Title: **WP2.7 and 2.8 Techno-economic modelling (Existing and future)**

Document ID: Task 1: Literature Review

Date: 29th February 2024

Prepared For: Centre for New Energy Technologies (C4NET)

Lead Researcher: Dr Reza Razzaghi & Prof Mahdi Jalili
Department of Electrical and Electronics Engineering
Monash & RMIT University

Research Team: Dr Imran Azim, Dr Nameer Al Khafaf, Dr Mohsen Khorasany
Department of Electrical and Electronics Engineering
Monash & RMIT University

Contact: Prof Mahdi Jalili & Dr Reza Razzaghi
Mahdi.jalili@rmit.edu.au & reza.razzaghi@monash.edu

Table of Contents

Abbreviations and Acronyms

AER	Australian Energy Regulator
AEMO	Australian Energy Market Operator
AEMC	Australian Energy Market Commission
NER	National Electricity Rules
NEM	National Electricity Market
DER	Distributed Energy Resource
PV	Photovoltaic
EV	Electric Vehicle
CEV	Commercial Electric Vehicle
PEV	Plug-in-EV
EVSE	Electric Vehicle Supply Equipment
DNSP	Distribution Network Service Provider
DSO	Distribution system operator
DR	Demand Response
LEM	Local Energy Market
P2P	Peer-to-Peer
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
TSS	Tariff Structure Statement
LRMC	Long-run Marginal Cost
NPO	Network Pricing Objective
ToU	Time-of-Use
FiT	Feed-in-Tariff
PFiT	Premium Feed-in-Tariff
DFiT	Distributor Feed-in-Tariff
KWH	Kilowatt-Hours
HH	Half Hour
CPP	Critical Peak Pricing
PTR	Peak Time Rate
VAPP	Variable Peak Pricing
RTP	Real-Time Pricing
IBR	Inclining Blocking Rate
VPP	Virtual Power Plant
LV	Low Voltage
EPEX	European Power Exchange
DUoS	Distribution Use of System
CS	Capacity Subscription
CPO	Charge Point Operator
SOC	State-of-Charge
FES	Future Energy Scenarios

DERMS	Distributed Energy Resource Management System
ADMS	Advanced Distribution Management System
TSO	Transmission System Operator
DMO	Distribution Market Operator
DEIP	Distributed Energy Integration Program
FCAS	Frequency Control Auxiliary Services
DLC	Direct Load Control
SGIP	Self-Generation Incentive Program
OE	Operating Envelope
DOE	Dynamic Operating Envelope
SOE	Shaped Operating Envelope
OPF	Optimal Power Flow
DOPF	Distributed Optimal Power Flow
QoS	Quality of Service
QoE	Quality of Experience
MMF	Min-Max Fairness
GEB	Grid-Interactive Efficient Building
AMI	Advanced Metering Infrastructure
BMS	Building Management System
AI	Artificial Intelligence
PPA	Power Purchase Agreement
ESB	Energy Security Board
IESS	Integrating Energy Storage Systems
ESS	Essential System Services
CSIP-AUS	Common Smart Inverter Profile Australia
HEMS	Home Energy Management System
CIM	Common Information Model
EI	Equality Index
ICT	Information and Communication Technology

Executive summary

This report reviews the literature of the complex interplay among electricity tariffs, network costs, and the integration of distributed energy resources (DERs) in today's evolving energy sector. Electricity tariffs and network costs serve as foundational elements in energy systems, shaping consumption behaviours, investment strategies, and overall economic feasibility. Tariffs, structured around usage, serve as a primary revenue source for utilities, reflecting the underlying costs of energy generation, transmission, and distribution. Meanwhile, network costs encompass expenditures necessary for maintaining the infrastructure critical for reliable electricity supply. Achieving a balance between economic efficiency and social/environmental objectives is pivotal in tariff formulation. The rise of DERs signifies transition from centralised energy models towards decentralised ones, empowering consumers to actively engage in the energy market and contribute to decarbonisation efforts. Effective DER management presents both challenges and opportunities, necessitating investments in monitoring and control technologies to ensure grid stability and reliability. Current approaches include diverse strategies such as net metering and demand-side management to optimise DER utilisation. Future energy markets are poised for transformation to maximise network hosting capacity and resource efficiency. Leveraging advanced grid management technologies and demand-side flexibility strategies like demand response programs and energy storage integration will be critical in achieving these goals. Peer-to-peer (P2P) energy trading platforms offer a promising avenue for enhancing resource allocation and grid efficiency. As the energy demand is set to increase significantly due to the electrification of heating and cooling and the electrification of transportation, there is a need to leverage DER for provision of flexibility to avoid expensive investments in electrical infrastructure resulting in increased energy cost to energy consumers. Moreover, future energy markets can be implemented to contribute to enhancing the network hosting capacity in the medium term. Hence the proposed research includes assessing the impact of electrification of heating and transport on the network and implementing future markets models along with DER management to mitigate any network issues.

1 Introduction

In the ever-evolving landscape of the energy sector, the interplay between electricity tariffs, network costs, and the integration of distributed energy resources (DERs) has become a focal point of discussion. As societies worldwide strive for sustainability and resilience in their energy systems, understanding the intricacies of these elements becomes paramount. This literature review aims to shed light on the dynamics of electricity tariffs and network costs, delve into the current management practices of DERs, and explore the potential future energy markets poised to enhance network hosting capacity.

Electricity tariffs and network costs constitute fundamental components of the energy ecosystem, influencing consumption patterns, investment decisions, and the overall economic viability of energy systems. Tariffs, typically structured as the price per unit of electricity consumed, play a pivotal role in revenue generation for utilities while also reflecting the underlying costs of generation, transmission, and distribution. These tariffs can vary significantly based on factors such as time of use, demand patterns, and regulatory frameworks. Network costs, on the other hand, encompass the expenses associated with building, operating, and maintaining the physical infrastructure necessary for electricity transmission and distribution. This infrastructure includes substations, transformers, power lines, and other grid components vital for ensuring the reliable delivery of electricity to end-users. Network costs are often substantial and are influenced by factors such as population density, geographical terrain, and technological advancements. The intricate relationship between electricity tariffs and network costs underscores the need for a balanced approach to pricing that aligns economic efficiency with social and environmental objectives. Regulatory bodies and policymakers face the challenge of designing tariff structures that incentivise efficient resource allocation, encourage renewable energy integration, and mitigate the impacts of peak demand while ensuring affordability and equity for consumers.

The emergence of DER marks a paradigm shift in the traditional centralised model of electricity generation and distribution. DERs encompass a diverse array of small-scale energy technologies deployed at or near the point of consumption, including solar photovoltaics (PV), wind turbines, battery storage systems, electric vehicles (EVs), and demand response programs. The term DER here refers to both distribution network operator owned resources and consumers owned resources, which are usually referred to as consumer energy resources. These decentralised assets empower consumers to actively participate in the energy market, reduce their reliance on centralised utilities, and contribute to decarbonisation efforts. Effective management of DER poses both challenges and opportunities for grid operators, utilities, and policymakers. Integrating DER into the existing infrastructure requires investments in advanced monitoring, control, and communication technologies to ensure grid stability, reliability, and resilience. Furthermore, the intermittent nature of renewable energy sources like solar and wind necessitates innovative approaches to forecasting, dispatching, and balancing supply and demand in real-time. Current practices in DER management encompass a range of strategies, including net metering programs, feed-in tariffs, time-of-use pricing, demand-side management initiatives, and export limitation policies. These initiatives aim to optimise the utilisation of DER, minimise grid congestion, and enhance system flexibility while providing economic incentives for consumers to adopt clean energy technologies. Despite the progress made in DER integration, significant challenges remain, including regulatory barriers, market fragmentation, technological interoperability, and financial incentives misalignment. Achieving seamless coordination and interoperability among diverse DER assets requires collaborative efforts across stakeholders, standardisation of communication protocols, and adaptive regulatory frameworks that incentivise innovation and investment in DER infrastructure.

As the energy transition accelerates and the penetration of DER continues to rise, future energy markets are expected to undergo profound transformations aimed at maximising network hosting capacity and optimising resource utilisation. Network hosting capacity refers to the ability of the grid to accommodate additional DER without compromising reliability or safety constraints. One potential avenue for increasing network hosting capacity is the adoption of advanced grid management technologies to enable dynamic operating envelope and energy trading platforms. These technologies enable real-time monitoring, control, and optimisation of DER while facilitating peer-to-peer (P2P) energy transactions and grid-balancing services. Another strategy involves leveraging demand-side flexibility through demand response programs, energy storage systems, and vehicle-to-grid (V2G) integration. By incentivising consumers to adjust their energy consumption patterns in response to grid conditions, demand-side flexibility can alleviate congestion, reduce peak demand, and enhance overall grid resilience. Furthermore, the evolution of energy markets towards greater decentralisation and democratisation holds promise for enhancing network hosting capacity. P2P energy trading platforms empower prosumers (producer-consumers) to directly exchange surplus energy with their peers, thereby optimising resource allocation, reducing transmission losses, and enhancing grid efficiency.

The rest of the report is structured as follows: section 2 covers the current electricity market tariff structure and briefly discusses the regulatory process for tariffs, section 3 covers the existing methods for managing DERs including reference to projects from Australia and worldwide, section 4 covers the potential future market structure and multi-sided markets using case studies from both Australia and other countries and finally section 5 provides insights from the literature and proposed way forward.

2 Existing Tariff Structures

Electricity tariff structures in Australia are complex arrangements designed to manage the costs associated with generating, transmitting, and distributing electricity to consumers. These structures are governed by distribution network service providers (DNSPs) and the Australian Energy Regulator (AER), which play crucial roles in ensuring fairness, efficiency, and transparency in electricity pricing. The Tariff Structure Statement (TSS) serves as a comprehensive document that outlines the principles, methodologies, and components of electricity tariffs, guiding both consumers and stakeholders through the intricate landscape of pricing mechanisms [1].

An explanatory overview of network tariffs in the context of electricity distribution is discussed in [2]. It defines DNSPs as entities owning and operating low voltage poles and wires, delivering electricity to consumers. Network tariffs, essential for revenue recovery and infrastructure maintenance, include costs for transmission network services and any government-imposed schemes. DNSPs engage in extensive planning and consultation processes to develop tariff structures that balance the interests of consumers, network operators, and regulators. The AER regulates network tariffs through a two-step process: DNSPs submit a five-yearly revenue proposal, including a TSS and indicative tariff levels. Annual pricing proposals are assessed based on the approved TSS. DNSPs propose tariff structures in accordance with the National Electricity Rules (NER), engaging stakeholders in TSS development. Since 2014, Rules mandate DNSPs to make tariffs more cost-reflective, aligning with long run marginal costs. Network tariff trials, permitted by Rules, enable DNSPs to experiment with new tariffs, informing strategies and exploring innovative approaches. Trials are subject to certain limits defined by Rules, with increased thresholds introduced in 2021. Stakeholders are encouraged to engage with relevant DNSPs for those interested in network tariff trials, emphasising that the AER does not initiate such trials but offers guidance.

The AER's regulatory decisions are guided by principles of fairness, transparency, and accountability, aiming to strike a balance between the interests of consumers and network operators. It engages in extensive stakeholder consultation, economic analysis, and regulatory scrutiny to ensure that electricity tariffs are set at levels that reflect the true costs of providing electricity services. By promoting competition, innovation, and investment in network infrastructure, the AER contributes to the long-term sustainability and resilience of Australia's electricity sector.

The TSS is a key regulatory document that outlines the principles, methodologies, and components of electricity tariffs set by DNSPs [3]. It provides consumers, stakeholders, and regulators with comprehensive information about how electricity tariffs are structured, calculated, and applied. The TSS typically includes the following elements:

1. Tariff Components: The TSS describes the various components of electricity tariffs, such as fixed charges, variable charges, demand charges, and network charges. It explains how these components are calculated based on factors such as energy consumption, peak demand, network usage, and service availability.

2. Tariff Methodologies: The TSS outlines the methodologies used to determine electricity tariffs, including cost allocation, cost recovery, pricing principles, and tariff design principles. It explains

how costs are allocated across different customer classes, geographic regions, and service categories to ensure fairness and equity.

3. Tariff Structures: The TSS presents different tariff structures and options available to consumers, such as time-of-use tariffs, flat-rate tariffs, demand tariffs, and feed-in tariffs. It explains the benefits, drawbacks, and implications of each tariff structure, helping consumers make informed choices based on their preferences and usage patterns.

A separate reference [4] discusses methods for designing tariffs for distribution network services to ensure economic efficiency while meeting revenue constraints. It delves into the tension between traditional welfare economics advocating pricing based on long-run marginal costs (LRMCs) and the prevalent use of embedded costs, posing challenges in residual cost recovery. The study underscores Australia's progression toward LRMC-based pricing and the imperative of effectively recovering residual costs. Ramsey pricing, nonlinear pricing, equity considerations, and gradualism are explored as factors influencing tariff design, alongside a simple tariff design model illustrating stylized tariff structures. Proposed alterations to residential rate structures by utilities to address revenue loss concerns due to increased distributed solar generation adoption is explored in [5]. The impact of various rate adjustments on both PV and non-PV customer bills is analysed, stressing the necessity of localised analysis for accurate characterisation of impacts. It concludes by highlighting the importance of assessing rate changes' impacts on different customer categories and electricity consumption patterns amidst the expanding solar industry.

Reference [6] delves into the growing interest in aligning electricity tariffs with the true cost of delivering network services to consumers. It underscores the significance of diminishing cross subsidies among diverse consumers and offering precise price indications to encourage efficient network utilisation. While numerous proposed tariffs aimed at reflecting costs incorporate a demand (capacity) element, executing such tariffs proves intricate. The document presents a technique for visually appraising the cost-reflectivity of a demand charge network tariff. Through this approach, the authors evaluate a typical demand charge network tariff proposal within the Australian National Electricity Market (NEM) and scrutinise actual consumption data from 3876 households in Sydney. The evaluation unveils a lack of cost-reflectivity concerning matching customer bills with their impact on network peak demand. The passage stresses the potential adverse effects on the economic efficiency of such tariffs, highlighting insufficient policy focus on this matter. Subsequently, the authors illustrate how the structure of demand charge tariffs can be modified to bolster cost-reflectivity, proposing the applicability of the method to any tariff incorporating a capacity-based component. This paper discusses the significance of network costs in electricity industries, particularly for smaller customers, and the historical lack of focus on the efficiency of tariffs for residential customers. It highlights the challenges in designing cost-reflective tariffs that align with network costs and incentivise efficient customer decision-making. The discussion emphasises the increasing pressure on existing tariff structures due to factors like rising peak demand, declining network load factors, and the emergence of new technologies. The paper focuses on the Australian NEM and ongoing efforts to develop more cost-reflective tariffs. The network pricing objective (NPO) of the NEM aims for tariffs to reflect efficient costs of service delivery. The text explores the two stages of tariff design—structure and allocation—and examines the demand charge component. It assesses DNSP's demand charge tariff for cost-reflectivity and proposes alterations for improved efficiency. The paper concludes with a discussion of the findings and their implications.

Reference [7] explains how the electricity market functions, covering four key stages: generation, distribution, retail, and consumption. Generators produce electricity, distributors manage power lines, and retailers sell energy to consumers. The costs in an average Australian energy bill are divided into wholesale energy costs (34%), network costs (46%), environmental costs (9%), and retail costs (11%). There are various tariff types, such as single rate, time of use, and natural gas tariffs, influencing how consumers are charged. Usually, distributors set tariffs approved by the AER, and retailers are responsible for pricing. Solar feed-in tariffs and plan benefits are also explained. Rates and charges, comparison to reference prices, and the distinction between fixed and variable rates are highlighted as important factors when choosing an energy plan.

The prices for network services charged by CitiPower and Powercor, fall into two categories: network charges and alternative control services [8]. Network charges cover the cost of delivering electricity through transmission and distribution networks, while alternative control services include metering, public lighting, and customer-requested services. These charges constitute approximately "33% of a Powercor customer's bill and 29% of a CitiPower customer's bill"[8]. The percentage of network costs for other DNSPs in Victoria is between 28% and 35% of the average Victorian energy bill [9] which is lower than the average Australian network cost of 46% [7]. The network charge varies based on the selected tariff and is subject to a revenue cap set by the AER. The recently approved annual network pricing proposals for 2023-2024 will result in a modest increase for both Powercor and CitiPower customers. Despite this, both companies are among the lowest-cost networks in the country, particularly for residential customers. The average annual bill encompasses wholesale electricity costs, retail charges, environmental policies, transmission and distribution network costs, and metering charges. The funds collected from these charges are utilised for maintaining network safety and reliability, extending and upgrading the network, day-to-day operations, connecting new customers, maintaining public lighting, and providing metering services.

2.1 Energy Use Tariffs

The energy use tariffs govern how end users are billed for their use of energy. Information about different types of electricity and gas tariffs, guiding consumers on choosing the right plan based on their needs is discussed in [10]. It covers single rate tariffs, time-of-use tariffs, controlled load tariffs, and demand tariffs for electricity. Single rate tariffs have a consistent rate throughout the day, while time-of-use tariffs vary based on peak, off-peak, and shoulder periods. Controlled load tariffs are specific to certain appliances, charging lower rates for off-peak usage. Demand tariffs consider the intensity of electricity usage at a specific point in time, requiring a smart meter. Gas plans generally use single rate tariffs with tariff blocks, where rates vary based on usage levels. Some gas plans also include seasonal rates, often higher in winter. The text emphasises the importance of understanding these tariff structures to optimise energy costs.

The details of energy plans, focusing on time-of-use (ToU) tariffs, particularly in electricity plans have been outlined in [11]. It distinguishes between flat-rate plans, where customers pay the same rate throughout the day, and ToU plans, where charges vary based on usage time. ToU plans require a smart meter and involve components such as fixed supply charges, off-peak usage, solar sponge usage, and peak usage, each with specific pricing structures. The potential benefits of ToU pricing are discussed, including advantages for individuals who are home during the day, can schedule appliance usage during cheaper periods, or possess energy storage devices for high-cost tariff periods. Ref. [11] also delves into the concept of cost-reflective pricing in South Australia, part of the NEM. It explains that electricity sales are traded through the NEM, a wholesale market where prices respond to supply and demand. The shift to cost-reflective pricing, initiated in 2014 by the Australian Energy Market Commission (AEMC), aims to reveal the true cost of delivering electricity at different times, addressing peak demand and reducing the need for network infrastructure expansion.

In General energy use tariffs for residential customers in Australia can vary based on several factors including location, energy provider, consumption patterns, and government regulations. A general overview of how energy tariffs typically work for residential customers:

1. Types of Tariffs:

- Flat Rate Tariffs: Customers pay a fixed rate for each unit of energy consumed regardless of the time of day or season.
- ToU Tariffs: Charges depend on the time of day when the energy is consumed. Peak hours usually have higher rates, while off-peak hours have lower rates.
- Controlled Load Tariffs: Customers have a separate meter for specific appliances such as hot water systems or pool pumps. These appliances are powered at a lower rate during off-peak hours.

2. Billing Structure:

- Energy consumption is measured in kilowatt-hours (kWh), and customers are billed based on their usage.
- In addition to energy charges, bills may include other fees such as supply charges, service fees, network charges, and government levies.
- Some providers offer discounts for prompt payment, online billing, or bundling services like gas and electricity.

3. Tariff Variation by Location:

- Energy tariffs can differ between states and territories in Australia due to varying regulations, energy sources, and distribution networks.

4. Government Initiatives and Rebates:

- Governments may offer rebates, subsidies, or incentives to encourage energy efficiency and renewable energy adoption.
- Programs like Solar Feed-in-Tariffs (FiTs) provide homeowners with credits for excess solar energy fed back into the grid.

5. Smart Metering:

- Smart meters are increasingly being deployed across Australia, providing real-time data on energy consumption and enabling more accurate billing and facilitating ToU tariffs.

6. Regulatory Environment:

- Energy tariffs are subject to regulation by government authorities such as the AER and state-based regulatory bodies.
- These regulators oversee pricing, network infrastructure investment, and consumer protection measures.

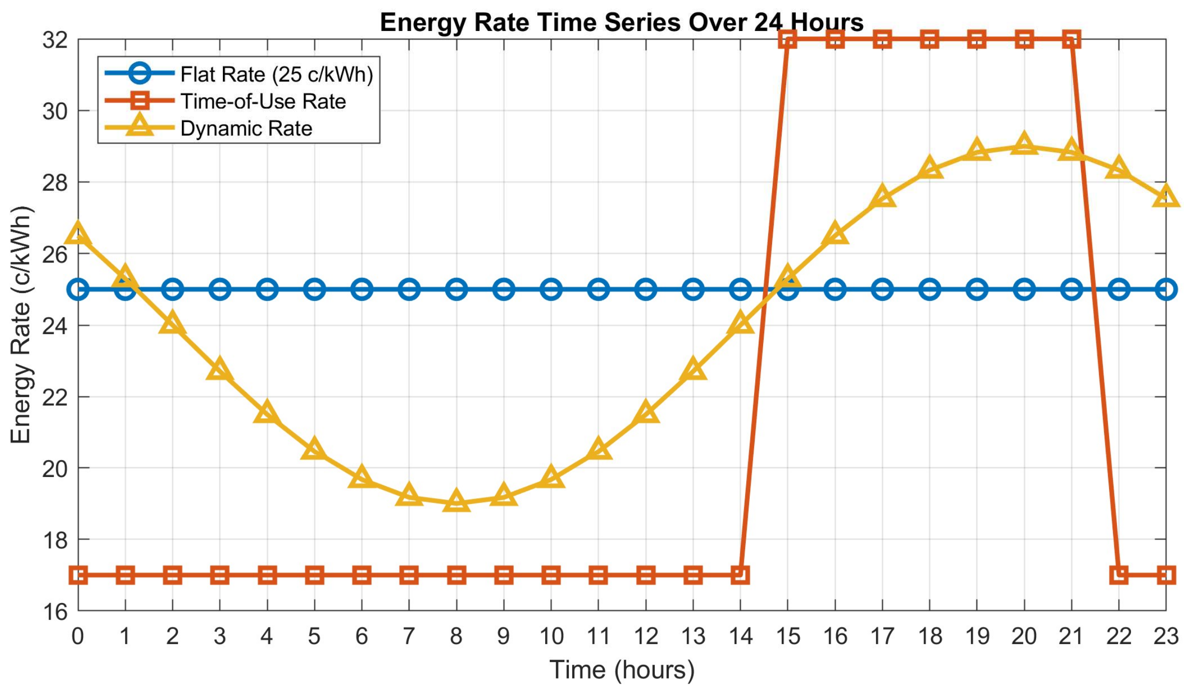

Figure 1: Comparison of energy use tariffs across the day

2.1.1 Flat rate

The single rate tariff charges a consistent rate for energy consumption throughout the day, making it suitable for individuals who primarily use appliances during evenings or prefer a flat rate; it's also known as flat rates or standard rates [12].

2.1.2 Time-of-Use rate

ToU tariffs are utilised with a fully communicating smart meter, often in conjunction with solar panels and batteries, where charges vary based on the time of day. There are three main periods: peak, which occurs late afternoon and evening on weekdays when electricity costs the most; shoulder, which represents periods costing less than peak but more than off-peak, occurring between peak and off-peak times; and off-peak, generally overnight, offering the cheapest electricity rates [12].

The implementation of ToU pricing in Australian homes, aimed at encouraging consumers to shift electricity usage to off-peak hours. While ToU pricing could theoretically reduce peak loads and lower prices, it may not effectively change consumption patterns and could lead to higher costs for households [13]. The concept of price elasticity of demand is introduced in [13], arguing that despite electricity companies claiming high elasticity, data suggests demand in Australia is likely inelastic. Analysis based on ToU pricing offers and consumption patterns indicates potential increases in annual bills, even with optimistic elasticity assumptions. The report also questions the validity of higher elasticity estimates and challenges the justification for ToU pricing, particularly noting declining peak loads since 2009. Ultimately, it is suggested that ToU pricing might benefit electricity companies more than consumers, particularly burdening low-income households unable to adapt their electricity usage.

Another study [14] introduces a fresh approach to crafting ToU tariffs for residential clients by employing clustering techniques to transform flat rate tariffs. Instead of fine-tuning precise prices for each billing period, the focus of the method lies in devising foundational window patterns of ToU tariffs. It utilises the Gaussian Mixture Model clustering technique to categorise half-hour interval flat rate tariffs within a day into clusters, thereby establishing ToU tariffs based on fluctuations in energy price and system loading demand. Motivated by the aim of attaining a 15% renewable energy consumption target by 2020 in the UK, the paper stresses the significance of customer engagement with power networks as a viable alternative to costly and time-consuming network reinforcement. ToU tariffs derived from wholesale energy prices can prompt customers to adapt their electricity usage in response to price fluctuations. Challenges in ToU tariff formulation include determining tariff rates and shaping. The proposed method tackles these hurdles and investigates the impact of ToU tariffs on domestic demand response, considering energy cost reduction and peak shaving. The effectiveness of the proposed method in crafting two categories of ToU tariffs: price-oriented and load-oriented is quantified in the response to these tariffs in terms of savings on electricity bills and reduction in peak demand, revealing that price-oriented ToU tariffs excel in cost savings, whereas load-oriented ToU tariffs are more effective in reducing peak demand.

