding it.

The line in black represents the GHG emissions in t_{CO2e}, of the benchmark scenario also called the 'do-nothing' scenario, where all the electricity need of the precinct is imported from the Grid. The line in orange represents the energy consumption in GWh (scale removed for confidentiality of the data) that will considered the same across all the scenarios simulating the introduction of solar on the precinct (see section b.).

2. GHG emissions after introduction of solar on the precinct

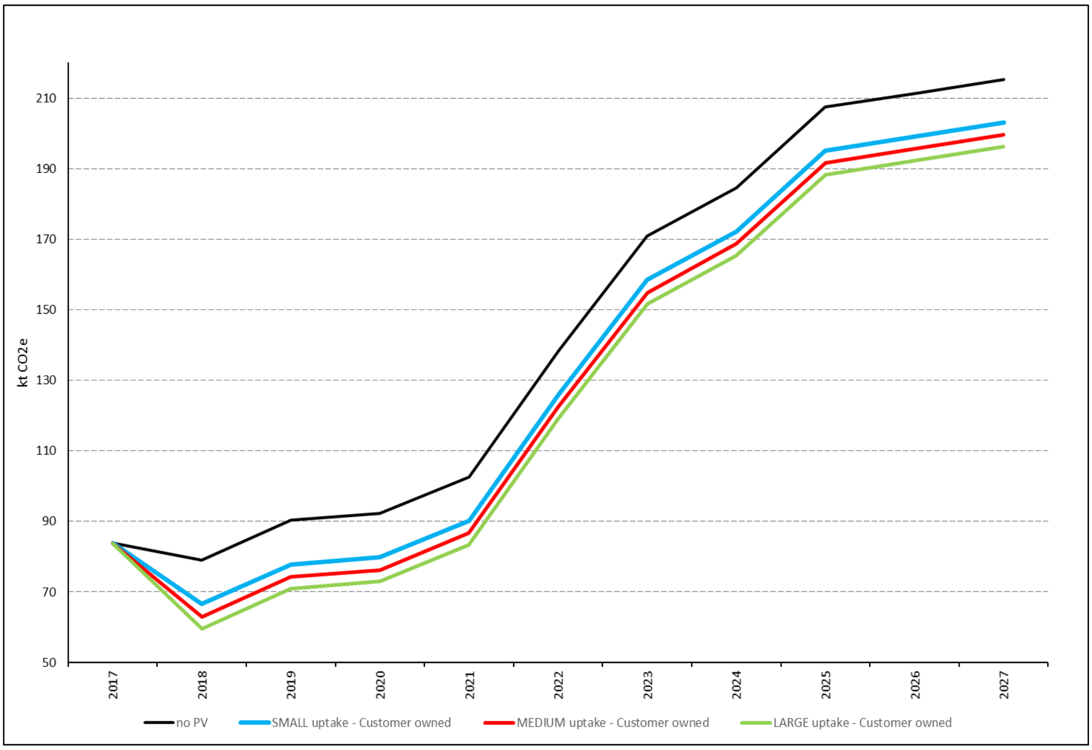

Figure 47: 10-year GHG emissions saving with rooftop solar

Figure 47 shows the GHG emissions when a portion of the electricity used on the precinct is produced onsite by solar panels owned by the customers. In year 1 (2017 in the case study), there is a massive program of installation of solar panels on the roof of existing buildings leased by tenants. This is represented by the dip on the first year in all the coloured lines.

The installed PV capacity at the end of this first year depends on the assumed uptake as defined in **Table 15** (p195). The three levels of uptake were called SMALL (9.8MW), MEDIUM (12.6MW) and LARGE (15.3MW). However, it is assumed that the following years all new buildings are also fitted with solar panels (with a capacity dependent on the uptake level selected), so PV production (and reduction in GHG emissions) is growing organically with the load.

So, in Figure 47, the blue line shows the reduction in GHG emissions corresponding to the SMALL uptake of rooftop solar, the red line for the MEDIUM uptake, the green line for the LARGE uptake, and the black line the GHG emissions of the 'do-nothing' scenario, the reference scenario where there is no onsite solar generation.

Appendix 3

Permission statements from the copyright owners of third-party copyright material reproduced in the thesis were received by email:

Figures 4 p18 & 5 p19

Andrew - Department of Agriculture, Water and the Environment - Media Team

(May 25, 2020)

Hi Lio

No issues with you using the figures.

Figure 6 p20

Robert Passey - APVI - Treasurer & Analyst

(May 25, 2020)

Hi Lio,

Of course!

Figure 14 p67

Allison Bermudez - Midcontinent Independent System Operator – Media Team

(August 25, 2020)

Hi Lio,

You have permission to reproduce the figure in your PhD thesis with the proper citation.

Figure 21 p126

Catherine Mitchell – University of Exeter - Professor of Energy Policy

(May 25, 2020)

Yes of course - very happy to.

Figure 23 p136 and Table 20 p222 (two authors)

Dr Dev Tayal

(May 25, 2020)

Ok by me - thanks for asking - good luck!

Dr Vanessa Rauland

(June 03, 2020)

Hi Lio!

Yes, that's fine to reproduce those figures with appropriate acknowledgement.

<u>Figure 25 p142</u>

Katie Sheppet – ENEL X - Communications Lead – Australia and New Zealand

(May 26, 2020)

1) *Hi Lio, thanks for getting in touch.*
   Could you please provide a little more context on your thesis and the placement of the visual? There shouldn't be a problem however we'd appreciate the opportunity to review it beforehand.
2) *Thanks for letting me know!*
   It all sounds great, wishing you the best of luck.

<u>Figure 27 p153</u>

Dr Thorsten Helm

(August 22, 2020)

Hi Lio,

Yes, I'm happy for you to reproduce my table in your PhD thesis.

<u>Figure 28 p165</u>

Ian Barker – Perth Airport Pty Ltd - Infrastructure Manager

(May 26, 2020)

Lio

Yes, you may use the aerial photo

<u>Figure 37 p194</u>

Angie Silva - Balance Utility Solutions - Communications and Marketing Officer

(May 26, 2020)

Hi Lio,

Congrats on making the Phinish line:) Sure no worries to use the image.

The other material reproduced in this thesis were either under Creative Commons or their authors clearly indicated reproduction authorised with the proper referencing.