The challenges faced by electricity distribution networks in Southeast Queensland due to the high adoption of rooftop solar PV systems in detached households is discussed in [15]. The mismatch between solar PV production and household load patterns, coupled with a flat-rate variable charge in the existing tariff structure, results in cross-subsidies and inefficient pricing. A Three-Part Demand Tariff is proposed as a more equitable, cost-reflective and efficient pricing structure. This tariff includes a variable kWh charge, a fixed charge and a maximum kW demand charge. The analysis uses interval meter data to compare the proposed tariff with existing ones and demonstrates that it can reduce implicit subsidies and enhance tariff stability. The study also quantifies implicit subsidies related to air-conditioners and solar PV units, suggesting that a demand tariff can address these issues. The article concludes by highlighting the need for stable tariff structures, especially in the context of increasing solar PV adoption.

Ref. [16] delves into estimating the elasticity of substitution concerning households under ToU electricity tariffs in Victoria, Australia. This elasticity gauges how consumers react to fluctuating prices over time, particularly the shift in consumption from peak to off-peak periods based on price disparities. The analysis involves a sample of 6957 households, revealing that, on the whole, the disparity between peak and off-peak prices minimally influences consumption. This lack of responsiveness aligns with earlier studies conducted in the United States during the 1980s. The study further examines the influence of variables such as rooftop PV and socio-economic status on responsiveness. Findings indicate a generally weak response, where a 1% rise in peak period prices corresponds to a mere 0.2% transition in consumption from peak to off-peak hours. Surprisingly, households equipped with rooftop PV systems demonstrate a similar elasticity of substitution as those without, suggesting that the installation of rooftop PV systems does not notably impact load-shifting behaviour. Furthermore, households in the lowest socio-economic bracket exhibit no reaction to ToU tariffs, possibly due to less efficient appliances and increased inconvenience in load shifting. The study raises doubts about the efficacy of ToU tariffs in incentivising load shifting despite technological advancements, market deregulation, and policy support. It underscores the necessity for further investigation into factors influencing responsiveness, including the role of technology, consumer behaviour, and tariff structure. Ultimately, it suggests that the argument for mandating ToU tariffs as the default pricing model lacks persuasiveness, advocating for consumer choice in selecting ToU tariffs based on their preferences rather than compulsory enrolment.

Ref. [17] outlines a pricing trial carried out in the Mueller neighbourhood in Austin, focusing on tech-savvy energy users equipped with EVs, photovoltaic systems, and energy-efficient homes. The trial aimed to gauge these consumers' reactions to electricity pricing signals, particularly under traditional ToU pricing structures. Over the span of 18 months, participants received electricity at experimental rates, including discounted rates during a designated 'wind-enhancement period' and elevated rates during summer critical peak periods. In response to ToU pricing, EV owners among the participants shifted their vehicle charging to nighttime wind enhancement periods, and activities like laundry were postponed to off-peak hours. The proportion of energy consumption shifted to off-peak periods mirrored findings from ToU studies targeting more conventional homeowners. However, the overall reduction in peak demand during critical peak pricing (CPP) events was lesser compared to studies involving typical consumers, reflecting the lower overall energy usage in energy-efficient residences. The study highlights the significant impact of PEV (plug-in EV) charging, with daytime charging prevailing in the absence of pricing incentives and education. The study suggests that, with suitable incentives and guidance, PEV owners could predominantly shift their daily charging to overnight hours, offering a potential tool for grid operators to manage renewable generation. It emphasises the necessity of educating PEV owners about charging management and offering financial incentives to promote off-peak charging. Additionally, it acknowledges that, as PEV sales continue to rise, providing appropriate price signals to regulate charging patterns will pose a challenge for electric utilities. In essence, the study elucidates the responses of tech-savvy energy consumers, particularly those with EVs, to ToU pricing and the potential ramifications for grid management.

The initial findings from a three-year investigation into the effects of ToU rates in Ontario, Canada is discussed in [18]. Unlike previous research, this study examines the real-world implementation of ToU rates as part of a comprehensive program rather than in a controlled experimental environment. Employing a natural experiment methodology, the researchers selected samples from four local DNSPs to form control and treatment groups. Utilising the Addilog model of consumer demand, the study estimated substitution elasticities between peak, mid-peak, and off-peak periods. It analysed load-shifting impacts, energy conservation effects, and substitution elasticities for residential and general service customers across summer and winter, and Ontario Power Authority peak demand months. The results suggest that residential customers consistently adjusted their usage patterns in response to ToU pricing, decreasing peak and mid-peak consumption while increasing off-peak usage. This behaviour was more pronounced in summer compared to winter, with peak demand during OPA's peak period decreasing by 1.3% to 5.6%. Energy conservation effects were generally minimal or non-existent, with some unexpected positive elasticities due to data limitations. Comparisons with international ToU studies indicated similar peak reduction impacts in Ontario based on the peak-to-off-peak price ratio, but conservation impacts were limited, ranging from 0.05% to 0.45% annually and varying by DNSP. Load-shifting impacts for general service customers were smaller and less clear than for residential customers, with unexpected substitution patterns. Energy conservation effects for both customer groups were insignificant. Methodological challenges, including the absence of a randomized controlled experiment and phased ToU rate deployment, were addressed. In summary, the study highlights the significant evidence of load shifting among residential customers in response to ToU rates, with lesser effects observed for general service customers. Energy conservation impacts were generally modest, and the study encountered challenges in ensuring methodological consistency across diverse DNSPs. The paper emphasises the importance of understanding customer behaviour and impacts for effective evaluation of ToU programs.

2.1.3 Demand rate

Demand tariffs, introduced to encourage reduced electricity usage during peak demand, aim to alleviate strain on the grid by influencing charges not only based on total energy consumption but also on the highest power demand within a specified period. These tariffs are designed to motivate households and businesses to use less electricity during times of peak demand [12].

Ref. [19] investigates the necessity of aligning electricity tariffs with the actual cost of providing network services to consumers, with a particular focus on demand charge network tariffs. The study introduces a methodology for evaluating the cost-reflectivity of demand charge network tariffs, applying it to a proposal within the NEM. The analysis indicates a low level of cost-reflectivity, impacting the economic efficiency of such tariffs. Suggestions are made to adjust the demand charge tariff to better reflect costs. The challenges associated with implementing cost-reflective tariffs are highlighted, emphasising the importance of ensuring that customer bills align with their contribution to network peak demand. These challenges include rising peak demand, decreasing network load factors, and the emergence of new technologies which are driving interest in more cost-reflective tariffs. The study evaluates the cost-reflectivity of a DNSP's demand charge tariff using a methodology based on long-run marginal costs and coincident demand, comparing the tariff structure with the customer's contribution to network peaks. The analysis is based on half-hourly load data from 3876 residential customers in Sydney, Australia. The study underlines the significance of long-run marginal costs in determining network service charges and discusses the challenges associated with estimating future costs, utilising data from the Smart Grid Smart City trial and South Australia Power Network's Low Voltage (LV) Residential Actual Demand Tariff for analysis. The main findings suggests that current demand charge tariffs may not adequately correlate charges with customer-driven network peak demand and proposing the application of the demand charge to coincident demand during peak months to enhance cost-reflectivity. It advocates for a re-evaluation of arguments against coincident demand tariffs, gathering customer feedback through focus groups, and quantifying financial outcomes for networks and customers through regulation.

The transformation of electricity pricing within the Australian NEM in reaction to significant shifts in the energy sector, particularly the integration of renewable technologies, is explored in [20]. The study examines historical pricing approaches, tracing the progression from basic throughput charging to more intricate structures incorporating energy throughput charges, fixed charges, demand charges, and ToU pricing. It also highlights the impact of consumer-led changes, particularly the widespread uptake of small-scale solar PV installations, contributing to a more decentralized and varied energy market. Discussion centres on network tariffs, addressing the necessity within the Australian regulatory framework for these tariffs to recuperate overall network costs. It stresses the necessity for tariff reform to reflect network cost drivers more accurately, particularly considering increasing adoption of renewable energy. The concept of demand charges is introduced, alongside ongoing reforms in network tariffs aimed at diminishing reliance on volumetric charges and incorporating fixed and demand charge elements. The study explores the introduction of demand subscription tariffs, which necessitate customers to subscribe to a specific demand level and pay a monthly fixed charge for that level during peak periods. Digital technologies will enable customized pricing for each customer, reflecting costs dynamically for the first time in the sector's history. The role of retailers in packaging these cost structures for consumers is also recognized.

2.1.4 Dynamic rate

The implementation of variable rates for residential customers in light of the widespread integration of smart meters is discussed in [21]. An examination of global research on variable rates reveals discrepancies in findings, which are largely resolved by correlating demand response with the peak-to-off-peak price ratio. The paper traces the history of variable rate studies from the 1970s to the present, highlighting successive waves of experiments and their progression. The authors introduce 'Arcturus,' an extensive database containing findings from dynamic pricing initiatives worldwide. This database encompasses 337 experimental and non-experimental pricing strategies from over 60 trials across four continents, involving more than 1.4 million customers. Various designs of variable rates, including ToU, critical peak pricing (CPP), peak time rebate (PTR), and Variable Peak Pricing (VAPP), are examined. The studies demonstrate a growing interest in variable pricing experiments over the past two decades. The paper highlights the influence of the peak-to-off-peak price ratio on demand response and explores the effects of enabling technologies such as smart thermostats and in-home displays. It also discusses the potential incorporation of new rate designs that combine variable rates with demand charges, demand subscription services, and transactive energy in future research. The conclusion asserts the reliability and predictability of price-based demand response, particularly with the support of enabling technologies, and anticipates further advancements in the field.

Ref. [22] examines the equity of dynamic tariffs as a strategy to encourage consumers to adjust their electricity usage patterns in response to fluctuations in network demand, particularly during peak times. The emergence of intermittent renewable energy sources and growing electricity consumption has posed challenges in managing network congestion. It delves into the conflict between economic rationales supporting dynamic pricing and public perceptions of injustice through both theoretical analysis and empirical investigation. The notion of fairness is broadly defined, extending beyond mere inequality to encompass ethical considerations. Through a mix of theoretical evaluation and survey data from Dutch households, the study evaluates the fairness of dynamic tariffs in comparison to transport and capacity tariffs and Ramsey pricing. The methodology integrates economic, ethical, and behavioural criteria into an evaluation framework, employing both top-down and bottom-up approaches. It identifies four primary types of grid tariffs: transport and capacity charges, (socialised) flat rates, dynamic tariffs, and Ramsey pricing. The fairness assessment indicates that dynamic tariffs are viewed as less equitable than transport and capacity tariffs but fairer than Ramsey pricing. Implementation conditions, such as providing clear justifications, ensuring basic needs are met, addressing concerns about peak usage, and enhancing predictability, are identified as key factors influencing the fairness of dynamic tariffs. The conclusion points out the necessity of an interdisciplinary approach that integrates economic, social science, and ethical perspectives. It suggests that the fairness of dynamic pricing depends on specific implementation conditions and suggests avenues for further research, including exploring and testing fairness-enhancing conditions.

The importance of advancing retail electricity markets to align with the transition to a net-zero economy is discussed in [23]. It emphasises the need for effective transmission of wholesale electricity expenses to consumers and examines customer engagement strategies to enhance this link. Three main strategic themes are highlighted: 'Customer Focus,' 'Tariff Design,' and 'Innovation.' The study reviews current trends and stresses the significance of integrating market mechanisms and technology for resilient retail electricity market function. Challenges and opportunities associated with transitioning to a net-zero economy are explored, with a focus on market harmonisation and smart grid technologies. The study also examines traditional and emerging retail electricity pricing models, including the role of dynamic pricing and green tariffs. The conclusion emphasises the pivotal role of customer engagement strategies and suggests areas for future research to support net-zero objectives.

Another study focused on examining the deployment of distributed flexibility in electricity generation by incentivising prosumers for system-friendly actions [24]. It proposes a two-step tariff for feed-in electricity with dynamic tariff switching times, using the European Power Exchange (EPEX) Day Ahead price as a suitable price signal. The study aims to influence distributed energy system behaviour, comparing the proposed dynamic tariff with other tariff structures and the EPEX Day Ahead price. Simulated operation of a micro-combined heat and power system unit evaluates the impact of financial incentives on system operation parameters, complexity reduction, and benefits for system operators and end-consumers. The dynamic two-step tariff aligns well with highly variable incentives and could replace time-of-use incentives, offering a simplified tariff structure to deploy decentralised unit flexibility in the distribution grid.

Furthermore, [25] examines the obstacles and potentials linked with merging retail electricity and natural gas markets, particularly focusing on dynamic pricing and demand response (DR) management. The paper surveys existing literature on dynamic pricing methodologies and integrated DR management for multiple energy systems. The findings of the study demonstrate that dynamic pricing leads to reduced prices during off-peak periods, motivating consumers to shift energy consumption to those time frames. This dynamic pricing tactic results in increased profits for both utility companies and DR aggregators, ultimately enhancing social welfare.

Ref. [26] delves into the interaction between retail rate reforms, particularly ToU tariffs, and climate policy within the Fujian electricity market in China. Its objective is to comprehend how the adoption of ToU pricing interfaces with emissions trading schemes and its repercussions on the welfare of electricity producers and consumers. The study categorises existing literature on ToU tariffs into three themes: factors influencing consumer acceptance, structural design, and the impacts of implementation, noting conflicting conclusions on their economic, environmental, and social impacts. The outcome summarises the impacts of the interaction between retail tariffs and climate policy, reporting an increase in tariff rates, demand response, producer rent, and a decrease in consumer rent and overall welfare. It highlights the potential challenges and trade-offs in achieving social and environmental benefits while considering the losses to consumer rent and overall welfare. The paper also proposes policy implications, emphasising the need to reduce the cost of compliance to climate policy for a successful transition to a competitive and low-carbon electricity market. It also advocates for integrative electricity pricing that includes climate change policies to achieve carbon neutrality and sustainable development goals.

Ref. [27] explores the growing adoption of renewable energy within electricity networks and the obstacles associated with managing intermittent generation and demand fluctuations. It notes that tariff systems play a crucial role in influencing demand, particularly for residential customers historically subject to fixed electricity tariffs. Various demand response programs are examined, with a focus on price-based signals like ToU, CPP, and RTP. The study highlights the challenge of developing precise control and market frameworks for DR programs and suggests a specific tariff design to tackle this issue. This proposed design aims to achieve cost reflectivity and dynamic pricing by distinguishing between fixed and variable cost components within tariffs. The paper also discusses barriers to implement flexible tariffs, including load barrier design, potential revenue reduction for grid operators, and relatively minor savings in energy procurement costs. It suggests that certain tariff designs could lead to undesirable opportunistic bidding of automatable devices and proposes a specific combination of flexible power and energy components to optimise both energy procurement and stable peak demand.

Ref. [28] delves into the repercussions of implementing a hybrid time-varying tariff strategy on residential electricity usage within the context of China's evolving electricity market. It investigates how residential consumers react to complex rate structures, indicating that they likely perceive and react to average prices. Using Zhejiang province as a case study and leveraging price elasticity estimates from prior research, the study evaluates the effects of time-varying tariff strategies on a typical household's electricity usage and expenses, considering fixed tariffs, inclining block rate (IBR), and time-of-use inclining block rate (ToU-IBR) schemes. The findings reveal patterns in electricity expenses, average electricity prices, and changes in electricity consumption under different tariff structures. Notably, the study suggests that ToU-IBR pricing may offer advantages over other options, resulting in reduced household electricity bills due to lower average prices. It suggests that China's hybrid pricing policy could contribute to conserving resources by curbing electricity consumption. Nevertheless, the study recognizes limitations, including the necessity to account for various household characteristics and conduct sensitivity analyses on crucial parameters. The study concludes by advocating for further research to develop a demand response model that integrates price-based and incentive-based measures for a more comprehensive evaluation of the impacts of time-varying tariff strategies on residential electricity demand.

2.2 Feed-in-Tariffs

Ref. [29] discusses environmentally friendly choices in energy, focusing on solar plans. It mentions the potential cost savings of installing a solar energy system based on factors such as energy usage, chosen offers, and installation expenses. Solar systems, utilising photovoltaic panels, can be connected to the grid or operate off-grid. When connected, individuals may receive payment for excess electricity fed back into the grid, subject to government rules and retailer-specific solar FiT. Two types of FiT, net and gross, are explained, with their usage varying across Australian states and territories. The article also advises that installing a solar system does not guarantee cheaper electricity bills, emphasising considerations such as system size, sunlight exposure, energy usage patterns, chosen energy plans, and potential additional costs like meter installation. It also highlights the importance of understanding the terms of agreements with solar panel suppliers, including electricity price structures, system maintenance, and ownership issues.

The financial benefits of utilising solar energy from rooftop panels, emphasising the process of feeding excess solar energy back into the grid is highlighted in [30]. This surplus energy results in a FiT, a payment credited on the electricity bill and provided by the electricity retailer. The FiT rates vary across Australian states, and specific details for each state are outlined. In New South Wales, Victoria, South Australia, and Queensland, Simply Energy offers standard FiTs, with potential eligibility for higher rates based on individual plans. Additionally, premium feed-in-tariffs (PFiT) in Victoria and distributor feed-in-tariffs (DFiT) in South Australia are discussed, each with distinct eligibility criteria and conditions, such as property linkage and tariff continuation after moving. The Solar Bonus Scheme FiT in Queensland is explained, including conditions for maintaining eligibility. The text concludes with information on the Australian Capital Territory's (ACT) FiT provided by Simply Energy and encourages readers to explore state-specific details.

The challenges stemming from the increased adoption of local PV generation and storage among residential grid users in European countries are discussed in [31]. It delves into the conflict between traditional energy-based grid tariffs and the rising trend of self-generation. A proposed framework aims to evaluate tariffs by taking into account user responses, particularly regarding PV generation and battery storage. Key issues highlighted include the impact of local self-generation on grid costs and the issues caused by injection peaks for grid operators. The current energy-based tariffs are found inadequate in incentivising users to reduce injection peaks, necessitating a reflective tariff design. Various tariff proposals are examined, including capacity-based and time-differentiated tariffs, with an emphasis on considering user reactions when assessing the suitability of tariff designs. Efficiency measures for tariff evaluation are formalized, focusing on cost-reflectivity, minimising future costs, and the impact on PV generator profits. A simulation model framework is developed to quantify these measures within the context of self-generation with PV and storage, incorporating aspects such as grid dynamics, tariff structures, user responses, commodity prices, subsidies, and investments. An initial capacity tariff is implemented in Flanders and Germany, accounting for increasing levels of self-generation. The study points out the importance of considering and quantifying criteria when comparing tariffs, highlighting a trade-off between different criteria. Insights into tariff design are provided through the case study, emphasising the careful consideration of components such as off-take capacity and injection, while factoring in the costs of user responses. In summary, the study presents a framework for evaluating the reflectivity of externally provided grid tariffs, particularly in the context of user responses through PV and storage. This modular framework is tailored for comparing and validating existing tariffs or testing new proposals. The case study findings stress the importance of a balanced approach in tariff design, ensuring that costs for user responses are reasonable relative to system benefits. Future research directions include comparing different tariff designs and incorporating additional devices into the user model.

2.3 EV Tariffs

The impact of EV charging is a prominent focus not only in extensive research but also as a pivotal element in government energy policies and the evolution of commercial services [32]. Deregulated energy systems, exemplified by countries like Australia and the UK, are undergoing swift transformations in demand dynamics. Simultaneously, they are navigating a diverse range of emerging consumer tariffs and services, which may be facilitated or constrained by interventions from electricity system operators and network owners [33, 34]. While there is potential for significant benefits, including carbon reduction, cost savings, and enhanced security, this evolving landscape carries the inherent risk of unforeseen negative consequences. Conflicting incentives or unexpected simultaneous behaviours within this dynamic context could lead to unintended challenges, underscoring the importance of a nuanced and adaptive approach to the integration of EV charging within these changing energy ecosystems. Many studies have examined electricity tariffs [35], both with and without considering EV loads. However, there remains a need for a comprehensive review that integrates these various aspects into a unified process. This study aims to conduct a critical review of the most recent research on EV tariffs, categorising and organising them into distinct sections based on their design.

The study conducted in [36] explored the influence of charging fees and battery levels on users' demand elasticity within the context of coordinated charging/discharging optimisation. The findings aimed to establish demand response conditions, offering users valuable insights for autonomously responding to optimisation strategies. The study's parameters involved 3,000 EVs, each equipped with a 35 kWh battery. Additionally, the uncoordinated charging electricity price (fixed electricity price) was calculated as the average of the peak-flat-valley prices, amounting to

0.841 yuan/kWh. In a similar line, in [37], the authors focused on EV dwell periods that frequently exceeded required charge session durations, introducing a variable element to charging behaviour. To comprehend this variability, two types of ToU rate responses were implemented, offering a nuanced insight into diverse charging scenarios. In the first scenario, customers promptly reacted to off-peak rates, while the second scenario portrayed a more dispersed customer response, where a preference for off-peak rates persisted, but reactions to lower rates were randomly distributed. In both scenarios, the primary charge scheduling objective was to ensure sufficient time for delivering the required energy before factoring in ToU rate responses. The first scenario aligns with a probable outcome based on customer charge scheduling, while the second scenario strategically distributes demand and restricts customer reactions to sudden changes in electricity costs immediately after 7 pm. Throughout the study, on-peak hours were defined from 12 pm to 7 pm, with all other times of the day considered off-peak utility rate periods. In summary, the two ToU responses were classified as follows:

1. **ToU Immediate:** EV customers strategically avoided peak electricity costs, initiating charging immediately after the on-peak period concluded at 7 pm.
2. **ToU Random:** EV customers ceased charging during on-peak hours and resumed charging at random intervals when off-peak rates resumed.

In [38], an extensive investigation incorporated various EV tariffs, including the static ToU summer electricity price (known as E19), the commercial electricity vehicle (CEV) rate, introducing a capacity subscription in place of the demand charge with updated ToU rates to encourage morning peak solar charging. Additionally, the study considered a purely ToU rate schedule known as ToU-EV-8, which distinctly penalises the evening peak period, as illustrated in the figure below.

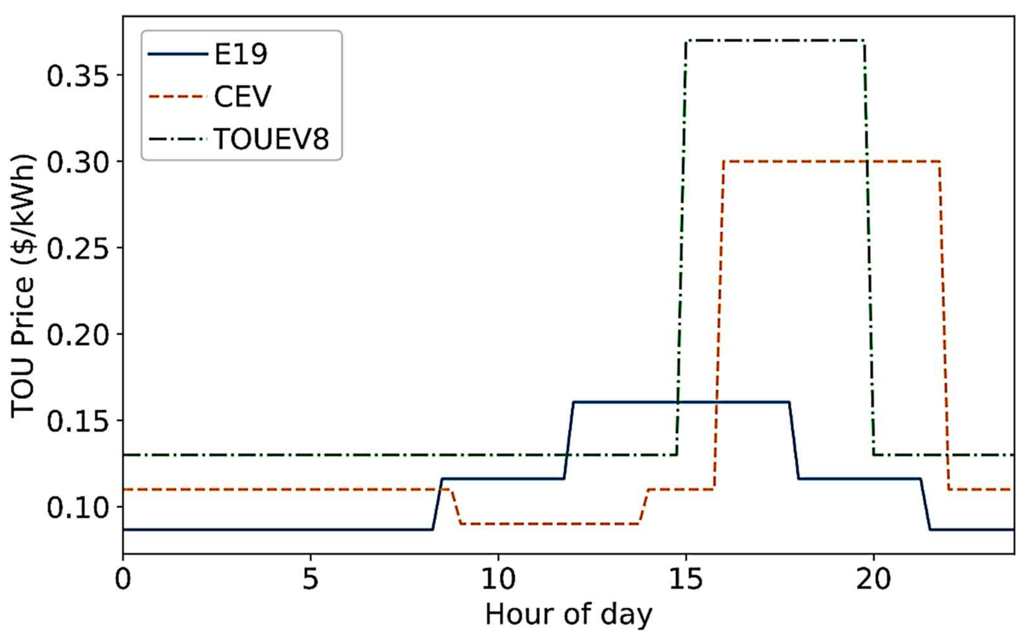

Figure 2: TOU energy schedules prices—E19 and CEV summer rate schedules, along with ToU-EV-8 summer rate schedule— Peak pricing occurs at midday for E19 and in the evening for the CEV and ToU-EV-8 rate schedules.

In [39], the authors investigated the impact of EVs on distribution substations using both a flat tariff (fixed at 0.18 €/kWh) and a dynamic tariff to implement simple and optimal smart charging at varying EV penetration levels and renewable generation, detail is shown in the following table:

Table 1: Average EV tariffs in cent/kWh [39].

Renewables penetration level	**EV penetration level**		
	16%	**50%**	**100%**
Low	15.64	16.42	17.13
Medium	14.42	15.25	16.05
High	12.23	13.12	14.05

The authors created a hypothetical dynamic tariff, assuming the wholesale cost component aligns with the spot market price. They employed regression analyses, revealing a significant dependency of the spot market price on the residual load influenced by EV charging decisions and fluctuating renewable energy generation. The study ultimately established a meaningful two-parameter linear model for a dynamic electricity price.

In [40], the authors conducted a comprehensive simulation to model the dynamic electricity demand patterns arising from a fleet of grid-connected EVs. The introduced model encompasses a diverse set of plausible tariffs, including a strategic approach explicitly aimed at minimising grid carbon emissions. Also, houses with one EV each use dedicated chargers linked to a secondary substation, optimising charging prices through a control algorithm, considering various tariffs in the UK. The model incorporates on-demand, smart, and capacity-managed charging for 384 houses connected through low-voltage feeders. All collectively described as tariffs are as follows:

Flat: The cost of electricity remains constant per unit (kWh) throughout the day, weekdays, or weekends (p/kWh).

Informed Distribution Use of System (DUoS): A stepwise tariff fluctuating across three-time bands (green, amber, and red) during the day. The red band signifies the highest price during peak demand (p/kWh).

Economy 7: A two-price stepwise tariff with a lower rate applicable for 7 overnight hours (p/kWh).

Dynamic: Prices vary every Half Hour (HH) with distinct values for each HH period (p/kWh).

Carbon Intensity: Fluctuating carbon intensity values per half hour (HH) (gCO2/kWh).

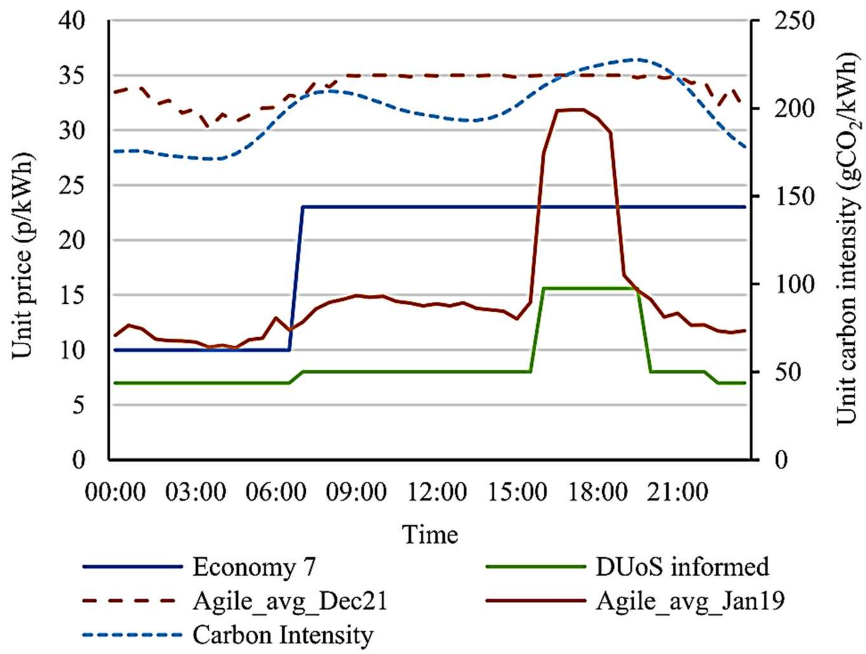

Figure 3: Electricity price in different tariffs in the UK [39]

In each scheduling window, the algorithm reviews all tariffs in set C. If a user applies a tariff for smart charging, that tariff is included in C. The authors introduced a matrix with two columns: time stamp, t, and the tariff of that time stamp, C. This matrix is sorted by tariff in ascending order. The time with the lowest tariff is chosen, and all the EVs connected at that time using this tariff (EV_{ti}) are considered charged. Their remaining demand is then updated accordingly. This process repeats, selecting times with progressively higher tariffs until all EVs meet their energy demand.

In [41], and [42] the authors explore how commercial customers strategically optimise their EV charging to minimise costs. The analysis incorporates real-world tariffs and accounts for the voltage impacts of EV charging on a realistic distribution feeder. Commercial customers with peak energy consumption of up to 499 kW are presented with the choice between two tariffs—namely, B-10 and B-19—as their electricity rate, regardless of whether they own EVs. Alternatively, those commercial customers who possess EVs can select the Battery Electric Vehicle (**BEV**) tariff (Single ToU hour Schedule) for charging their EVs on-site. However, the prerequisite for opting for the BEV tariff is the installation of a separate meter for EVs, while the continued use of either the B-10 or B-19 tariff is maintained for other electrical loads. Consequently, the researchers crafted a model for customers with EVs, delineating their building loads under the B-10 tariff and allocating the BEV tariff specifically for their EV charging needs. Introducing a fourth tariff model, labelled the TEST-EV tariff, they integrated the pricing and ToU hours of the BEV tariff while adopting the power pricing structure of the B-10 tariff.

The B-10 and B-19 tariffs adhere to a three-season ToU hour schedule, whereas the BEV tariff follows a consistent schedule throughout the year. Each ToU schedule encompasses up to three pricing periods per day. For instance, in summer ToU hours, these periods comprise "Peak," "Partial Peak," and "Off-Peak" hours and spring ToU hours encompass "Peak," "Off-Peak," and "Super Off-Peak" hours (as shown in Figure 4). While the BEV tariff aligns with the spring ToU schedule, its application extends throughout the year. Additionally, winter ToU hours mirror the spring ToU schedule but exclude a "Super Off-Peak" period. Each period incurs different volumetric energy consumption charges, with "Peak" registering as the most expensive and "Super Off-Peak" being the most economical.

The B-10 tariff operates on a fixed-level demand charge structure, where customers are billed based on their peak power consumption in a billing cycle. Conversely, the B-19 tariff introduces time-differentiated demand charges, replacing the fixed-level demand charge. These charges are computed based on the maximum power consumption during various intervals aligned with TOU periods. In the B-19 tariff, customers encounter distinct demand charges for their maximum power consumption in the "Peak" ToU period, the "Partial Peak" period, and a cumulative demand charge for the highest power consumption at any point in the billing period. The latter demand charge may overlap with the "Peak" or "Partial Peak" demand charge if the overall maximum power consumption occurs during one of these ToU periods. In billing periods lacking a "Partial Peak" ToU period, billing is restricted to the "Peak" and overall maximum power consumption.

Furthermore, the authors analyse the charging strategy under the BEV subscription model, customers acquire their anticipated power in 10 kW blocks for a smaller EV charging load (BEV-1) or 50 kW blocks for a larger EV charging load (BEV-2). Irrespective of the actual power consumed by the EVs in a given billing period, customers are charged for the purchased blocks. After the billing period, the customer's maximum EV power usage is compared to the chosen subscription level. Should the customer's maximum EV power exceed the total power purchased in the subscription blocks, they incur a volumetric overage fee. Essentially, this overage fee operates as a high fixed-level demand charge for EV power that surpasses the chosen subscription level. Conversely, if the maximum EV power consumption is equal to or less than the subscription blocks acquired, no additional fees are levied. The subscription mechanism of the BEV tariff exemplifies a three-part tariff design that comprises an access price, an allowance, and a marginal price for any usage exceeding the allowance. This allowance level distinguishes a three-part tariff from a two-part tariff, which features an access fee (fixed costs) and a marginal price (volumetric cost).

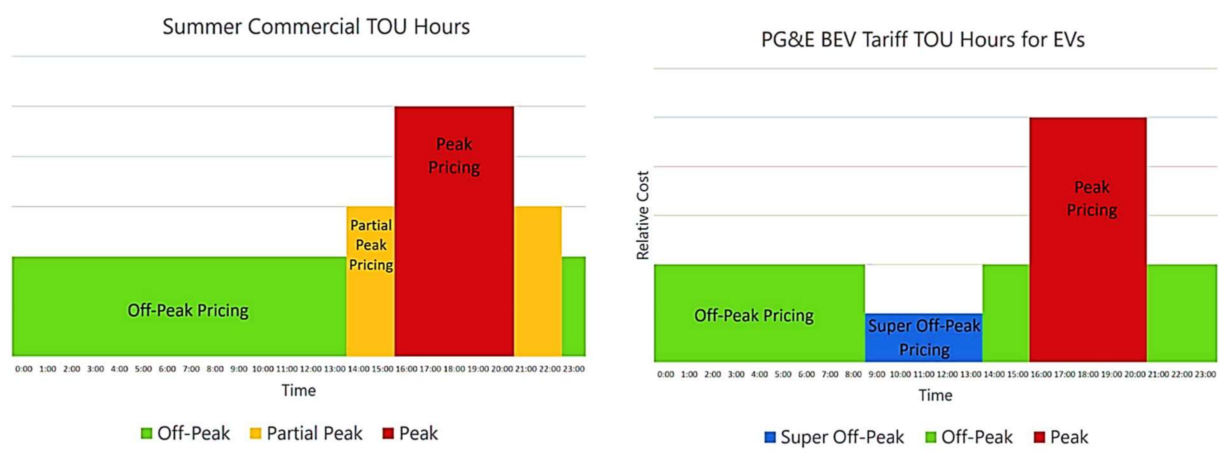

Figure 4: Electricity price in different TOU periods

When we look at the BEV tariff compared to the B-10 or B-19 tariffs, the BEV one charges the customer less, even if EV owners use more power and have to pay an extra fee. But here's the thing: with the B-10 and B-19 tariffs, the authors figured out how much EV owners owe by measuring how much power EV owners use. With the BEV tariff, EV owners have to guess how much power they will need and pick a subscription level based on that. To see exactly how the lower charge and the new subscription approach affect things, the authors made up a tariff called TEST-EV. It works just like the BEV tariff, except for how it calculates costs. Instead of subscriptions, TEST-EV uses a charge per kW that comes from the subscription prices in the BEV tariff. The diverse tariff options are outlined comprehensively in the following table below for easy comparison.

Table 2: The retail tariffs for different strategies

B-10			**B-19**	**Test-EV-2-S**	**Test-EV-2-1**
Season		**$/kWh**	**$/kWh**	**$/kWh**	**$/kWh**
Summer	Peak	0.26824	0.16285	1.9112	1.2410
	Partial peak	0.26824	0.13284		
	Off-peak	0.17399	0.11162		
Winter	Peak	0.19198	0.14379	1.9112	1.2410
	Partial peak	0.15650	0.11154		
	Super off-peak	0.12016	0.06826		

In [43], which was conducted in the UK, the authors focused on the pivotal role of electricity tariffs and consumer behaviour in shaping business models like vehicle-to-grid (V2G) and vehicle-to-home (V2H) services. The study introduced diverse scenarios comparing flat tariffs, two-rate Economy 7, Economy 10, and a three-rate ToU tariff. While the flat tariff, priced at 0.144 £/kWh, lacks the incentive to encourage the shift of electricity use from peak to off-peak hours due to the absence of economic rewards, two-rate Economy 7 and Economy 10 tariffs could potentially offer improved demand side management. For Economy 7, which applies peak and off-peak rates, the average rates were 0.174 £/kWh during the day and 0.079 £/kWh at night in 2017. Economy 7 customers enjoyed seven hours of off-peak pricing between 22:00 and 8:30, while Economy 10 offered ten hours of off-peak rates distributed across 24 hours, typically including three hours in the early afternoon, two in the late evening, and five overnight, contingent on location and energy supplier. The three-rate ToU tariff considered variations for weekdays and weekends, featuring a penalty period with extremely high electricity prices at 0.2999 £/kWh between 16:00 and 20:00 during weekdays, as outlined in the table below.

Table 3: The retail tariffs for different strategies

Three ToU tariff				**Economy 7**		
Time of day	**weekday**	**weekend**		**Time of day**	**weekday**	**weekend**
Midnight- 7 am	0.0641	0.0641		**Midnight- 7am**	0.079	0.079
7 am -4 pm	0.1402	0.1402		**7 am- Midnight**	0.174	0.174
4-8 pm	0.2999	0.1402				
8 pm-Midnight	0.1402	0.1402				

* All price is based on £/kWh

The study results showed that, on average, Economy 7 users consumed 42% of electricity during off-peak hours and 58% during peak hours, with variations observed for both profiles on weekends and weekdays. The three-rate tariff closely aligned with the demand curve, suggesting potential higher electricity costs if consumer behaviour remained static. Conversely, the two-rate tariff structure exhibited a less optimal match, particularly failing to adjust for the evening peak.

In [44], the authors conducted a comprehensive evaluation of a novel tariff model gaining prominence in the Netherlands known as the Capacity Subscription (CS) model. This innovative tariff structure is deemed more equitable and reflective of costs compared to the existing fixed network electricity rate. In this proposed system, consumers proactively subscribe to a predetermined level of network capacity. Within this subscribed capacity, they have unrestricted access to the network without incurring additional charges at any time. However, if their load consistently exceeds the subscribed capacity over a specified time interval (e.g., 15 minutes), there are currently two primary penalty variants. In one approach, consumers face an additional fee per kWh of exceedance, while in the other, they are shifted to the next higher subscription category for the subsequent settlement period.

This tariff system inherently reflects costs more accurately than the fixed tariff, as peak loads beyond the subscribed capacity incur higher charges. Furthermore, it incentivises consumers to keep their EV charging power below the subscribed capacity, promoting a more distributed and efficient use of the network over an extended period. This approach minimises the risk of network component overload. Although the settlement fees for exceeding subscribed capacity introduce some unpredictability, in practice, charges remain relatively stable. In cases of frequent exceedances, households have the option to select the next higher subscription level, contributing to a more manageable and adaptable system.

Along the same line, in [45], the authors investigated into examining the economic repercussions and efficiency of CS tariffs for both consumers and distribution system operators (DSO). Under this tariff structure, customers subscribe to a designated capacity level, reminiscent of prevailing grid tariff frameworks. The CS tariff encompasses an annual fixed cost mirroring DSO fixed costs, similar to an internet subscription's fixed fee for a specific bandwidth speed. Additionally, a capacity cost per kW is levied, distinguishing it from traditional tariffs. Notably, demand below the subscribed capacity incurs a minor energy term reflecting marginal grid losses, while demand exceeding the subscribed capacity triggers a higher energy term, penalising excess usage. This design incentivises consumers to maintain their demand below the subscribed capacity level.

However, the authors identify a sub-optimal aspect in the "static" nature of the CS tariff, which consistently penalises excess consumption irrespective of grid congestion. To address this, they propose a "dynamic" CS alternative, activating capacity limits only during grid capacity scarcity. In scarcity situations, consumers are physically constrained to their subscribed capacity using load-limiting devices. This dynamic CS approach proves more efficient, eliminating penalties for using capacity during non-scarcity periods. Nevertheless, consumers experience a partial loss of load, constituting a welfare loss that necessitates consideration in cost optimisation efforts. All cost levels related to CS-based tariffs are shown in the following:

Table 4: All cost levels related to CS-based tariffs

Cost elements	**Cost**
Fixed cost	135 €/year
Capacity cost (static)	67.5 €/year
Capacity cost (dynamic)	54 €/year

In [46], the authors emphasise the significant impact of electricity tariffs on charging behavior, particularly concerning the timing of charging activities. In their study, they categorise households into two types based on meter configurations, and consequently, the presumed electricity tariffs for the 84 resident vehicles. Households with standard meters are assumed to be on a flat rate tariff, where the average price per kWh is 22.77 $/kWh. Conversely, households equipped with economy meters are presumed to operate on an Economy 7 tariff, balancing a higher day unit rate of 27.55 $/kWh with a reduced night unit rate of 15.93 p/kWh. Charging for households on a standard tariff begins immediately upon plugging in the EV, given the flat rate nature that eliminates timing considerations for financial reasons. On the other hand, households on the Economy 7 tariff delay EV charging until midnight, when the more cost-effective off-peak hours commence, assumed to be from 00:00 to 07:00.

Assessing the complexity of electricity tariffs can be subjective, influenced by individual user traits such as their willingness and availability to engage with network tariffs or the presence of a smart home energy management system. In [47], the authors proposed a categorisation based on four levels of increasing difficulty for tariff assessment. These levels span from simple traditional tariffs to more complex models:

1. Fixed Tariff:

– Charge: €250 per customer per year.

2. Volumetric Day-and-Night Tariff:
   - Daytime charge: 5 cents/kWh
   - Nighttime charge: 2.5 cents/kWh
3. CS Tariff:
   - Subscription levels: 2, 4, 8, and 17.3 kW
   - Yearly charges: €192, €252, €480, and €900
   - Penalty: €0.5 for every kWh exceeding the subscribed capacity.
4. Mixed Measured Capacity and TOU Volumetric Tariff:
   - Modelled after the current distribution tariff in Spain.
   - Measured capacity peak charge: €19.318/kW per year

The volumetric charges are defined as follows:

- 0.0559 cents/kWh (12 am to 8 am)
- 1.7076 cents/kWh (8 am to 10 am, 2 pm to 6 pm, 10 pm to 12 am)
- 2.2658 cents/kWh (10 am to 2 pm, 6 pm to 10 pm)

Table 5 provides a comparative evaluation of the performance of four tariffs, with rankings based on their relative performance. The assessment considers both low and high EV penetrations for cost reflectiveness, recognizing significant variations in results. Efficiency is evaluated only for high EV numbers, highlighting that volumetric and fixed tariffs fare poorly under such conditions. This observation underscores the outdated nature of many current tariffs, particularly those that are not well-equipped for grids with a high proportion of flexible loads. Notably, capacity-based tariffs demonstrate superior performance in terms of both efficiency and cost reflectiveness in grids with substantial flexible loads.

Table 5: The performance of the four tariffs was comparatively assessed relative to each other.

Tariff	**Cost-refl. Low EV**	**Cost-refl. high EV**	**Efficiency high EV**	**Simplicity**
Fixed	--	--	--	++
Vol. Day–Night	++	-	--	+
Capacity subscription	+	++	++	-
Mixed Capacity-ToU Vol.	+/++	+	+	--

In [48], focused on minimising charge point operators' (CPOs) costs and power losses while maximising EVs' state-of-charge (SOC) using dynamic day-ahead tariffs. A comparison was made with introduced stacked tariffs, managed by the DSO. The stacked dynamic tariff incorporates day-ahead electricity costs and dynamic network costs, demonstrating a 34.1% reduction in congestion compared to using day-ahead tariffs alone, which resulted in 6.6% more congestion in the lines during peak periods from 4-9 pm.

In [49] the author discusses the importance of time-of-use (ToU) tariffs in promoting efficient EV charging behaviour and evaluates Synergy's new midday saver tariff in Western Australia. The author emphasises the significance of well-structured tariffs to encourage EV owners to charge during optimal times, such as daytime when solar energy is abundant or nighttime with spare network capacity. The midday saver tariff offers cheaper electricity rates during the middle of the day and night but introduces higher costs during the peak period (3 pm to 9 pm) and an increased daily supply charge. The analysis compares the standard flat tariff with the midday saver tariff for a household with an EV doing 15,000km of driving annually. While the midday saver tariff incentivises off-peak charging, it relies on the assumption that a significant portion of the household energy is not consumed during peak hours. The potential annual savings for an average consumer with an EV under the midday saver tariff are estimated to be around $500, considering specific charging behaviour patterns. The author suggests areas for improvement, such as addressing the 50c/kWh peak rate during 3 pm to 9 pm, which may not benefit consumers with high existing peak-time energy usage. Additionally, proposing a lower rate for the middle-of-the-night period could attract drivers who are not at home during the day. The article concludes by expressing interest in monitoring the effectiveness of the midday saver tariff in promoting cost-efficient EV charging behaviour.

Diverse pricing models are designed to accommodate different consumer needs, encourage energy efficiency, and manage overall demand on the electrical grid. In the following, we categorised them into different groups.

1. **Time-varying energy-based tariffs:**

1. **Flat Price:** This is a fixed rate for electricity consumption, where the same price is charged regardless of the time of day or night [50-52].

2. **Time-varying energy-based tariffs [35]:**

1. ***Dynamic TOU pricing*** relies on smart charging services aligned with day-ahead wholesale energy market prices [53, 54].
2. ***Dynamic charging based on other real-time inputs*** enables consumers to optimise EV charging by considering factors like carbon intensity or the availability of renewable energy [55, 56].
3. ***Static ToU*** pricing involves predetermined lower charging prices during off-peak hours, often established annually. This tariff has a few fixed rates for grid peak and non-peak periods. The periods and the rates are decided ex-ante and do not differ daily but may change with seasons, weekends, and holidays [57-60].

4. ***Balancing mechanism-based tariffs optimises EV charging*** to support grid balance, utilising real-time signals or procuring flexibility from transmission system operators or market participants.
5. ***Local network or DSO*** signals, whether static, dynamic, or a blend, reflect conditions on a distribution system level, influencing EV charging behaviour.
6. ***Critical peak pricing:*** The most critical days or hours are dynamic, and the rate is fixed [61, 62].
7. ***Variable peak pricing:*** Predetermine peak periods, and the rates vary dynamically [63].
8. ***Real-time pricing:*** Rates can vary on an hourly and day-to-day basis. This tariff is often related to wholesale prices in the literature but is also applicable to grid conditions [63-65]
9. ***Peak Time Rebate:*** In this pricing scheme, customers are provided with rebates for using electricity under a certain preset limit in peak hours. Customers are rewarded for load reduction during peak hours.

3. Capacity-based tariffs

1. ***CS:*** Customers subscribe to a capacity typically lower than their installed capacity. The subscription can be changed periodically, for example, yearly. Electricity consumption above the subscribed level is subject to significantly higher rates, either always or only in strained grid situations. These periods are determined ex-post based on the customers' actual capacity usage, typically calculated as the average over an hour or less. The literature also uses the terms contracted capacity charges based on subscribed capacity or demand subscription services for this tariff [32]
2. ***Measured peak demand:*** based on the customers' peak demand, measured as the actual average power used over an hour or less. Generally, the measurement cycle of the peak is a tariff characteristic and can, for example, be yearly, monthly, or daily. This tariff is also widely known as demand charges, peak demand charges, capacity usage-based tariffs, and measured capacity [32, 66].

The potential research areas and criteria for EV tariff design are categorised and summarised in the following Figure 5:

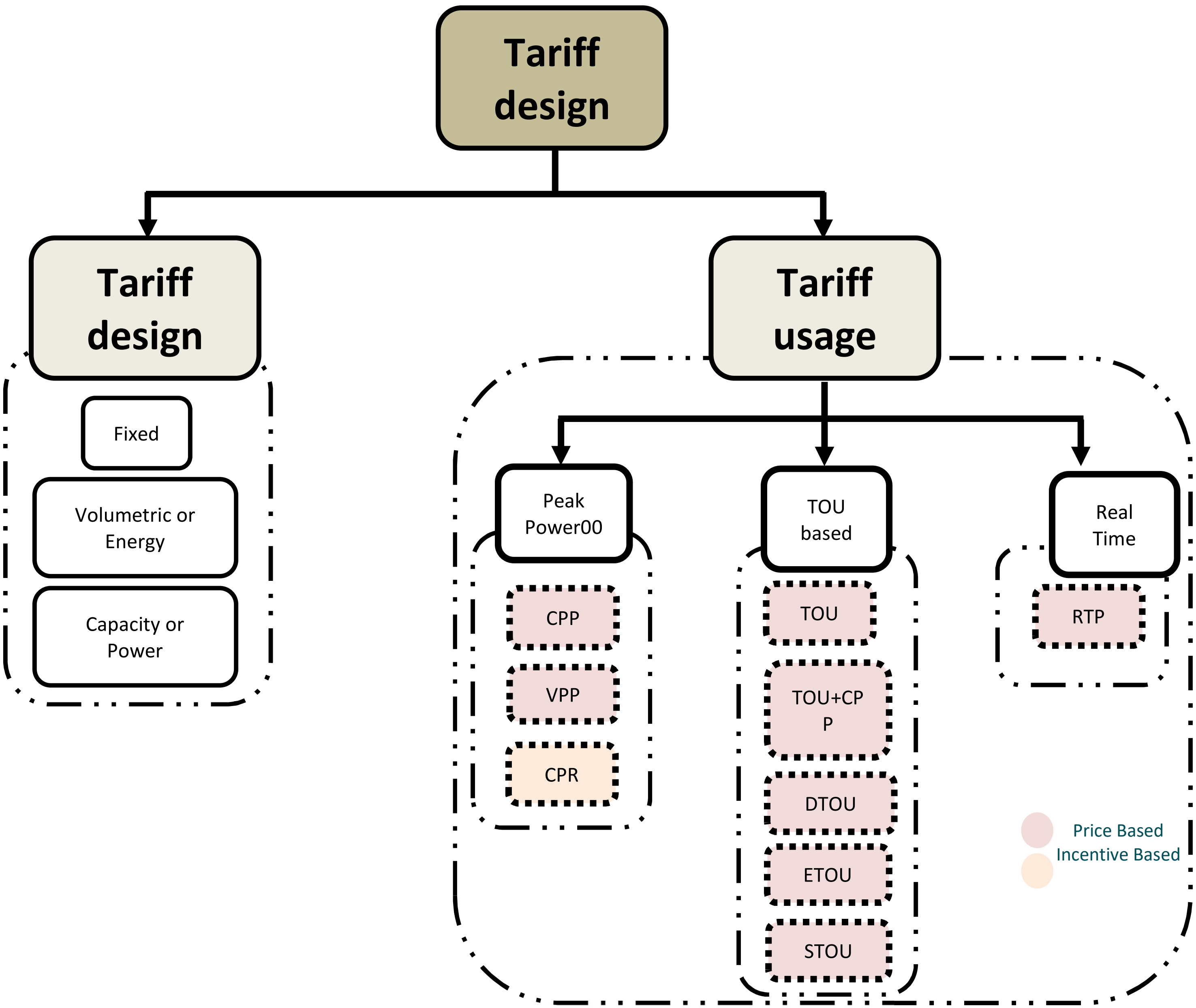

Figure 5: Categorize the variety of EV tariff designs

2.4 VPP Tariffs

Virtual power plants (VPPs) represent a transformative approach to energy management and distribution in Australia, leveraging advanced technology to integrate and optimise diverse energy resources. Essentially, VPPs aggregate DERs such as rooftop solar panels, battery storage systems, and smart appliances, coordinating them into a unified network capable of responding to grid demands in real-time. This collective capacity enables VPPs to function akin to traditional power plants, providing grid stability, flexibility, and additional services without relying solely on centralised generation.

One of the key components of VPP implementation in Australia is the development of innovative tariff structures by energy retailers and distributors. These tariffs aim to incentivise consumer participation in VPP programs while ensuring fair compensation for their contributions to grid stability and reliability.

Several types of tariffs are commonly associated with VPPs in Australia using the retailer's normal energy use tariffs:

1. FiTs: Similar to traditional solar FiTs for VPP participants compensate them for the excess energy they generate and contribute to the grid. However, VPP-enabled FiTs may be dynamic, adjusting based on market conditions, grid demand, and the availability of renewable energy.

2. Demand Response Tariffs: These tariffs reward consumers for reducing their energy consumption during peak demand periods or in response to grid instability. VPP participants can receive incentives or reduced rates for curtailing their energy usage when called upon by the VPP operator, thus helping to balance supply and demand on the grid.

3. ToU Tariffs: ToU tariffs vary electricity rates based on the time of day, reflecting fluctuations in demand and generation. VPP participants can capitalize on lower rates during off-peak periods to charge their batteries or perform energy-intensive tasks, optimising their energy usage and potentially earning credits for exporting energy during peak periods.

By offering these innovative tariff structures, energy retailers and distributors in Australia incentivise consumers to participate in VPP programs, thereby unlocking the full potential of distributed energy resources and advancing the transition to a more decentralized, resilient, and sustainable energy system.

The Alice Springs Solar Connect: Batteries program offers households the opportunity to participate in VPP battery trials, where 1.75kWh of their battery's capacity is reserved for providing daily grid support services in exchange for a monthly VPP credit on their electricity bill [67]. Participants can choose between their existing standard tariff or a special 7-11 tariff designed for the trial, which optimises battery charging and discharging for financial returns and accommodates more solar in the community. Eligible participants need to be Jacana Energy customers, own the home they wish to register, have continuous internet connection, and own an eligible solar and battery storage system. For new installations, households receive a $500 VPP voucher, while existing systems qualify for a $200 voucher. Both groups receive a $50 monthly credit for 12 months. The 7-11 tariff schedules the battery to absorb solar energy during midday and offers varying rates throughout the day for consumption and feed-in. Supported inverters include models from manufacturers like Fro-nius, Sun-grow, SMA, Solax, and Red-back, among others, with excluded models from ABB, Delta, Enphase, Good-we, and SolarEdge. The tariff rates vary based on time periods and solar/battery behaviour, with different rates for solar PV behaviour and battery behaviour during specific time slots, allowing households to optimise their energy usage and grid support while earning credits on their electricity bills.

Table 6: Alice Springs VPP program rates

Time period	Consumption rate (c/kWh)	Feed-in rate (c/kWh)
7am – 11am	26.653	17.6
11am – 7pm	15.4	4.4
7pm – 11pm	26.653	17.6
11pm – 7am	15.4	4.4

Discover Energy's VPP Premium Plan offers eligible battery and solar customers an industry-leading solar feed-in tariff of 30 cents per kWh for the initial 3.28 kWh exported daily, coupled with profit-sharing opportunities through energy trading [68]. The paradigm shift towards receiving compensation for electricity rather than incurring costs reflects the direction of future energy consumption. Discover Energy's VPP initiative epitomizes this forward-looking energy landscape, demonstrating that the future is already within reach. Under the Discover Energy VPP Premium Offer, solar feed-in rates are as follows in the table:

Table 7: Discover Energy's VPP premium plan

Block	Feed-in rate (c/kWh)
First 3.28 kWh	30
Next 3.28 kWh	18
All remaining kWh	9

Usage thresholds are calculated daily, and customers have the flexibility to terminate this Energy Plan at any time. Participation is limited to Discover Energy VPP Approved Operated Products, with eligible inverter brands including GoodWe, Sungrow, Solar Edge, Alpha ESS, Growatt, QCELLS, and Huawei [68].

The emergence of VPPs and associated tariff structures represents a significant step forward in Australia's energy landscape, facilitating greater integration of renewable energy, enhancing grid stability, and empowering consumers to play an active role in the energy transition. As technology continues to evolve and VPPs become more prevalent, these initiatives hold promise for a cleaner, more efficient, and more equitable energy future.

2.5 Community Battery Tariffs

In Victoria, Australia, the concept of community battery trials has gained traction as a promising approach to enhancing energy reliability, affordability, and sustainability within communities. Community battery trials involve the installation of large-scale batteries in local neighbourhoods, which can store excess energy generated from renewable sources like solar panels. This stored energy can then be used during peak demand periods or emergencies, reducing strain on the grid and providing backup power during outages.

One significant aspect of these trials is the development of innovative tariff structures by various electricity distributors such as Powercor and Jemena. These tariffs aim to incentivise community participation in the utilisation of community batteries while ensuring fair and cost-effective energy distribution. Each distributor may offer slightly different tariff structures tailored to their specific service areas and community needs.

Ref. [69] discusses the importance of community battery services in the transition to renewable energy. It emphasises the need for energy storage to manage the fluctuations in renewable energy generation. Community batteries, often owned and operated by local governments or organisations, play a crucial role in integrating renewables into the grid while ensuring reliability. The benefits of community batteries include sharing locally generated solar energy, reducing carbon emissions, and providing reliable power during peak demand. Power companies like Powercor take on various roles in supporting community battery projects, either as project leads or delivery partners. They offer services such as project development, connection support, and tariff structures tailored for community batteries. Additionally, they provide data services and revenue opportunities for third parties involved in battery projects. Examples of community battery projects, like the one in Tarneit developed by Powercor and supported by the Victorian Government, demonstrate the effectiveness of such initiatives. The text also provides contact information and references for further information on community battery services and partnership opportunities.

Table 8: Community battery trial tariff for retailers offered by Powercor.

Time Period	Import Rate (c/kWh)	Export Rate (c/kWh)
10am – 3pm	-1.5	0
4pm – 9pm	25	-1.0
All other times	0	0

Ref. [70] outlines the introduction of trial tariffs by Jemena starting from July 1, 2023, in response to customer demand and regulatory provisions. These trial tariffs are initially aimed at business customers but can be explored for residential or other customer types . The community battery tariff, introduced as a trial, aims to encourage the use of community batteries by offering favourable rates for storing and distributing solar energy. Additionally, a site-specific sub-transmission tariff is introduced to cater to large customers with varying energy needs, providing flexibility while recovering network costs. The parameters and components of these tariffs are subject to change based on trial results and regulatory requirements.

Table 9: Community battery trial tariff for retailers offered by Jemena.

Time Period	Import Rate (c/kWh)	Export Rate (c/kWh)
10am – 3pm	-1.5	0
3pm – 9pm	4.5	-1.5
All other times	0	0

While the specific details of these tariff structures may vary, the overarching goal remains consistent: to promote sustainable energy practices, alleviate pressure on the grid, and empower communities to take control of their energy consumption and production. Overall, the introduction of community battery trials and innovative tariff structures in Victoria reflects a proactive approach to addressing the challenges of modern energy distribution.

3 Distributed Energy Resources Management

Smaller-scale devices known as DERs are a part of the local distribution system that supplies homes and businesses with energy. DER comprises of DNSP or other entity owned resources such as community battery, and resources owned by consumers, such as CER. DERs can produce, consume, or store energy. Also, energy demand can be actively managed by DERs [71]. DERs can be either passive or active. Passive DERs simply react to available resources, such as rooftop solar PV generation responding to sunshine or pre-set internal programming and settings. In contrast, active DERs modify their behaviour in response to control signals from an external party or system [72]. Modern energy systems need to be adaptable to accommodate a high penetration of DERs to satisfy both base and controllable demand, contributing to affordable energy prices during periods of wind and sunshine, for instance [73].

Over the past ten years, Australia has seen a notable increase in the accommodation and utilisation of DERs. Between 2010 and 2018, around 6000 MW of small-scale solar PV systems were installed in the NEM. It is expected that the DER uptake trend will continue. Around 16000 MW of residential rooftop solar PV capacity, 7500 MW of home battery storage, and 25% of all vehicles in Australia are expected to be EVs by 2039. Nearly two out of every three customers are anticipated to have DER by 2050 [74]. Similar trends are also noticeable in other countries. For example, the UK has set a target to cut 80% of emissions by investing on renewables by 2050 [75]. The USA has established an ambitious decarbonisation goal through DERs. It targets 100% clean energy by 2035 and a net-zero emissions economy by 2050 [76].

The customers who purchase DERs are the primary beneficiaries. Distributed solar PV systems can lessen a household’s or business's reliance on the grid by providing them with affordable energy. Solar PV systems protect owners from outages, such as those that occur during extreme weather occurrences, when combined with energy storage. With DERs, customers can generate and use more energy according to their own requirements and preferences. Aside from facilitating fuel switching, distributed solar PV systems can also aid in decarbonisation when they replace internal combustion engine vehicles and other fossil fuel-based generators [77].

Some other potential DER services include network reliability by providing autonomous inverter responses and islanded operation, network capacity and support by supplying energy during peak hours and dealing with voltage issues, essential system services by providing contingency reserves and regulating frequency, reserve capacity by demand reduction and generation increase, wholesale energy value by providing energy generation and decreasing energy losses, and risk management by providing generation support and energy arbitrage services [72].

However, the grid is facing significant dangers due to the DER's rapid and widespread adoption. High concentrations of DERs, particularly rooftop solar photovoltaic PV systems, if left unmanaged, may negatively affect consumers by undermining the security and dependability of the grid, increasing expenses, and creating a growing gap between those who can install DERs and those who cannot. As rooftop solar PV becomes more widely used, daytime and evening demand may decrease to the point where there is a serious risk to the stability of the system. There may also be difficulties to the network operators because of the invisibility of DER’s location. Further, physical network limits may be jeopardised by the excessive local penetration caused by the DERs [72].

Short-time and long-time strategies can be implemented to expedite network-aware and economically viable DER exports and imports. The future energy scenarios (FES), led by the electricity system operator (ESO), UK, outline some credible ways for DER management that include net zero policy and delivery, empowering change, digitalisation and innovation, energy efficiency, distributed flexibility, transport flexibility, locational signals, strategic network investment, and connections reform [78].

3.1 Concepts of DERMS, ADMS, DSO, and DMO

To offset the consequences of rapid DER uptakes, systematic coordination and management of DERs are required. The DER management system (DERMS) is a solution that enables the delivery of grid services at the distribution level and allows for the aggregation and optimisation of DERs while realising their full potential. DERMS functional specifications include base functions, optional functions, and grid services. DER device information related to registration, grouping, and capability functions; dispatch, scheduling, and control of DER operation; and DER monitoring are base DERMS functions. In contrast, optional functions of DERMS address weather status and data monitoring, DER visibility, asset allocation and optimisation, business rules, and real-time settlements. On the other hand, grid services deal with actual energy delivery, load and constraint management, voltage support, frequency response, resilience, and reserve capacity ramping [79].

According to Smart Electric Power Alliance (SEPA), an American non-profit organisation envisioning a carbon-free energy system, some DERMS requirements are system integration, cybersecurity, high resilient design, scalability, maintainability, information technology services, user interface, reporting, configuration, control systems, dynamic topology, contract management, business rules, historian analysis, constraint management, forecasting, and testing [80]. Horizon Power's Onslow DER Project is an example of a DERMS project in the isolated city of Onslow, Western Australia (WA). The goal of this project is to address concurrent DER penetration concerns and enable increased hosting capacity. The project has resulted in the creation of the nation's largest DER microgrid, which is managed by a comprehensive DERMS [81].

Advanced distribution management system (ADMS) is another type of DER management technique that provides adaptable solutions to meet the fundamental needs of digital grids to ascertain network resilience and reliability. It also has the scalability to assess the operations' results and contribute to the new requirements, which include minimising network costs and enhancing asset optimisation intelligently and proactively. An integrated ADMS architecture provides geospatial electrical diagram, network connectivity analysis, real-time distribution operation model, switching order management, volt/var optimisation and control, conservative voltage regulation, load forecasting, intelligent alarm processing, feeder balancing and loss reduction, distribution contingency analysis, switching optimisation and sequence management, fault location, isolation and service restoration, relay protection re-coordination, protection and asset management solution, storm assessment, trouble call management, crew dispatch and workforce management, outage analysis and reporting, and reliability assessment [82].

The concept of DSO has also come to light in recent years due to the expanded responsibilities and tasks for the DNSP caused by the DERs' operational complexities. Two notable issues have given rise to the DSO concept: the challenge of controlling high levels of flexible DER interconnection and utilisation for bulk distribution system operations and the growing effects of DER use on uncoordinated bulk distributed system operations. In locations where DERs are employed for network service, the DSO may need to coordinate with the transmission system operator (TSO), a broader system operator at the transmission network level. This coordination is referred to as the DSO-TSO coordination [83].

Two DSO models have been recommended by the Newport Consortium based on UK Open Networks analysis. In the first DSO model, all of the information related to DER coordination goes through the DSO, enabling the DSO to leverage large-scale optimisation decomposition. A few issues with real-time information exchange or complete grid state visibility may be encountered while managing flexibility resources. In contrast, DSO and TSO share the DER coordination in the second DSO model, which results in a more intricate arrangement between these operators and the aggregators, i.e., assigned parties aggregating DERs. Because extra coordination roles are involved in the second DSO model, it is more vulnerable to cyber security and escalates the scalability issue compared to the first DSO model [83].

Moreover, a market for the supply of system and network services may need to be established when the number of DERs capable of providing network services increases. This is where the concept of a distribution market operator (DMO) comes in. By providing DER consumers and aggregators with market access and optimising the supply of services, such as voltage regulation and frequency control, as well as energy from DER within the DSO-provided operating envelopes through coordinated interfacing, the DMO manages and settles the distribution market. In order to facilitate DER's participation in the wholesale market and the supply of ancillary services, the DMO also furnishes the upstream market operator with information [84].

The DMO acts as an independent entity without any influence from DER customers, aggregators, or system operators. This is to ensure fairness in market settlements, manage DERs in the most cost-effective and efficient fashion, and abide by distribution system security and reliability requirements during market clearing [72].

3.2 DER Visibility

To better understand local power quality, flows, restrictions, and the real-time capabilities of DERs, DSOs need to have more visibility into the distribution network. The approaches used today to estimate network requirements have proven to be both quite accurate and reasonably priced. But as DER levels rise (especially for rooftop solar PV systems, behind-the-meter and front-the-meter batteries, and EVs), the tools and techniques used for assessment may not be suitable. Thus, DSOs may not be able to administer the network and publish distribution limits if there is not enough depth of real-time network visibility, hindering the provision of optimal solutions to manage the DER-rich networks while respecting technical constraints [72].

In Australia, AEMO, Western Power, and Energy Policy WA (EPWA) have combinedly recommended two actions for distribution network visibility: 1) conducting an evaluation of the distribution network's visibility capacity and creating a plan for investing in static and dynamic technologies to increase visibility in order to meet the needs of upstream systems, DMOs, and DSOs; 2) providing a static DER data register along with procedures to facilitate data gathering and upcoming DSO functionality [72]. The AEMC acknowledges the additional expenditures required for improving DER visibility and encourages DNSPs to develop business cases quantifying cost-benefit analysis to manage DERs efficiently in the long run [74].

In recent years, around 34 projects (25 direct and 9 indirect) have been trialled or are in the process of being trialled across Australia to improve DER visibility, focusing on the capability to monitor the location of DER installations and their operational capacities in real-time to optimise their benefits and control any possible effects on both local distribution networks and wider power systems [71]. One of the prominent projects named DER Visibility and Monitoring Best Practice Guide, which has been led by the industry, aims at establishing a standard for static and dynamic near real-time data collection for DERs [85]. The Distributed Energy Integration Program (DEIP) EV Data Availability Taskforce is another pioneering project that has looked into the requirements for EV data, including potential repository options [86].

3.3 Price-responsive DER

Alongside the quick adoption of DERs, DER technology is developing at a rapid pace to provide DER customers with new capabilities, enabling them to take control of their energy use and costs. A variety of smart features and functionalities are being included in DER-embedded software. One of the smart aspects is the capability to receive and react to external price signals called price-response DERs. Value from customers' price-responsive DER is being facilitated by the emergence of new business models and services. A VPP is one example, which is a network of resources coordinated by an aggregator to supply energy market and distribution network services. Aggregators control the behaviour of several DER customers to optimise energy generation, storage, and DR to maximise the value derived from DERs [87]. This entails offering following two ancillary services:

- *Market Services:* Market ancillary services keep generation and demand in balance to operate the power system safely. Examples include energy arbitrage and frequency control auxiliary services (FCAS) [88].
- *Network Services:* Network ancillary services are non-market ancillary services required to maintain the security and reliability of the power system, such as voltage support [88].

Currently, networks provide a variety of rates, such as controlled load, seasonal, and static tariffs. The existing approach, however, does not maximise the value for and from price-responsive and flexible DER, even while it permits DNSPs to operate and manage distribution networks in a safe manner. Two noteworthy reasons are the exclusion of network constraints in network tariffs and the too conservative consideration of network limits during normal operational conditions. This has led DNSPs to explore new options, and one of the options is dynamic network pricing [87].

Dynamic network pricing adds more layers of sophistication while utilising preexisting ideas of time-varying network pricing. This method ensures pricing is both efficient and easy for customers to understand by utilising modern, price-responsive DER and sophisticated automation. DNSPs or DSOs can incentivise the use of available network capacity and reward behaviours that support the local network and market by employing time- and location-specific incentives instead of system-wide rewards, which better reflect real-time network and market conditions. Some notable factors need to be considered for dynamic network pricing include the usual load and generation profiles of DER customers, DER penetration, daily weather, and local network characteristics [89].

The SAVE Project is an example of a dynamic pricing project that has been trialled in the UK led by Solvent Achieving Value from Efficiency (SAVE). Through the dynamic pricing trial, SAVE has attempted to determine how price signals can lead to DER customers' habitual changes in the method and time they use their energy. This has been accomplished by means of a daily price signal that indicates periods when the cost of consuming energy is higher or lower [90]. Project Edith is another project conducted in Australia that has created a pricing engine to enable DER customers to participate in the ancillary services by giving them dynamic pricing signals [91].

3.4 DR Programs

DR is the voluntary decrease or shift in a customer's energy use that can help maintain grid stability by balancing the supply and demand of energy. It can be advantageous to increase the flexibility and dependability of energy systems, especially if those systems include a growing proportion of DERs. Additionally, DR offers a rapid and economical means of lowering peak demand, reducing blackouts, and switching peak loads to off-peak or high solar PV hours while obviating the need for expanding energy facilities or increasing energy generation. DR participants also receive some rewards for voluntarily reducing or adjusting their energy usage [92].

3.4.1 Controllable Load-driven Programs

Controllable load-driven programs are the most common form of DR programs. There are four types of controllable load-driven DR programs [93]:

- *Shape:* Adjusting load demand routinely in accordance with a typical long-term pattern.
- *Shift:* Adjusting load demand occasionally following an external signal.
- *Shimmy:* Adjusting load demand within brief timeframes following an external signal.
- *Shed:* Completely switching off load demand.

In general, Shape, Shift, and Shimmy DR programs are classified into price-based and incentive-based programs. Price- or time-based DR exhibits a variable energy tariff, which is determined by the current level of energy expenses. This strategy offers reduced charges during times of low load demand and higher tariffs during times of high demand in an effort to balance out energy use. While a price-based DR program can perform well in real-time energy balance, participants may encounter difficulties in adjusting their energy usage behaviour in accordance with price signals. Contrarily, an incentive-based DR program enables participants to receive financial incentives, rewards, or discounts in lieu of adjusting their energy usage behaviour, facilitating their motivation to respond to system needs. Incentive-based DR programs could be of two kinds: 1) classical DR programs, such as direct load control (DLC), and 2) market-based DR programs, like emergency DR, demand bidding, and supplementary market services programs [94].

A number of controllable load-driven DR program projects have been initialised in Australia. AGL Demand Response is one of the projects in New South Wales (NSW). The residential load control trial has considered the control of air conditioners and EVs charging, contributing to nearly 3.9 MW reductions in load demand [95]. Embertec's Targeting and Automated Control of Residential Air Conditioning Loads is another DR program project based in South Australia (SA) that focuses on controlling the air conditioners of households [96]. Shell Energy is also running several DR programs across Australia, known as Wholesale DR, Emergency DR, Ancillary Services DR, and Network DR [97]. Energy Smart Heat Pump is a market-ready DR technology aiming at decarbonising heating systems in the UK [98].

3.4.2 Battery-driven Programs

As long as usable battery capacity is available during the peak period, batteries can contribute to both DR and demand-shifting capacity. A battery's demand reduction capacity and usable storage capacity have a linear relationship in order to calculate the peak reduction capacity. A battery may drain around 51.2% of its usable capacity during peak demand. However, one important impediment to adoption is the capital cost of batteries, which can be mitigated by offering upfront governmental and non-governmental incentives [99].

Various battery incentive programs have been undertaken in Australia. For instance, in Australia Capital Territory (ACT), Next Generation Energy Storage Program has enabled around 5000 DER customers to purchase batteries at a discounted rate. In Queensland (QLD), Interest-Free Loans for Solar & Storage Program has launched loans and grants for 1000 customers to install a combination of solar PV and battery storage systems. Smart Energy for Homes & Businesses Program in NSW has offered incentives for homes and businesses to purchase batteries. Up to 40000 battery storage systems have been discounted by the Home Battery Scheme in SA. Victoria (VIC) has launched two programs called Battery Storage Incentive and Solar Homes Package, aiming to accelerate battery storage and solar PV system installation [100]. In California, USA, the Self-Generation Incentive Program (SGIP) has been introduced to incentivise state-level storage systems at the residential level [101].

3.5 EV Charging Coordination

The process of recharging an EV's battery is known as EV charging. The EV is charged by connecting it to a charger or charging station. Energy is supplied to charge EVs at a charging station, sometimes referred to as an EV charging station or an EV supply equipment (EVSE). EV chargers come in various varieties, such as Level 1 chargers, Level 2 chargers, and DC fast chargers. Level 1 chargers use a regular AC power socket to provide a minimal charging capacity and are usually used at home or in offices. In contrast, Level 2 chargers are able to charge an EV more quickly and with a higher capacity. These chargers are frequently seen in public charging stations or locations where EVs are left parked for long periods of time, like parking lots and shopping centres. In comparison to Level 1 and Level 2 chargers, DC fast chargers offer an even larger charging capacity and can charge an EV significantly faster. These chargers are perfect for long-distance driving or for EV drivers who need a fast charge [102].

Charging numerous EVs in a sustainable manner necessitates well-functioning EV charging coordination. Two main categories of EV charging coordination techniques are direct control and indirect control. A central entity manages EV charging on behalf of the owners under a direct control coordination approach. In this control scheme, EVs also surrender data to the central entity, enabling it to perform global optimisation with complete access to data and the management of EVs. Direct control performs well in small-scale applications. However, it necessitates extensive communication infrastructure, involving computational expenses, and is vulnerable to a single point of failure at the central entity [103].

On the contrary, EVs independently perform local optimisations to establish charging schedules under indirect direction. This can be an automated reaction in which a local controller executes local optimisation, or a manual response in which EVs respond to pricing signals manually. Three kinds of indirect control can be distinguished: mediated coordination, bilateral coordination, and implicit coordination. Each type of indirect control can also be separated into cooperative and competitive types [103].

- *Mediated Coordination:* A central entity gathers data on EVs and relays signals back to them through mediated coordination, allowing them to be charged without direct management. In mediated competition, both EVs and a central entity maximise their own financial benefits, whereas social welfare is maximised in mediated cooperation [103].
- *Bilateral Coordination:* EVs exchange information bilaterally, and there is no signal centralisation during bilateral coordination. Applications where there is a communication infrastructure and where EVs feel comfortable exchanging information bilaterally are the best suited for this coordination strategy. In bilateral competition, EVs maximise their own financial benefits through bilateral communication, whereas social welfare is maximised in bilateral cooperation [103].
- *Implicit Coordination:* EVs that participate in implicit coordination keep their personal information private from both peers and a central entity. EVs may use historical system data or monitor their present, more comprehensive information environment to aid in their autonomous decision-making. In implicit competition, EVs maximise their own financial benefits without disclosing their private information, whereas social welfare is maximised in implicit cooperation [103].

Charge Collective is a collaborative EV charging project in the UK that brings local authorities, EV owners, and public charging stations together for coordinated EV charging and contributes to net zero carbon emissions [104]. The Faster Project is another EV charging project that focuses on facilitating a smooth and sustainable EV transition in Ireland, Northern Ireland, and Western Scotland [105].

3.6 Modern Inverter Functionalities

Inverters are used to link DERs to the grid. Inverters control how the DERs connected to them communicate with the power grid and specify how these resources have to operate in various system scenarios. The expected behaviour and performance of inverters in Australia and New Zealand at residential levels, as well as the required testing for conformity, are specified in AS/NZS 4777.2 [106].

3.6.1 Export Limit

An export limit is the highest quantity of locally produced energy that can be exported to the grid or fed back into it, above what is needed for personal use. The export limit is meant to contribute to the stability and safety of the system. The installation of an export limiter, a sensor that measures the amount of power supplied to the grid, is required in order for the DER system to be export limited. Export limits are usually set according to the technical connection requirements of DNSPs [107]. For instance, AusNet Services has fixed a 5 kW export limit per phase at the residential level in VIC because of network restrictions [108].

SA Power Networks has set both fixed and flexible export limit schemes in SA. A fixed export limit scheme allows residential customers to export 1.5 kW per phase, whereas between 1.5 kW and 10 kW per phase can be exported back to the grid in a flexible export limit scheme [109]. In the UK, SP Energy Networks has enforced a 3.68 kW export limit per phase for Central and Southern Scotland, North Wales, Merseyside, Cheshire, and North Shropshire [110]. In some cases, a zero-export limit may be in practice while DNSPs upgrade their infrastructure, which restricts customers from exporting anything to the grid [111].

3.6.2 Volt-Var Control

Volt-var capability is mandatory for grid-connected inverters in Australia and New Zealand as per AS/NZS 4777.2.2020 requirements. For example, all DNSPs in VIC require sinking reactive power at 44% of rated VA and exporting reactive power at 44% of rated VA if overvoltage and undervoltage occur, respectively. Ausgrid, an NSW-based DNSP, mandates leading reactive power (with 0.8 power factor) at 60% of rated VA and lagging reactive power (with 0.8 power factor) at 60% of rated VA if undervoltage and overvoltage take place, respectively [112].

3.6.3 Volt-Watt Control

Volt-watt capability is also necessary for grid-connected inverters in Australia and New Zealand as per AS/NZS 4777.2.2020 criteria. For instance, in the event of an overvoltage, all DNSPs in VIC require real power to be 20% of rated VA. Other DNSPs around Australia also impose this rule [112].

3.7 Dynamic Operating Envelope

The behaviour of a distribution network, or DER, that can be supported before its operational or physical boundaries are crossed is known as its operating envelope (OE). If OE is allocated in each time interval to DERs or connection points, it is called dynamic OE (DOE). For a connection point or specific DER assets, a DOE essentially establishes upper and lower limitations on the power that can be imported or exported in a specific amount of time. Some key benefits of DOE include addressing multiple challenges existing at the distribution and whole system levels, an easy-to-implement aspect to comply with existing network standards, and a progressive deployment feature to implement at various segments of the networks as required [113].

Several challenges are also associated with DOE implementation, such as estimating accurate hosting capacity, information sharing safeguarding cyber vulnerabilities, cost-effective software and hardware development, the requirement of advanced techniques to distribute DOE responses among DER customers, and adequate incentives in cases of export or import curtailments. In spite of these challenges, DOEs offer potentials to achieve numerous operational objectives for network and system operators. Some of the outstanding uses of DOEs are as follows [114]:

- *Managing solar PV export:* Peak solar PV export is only likely to exceed operational or physical constraints when there is minimal underlying demand and maximum solar PV generation. A DOE assists in this situation by indicating that a DER customer connection point's export should be lowered overall or by a certain amount.
- *EV charging:* Since EVs charge mostly in the evening, this could have a major negative impact on the network. The DOE can give customers a clear signal to postpone or lower EV charging power in order to prevent exceeding voltage or thermal limitations.
- *DER market participation:* DER customers and assets can employ the extra network capacity to participate in energy and related services markets, which is one of the DOEs' key use cases. DER participation may be limited by the DOEs to assure the safe and secure functioning limits of distribution networks.
- *Maintain system security:* The use of DOEs to preserve system security restrictions amid spikes in solar PV generation is gaining popularity. Solar PV curtailment is one possible option to reduce the minimum demand on the grid and DOEs could help achieve this.
- Assessing dynamic line rating: Another DOE-use case could be adjusting line ratings to account for current environmental factors (like temperature) in order to optimise load or generation while preserving safety and reliability.

3.7.1 Shaped OE (SOE)

With the aim of enhancing network utilisation and market access for DERs, the shaped operating envelope (SOE) represents an evolution of the DOE concept, incorporating customer and aggregator preferences and network support. The improvements of a SOE over a DOE include: the allocation of OE taking customers and aggregators preferences, improved energy market performance, and fairness into account; and the automated network support provisions to meet the primary objectives. Through these improvements, SOEs allow DER customers and aggregators to get more value out of their DER assets and provide additional services. The energy market can also function more effectively through increased competition and participation when it is implemented at the market scale. Furthermore, higher levels of network throughput can be attained using SOEs that better match customers' intentions, which may prevent the need for network augmentation in many situations. Not just for customers with significant volumes of DER, but also for all consumers, these indirect benefits contribute to driving down the cost of energy usage [115].

3.7.2 Computational Methods

DOE calculation and allocation involve three steps in each time interval, e.g., every 5 minutes apart. In Step 1, historical or forecasted meter readings of all participating customers are gathered by the DSO. In Step 2, DSO runs an automated algorithm considering network data and requirements to compute export and import limits. In Step 3, customers are provided with export and import limits to schedule their energy exchanges [116]. The DSO and customers can communicate via the internet utilising a standardised communications protocol like the CSIP-AUS v1.0 standard. Also, the devices belonging to customers need to be DOE enabled, i.e., they should be configured to receive DOE signals and adjust their performance in order to ensure that the prescribed export and import limits are not exceeded [117].

In recent years, two DOE computational methods have been used significantly, such as:

- *State Estimation-based Method:* In this approach, distribution system state estimation and capacity-constrained state optimisation are utilised to compute DOEs. A linear map between control variables (i.e., import and export) and constrained output variables (i.e., voltage and line flow constraints) is established using an analytical Jacobian method [118].
- *Power flow-based Method*: In this approach, a three-phase AC power flow is performed, which can be done in two ways: 1) running power flow iteratively until maximised or shaped export and import limits are determined, respecting network constraints [119]; 2) running an optimal power flow (OPF) exclusively taking network constraints into consideration [120].

3.7.3 Equity Metrics

Equity, or fairness, in DOE is a subjective attribute that has been introduced to ensure customers' content. Equity metrics judge the performance of DOE objective functions with respect to fairness. Higher values on the equity metrics scale, which ranges from 0 to 1, denote superior DOE implications for customers. Common equity metrics include [121]:

- Quality of Service (QoS): In accordance with the coefficient of variation of the solution, QoS shows the equity of capacity allocation. From the perspective of the customers, this equity metric guarantees that capacity is allocated to everyone. Customers should be allocated the same capacity as their neighbours in order to be fair. Furthermore, the DOE operation becomes more equitable if they are allocated more capacity collectively.
- Quality of Experience (QoE): The QoE measures the equity of the capacity allocated according to the solution's standard deviation. From the perspective of the customer, this equity metric guarantees that, even in cases where they are severely curtailed, everyone is affected uniformly to enable DOE operation to be equitable.
- Min-Max Fairness (MMF): The MMF refers to the equity of the capacity allocated according to the solution's range. From the perspective of the customer, this equity indicator makes sure that there is as little disparity as possible between the DOE operation's winners and losers.

3.8 Grid-interactive Efficient Buildings

Grid-Interactive efficient buildings (GEBs) signify a notable progression in sustainable infrastructure, providing a comprehensive solution to energy efficiency and grid stability. These buildings employ various technologies and approaches to optimise energy usage, minimise wastage, and actively engage with the electricity grid, thereby supporting overall system resilience and dependability [122]. At the heart of GEBs lies the efficient management of DERs, encompassing diverse small-scale power generation and storage units like solar panels, wind turbines, batteries, and EVs. The core concept of GEBs is their grid-interactive capabilities, enabling them to dynamically respond to grid conditions and demand signals. This capability allows GEBs not only to draw power from the grid but also to generate, store, and distribute energy back into the grid as required. Through advanced sensors, controls, and communication technologies, these buildings can intelligently adapt their energy usage patterns, collaborate with nearby buildings, and contribute surplus energy to support grid operations.

One of the primary strategies in GEBs is demand response [123], where building systems adjust electricity usage automatically in response to price signals or grid limitations. For instance, during peak demand or high electricity prices, GEBs may temporarily reduce non-essential operations like HVAC systems or lighting to ease strain on the grid and lower costs for occupants. Conversely, during times of abundant renewable energy generation or low electricity prices, GEBs can increase energy usage or store excess energy for later use, maximising the utilisation of clean energy resources. The integration of DERs is crucial for enhancing the grid-interactive capabilities of GEBs. Solar PV panels are commonly deployed in buildings, harnessing sunlight to generate onsite electricity. These solar arrays not only offer renewable energy but also decrease dependence on centralised power plants, thereby enhancing energy resilience and security. Additionally, surplus solar energy can be stored in batteries or fed back into the grid, allowing GEBs to actively participate in the energy ecosystem.

Battery storage systems are another critical component of DERs in GEBs, facilitating efficient management of fluctuating energy supply and demand [124]. By storing excess energy during low-demand periods or high renewable generation, batteries can discharge power during peak hours or when renewable generation is limited, optimising energy usage and mitigating grid instability. Moreover, battery storage enhances GEB resilience by providing backup power during outages or emergencies, ensuring uninterrupted operation of essential services. In addition to generation and storage, EVs are becoming integral DERs in GEBs, offering both energy storage and demand flexibility capabilities. Through V2G technology, EV batteries can act as mobile energy storage units, charging during off-peak hours and discharging electricity back into the grid during peak demand periods. This bidirectional energy flow maximises renewable energy utilization and provides an additional revenue stream for EV owners, encouraging the adoption and integration of electric mobility solutions.

Efficient management of DERs in GEBs necessitates robust communication and control systems to coordinate the diverse array of distributed assets. Advanced metering infrastructure (AMI) and smart building management systems (BMS) play a crucial role in real-time monitoring of energy consumption, generation, and storage, enabling optimised decision-making and resource allocation. Furthermore, machine learning algorithms and artificial intelligence (AI) technologies can analyse extensive datasets to forecast energy demand patterns, optimise DER dispatch, and anticipate grid conditions, thereby improving the efficiency and reliability of GEB operations. Policy and regulatory frameworks also play a pivotal role in facilitating DER integration into GEBs and incentivising investments in grid-interactive technologies. Measures like net metering, FiT, and DR programs encourage building owners to deploy renewable energy systems, install energy storage solutions, and adopt demand-side management strategies. Moreover, standards and interoperability protocols ensure compatibility and smooth integration of diverse DERs and grid infrastructure, fostering a cohesive and resilient energy ecosystem. The Green Building Council of Australia (GBCA) launched its first report on grid-interactive buildings in June 2023, highlighting the crucial role they will play in achieving a zero-carbon future [125]. Some of the case studies on GEB in Australia mentioned in GBCA report are highlighted below:

1. University of Technology Sydney (UTS) Dr Chau Chak Wing Building: The building adjusted its temperature setpoints on a particularly high-demand day to avoid increased network capacity charges. By temporarily lowering the setpoint and then raising it during peak hours, they managed to maintain comfort while reducing costs.

2. Grosvenor Place: Utilising an all-electric HVAC system with a thermal storage plant, Grosvenor Place shifted its electrical loads from peak to off-peak periods. By running chillers as heat pumps during a sunny day, they reduced greenhouse gas emissions significantly, leveraging solar power and minimising reliance on coal-fired generators.

3. EG Funds Management: Committed to achieving 'Real Zero' carbon by 2030, EG employs grid interactivity and a data-driven approach to emission reduction. By analysing real-time grid carbon intensity and focusing on reducing carbon-intensive energy usage, EG aims to surpass net zero targets and deploy efficient emissions reduction tactics.

4. Sydney Opera House: Through an innovative power purchase agreement (PPA) tied to renewable energy production, the Opera House optimises its energy consumption. By pre-cooling venues during periods of abundant renewable energy and gradually adjusting conditions during drops in supply, they achieved significant load reduction without compromising comfort. Although emissions savings were not realised due to ample renewable energy availability, the success of the experiment underscores the potential of load flexibility strategies and the importance of automated responses based on forecast signals.

3.9 Virtual Power Plants

A Virtual Power Plant is a decentralised network of interconnected energy assets, such as solar panels, wind turbines, batteries, and demand response systems, orchestrated through advanced software and communication technologies [126]. Unlike traditional power plants, which rely on centralised generation facilities, VPPs leverage the capabilities of DERs distributed across various locations. This innovative approach enables efficient aggregation and optimisation of DERs, offering numerous benefits in terms of grid stability, flexibility, and sustainability [127]. One of the primary objectives of VPPs is to enhance the integration of renewable energy sources into the grid. As the world increasingly transitions towards cleaner energy alternatives, such as solar and wind power, the intermittent nature of these sources poses challenges for grid operators. VPPs address this issue by aggregating diverse DERs and balancing their generation profiles in real-time. By intelligently managing the supply and demand fluctuations, VPPs contribute to a more stable and resilient grid, reducing reliance on fossil fuels and mitigating greenhouse gas emissions. Moreover, VPPs play a crucial role in optimising energy consumption and reducing costs for both utilities and consumers [128]. Through demand response capabilities, VPPs enable dynamic adjustments to electricity usage based on grid conditions and price signals. By curtailing or shifting energy consumption during peak periods, VPP participants can alleviate strain on the grid and avoid expensive peak-hour electricity rates. This not only enhances grid reliability but also helps lower energy bills and improve overall efficiency.

Another key advantage of VPPs is their ability to provide ancillary services to the grid [129]. These services include frequency regulation, voltage control, and reactive power support, which are essential for maintaining grid stability and reliability. By harnessing the flexibility of DERs, VPPs can rapidly respond to grid disturbances and provide valuable support during emergencies or unexpected events. This capability enhances the resilience of the grid and reduces the need for costly infrastructure upgrades. Furthermore, VPPs empower consumers to actively participate in the energy market and unlock new revenue streams from their DER assets. By connecting residential, commercial, and industrial systems to the VPP platform, users can monetize their excess energy generation or participate in demand response programs. This not only incentivises investment in renewable energy technologies but also fosters a more decentralised and democratised energy system.

Despite their numerous benefits, the widespread adoption of VPPs faces several challenges, including regulatory barriers, interoperability issues, and cybersecurity concerns [130]. As VPPs rely on seamless integration and communication between diverse DER assets, interoperability standards and protocols are essential to ensure compatibility and reliability across different systems. Moreover, robust cybersecurity measures are critical to safeguarding VPP infrastructure from potential cyber threats and malicious attacks. As technology continues to advance and regulatory frameworks evolve, VPPs are poised to play a central role in shaping the future of energy systems, driving innovation, resilience, and sustainability for energy systems.

Some examples of VPP trials in Australia include SA Power Networks VPP Trials: SA Power Networks, the DNSP for South Australia, conducted various VPP trials to explore the potential of DERs in supporting grid operations. These trials involved partnerships with technology providers and residential customers to test the feasibility and effectiveness of VPPs in managing local grid constraints. These include Tesla's VPP in South Australia [131] and AGL's Virtual Power Plant in Adelaide [132]. Table 10 illustrates a summary of the aforementioned DER management techniques.

Table 10: Summary of DER Management Techniques

Technique	Overview of the technique	References
DERMS	• To enable the delivery of grid services at the distribution level and allow for the aggregation and optimisation of DERs while realising their full potential.	[79]-[81]
ADMS	• To provide adaptable solutions to meet the fundamental needs of digital grids to ascertain network resilience and reliability.	[82]
DER visibility	• To better understand local power quality, flows, restrictions, and the real-time capabilities of DERs.	[71], [72], [74], [84], [85]
Price-response DERs	• To offer market and network ancillary services in response to external prices.	[87]-[91]
Controllable load-driven DR programs	• To introduce Shape, Shift, and Shimmy DR programs in either a price-based or incentive-based format.	[93]-[98]
Battery-driven DR programs	• To contribute to both DR and demand-shifting capacity pertaining to usable battery capacity.	[99]-[101]
EV charging coordination	• To charge numerous EVs in a sustainable manner using either direct or indirect control.	[102]-[105]
Modern inverter functionalities	• To control how the DERs connected to inverters communicate with the grid and specify how these resources have to operate in various system scenarios.	[106]-[112]
DOE	• To establish upper and lower limitations dynamically on the power that can be imported or exported.	[113]-[121]
GEB	• To control demand and generation of buildings to provide flexibility to the grid.	[122]-[125]

VPP	• To control large scale of DER so they function as one large power plant.	[126]-[132]

4 Two-sided Market Structures

A two-sided energy market refers to a market involving more DER capacity utilisation for participating customers and more visibility over their energy demand. DER customers are provided with the opportunity to export and import their excess energy, e.g., excess solar PV generation, and unmet demand (e.g., EV charging) or reduced demand (e.g., DR program), respectively, based on price signals and receive incentives [133]. Some of the other potential benefits of two-sided markets include real-time scheduling of DERs to stabilise the electricity grid, balancing energy supply and demand in real-time for market reliability, and engaging customers and other stakeholders, such as market operators, network operators, and retailers, proactively to operate the market efficiently [134].

Some challenges are also associated with the deployment of two-sided markets, including new frameworks and regulations to expedite agile participation of DERs, compatibility assessment of DER market services satisfying local and network constraints, and innovative platforms to facilitate DER customers conducting energy transactions in customer-centric ways. In this section, these challenges are addressed by analysing potential frameworks, market services, and trading arrangements.

4.1 Participation of DERs

The success of two-sided market structures ultimately lies in the active participation of DERs. To do so, a coordination between continuous development of DERs, innovative DER control and management frameworks, and new regulatory actions is required [135].

4.1.1 Framework Fundamentals

Framework fundamentals include principals for integrating DERs in two-sided markets, enabling features for the activation of DERs, data, control, and observability, and actions to activate DERs [136].

4.1.1.1 Principles for Integrating DERs

Six guiding framework principles to integrate DERs in two-sided markets are as follows [136]:

- Reliable design to maintain overall market operation.
- Combination of observability and controllability to run efficient markets.
- Consideration of different DER constraints.
- Consideration of electricity grid stresses to avoid congestion.
- Flexible design to reduce uncertainty and manage variability.
- Impacts of non-market incentives on designed markets.

4.1.1.2 Enabling Features for the Activation of DERs

The distinguishing features that shape the ability of an electricity system to integrate DERs are as follows [136]:

- New grid code requirements to control DER behaviour.

- New DER metering infrastructures to track DER readings.
- Active electricity system management capabilities, new connection practices, and utilisation of distribution network hosting capacities to deal with DER export and import impacts.
- Temporal and spatial aggregations of DERs to facilitate their market participation.
- Electricity network usage charges and loss factors.
- Involvement of integrated utilities.

4.1.1.3 Data, Control, and Observability

Activation of DERs in two-sided markets requires high-quality data exchanges between participants and operators, control of DER operation, and improved DER observability. The following features are fruitful for executing efficient integration of DERs [136]:

- Establishing DER data requirements and standards.
- Modelling DER data formats to store and share data using an efficient data-exchanging architecture.
- Mapping DERs to connect to the electricity system.
- Introducing metering requirements for accurate billing settlements.
- Establishing interconnection requirements to control of DER operation and improve its observability.

4.1.1.4 Actions to Activate DERs

The final framework requisite for DER inclusion in two-sided markets is the action to activate DERs, which includes [136]:

- Ensuring desired outcomes for DER market integration to keep participants motivated.
- Determining if the direct or indirect participation of DERs is beneficial.
- Understanding how ancillary services provided by the DERs impact the market operation.
- Understanding how the activation of DERs impacts the operation of electricity network.
- Determining how geographical scope limits DER aggregations with different resource constraints.
- Reviewing network usage charges for charging of distributed storage systems.

4.1.2 Regulatory Initiatives

To support the participation of DERs in two-sided markets, some changes in regulation are taking place in different parts of the world. For instance, the Federal Energy Regulatory Commission (FERC), which is responsible for regulating energy industries in the US, has introduced three initiatives to accelerate DER integration that include order-on DR, energy storage, and continuing proceeding on DER [136]. FERC Order 745, launched in 2011, mandates independent system operators (ISOs) to allow participation in DR programs. FERC Order 841, launched in 2018, directs ISOs to eradicate existing barriers hindering DERs from engaging in numerous market products such as energy, capacity, and ancillary services. From December 2019, all DER markets are required to comply with FERC Order 841 and permit electric storage systems to participate in energy markets. In another proposed rulemaking, introduced in 2017, FERC advises the aggregation of DERs and allows their participation in energy markets [136].

The European Commission also put into practice several key changes during the European internal energy market review back in 2016 to authorise DER customers to engage in energy markets. The regulatory changes, proposed in early 2019, include providing system operators access to control DERs for ancillary services; catering generation, storage, and demand response on an equal footing for energy, balancing, and auxiliary services; increasing the convergence of the various tariff structures; and enhancing data interchange by standardising data collection and data sharing formats [136].

In Australia, some regulatory initiatives have also been taken to encourage DERs to participate in energy markets. For example, the marketplaces and structures of the AEMO workstream, which includes the recently completed Open Energy Networks project with Energy Networks Australia and ongoing work with the Energy Security Board (ESB) focusing on the design process of post-2025 two-sided markets, aim to define and establish market frameworks to successfully integrate DERs [137]. The Open Energy Networks project has identified four different market structures to optimise and coordinate DERs, such as single integrated platform, two-step tiered, independent DSO, and hybrid model (DSO and DMO). Among these, the hybrid model has been labelled as the most convenient model for further exploration, as it can cater to the needs of DER customers and operators without incurring unbearable expenses [138]. On the other hand, Post-2025 DER Implementation Plan dives into an interoperability policy framework to support customers to swap between DER customers easily and achieve interoperability between DER devices and supporting systems, as well as process interfaces to maximise the value from their DER assets [139].

In addition, AEMO has proposed a reform known as Flexible Trading Arrangements as part of the DER Implementation Plan of ESB, which aims to separately meter controllable and uncontrollable resources to permit households to assign deals with two different retailers: one charges controllable resources while the uncontrollable resources are charged by the other. Furthermore, in 2021, the Integrating Energy Storage Systems (IESS) rule reformation was accomplished to modify the bidding, registration, and cost-recovery procedures to better suit the needs of bidirectional energy flows in the market. Moreover, the Whole of System Plan, which takes into account investment and planning paths to comprehensively examine all types of loads and generation, is a part of Western Australia's Energy Transformation Strategy that has been introduced to identify how new capacity mechanisms and Essential System Services (ESS) would produce a wider range of revenue streams. Finally, dynamic export management programs are being brought to different Australian states to better utilise local network capacities [140].

4.2 DER Market Services

To expedite the adoption of DERs, new business models enabling DER market services are needed [141]. Also, due to increased installations of DERs and advancements in technical capabilities, the way DERs supply services to the market may need to evolve with further expansion of their ranges of services. This can certainly ensure greater dispatchability and visibility for market operators and contribute towards efficient DER integration in markets. However, the liberalisation of the DER-driven energy market presents several obstacles, as listed below [140]:

- *Sub-metering:* Delivering an accurate response at the connection point is challenging due to the combination of active DERs and passive loads influencing energy flows. One alternative option would be measuring DERs separately from passive loads by introducing sub-metering arrangements and enabling them to engage in the market easily.
- *Performance Standards:* It is crucial for DER to be able to show continuous compliance and the capacity to achieve performance standards, as DER offers more capacity that markets would rely on. Existing compliance of DERs with technical settings in Australia and New Zealand include the Inverter Standard (AS/NZS 4777.2) and Demand Response Standard (AS/NZS 4755.2) [142].
- *Aggregation and Constraints:* As aggregations of DERs interested in market participation grow in size, market operators would need to have a better understanding of the distribution of such capacity across whole electricity regions. Further, local network capacity allocation could impact market services offered by the DERs. Also, a complexity may arise when offering DER capacity in both market and network services simultaneously. In the following subsections different market services are introduced considering aggregated DERs and network constraints.

4.2.1 Market Services with Network Constraints

Using DER in markets while respecting local network restrictions is one intriguing way to integrate DERs effectively. In this model, network constraints can be incorporated while DERs bid at the market level. Hence, the network capacity allocation to DERs can influence the bidding process [140]. In this market model, four actors are involved, as follows [143]:

- *DSO*: DSO monitors local network capacity and evaluates export and import limits.
- *DMO*: DMO takes bids from consumers and prosumers and dispatches markets.
- *Trader:* The trader/aggregator bids DER services, following the network constraints, into markets.
- *Customers:* DER owners who select a trader to bid on their assets.

While network constraints can be maintained, the different functions and objectives of four participants may create market model complexities. One simple model could be that DSO determines export and import limits, i.e., DOEs, and sends them to traders. Afterwards, the traders send their bids adhering to network constraints to the market operator, i.e., DMO, to settle the market. To ensure better operational market outcomes, DOEs can also be sent to the DMO. However, some current challenges in implementing DOEs include setting consistency, figuring out the operational objective functions for different networks, ascertaining asset registration, installation, and maintenance, providing customers with correct connection information and offers, and applying DOEs while importing energy [140].

4.2.2 Market Services with Network Services

With the increase in density of DERs, their generation and consumption at different times in a specific location can be utilised to evade expenses incurred for network upgrades [144]. This DSO-governed network service from DERs can also be incentivised. Nevertheless, a complexity may arise in coordinating network services with market services, as both services are managed by separate actors, i.e., market services and network services are run by the DMO and DSO, respectively. For example, if a DER trader enrols in both market service and network service programs, and both DMO and DSO request support at the same time, it is impossible for the DER customer to fulfil both requests simultaneously [140].

One way to avoid conflicting capacity requests is that DSO and DMO request the service from a DER trader in advance, e.g., 12-24 hours before the actual service procurement, on a first-come, first-served basis. Another way could be the consideration of a single entity that acts as both a DSO and a DMO and dispatches both network service and market service equitably. Additionally, priority service could be assigned if a DER trader is registered for both market and network services [140].

4.2.3 Market Services with Network Services and Network constraints

Consideration of local network export and limit limits, i.e., DOEs, while DSO arranges network services from different DER sites can certainly be fruitful in ensuring network integrity and avoiding further network expenditure. However, a combination of market services with network services and network constraints requires the involvement of various actors in DER operations, leading to the need for access to different sorts of information related to [140]:

- Installation of new DERs, registration for export and/or import plans, and joining the portfolio of a DER trader.
- Operational data of DER customers and trader to monitor the system in real-time.
- Sending network constraints and visibility to each individual DER customer and the substation, respectively.
- Forecasting demand and price to settle the market accurately.
- Obligations, bids, and dispatches across diversified local and system services.
- Potential cybersecurity threats stem from data exchange between multiple actors.

A modern technology-integrated coordination between local and system levels could be an effective approach. For this purpose, a hybrid structure can be adopted, as discussed in [138].

4.2.4 Market Integration Trials

In the recent past, a number of DER market integration trials have been conducted, backed by several industry collaborations and governmental support. Table 11 and Table 12 present a list of some DER market integration projects that have been/are being trialled in and outside Australia, respectively.

- *Project EDGE*: Project EDGE is one of the prominent end-to-end DER integration trials in Victoria (VIC) led by AEMO, AusNet, and Mondo, in which a DER marketplace is tested with 1000 customers. The main objectives include enabling DERs to participate in the energy market and trade network services adhering to the network constraints, exchanging data in an efficient fashion among all actors through an integrated data hub, and performing a social science study to assess the opinions of DER customers [140]. This project uses sub-metering arrangements and provides a DER trader with an opportunity to offer local constraints-aware market and network services through a common data sharing hub. Local constraints are addressed by the application of DOEs using the common smart inverter profile Australia (CSIP-AUS) communication protocol. The market bidding process is aligned to a scheduled bidirectional unit (SDU) following the revised rule IESS [145].

- *Project Symphony*: Project Symphony is a VPP-scale DER trial collaborative project between AEMO, Western Power, and Synergy in Western Australia (WA) with 500 target customers (possessing at least 900 DER assets) [146]. This project creates three platforms to facilitate DER integration (with connection point metering arrangements) and data sharing that include a DSO platform to identify maximum network hosting capacity through DOEs (using the CSIP-AUS-driven local constraints communication protocol) with accurate forecasting of load and generation, a DER integration platform to receive bids from aggregated DERs to arrange both market and contracted network services, and an aggregated platform to onboard DER customers to ensure dispatch flexibility [140].
- *Project Edith*: Ausgrid and Reposit Power are the project partners running Project Edith as a trial to test distribution network power flow management tools and their compatibility with DER market participation, involving 300 customers, in New South Wales (NSW) [147]. The project's main focus is on utilising and expanding the infrastructure that already exists while also creating tools that could be easier to use and less complicated to upgrade systems in order to sustain high levels of DER uptake. The two main tools employed in this project aim to manage network capacity via subscription model-based DOE allocation via the CSIP-AUS communication protocol and incentivise actors. Project Edith adopts a simple connection point-based market model for point-to-point data transfer of pricing, constraints, and bids between the DSO, trader, and DMO. Dynamic network pricing is also used for providing network support [140].
- *Project Converge*: Evoenergy, Australian National University (ANU), and Zepben are working together on Project Converge, a test platform with 1000 connection point customers in the Australian Capital Territory (ACT) that aims to maximise the advantages of DERs while staying within the operational and physical bounds of the distribution system [148]. SOEs, DOEs with bid-optimised objectives, give priority to assigning network capacity (CSIP-AUS is used as a local constraints communication protocol) to locations with the lowest energy costs, and a real-time regulatory investment test for distribution (RIT-D) system, which can more effectively obtain network assistance at a lower cost than current processes, are two of the tools evaluated in Project Converge. In this project, market bids are first sent to the DSO to determine SOEs, and SOE-integrated market bids are then sent to the DMO for network-aware settlements. Data transfer between various actors follows point-to-point approach [140].

- *Reliability and Emergency Reserve Trader (RERT) Trials:* ARENA and AEMO have established RERT trials in different states of Australia to identify the potential of DR programs in managing the grid as part of the market services. The participating Australian states include South Australia (SA), VIC, and NSW [149]. The trials have been successful in convincing customers to join DR programs. However, some barriers have been identified, such as that some customers may wish to retain complete control over their assets while others may prefer automated load control governed by the centralised entity; DER monitoring and control devices could be expensive; and real-time variations in customers' assets need to be considered before pledging for DR programs [140].
- *CONSORT Bruny Island Battery Trial:* A field test in Tasmania (TAS) and research initiative financed by ARENA, CONSORT Bruny Island Battery Trial explores how customers might employ batteries (operating in conjunction with solar PV systems) to help manage the network and control their energy consumption. In addition to the power network operator TasNetworks and the Canberra-based startup Reposit Power, CONSORT is a partnership among three universities: the ANU, the University of Sydney, and the University of Tasmania [150]. 34 battery systems have been installed in the trial, focusing on pricing issues, household reactions to the new technology, good load forecasting, and orchestration algorithms for network support from home energy management systems (HEMS). The network constraints are solved by distributed optimal power flow (DOPF) in live operations [140].
- *Networks Renewed:* Through the development of small-scale solar PV and battery storage system facilities, the Networks Renewed project, partnered by the University of Technology (UTS), Sydney, Reposit Power, Essential Energy, AusNet Services, the Australian PV Institute, and United Energy, has looked into ways to enhance the quantity of DER in Australia while also enhancing the quality and dependability of the country's distribution networks in three locations across NSW and VIC, involving 90 customers. The major outcomes of this project are providing solar PV- and battery-based alternatives to support network voltages; making voltage support services available to network businesses; satisfying DER customers; and assessing the value of network services supported by DER customers [151].
- *AusGrid VPP Trial:* The VPP Trial by Ausgrid investigates how the grid may work with DERs and collaborate with businesses and customers to maximise grid operational efficiency and save costs for customers. Ausgrid's partnership with ShineHub, Reposit Power, and Evergen has unlocked the opportunity to offer greater flexibilities for customers to participate in the VPP trial. 750 household battery customers across NSW, with a total battery power of 3.4 MW and storage capacity of 7.3 MWh, have engaged in the trial [152]. Two key findings of the trial are that some batteries need to be charged before a network event and that charging too soon before an event can result in peak demand; and DER, engaged in numerous services, can affect VPP availability on days of high demand because they can be committed to catering other services [140].
- *Evolve Project:* The goal of the Evolve Project, led by Zeppelin Bend Pty Ltd, ARENA, The ANU, Energy Queensland, Ergon Energy, Energex, Essential Energy, Endeavour Energy, Ausgrid, Reposit Power, Evergen, Redback Technologies, SwitchDIn, and the

NSW Government across ACT, NSW, and Queensland (QLD), is to maximise DERs' participation in the energy, ancillary, and service markets in order to enhance their network hosting capacity, all the while making sure that the secure technical boundaries of the electricity networks are not crossed. In this project, Evolve platform and DER aggregators communicate using the IEEE 2030.5 protocol, whereas, the DSO shares data with the Evolve platform using the IEC- common information model (CIM). OAuth2 protocol is used to authenticate the communication between DSO and DER with the Evolve platform. The DOE is also employed to address the network constraints [153].

- *Flexible Exports for Solar PV Trial:* The SAPN and Ausnet Flexible Exports for Solar PV Trial is a South Australian in-field trial that offers dynamic export limits to customers in network-constrained areas. Dynamic export limits, one aspect of DOEs, are frequently significantly higher than their usual static export limits and avoid permanent zero-export settings [154]. Tens of installers and hundreds of users have taken part so far, providing practical insight into what a widespread implementation of adjustable export limits might entail. In this trial, variable export limits are communicated to the customers via the CSIP-AUS protocol. Technology providers SolarEdge, SMA, and Fronius, as well as gateway provider SwitchDin, are integrating with this CSIP-AUS signal to receive export limits and use onsite solar PV generation to stay below that limit [140].
- *Advanced VPP Grid Integration:* In order to show how a VPP can function in energy markets by exporting a higher level of energy while abiding by dynamic export constraints, SAPN and Tesla have collaborated to create the Advanced VPP Grid Integration [155]. In this trial, SAPN uses an application programming interface (API) to send site-level export limits, DOEs, to Tesla, and Tesla makes sure that these limits are followed by all bids placed into the market (made by Energy Locals as the registered market participant) and by the VPP's operations. Some notable findings are that during solar PV hours, the VPP could boost its overall export capacity from 5 MW to 6–8 MW; forecasted export limitations for scheduled maintenance or unplanned outages are successfully overridden by SAPN; operational data, DOEs, and registration information could be sent over the internet via the developed API (based on IEEE 2030.5).

Table 11: Some DER market integration trials in Australia

Project name	Location	Target customers	Metering point	Data transfer	Market and network services	Network constraints
Project EDGE	VIC	1000	Connection point or sub-metering	Common data sharing hub	Both	Solved by DOE
Project Symphony	WA	500	Connection point	Platform integrations	Both	Solved by DOE

Project Edith	NSW	300	Connection point	Point-to-point	Both	Solved by DOE
Project Converge	ACT	1000	Connection point	Point-to-point	Both	Solved by DOE
RERT Trials	SA, VIC, NSW	N/A	Connection point	N/A	Market service	Not considered
CONSORT Bruny Island Battery Trial	TAS	34	Connection point	N/A	Network service	Solved by distributed OPF
Networks Renewed	NSW, VIC	90	Connection point	N/A	Network service	Not considered
AusGrid VPP Trial	NSW	750	Connection point	N/A	Network service	Not considered
Evolve Project	ACT, NSW, QLD	N/A	Connection point	Platform integrations	Both	Solved by DOE
Flexible Exports for Solar PV Trial	SA	N/A	Connection point	Point-to-point	None	Solved by DOE
Advanced VPP Grid Integration	SA	N/A	Connection point	Point-to-point	Market service	Solved by DOE

- *APG FlexHub:* Austrian Power Grid AG (APG) and the Energy Web Foundation (EWF) have launched a FlexHub concept that facilitates DERs to take part in market services. The FlexHub concept effectively streamlines registration and qualification, the bidding process, and financial settlements for DERs under one umbrella by utilising several open-source software applications from the Energy Web decentralised operating system (EW-DOS), including Energy Web's blockchain platform. By utilising the EW-DOS solution, DERs can leverage self-sovereign identities (SSIs) and decentralised identifiers (DIDs). Customers can also register their devices directly through the EW-DOS approach, while accredited third parties, like installers, can independently verify the details of any particular unit (like residential batteries). This is because a single central entity is not in charge of maintaining an accurate catalogue of all DERs [156].

- *Distributed ReStart:* The Distributed ReStart project, which has been financed by the Network Innovation Competition (NIC), is a collaboration between the National Grid Electricity System Operator (ESO), SP Energy Networks (SPEN), and TNEI, a specialised energy consultancy. The project investigates the potential applications of distributed energy resources (DER) for power restoration in the extremely improbable case that the National Electricity Transmission System experiences a complete or partial outage with three focused work streams, such as the power engineering and trial work stream, the organisational and systems work stream, and the procurement and compliance work stream. The intended benefits include cost reduction to customers, carbon footprint reduction, innovation in procurement of network services, and future-proofing electricity networks [157].

- *Power Potential:* An obstacle to linking more DERs in the south-east region of the UK is being addressed by Power Potential, formerly known as TDI 2.0, a world-first trial to maximise network capacity. This project enables DERs to make extra money by offering network voltage control services. By connecting to National Grid ESO's platform for ancillary services through DERMS, created for the project by ZIV Automation), this is immediately accomplished. Day-ahead procurement is done in the local reactive power market. With services created within a safe operating envelope for the distribution network, the DERMS have been specifically designed to allow numerous DER to be merged in a VPP at the grid supply point [158].

- *Project PHOENIX:* The cutting-edge Project Phoenix, a partnership between National Grid ESO, ABB, The University of Strathclyde and Technical University of Denmark (DTU), aims to overcome the technological, engineering, and financial difficulties that are thought to be the primary obstacles to the widespread use of hybrid synchronous compensators (H-SCs) in DER-rich networks. In view of decreasing synchronous generation, this project combines two current technologies, synchronous condensers and static compensators, to provide dynamic voltage control, inertia, and short circuit level. This combination of technologies is labelled H-SCs and driven by an innovative master control system. Enhanced system stability, allocation of additional network capacity, minimisation of network operating costs, and roll-out for H-SC technology are the principal objectives of Project PHOENIX [159].

- *Charge Project:* In the Manweb region of SP Energy Networks, the Charge Project is an Ofgem-funded project designed to hasten the switch to electric transportation and assist in achieving the UK's 2050 net zero goals. Utilising transportation and electricity network planning data, the Charge Project has collaborated with PTV Group, Smarter Grid Solutions, and EA Technology to accelerate the installation of EV charging infrastructure. The Charge Project has developed ConnectMore, an interactive online map and cost estimator, with the goal of increasing the number of public charge points. The map indicates the locations of required charge points as well as those where the energy infrastructure can most effectively support them. Additionally, it creates new approaches and a DSO solution for the Smart Charging Connections rollout [160].

- *MYSE-TL Hybrid Project:* The local government and Chinese wind turbine manufacturer Ming Yang Smart Energy (MYSE) have reached an agreement for the construction of a large renewable-battery hybrid facility close to Tong Liao (TL) City in the Inner Mongolia region of China. The demonstration project is focused on addressing issues unique to TL City, like peak shaving capacity and power generation deficiencies, as well as the demand for affordable energy rates. It is based on the real growth of the city's power industry. As it would be implemented gradually and adjusted based on the needs of the city, the comprehensive on-grid energy price would actually not be greater than the existing thermal benchmark energy price. However, DER curtailments could be an issue, which can be solved by considering network constraints [161].

- *Aggregate DER Pilot Project:* The Electric Reliability Council of Texas (ERCOT) has launched a pilot study to assess the involvement of aggregated DERs in the ERCOT energy market under the Public Utility Commission of Texas' (PUCT) directive. In this trial, aggregated DERs are defined as resources that can respond to ERCOT despatch instructions and are made up of several premises connected at the distribution system level. The main purposes include examining the operational advantages and difficulties associated with aggregating heterogeneous DERs; assessing how aggregated DERs can offer ancillary services and receive competitive incentives; investigating the impacts on aggregated DERs on the grid, especially network congestion; and identifying potential challenges to roll-out for new DER-related trial projects [162].
- *Flexible Interconnect Capacity Solution:* Using the Strata Grid DERMS platform, the Flexible Interconnect Capacity Solution project has connected a few new PV solar farms in Spencerport, New York, to AVANGRID's electric network. This project is one of several that AVANGRID is working on in support of New York's Reforming the Energy Vision (REV) initiative, which seeks to transform the state's electricity infrastructure. According to the project designers, the use of DERMS technology lowers grid integration expenses when compared to traditional connection prices and is reportedly the first of its kind in the US. Despite the network's apparent capacity, the technology enables large-scale producers of DERs to connect to it [163].
- *Decentralised Energy Resources:* In cooperation with EQUIGY (a crowd balancing platform provider), Swissgrid and ewz have run a pilot project on coordination between distribution and transmission system operators with regard to integrating DERs into the grid and providing network service in a decentralised way. On EQUIGY’s crowd balancing platform, a rule-empowered coordination strategy between system operators has been designed and put into practice. A battery that is linked to the distribution grid of ewz has been used to test the concept and its application. Through the multi-purpose use of flexibility made possible by this project, DER aggregators can offer various system operator services via a single interface. Moreover, the concept minimises integration effort by enabling system operators to conduct grid security research using their own tools independently of the crowd balancing platform [164].

Table 12: Some DER market integration trials outside Australia

Project name	Location	Target customers	Metering point	Data transfer	Market and network services	Network Constraint

APG FlexHub	Across Austria	N/A	Connection point	Blockchain platform	Market service	Not considered
Distributed ReStart	Across UK	N/A	Connection point	N/A	Network service	Not considered
Power Potential	Southeast region, UK	N/A	Connection point	N/A	Market service	Solved by DERMS
Project PHOENIX	Across UK	N/A	Connection point	N/A	Network service	Solved by H-SCs
Charge Project	Manweb region, UK	N/A	Connection point	ConnectMore	None	Not considered
MYSE-TL Hybrid Project	Inner Mongolia, China	N/A	Connection point	N/A	Market service	Not considered
Aggregate DER Pilot Project	Texas, USA	N/A	Connection point	N/A	Market service	Considered but not solved
Flexible Interconnect Capacity Solution	New York, USA	N/A	Connection point	Strata grid platform	Market service	Solved by DERMS
Decentralised Energy Resources	Switzerland, Germany	N/A	Connection point	Crowd balancing platform	Network service	Not considered

4.3 DER-enabled Trading in Local Energy Markets

A local energy market (LEM) is a marketplace where customers, who are geographically and socially close to each other, can exchange energy procured from local DERs. LEM allows DER customers to trade as both energy suppliers and consumers. Non-DER customers can also buy energy from the surplus of DER customers within the LEM. The LEM is connected to a superimposed energy network, i.e., the grid, so that in case of unmatched energy supply and demand in the LEM, supply/demand is exported/imported via the grid [165]. LEM offers several benefits that include accelerating reductions in carbon emissions by the utilisation of locally produced energy, lowering energy usage costs for customers, improving business cases for stakeholders, and increasing flexibility in the local network [166].

P2P energy trading is one of the advantageous features of a LEM that encourages customers to trade between themselves via a secure trading platform with no or limited intervention from a centralised entity. In P2P energy trading, both DER and non-DER customers are given the freedom to select from whom they buy and sell electricity. It can be operated as alternatives to FiT and ToU prices with the confirmation that all customers would receive better monetary gains due to their mutual negotiations. Further, the utilisation of storage systems and controllable loads could be accelerated during both peak demand and solar PV periods [167]. The most attractive areas for P2P trade arrangements could be new precincts that are energy-self-reliant and can mostly control their own electricity distribution with marginal support from the grid [168].

4.3.1 Structures and Active Participants

In contrast to the current energy market, which uses a top-bottom strategy, P2P trading in the LEM necessitates a bottom-up strategy to consider the active roles of DER customers. A LEM can be classified into three structures based on how participants coordinate mutually for energy trading: a decentralised LEM, a community-based LEM, and a hybrid LEM [169].

- *Decentralised LEM Structure:* A decentralised LEM is completely taken care of by the DER customers without the involvement of any centralised bodies, like the DSO or DMO. DER customers make their trading decisions autonomously using a secure trading platform. The trading quantities of DER customers are determined by employing advanced energy management systems. While an entirely decentralised LEM structure may lead to a DER customer-centric mechanism, it could also suffer from reliability issues [169].
- *Community-based LEM Structure:* A community-based LEM is operated by a community manager, which could be either a DSO or DMO, while DER customers exchange their common interests with the community manager in a competitive way. Community storage systems can play a vital role in managing this type of LEM structure. However, accurate coordination among all DER customers is required to schedule community energy balance. In addition, fairness could be an issue while LEM benefits are shared among DER customers [169].
- *Hybrid LEM Structure:* A hybrid LEM structure, which combines community-based and decentralised LEM structures, is thought to be the most appropriate market structure for contemporary energy networks. In this market structure, DER customers can decide on their trading quantities and partners on their own, while DMO and DSO provide market and network information, respectively. In other words, DER customers carry out P2P transactions independently under the supervision of the DMO and DSO. Distributing payoffs for all participants could be challenging in this LEM structure [169].

All three types of LEM structures adopt mainly three operational time horizons, such as day-ahead, intraday, and balancing operations. In a day-ahead LEM operation, the market settlement is conducted based on forecasted local energy supply and demand. In contrast, an intraday LEM operation settles the market multiple times within a day according to the actual local energy supply and demand. On the other hand, a balancing LEM operation assists in the real-time matching of local energy supply and demand [170].

4.3.2 Coordination and Trading Platform

Proper coordination among different DER customers and operators certainly influences the well-functioning of a LEM. In general, there could be three categories of LEM coordination, which include bilateral coordination, mediated coordination, and implicit coordination. In bilateral coordination, DER customers communicate with each other directly following a decentralised LEM structure, whereas a mediator aids in communicating between DER customers in mediated coordination following a community-based LEM structure. On the contrary, implicit coordination enables DER customers to communicate with each other and abide by the guidelines of a mediator following a hybrid LEM structure [171].

P2P energy trading in the LEM is built on the foundation of a decentralised trading platform which can be provided by the blockchain technology, for example. Blockchain technology can safely and irreversibly record energy transactions by utilising a transparent and decentralised ledger. Smart contracts automate trade in the LEM, guaranteeing confidence and doing away with the need for middlemen. They are self-executing trading contracts with the terms of the LEM agreement explicitly encoded into code. The strengths of blockchain in P2P energy trading-based LEM include [172]:

- *Empowerment:* All DER customers can track and control their local energy export and import.
- *Transparency:* P2P transaction histories and recorded permanently and are visible to all participants, fostering a trustworthy trading platform.
- *Security:* The distributed architecture of blockchain guards against fraud and tampering.
- *Efficiency:* Automation mechanism expedites settlements and lowers LEM transaction costs.

At present, four different kinds of blockchain structures exist [173]:

- *Public Blockchain:* Public blockchains are totally decentralised, open to all users, and permissionless. With public blockchains, every node on the network has an equal right to access the blockchain, add new data blocks, and verify existing data blocks. The most well-known public blockchains are Bitcoin, Litecoin, Ethereum, and Polygon.
- *Private Blockchain*: A single organisation controls permissioned blockchains known as private blockchains, also called managed blockchains. Who can be a node in a private blockchain is decided by the central authority. Furthermore, not every node has the same rights to carry out tasks from the central authority. Because public access to private blockchains is restricted, these blockchains are only partially decentralised. Ripple, Hyperledger, and Solana are instances of private blockchains.

There are disadvantages to both private and public blockchains: public blockchains typically require more time to validate new data compared to private blockchains, while private blockchains are more susceptible to fraud and dishonest individuals. To overcome these drawbacks, the concepts of Consortium and Hybrid blockchains have emerged.

- *Consortium Blockchain:* Consensus blockchains are permissioned blockchains that, unlike private blockchains, are managed by a collection of organisations as opposed to just one. As a result, consortium blockchains have higher degrees of security due to their greater decentralisation than private blockchains. However, the process of establishing consortiums can be difficult since it calls for collaboration between several organisations, which poses both a logistical risk and an antitrust risk.

- *Hybrid Blockchain:* Hybrid blockchains are those that are managed by a single entity but that also have some oversight from the public blockchain, which is necessary for carrying out specific transaction validations. IBM Food Trust is one example of a hybrid blockchain.

4.3.3 Financial Settlements

One of the most crucial components for financial settlements in a LEM is a decision-making mechanism that serves to promote dynamic decentralised energy trading with competitive trading prices, increase community economic benefits, assess and distribute payoffs of DER customers, and balance local supply and demand within the community. Capturing the decision-making processes of diverse consumers is challenging, though. Additionally, for a LEM market to be successful, there must be clearly specified trading agreements, appropriate market solutions (traded amount and price per unit of traded quantity) for each participating DER customer, equitable welfare allocation, and satisfaction [174].

4.3.3.1 Pricing Strategy

DER customers can trade individually or as parts of a group in the LEM, encouraging them to trade their selling and buying quantities from the LEM first and then the remnants from grid trading. DER customers can be sorted based on their declared prices, e.g., sellers and buyers can be sorted based on their maximum and minimum declared prices, respectively. These prices should be in between the FiT and ToU prices to capture maximum benefits. In the case of identically declared prices, the maximum declared traded quantities can be considered [175]. Once the P2P deals are struck, the trading prices can be calculated using some methods, as follows:

- *Bill Sharing:* With the bill sharing approach, cost sharing is used to cover each DER customer's specific energy usage. But this payment comes in the form of a cost-sharing portion of a single energy bill for the LEM, which is tracked by the utility meter at the LEM-grid connection point. This expense is divided based on the overall energy consumption and exports of each DER customer. Every DER customer receives payment at a different rate for each kWh of energy exported and pays the same amount for each kWh of energy consumed [176].

- *Mid-Market Rate:* The trading price is assumed to be in the middle of FiT and grid prices by the mid-market rate. If total local supply and demand are equal, all DER customers trade at the mid-market rate. However, if total local supply is greater than demand, all buyers can trade at the mid-market rate, but sellers need to trade at a price lower than the mid-market rate (which is still higher than the FiT rate). Contrarily, if total local supply is lower than demand, all sellers can trade at the grid price, but buyers need to trade at a price higher than demand (which is still lower than the grid price) [176].

- *Auction-based Pricing:* An auction market is used in auction-based pricing to determine local energy supply and demand. Every DER customer actively participates in submitting offers or bids representing their local energy supply and demand. To allocate and specify the price strategy, these bids and offers are combined and managed according to pre-established rules. For instance, if total local energy is equal to demand, the market clearing price could be the highest declared offer among the sellers. If total local supply is greater than demand, the market clearing price could be the FiT rate. On the other hand, if total local supply is lower than demand, the market clearing price could be the grid price [176].

4.3.3.2 Equity Metrics

Equity in pricing strategy is another factor that can expedite DER customers' participation in the LEM. Energy policy has long focused on equity, but recently, as a result of customers' growing energy prices brought on by the global energy crisis, equity has gained more attention [177]. Some metrics, such as quality of experience, quality of service, and equality index indicators, can also be employed to evaluate the economic equity of LEMs.

- *Quality of Experience (QoE):* When the QoE value is one, the cost of energy is the same for all market participants. The trading price is linearly determined somewhere between the selling and buying prices under the supply-demand ratio pricing mechanism, which is based on the LEM's supply and demand ratio. Every DER customer who trades in the LEM receives the same price under this uniform pricing model. In these situations, the market coverage deviation can be detected more accurately by the QoE indicator than by the energy price deviation. Reduced QoE values, signifying a substantial variance in settled price, suggest that certain customers in the market need to engage with grid trading either alongside or instead of the LEM [178].
- *Quality of Service (QoS):* The parity of the traded energy shares in the LEM is measured by the QoS indicator. The amount of energy traded by each customer is the same if the value of QoS is one. The QoS indicator is more variable than the QoE indicator when it comes to the market's DER customer share, showing higher values when the share is close to 50%. Therefore, it appears that in the LEM, a 50/50 relationship between energy suppliers and consumers leads to the fairest resource distribution [178].
- *Equality Index (EI):* The difference in revenue that each market participant receives by taking part in the LEM as opposed to conducting business as usual is measured by the EI. As such, there is a clear correlation between this metric and customer income.

When examining the EI values, the scenario with equal demand is clearly the most equitable, whereas the scenario with varied demand is the most unfair in terms of income distribution. When compared to the income distribution, these values appear to depict the circumstances fairly. However, inferences about the market's fairness cannot always be made based solely on a low indicator number [178].

4.3.4 Impacts on Energy Networks

The actual energy delivery of P2P trading takes place over the distribution network, where customers are electrically connected. However, distribution networks usually possess some intrinsic features, like an uneven configuration, a greater number of dispersed nodes, a greater R/X ratio, and a non-linear character. Furthermore, when the energy network architectures were designed and built, local penetration and demand adjustment were not taken into consideration. As a result, network problems could arise, and to avoid those network complications, strategic approaches are needed [179].

4.3.4.1 Potential Network Issues

Some identified network issues include:

- *Voltage variations*: High P2P supply in the LEM could cause overvoltage problems, especially during high solar PV penetration. On the other hand, undervoltage issues could occur if consumers buy more energy from the LEM [179].
- *Phase Imbalance:* Phase imbalance encompasses both imbalances in voltage and current. Strongly imbalanced power values on the three phases might be caused by customer-centric trading in the LEM, resulting in increased voltages and losses [179].
- *Line Congestion:* Because DER penetration in distribution networks may rise as a result of LEMs, system congestion may worsen as a result of a lack of corresponding generation and available network hosting capacity. Unexpected increases in P2P demand might also cause line congestion [179].
- *Power Losses:* P2P trading in the LEM could also increase power losses, particularly if storage devices are employed. This is because if a consumer needs energy urgently and agrees to pay more than the peak ToU rate, storage operators may sell energy during off-peak hours without charging their devices, leading to more energy flow from the grid during peak hours [180].
- *Vulnerability to Cyber Attack*: Cybersecurity assaults are a concern for the functioning of energy networks since a LEM model relies heavily on data from smart meter devices. Also, DSO may need to share network data with customers to constitute network-aware LEM models [179].

4.3.4.2 Methods to Include Network Constraints

In general, methods to include network constraints in LEM trading can be categorised into groups, such as post-market clearing methods and pre-market clearing methods.

Post-Market Clearing Methods: In these methods, P2P trading in the LEM is performed first without considering network constraints, and then trading impacts on network voltages, line congestion, power losses, and so on are evaluated by performing DC power flow analysis, AC power flow analysis, or sensitivity-based analysis. Any P2P transactions that may create network issues are either completely blocked or reduced by adopting control- and optimisation-based mechanisms. Also, network-related costs, including power losses costs, are recovered from LEM participants [179].

Pre-Market Clearing Methods: Unlike post-market clearing methods, these methods take network constraints into account through effective network planning techniques before settling P2P transactions in the LEM [179]. This avoids the requirement for further modification of financial settlements. For instance, existing uniform power export and import limits can be inserted as constraints into the LEM models to ensure that they are never violated [181]. These limits can also be expanded further to use the available network hosting capacities in the LEM by incorporating an OPF-based formulation, which may result in better financial returns for DER customers [182].

4.3.5 P2P Trading Projects

Numerous P2P trading projects have been trialled in various parts of the world in recent times. These initiatives are mostly concerned with putting decentralised platforms in place so that both DER and non-DER customers can interact with one another and negotiate better financial terms. Table 13 and Table 14 present a list of some LEM projects that have been trialled in and outside Australia, respectively.

- *AGL VPP Energy Trading:* The goals of the AGL Virtual Trial of P2P (AGL VPP) Energy Trading, trialled in VIC led by AGL in partnership with IBM Australia and Marchment Hill Consulting, are to ascertain the suitability of distributed ledger technology (blockchain with synchronised protocols), study the data, and discover and value P2P energy deals. There are 68 residential DER customers in the AGL VPP study. Six of the 68 DER customers have batteries incorporated with their current solar PV systems, and all of them have smart air conditioning equipment. Additionally, there are 7 event days during which the DERs react to a DR requirement signalling by the local network service provider [183].
- *CUB:* The VB Solar Exchange program in VIC is powered by Powerledger's blockchain technology, which allows participants to track and exchange their extra solar PV energy for VB beer. This maximises the region's use of DERs. It also significantly decreases CUB's CO_2 emissions, contributing to sustainability target achievement. Participants receive slabs of VB delivered right to their door as a reward [184].
- *Evermore:* Powered by Powerledger's blockchain-enabled platform, the Evermore project consists of 24 apartments and a common area that use a hybrid system consisting of 54.6 kWh of solar PV systems and 156 kWh of batteries. This ongoing operation gives apartment owners and strata managers visibility into their energy use at 30-minute intervals. Curtin University, in collaboration with Development WA, the Australian Renewable Energy Agency, the Low Carbon Living Cooperative Study Centre, and the CSIRO, has been supporting the project [185].
- *Wongan-Ballidu:* Powerledger has conducted a six-month trial project in the Shire of Wongan-Ballidu in collaboration with Innovations Central Midlands WA Inc., BSC Solar, Sonnen, and CleanTech Energy. Ten locations have participated in the project's energy trading technology pilot. Commercial locations that feed excess solar power back into the grid are not compensated financially under the present FiT scheme. These sites can now profit from their excess solar PV energy for the first time, thanks to Powerledger's P2P energy trading technology [186].
- *RENeW Nexus:* AEMO, Curtin University, Murdoch University, DevelopmentWA, CSIROs Data61, Synergy, Western Power, energyOS, Powerledger, and the Australian Government's Smart Cities initiative are among the partners and supporters of the RENeW Nexus project, which consists of three parts. In the first part, 40 households use Powerledger's blockchain technology to exchange energy via P2P trading. The second part considers a residential VPP to provide greater monetary gains to participants. In the third part, a microgrid is considered to facilitate at least 36 households to export their solar PV energy surplus [187].

- *East Village:* This project is also sponsored by the Australian Government's Smart Cities and Suburbs initiative. By delivering affordable, clean, and resilient LEMs, East Village in Knutsford, WA, sets the standard for sustainable urban infill. The embedded network with a shared battery and each of the 36 households' 6.6 kW PV solar panels provide all of the energy for the homes. A clean energy retailer draws additional renewable energy from the grid when demand exceeds the amount of energy available within the embedded network [188].

Table 13: Some P2P trading trials in Australia

Project name	Location	Target customers	Trading platform	Financial beneficiary	Network constraints
AGL VPP Energy Trial	VIC	68	Blockchain with synchronised protocols	Solar PV, battery, air-conditioned customers	Not Considered
CUB	VIC	N/A	Blockchain	Solar PV customers	Not Considered
Evermore	WA	24	Blockchain	Solar PV, battery customers	Not Considered
Wongan-Ballidu	WA	10	Blockchain	Solar PV customers	Not Considered
RENeW Nexus	WA	48	Blockchain	Solar PV, battery customers	Not Considered
East Village	WA	36	Blockchain	Solar PV, battery customers	Not Considered

- *T77&077-BCPG: As for the non-Australian projects, i*n Bangkok, Thailand's T77 area, Powerledger has made P2P trading possible. The T77 project has recently been expanded by BCPG to encompass more buildings and solar assets due to the project's original stages' success. From 2.8 MWh per day across 4 buildings to 4.2 MWh across 7 buildings, the T77 project's total solar PV generation capacity has grown. BCPG can keep an eye on the energy generation and transactions amongst the participating buildings thanks to the platform. Invoicing for settlement and a summary of each participant's trading position can also be generated using it [189].

- *SEDA:* In order to demonstrate Powerledger's platform's potential to trade excess solar energy, SEDA and Powerledger have collaborated on a P2P energy trading trial. SEDA wants to expand Malaysia's solar PV rooftop market and promote the country's DER deployment. Tenaga Nasional Berhad (TNB), a Malaysian utility, has provided the interval meter data that Powerledger's platform used to mimic energy trading patterns between prosumers and consumers throughout the Malaysian grid [190].
- *BSES Rajdhani:* The first power distribution company in India to test P2P solar trading using Powerledger's technology is BSES Rajdhani Power Limited (BRPL). The project involves utilising 300 kW of pre-existing solar equipment to power a collection of gated communities located in the Dwarka area of Delhi. To reduce the quantity of energy that was spilt back into the system, homeowners with rooftop solar PV infrastructure during the trial are able to trade their extra energy with higher tariff customers as well as with their neighbours [191].
- *KEPCO:* The KEPCO project involves two phases. KEPCO has provided meter data from 8 participants at the selected site in Osaka City, Japan, for Phase 1. In Phase 2, 8 participants' meter data has been given by KEPCO, and Powerledger has combined the energy produced into kWh that are tokenised on the marketplace for DER credits. The foundation for enabling KEPCO's RE100 clients to employ non-fossil certificates in opposition to RE100 claims is provided by this marketplace. The Climate Group, an international non-profit, is spearheading the global RE100 effort in collaboration with CDP, a global disclosure network [192].
- *Brooklyn Microgrid:* Brooklyn Microgrid (BMG) is a group of company owners and residents of New York City who are committed to transforming the way energy is bought and sold, promoting local solar PV energy production. The network links New Yorkers with solar PV arrays to consumers looking to buy locally produced solar PV energy. Participants use the Brooklyn Microgrid smartphone app, empowered by blockchain technology, to access the neighbourhood energy marketplace. Users of the app have the option to purchase local solar PV energy credits via auction [193].
- *PowerNet:* The blockchain technology is used by American PowerNet's headquarters to trade solar PV power with other tenants in order to maximise clean energy for lower electricity bills and carbon savings. Using data from current meters, the technique leverages American PowerNet's distribution system and connected solar PV assets without requiring additional hardware, software, or engineering fees. The marketplace software keeps track of how much energy is consumed by PowerNet's solar PV panels as opposed to energy coming from the grid [194].
- *SOLgrid:* With rooftop solar home systems, SOLgrid is a P2P microgrid energy exchange network of small enterprises and rural homes. This has made it possible for energy to be distributed more effectively throughout rural communities, to provide access to larger loads, and to give the poorest residents in a community first-time mobile access. In other words, homes can sell their extra energy into the microgrid network, where nearby homes or businesses can purchase it in small amounts with mobile credits. SOLgrid’s solution is unique in that it enables homeowners to use mobile money to monetise the trading of excess energy [195].

- *P2P-SmartTest:* The P2P-SmartTest project looks into and illustrates a more intelligent power distribution system that integrates cutting-edge ICT, local markets, and creative business models. P2P methods are used to maintain second-to-second power balance, the quality and security of the supply, and the integration of demand-side flexibility and optimal operation of DER inside the network. The proposed project builds upon the consortium's extensive experience in power system economics, energy markets, business models, and information and communications technologies (ICT), particularly ICT for the energy sector, smart grids, microGrids, CELLs, VPPs, and DER integration [196].

- *Vandebron:* Customers and small-scale clean energy providers are directly connected through the Vandebron web platform. Energy generated by solar-powered business parks or wind turbine-equipped farmers is sold directly on the marketplace. This strategy acts as a promising endeavour in the P2P energy arena by offering a higher degree of transparency regarding the source and method of one's energy supply. It's simpler to picture a network where DER customers may share their extra energy with others thanks to platforms like Vandebron [197].

- *Piclo P2P Platform:* Piclo P2P Platform provides a cutting-edge online energy marketplace, acting as a matchmaker for LEMs. With the use of solar PV panels and batteries, Piclo P2P Platform makes it easier for people, groups, and companies to exchange P2P and offer balancing services to the nearby electrical grid. Piclo therefore contributes to the resolution of one of the main issues confronting the global energy system at the moment: how to add more DERs to the grid without compromising on reliability, efficiency, or cost [198].

- *Pebbles Project:* As part of the Smart Service World II initiative, the Federal Ministry for Economic Affairs and Energy has supported the Pebbles Project, which is a P2P energy trading platform based on blockchains. The goal of the project is to create, develop, and test a digital platform idea for grid service exchange and P2P trade. Both DER and non-DER customers of all sizes can take part in direct energy trading for the first time with a LEM like Pebbles. Another new element is the trading of flexibility, such as that from EVs or battery storage, and the consideration of the distribution grid's capacity. Local trade can produce both financial gains and an increase in area value production [199].

- *P2P Energy Cloud:* Researching and creating cloud-based solutions for a LEM platform is the goal of Peer Energy Cloud. This involves creating a digital marketplace for the exchange of local power and designing and creating cutting-edge recording and forecasting systems for use in so-called microgrids. The smart microgrid cloud services can access real-time usage data for forecasting by integrating local sensors and actuators at the end user through a separate secured fibre optic cable. One particular application scenario taken into consideration by the project is a microgrid in the Saarlouis urban region in Germany, which consists of multiple solar PV systems and about 500 residential customers [200].

- *Kiplo:* Kiplo is a platform for energy markets created to combine small and medium-sized energy loads, such as distributed generation systems, batteries, EV chargers, heaters, boilers, and chillers. Kiplo helps energy market operators and community managers through our VPP. Kiplo consists of three modules: it allows market operators to manage bids for better intraday and day-ahead planning; it allows both implicit and explicit DR programs to generate additional energy savings for community members; and it allows P2P trading within a community and optimisation of DER communities [201].

- *BEST Project:* In the BEST Project, the most effective way is to use blockchain technology for OLI Market's local electricity trading application. An open-source software called the electricity market bidding system (SMBS) has been created in collaboration with our partners weserbergland University of Applied Sciences, Energieforen Leipzig, fortiss, e-regio, and RLI. The fully automated trade aims to alleviate pressure on the nearby electricity system. Software uses a mix of trusted execution environments (TEE) and a blockchain to calculate local electricity supply and demand, coordinate those factors, and keep trades securely and traceably [202].

Table 14: Some P2P trading trials outside Australia

Project name	Location	Target customers	Trading platform	Financial beneficiary	Network constraints
T77 & 077-BCPG	Bangkok, Thailand	7	Blockchain	Solar PV customers	Not Considered
SEDA	Kuala Lumpur, Malaysia	14	Blockchain	Solar PV customers	Not Considered
BSES Rajdhani	Delhi, India	4	Blockchain	Solar PV customers	Not Considered
KEPCO	Osaka, Japan	8	Blockchain	Solar PV customers	Not Considered
Brooklyn Microgrid	Brooklyn, New York, USA	N/A	Blockchain	Solar PV customers	Not Considered
PowerNet	Florida, USA	N/A	Blockchain	Solar PV customers	Not Considered
SOLgrid	throughout Bangladesh	N/A	IoT-based platform	Solar PV customers	Not Considered
P2P-SmartTest	some parts of Europe	N/A	ICT-based platform	DER customers	Not Considered

Vandebron	Amsterdam, Netherlands	N/A	Online platform	Solar PV and wind customers	Not Considered
Piclo P2P platform	UK, Netherlands, Italy	N/A	Piclo Max	Solar PV and battery customers	Not Considered
Pebbles Project	Wildpoldsried, Germany	65	Blockchain	DER and non-DER customers	Not Considered
Peer Energy Cloud	Southwest of Germany	500	Cloud-based platform	DER and non-DER customers	Not Considered
Kiplo	Coimbra, Portugal	N/A	N/A	DER customers	Not Considered
BEST	Stuttgart, Germany	20	Blockchain	DER customers	Not Considered

5 Final insights and overview of proposed modelling framework

From the literature review, the following insights emerged:

- Tariff structures need to be adaptable to accommodate the evolving landscape of DERs and renewable energy integration. Flat rate tariffs are not suitable for the energy transition as it puts pressure on the grid during peak period.
- Implementing ToU tariffs can incentivise consumers to shift their energy consumption to off-peak hours, reducing strain on the grid during peak demand periods. However, these tariffs are not popular among consumers due to questionable overall benefits.
- Dynamic pricing based on real-time market conditions and grid congestion can optimise energy distribution, promoting efficient use of resources and reducing costs for consumers. However, the concept of fairness is usually one of the challenges in implementing dynamic pricing.
- Tariff structures should incorporate mechanisms for equitable distribution of costs and benefits among all stakeholders, ensuring affordability and fairness in energy pricing.
- P2P energy trading platforms empower prosumers to directly participate in the energy market, fostering a decentralised energy ecosystem and enhancing grid resilience.
- Demand response programs incentivise consumers to adjust their energy consumption in response to grid signals, reducing peak demand and mitigating the need for costly infrastructure upgrades.
- Interoperability standards and regulatory frameworks are essential for seamless integration of DERs into the grid, ensuring compatibility, reliability, and cybersecurity.
- Digital platforms and blockchain technology facilitate transactions and coordination among participants in multi-sided energy markets, enabling P2P trading and value exchange.
- Regulatory frameworks need to evolve to accommodate the dynamic nature of multi-sided energy markets, fostering innovation, competition, and consumer choice while ensuring grid reliability and stability.

The following points are considered in the proposed framework:

- Assessing the impacts of the introduced tariff structures on DER customers' cost savings and network profiles.
- Using the introduced tariff structures, how to develop potential future market models.
- Evaluating the impacts of potential future market models on both DER and non-DER customers' cost savings, network profiles, and network constraints.
- Applying DOE if any potential network issues, such as upper and lower voltage breaches and line congestion, are observed.
- Incorporating equity in DOE-enabled market models to motivate DER customers to participate in the local market.
- Identifying the potential uses of EVs in managing excess generation and curtailed amounts.

References

[1] P., Simshauser "Lessons from Australia's National Electricity Market 1998-2018: The Strengths and Weaknesses of the Reform Experience." (2019): n. pag. Web.

[2] "Regulatory Explainer Network Tariff Trials", Online: https://energyinnovationtoolkit.gov.au/regulatory-explainer-network-tariff-trials (Accessed on Jan. 5, 2024)

[3] "Network Tariff Reform", Online: https://www.aer.gov.au/about/strategic-initiatives/network-tariff-reform#:~:text=Tariff%20structure%20statements&text=The%20TSS%20sets%20out%20the,the%20expected%20impact%20on%20customers (Accessed on Jan. 5, 2024)

[4] B., Toby, et al. "Efficient Tariff Structures for Distribution Network Services." Economic analysis and policy 48 (2015): 139–149. Web.

[5] McLaren, Joyce et al. "Impact of Rate Design Alternatives on Residential Solar Customer Bills: Increased Fixed Charges, Minimum Bills and Demand-Based Rates." The Electricity journal 28.8 (2015): 43–58. Web.

[6] R., Passey, et al., Designing more cost reflective electricity network tariffs with demand charges, Energy Policy, Volume 109, 2017, Pages 642-649, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2017.07.045. [7] "Energy Prices Explained", Online: https://www.originenergy.com.au/pricing/explained/#energy-bill (Accessed on Jan. 5, 2024

[8] "Tariffs and Charges", Online: https://www.powercor.com.au/about-us/customer-experience/affordability/ (Accessed on Jan. 5, 2024)

[9] "Victorian Default Offer price review 2023-24", Online: https://www.esc.vic.gov.au/electricity-and-gas/prices-tariffs-and-benchmarks/victorian-default-offer/victorian-default-offer-price-review-2023-24#toc-how-cost-benchmarks-and-annual-bills-will-change-under-our-final-decision (Accessed on Feb. 6, 2024)

[10] "Which type of tariff is right for you?", Online: https://www.energymadeeasy.gov.au/article/electricity-tariffs?id=types-of-energy-plans (Accessed on Jan. 5, 2024)

[11] "Time of Use Tariffs", Online: https://www.energymining.sa.gov.au/consumers/energy-contracts-billing-and-rebates/time_of_use_tariffs (Accessed on Jan. 5, 2024)

[12] "Electricity Tariffs Explained", Online: https://www.simplyenergy.com.au/help-centre/moving-connections-metering/electricity-tariffs-explained (Accessed on Jan. 5, 2024)

[13] "Residential Time-of-Use Electricity Pricing in NSW", Online: https://australiainstitute.org.au/wp-content/uploads/2020/12/P705-Residential-Time-of-Use-Electrcity-Pricing-in-NSW-web_0.pdf (Accessed on Jan. 8, 2024)

[14] R., Li, et al. "A Novel Time-of-Use Tariff Design Based on Gaussian Mixture Model." Applied energy 162 (2016): 1530–1536. Web.

[15] P., Simshauser. "Distribution Network Prices and Solar PV: Resolving Rate Instability and Wealth Transfers through Demand Tariffs." *Energy economics* 54 (2016): 108–122. Web.

[16] K., Burns, and M., Bruce. “Do Households Respond to Time-Of-Use Tariffs? Evidence from Australia.” *Energy economics* 95 (2021): 105070-. Web.

[17] J., Zarnikau, et al. “How Will Tomorrow’s Residential Energy Consumers Respond to Price Signals? Insights from a Texas Pricing Experiment.” *The Electricity journal* 28.7 (2015): 57–71. Web.

[18] A., Faruqui, et al. “Impact Measurement of Tariff Changes When Experimentation Is Not an Option—A Case Study of Ontario, Canada.” *Energy economics* 52 (2015): 39–48. Web.

[19] R., Passey, et al. “Designing More Cost Reflective Electricity Network Tariffs with Demand Charges.” *Energy policy* 109 (2017): 642–649. Web.

[20] T., Nelson, et al. “Electricity Tariffs in a High-Penetration Renewable System: Insights from Australia’s National Electricity Market.” *The Electricity journal* 31.8 (2018): 57–63. Web.

[21] A., Faruqui, et al. “Arcturus 2.0: A Meta-Analysis of Time-Varying Rates for Electricity.” *The Electricity journal* 30.10 (2017): 64–72. Web.

[22] S.,Neuteleers, et al. “Assessing Fairness of Dynamic Grid Tariffs.” *Energy policy* 108 (2017): 111–120. Web.

[23] H., Hampton, et al. “Customer Engagement Strategies in Retail Electricity Markets: A Comprehensive and Comparative Review.” *Energy research & social science* 90 (2022): 102611-. Web.

[24] O., Selinger-Lutz, et al. “Dynamic Feed-in Tariffs with Reduced Complexity and Their Impact on the Optimal Operation of a Combined Heat and Power Plant.” *International journal of electrical power & energy systems* 118 (2020): 105770-. Web.

[25] S., Chen, et al. “Dynamic Pricing in Electricity and Natural Gas Distribution Networks: An EPEC Model.” *Energy (Oxford)* 207 (2020): 118138-. Web.

[26] P., Wesseh, et al. “Dynamic Tariffs and Climate Policy Interaction: An Economic Analysis of Welfare Implications in Retail Electricity Markets.” *Energy research & social science* 90 (2022): 102679-. Web.

[27] M., Schreiber, et al. “Flexible Electricity Tariffs: Power and Energy Price Signals Designed for a Smarter Grid.” *Energy (Oxford)* 93 (2015): 2568–2581. Web.

[28] F., Guang, et al. “Impacts of Hybrid Time-Varying Tariffs on Residential Electricity Demand: The Case of Zhejiang Province.” *Utilities policy* 61 (2019): 100969-. Web.

[29] “Choices that are good for the environment”, Online: https://www.energymadeeasy.gov.au/article/choices-that-are-good-for-the-environment?id=types-of-energy-plans (Accessed on Jan. 8, 2024)

[30] “Saving with solar”, Online: https://www.simplyenergy.com.au/help-centre/policies-and-commitments/solar-fit-policy {Accessed on Jan. 8, 2024)

[31] J., Jargstorf, et al. “Assessing the Reflectivity of Residential Grid Tariffs for a User Reaction through Photovoltaics and Battery Storage.” *Sustainable Energy, Grids and Networks* 1 (2015): 85–98. Web.

[32] M. Askeland, T. Burandt, and S. A. Gabriel, "A stochastic MPEC approach for grid tariff design with demand-side flexibility," Energy Systems, vol. 14, no. 3, pp. 707-729, 2023.

[33] A. P. Kaur and M. Singh, "Time-of-Use tariff rates estimation for optimal demand-side management using electric vehicles," Energy, vol. 273, p. 127243, 2023.

[34] N. V. Emodi, S. Dwyer, K. Nagrath, and J. Alabi, "Electromobility in Australia: Tariff design structure and consumer preferences for mobile distributed energy storage," Sustainability, vol. 14, no. 11, p. 6631, 2022.

[35] T. Rahman, M. L. Othman, S. B. M. Noor, W. F. B. W. Ahmad, and M. F. Sulaima, "Methods and attributes for customer-centric dynamic electricity tariff design: A review," Renewable and Sustainable Energy Reviews, vol. 192, p. 114228, 2024.

[36] L. Zhang, C. Sun, G. Cai, and L. H. Koh, "Charging and discharging optimization strategy for electric vehicles considering elasticity demand response," Etransportation, vol. 18, p. 100262, 2023.

[37] C. B. Jones et al., "Impact of Electric Vehicle customer response to Time-of-Use rates on distribution power grids," Energy Reports, vol. 8, pp. 8225-8235, 2022.

[38] S. Powell, E. C. Kara, R. Sevlian, G. V. Cezar, S. Kiliccote, and R. Rajagopal, "Controlled workplace charging of electric vehicles: The impact of rate schedules on transformer aging," Applied Energy, vol. 276, p. 115352, 2020.

[39] F. Salah, J. P. Ilg, C. M. Flath, H. Basse, and C. Van Dinther, "Impact of electric vehicles on distribution substations: A Swiss case study," Applied Energy, vol. 137, pp. 88-96, 2015.

[40] F. Daneshzand, P. J. Coker, B. Potter, and S. T. Smith, "EV smart charging: how tariff selection influences grid stress and carbon reduction," Applied Energy, vol. 348, p. 121482, 2023.

[41] P. K. Phanivong, "Bridging the Gap in Distributed Energy Resource Operations: Advancements in Tariff Designs and Load Optimization for Congestion Management," University of California, Berkeley, 2023.

[42] P. K. Phanivong and D. S. Callaway, "The Impacts of Retail Tariff design on Electric Vehicle Charging for Commercial Customers," IEEE Transactions on Energy Markets, Policy and Regulation, 2023.

[43] S. Küfeoğlu, D. Melchiorre, and K. Kotilainen, "Understanding tariff designs and consumer behaviour to employ electric vehicles for secondary purposes in the United Kingdom," The Electricity Journal, vol. 32, no. 6, pp. 1-6, 2019.

[44] R. Hennig, M. Jonker, S. Tindemans, and L. De Vries, "Capacity subscription tariffs for electricity distribution networks: Design choices and congestion management," in 2020 17th International Conference on the European Energy Market (EEM), 2020: IEEE, pp. 1-6.

[45] S. Bjarghov, H. Farahmand, and G. Doorman, "Capacity subscription grid tariff efficiency and the impact of uncertainty on the subscribed level," Energy Policy, vol. 165, p. 112972, 2022.

[46] T. R. McKinney, E. E. Ballantyne, and D. A. Stone, "Rural EV charging: The effects of charging behaviour and electricity tariffs," Energy Reports, vol. 9, pp. 2321-2334, 2023.

[47] R. J. Hennig, D. Ribó-Pérez, L. J. de Vries, and S. H. Tindemans, "What is a good distribution network tariff?—Developing indicators for performance assessment," Applied Energy, vol. 318, p. 119186, 2022.

[48] F. Verbist, N. K. Panda, P. P. Vergara, and P. Palensky, "Impact of Dynamic Tariffs for Smart EV Charging on LV Distribution Network Operation," arXiv preprint arXiv:2306.10775, 2023.

[49] https://www.linkedin.com/pulse/residential-tariffs-ev-charging-what-does-good-tariff-ross-de-rango/

[50] R. J. Hennig, L. J. de Vries, and S. H. Tindemans, "Congestion management in electricity distribution networks: Smart tariffs, local markets and direct control," Utilities Policy, vol. 85, p. 101660, 2023.

[51] I. Zenginis, J. Vardakas, N. Zorba, and C. Verikoukis, "Performance evaluation of a multi-standard fast charging station for electric vehicles," IEEE transactions on smart grid, vol. 9, no. 5, pp. 4480-4489, 2017.

[52] M. Sulaima, N. Dahlan, and Z. Yasin, "Effective electricity cost management in a manufacturing operation by using optimal ETOU tariff formulation," Journal of Electrical and Electronic Systems Research (JEESR), vol. 15, pp. 82-93, 2019.

[53] J. Cui, Z. Ran, W. Shen, and Y. Xin, "Study on multi-type flexible load control method of active distribution network based on dynamic time-sharing electricity price," Applied Energy, vol. 357, p. 122479, 2024.

[54] Y. Kabiri-Renani, A. Arjomandi-Nezhad, M. Fotuhi-Firuzabad, and M. Shahidehpour, "Transactive-Based Day-Ahead Electric Vehicles Charging Scheduling," IEEE Transactions on Transportation Electrification, 2024.

[55] P. Chakraborty and M. Pal, "Planning of fast charging infrastructure for electric vehicles in a distribution system and prediction of dynamic price," International Journal of Electrical Power & Energy Systems, vol. 155, p. 109502, 2024.

[56] T. Aljohani, M. A. Mohamed, and O. Mohammed, "Tri-level hierarchical coordinated control of large-scale EVs charging based on multi-layer optimization framework," Electric Power Systems Research, vol. 226, p. 109923, 2024.

[57] H. Suyono, M. T. Rahman, H. Mokhlis, M. Othman, H. A. Illias, and H. Mohamad, "Optimal scheduling of plug-in electric vehicle charging including time-of-use tariff to minimize cost and system stress," Energies, vol. 12, no. 8, p. 1500, 2019.

[58] I. S. Freitas Gomes, A. F. Abdin, J. Puchinger, and Y. Perez, "Unlocking Flexible Electric Vehicle Charging via New Rate Design," The Energy Journal, vol. 45, no. 3, pp. 251-291, 2024.

[59] W. Jeon, S. Cho, and S. Lee, "Estimating the impact of electric vehicle demand response programs in a grid with varying levels of renewable energy sources: Time-of-use tariff versus smart charging," Energies, vol. 13, no. 17, p. 4365, 2020.

[60] S. Kucuksari and N. Erdogan, "EV specific time-of-use rates analysis for workplace charging," in 2021 IEEE Transportation Electrification Conference & Expo (ITEC), 2021: IEEE, pp. 783-788.

[61] T. Schittekatte, D. S. Mallapragada, P. L. Joskow, and R. Schmalensee, "Electricity Retail Rate Design in a Decarbonized Economy: An Analysis of Time-Of-Use and Critical Peak Pricing," National Bureau of Economic Research, 2022.

[62] T. Schittekatte, D. Mallapragada, P. L. Joskow, and R. Schmalensee, "Electricity retail rate design in a decarbonizing economy: an analysis of time-of-use and critical peak pricing," The Energy Journal, vol. 45, no. 3, pp. 25-56, 2024.

[63] D. S. Pereira and A. C. Marques, "Are dynamic tariffs effective in reducing energy poverty? Empirical evidence from US households," Energy, vol. 282, p. 128848, 2023.

[64] J. Freier and V. von Loessl, "Dynamic electricity tariffs: Designing reasonable pricing schemes for private households," Energy Economics, vol. 112, p. 106146, 2022.

[65] K. Mohlin, E. Spiller, K. Tapia-Ahumada, and B. Unel, "Cost-Reflective Residential Electricity Tariff Design: Synthesis of research findings on the impacts on customer bills, adoption of distributed energy resources and pollution," Environmental Defense Fund Economics Discussion Paper Series, EDF EDP, pp. 21-07, 2021.

[66] T. Beaufils and P.-O. Pineau, "Assessing the impact of residential load profile changes on electricity distribution utility revenues under alternative rate structures," Utilities Policy, vol. 61, p. 100959, 2019.

[67] “Solar Connect: Batteries”, Online: https://alicespringsfuturegrid.com.au/battery-vpp (Accessed on Jan. 10, 2024)

[68] “Introducing the Discover Energy VPP Premium Plan”, Online: https://www.discoverenergy.com.au/blogs/de_en/439 (Accessed on Jan. 12, 2024)

[69] “Community Battery Services”, Online: https://media.powercor.com.au/wp-content/uploads/2023/10/12174049/12455-CPPC-VPN-Com_Battery_Services_Doc_v4-1.pdf (Accessed on Feb. 12, 2024)

[70] “Trial Tariffs”, Online: https://www.jemena.com.au/electricity/jemena-electricity-network/network-information/trial-tarrifs/#:~:text=To%20facilitate%20the%20uptake%20of,trial%20from%201%20July%202023. (Accessed on Jan. 12, 2024)

[71] “State of distributed energy resources technology integration report”, ARENA, Feb. 2021, Available Online: https://arena.gov.au/knowledge-bank/state-of-der-technology-integration-report/ (Accessed on Jan. 5, 2024).

[72] “DER roadmap: Distributed energy resources orchestration and responsibilities”, Energy Transformation Taskforce, Aug. 2020, Available Online: https://www.wa.gov.au/system/files/2020-08/Issues%20Paper%20-%20DER%20Roadmap%20%20Distributed%20Energy%20Resources%20Orchestration%20Roles%20and%20Responsibilities.pdf (Accessed on Jan. 5, 2024).

[73] “The future of distributed flexibility”, Ofgem, Mar. 2023, Available Online: https://www.ofgem.gov.uk/publications/call-input-future-distributed-flexibility (Accessed on Jan. 5, 2024).

[74] “Integrating distributed energy resources for the grid of the future”, Sep. 2019, AEMC, Available Online: https://www.aemc.gov.au/sites/default/files/2019-09/Final%20report%20-%20ENERFR%202019%20-%20EPR0068.PDF (Accessed on Jan. 5, 2024).

[75] “UK renewable energy roadmap”, Department of Energy & Climate Change, Jul. 2011, Available Online: https://assets.publishing.service.gov.uk/media/5a79e9bae5274a18ba50fb84/2167-uk-renewable-energy-roadmap.pdf (Accessed on Feb. 7, 2024).

[76] “Expanding the possibilities: When and where can grid-enhancing technologies, distributed energy resources, and microgrids support the grid of the future?”, Resources for the Future, Sep. 2023, Available Online: https://media.rff.org/documents/Report_23-13.pdf (Accessed on Feb. 7, 2024).

[77] “Unlocking the potential of distributed energy resources”, IEA, Available Online: https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c-ae78b645ce67/UnlockingthePotentialofDERs_Powersystemopportunitiesandbestpractices.pdf (Accessed on Jan. 6, 2024).

[78] “Energy future scenarios (FES)”, ESO, Available Online: https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes (Accessed on Feb. 7, 2024).

[79] A. D. R. Albertini et. al, “An overview of distributed energy resources management system guidelines and functional coverage”, In Proc. of the International Conference on Power Electronics, Smart Grid, and Renewable Energy, Trivandrum, India, Jan. 2022, pp. 1-6, Available Online: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9715935 (Accessed on Jan. 8, 2024).

[80] “DERMS requirements Version 2.0”, Smart Electric Power Alliance, Available Online: https://sepapower.org/resource/distributed-energy-resource-management-system-derms-requirements/ (Accessed on Jan. 8, 2024).

[81] “Onslow distributed energy resources management system (DERMS)”, Horizon Power, Available Online: https://www.horizonpower.com.au/your-community/getting-future-ready/onslow-distributed-energy-resources-management-system-derms/ (Accessed on Feb. 7, 2024).

[82] “etap ADMS”, etap, Available Online: https://etap.com/solutions/advanced-distribution-management-system (Accessed on Jan. 8, 2024).

[83] “Coordination of distributed energy resources; International system architecture insights for future market design”, Newport Consortium, May 2018, Available Online: https://aemo.com.au/-/media/files/electricity/nem/der/2019/oen/newport-intl-review-of-der-coordination-for-aemo-final-report.pdf?la=en (Accessed on Jan. 8, 2024).

[84] “Dynamics of a truly connected energy market”, ecogeneration, Available Online: https://www.ecogeneration.com.au/dynamics-of-a-truly-connected-energy-market/ (Accessed on Jan. 8, 2024).

[85] “DER visibility and monitoring best practice guide use case summary and context”, AEMC, May 2020, Available Online: https://www.aemc.gov.au/sites/default/files/documents/rule_change_submission_-_erc0301_-_solar_analytics_updated_-_20210114.pdf (Accessed on Jan. 9, 2024).

[86] “AEMO on behalf of the DEIP EV data availability taskforce”, AEMO, Feb. 2021, Available Online: https://aemo.com.au/-

/media/files/stakeholder_consultation/working_groups/der-program/deip-ev/2021/deip-ev-data-availability-taskforce-report.pdf?la=en (Accessed on Jan. 9, 2024).

[87] Project Edith overview report, Jul. 2022, Available Online: https://cdn.ausgrid.com.au/-/media/Documents/Reports-and-Research/Project-Edith/Project-Edith-2022.pdf?rev=eecbc81dcb9d4bc39d79362f8365de42 (Accessed on Jan. 5, 2024).

[88] "Guide to ancillary services in the national electricity market", AEMO, Oct. 2023, Available Online: https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/guide-to-ancillary-services-in-the-national-electricity-market.pdf (Accessed on Jan. 9, 2024).

[89] "Project Edith network support: A comparison of current and emerging solutions", Jul. 2023, Available Online: https://cdn.ausgrid.com.au/-/media/Documents/About-us/Future-Grid/Edith/Project-Edith-Knowledge-Sharing-Report-2.pdf?rev=5045c84d1ec241a5ac81c89546549828 (Accessed on Jan. 9, 2024).

[90] "Dynamic pricing trials", SAVE, Available Online: https://save-project.co.uk/dynamic-pricing-trials/ (Accessed on Jan. 9, 2024).

[91] "Edith", Available Online: https://bsgip.com/research/edith/ (Accessed on Jan. 9, 2024).

[92] "Demand response", ARENA, Available Online: https://arena.gov.au/renewable-energy/demand-response/ (Accessed on Jan. 10, 2024).

[93] "Flexible demand and demand control final report", RACE 2030, Oct. 2021, Available Online: https://www.racefor2030.com.au/wp-content/uploads/2021/10/RACE-B4-OA-Final-report.pdf (Accessed on Jan. 10, 2024).

[94] S. Hussain et. al, "Flexibility: Literature review on concepts, modelling, and provision method in smart grid", Sustainable Energy, Grids and Networks, vol. 35, Sep. 2023, pp. 101113: 1-23, Available Online:

https://www.sciencedirect.com/science/article/abs/pii/S2352467723001212 (Accessed on Jan. 5, 2024).

[95] "AGL demand response", ARENA, Available Online: https://arena.gov.au/projects/agl-demand-response/ (Accessed on Jan. 10, 2024).

[96] "South Australian demand management trials program", Available Online: https://www.energymining.sa.gov.au/industry/modern-energy/solar-batteries-and-smarter-homes/south-australian-demand-management-trials-program (Accessed on Jan. 10, 2024).

[97] "Demand Response", Shell Energy, Available Online: https://shellenergy.com.au/energy-solutions/demand-response/ (Accessed on Jan. 10, 2024).

[98] "Interoperable demand side response programme: Successful projects", Available Online: https://www.gov.uk/government/publications/interoperable-demand-side-response-programme-successful-projects/interoperable-demand-side-response-programme-successful-projects (Accessed on Feb. 7, 2024).

[99] "Peak demand reduction scheme", Oct. 2023, Available Online: https://www.energy.nsw.gov.au/sites/default/files/2023-

10/Peak_Demand_Reduction_Scheme_Consultation_Paper_Rule_Change_2.pdf (Accessed on Jan. 10, 2024).

[100] "Battery incentive programs around Australia (existing & proposed)", Nov. 2018, Available Online: https://switchdin.com/blog/2018/11/23/battery-incentive-programs-australia (Accessed on Jan. 10, 2024).

[101] "SGIP California home battery rebate: 2021", Energysage, Available Online: https://www.energysage.com/energy-storage/bring-your-own-battery-programs/california-energy-storage-incentives-sgip-explained/ (Accessed on Feb. 7, 2024).

[102] "What is EV charging? Understanding the basics and beyond", Jul. 2023, Available Online: https://wattlogic.com/blog/what-is-ev-charging/ (Accessed on Jan. 10, 2024).

[103] "Electric vehicles destination charging: An overview of charging tariffs, business models and coordination strategies", Renewable and Sustainable Energy Reviews, vol. 184, Sep. 2023, pp. 113534: 1-25, Available Online: https://www.sciencedirect.com/science/article/pii/S136403212300391X (Accessed on Jan. 10, 2024).

[104] "Charge Collective", UK Power Networks, Available Online: https://innovation.ukpowernetworks.co.uk/projects/charge-collective (Accessed on Feb. 7, 2024).

[105] "Faster Project", Available Online: https://www.fasterevcharge.com/ (Accessed on Feb. 7, 2024).

[106] "AS/NZS 4777.2 – Inverter requirements standard", AEMO, Available Online: https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/as-nzs-4777-2-inverter-requirements-standard (Accessed on Jan. 11, 2024).

[107] "What is an export limit and how does it work?", Synergy, Available Online: https://www.synergy.net.au/Your-home/Help-and-advice/Solar-credits-and-upgrades/DEBS---what-is-an-export-limit-and-how-does-it-work (Accessed on Jan. 12, 2024).

[108] "Up to 30 kW", AusNet, Available Online: https://www.ausnetservices.com.au/solar/solar-connections/up-to-30kw (Accessed on Jan. 12, 2024).

[109] "Flexible export eligibility", SA Power Networks, Available Online: https://www.sapowernetworks.com.au/your-power/smarter-energy/flexible-exports/flexible-exports-eligibility/ (Accessed on Jan. 12, 2024).

[110] "Export limit", SP Energy Networks, Available Online: https://www.spenergynetworks.co.uk/pages/export_limitation.aspx (Accessed on Feb. 7, 2024).

[111] "Solar export limiting or zero limit: What does it mean?", Available Online: https://isolux.com.au/solar-export-limiting-or-zero-export-what-does-it-mean/ (Accessed on Jan. 12, 2024).

[112] "Power quality response mode setting", Standards Australia, Available Online: https://www.energynetworks.com.au/miscellaneous/power-quality-response-mode-settings/ (Accessed on Jan. 12, 2024).

[113] L. Blackhall, “On the calculation and use of dynamic operating envelope”, Evolve project M4 knowledge sharing report, Available Online: https://arena.gov.au/assets/2020/09/on-the-calculation-and-use-of-dynamic-operating-envelopes.pdf (Accessed on Jan. 13, 2024).

[114] “N2 opportunity assessment: Low voltage network visibility and optimising DER hosting capacity final report”, RACE 2030, Dec. 2021, Available Online: https://racefor2030.com.au/wp-content/uploads/2023/03/N2-OA-Project-FINAL-Report-2021.pdf (Accessed on Jan. 15, 2024).

[115] P. Scott et. al, “Shaped operating envelopes: Technical design and implementation report”, Feb. 2023, Available Online: https://arena.gov.au/assets/2023/02/shaped-operating-envelopes-technical-design-implementation-report.pdf (Accessed on Jan. 15, 2024).

[116] M. M. Hoque et. al, “Dynamic operating envelope-based local energy market for prosumers with electric vehicles”, IEEE Transactions on Smart Grid (Early Access), doi: 10.1109/TSG.2024.3302270, Aug. 2023, pp. 1-13, Available Online: https://ieeexplore.ieee.org/document/10208161 (Accessed on Jan. 15, 2024).

[117] “Dynamic operating envelopes working group outcomes report, DEIP, Mar. 2022, Available Online: https://arena.gov.au/assets/2022/03/dynamic-operating-envelope-working-group-outcomes-report.pdf (Accessed on Jan. 13, 2024).

[118] M. R. Alam et. al, “Allocation of dynamic operating envelopes in distribution networks: Technical and equitable perspectives”, IEEE Transactions on Sustainable Energy, vol. 15, no. 1, Jan. 2024, pp. 173-186, Available Online: https://ieeexplore.ieee.org/document/10123018 (Accessed on Jan. 15, 2024).

[119] “Project EDGE public interim report, Jul. 2022, Available Online: https://arena.gov.au/assets/2022/07/project-edge-interim-public-project-report.pdf (Accessed on Jan. 15, 2024).

[120] M. I. Azim et. al, “Dynamic operating envelope-enabled P2P trading to maximise financial returns of prosumers”, IEEE Transactions on Smart Grid (Early Access), doi: 10.1109/TSG.2023.3297366, Jul. 2023, pp. 1-13, Available Online: https://ieeexplore.ieee.org/document/10208161 (Accessed on Jan. 15, 2024).

[121] “Project EDGE: Fairness in dynamic operating envelope objective functions”, Apr. 2023, Available Online: https://aemo.com.au/-/media/files/initiatives/der/2023/the-fairness-in-dynamic-operating-envelope-objectives-report.pdf?la=en (Accessed on Jan. 13, 2024).

[122] System modeling for grid-interactive efficient building applications

[123] S. A. R. Naqvi, K. Kar, S. Bhattacharya and V. Chandan, "Peak Power Minimization for Commercial Thermostatically Controlled Loads in Multi-Unit Grid-Interactive Efficient Buildings," in IEEE Transactions on Sustainable Energy, vol. 13, no. 2, pp. 998-1010, April 2022, doi: 10.1109/TSTE.2022.3140655.

[124] X. Huo, J. Dong, B. Cui, B. Liu, J. Lian and M. Liu, "Two-Level Decentralized-Centralized Control of Distributed Energy Resources in Grid-Interactive Efficient Buildings," in IEEE Control Systems Letters, vol. 7, pp. 997-1002, 2023, doi: 10.1109/LCSYS.2022.3230321.

[125] “Grid-interactive efficient buildings paper”, Online: https://new.gbca.org.au/case-studies/building/grid-interactive-efficient-buildings-paper/ (Accessed on Jan. 12, 2024)

[126] T., Sikorski, et al. “A Case Study on Distributed Energy Resources and Energy-Storage Systems in a Virtual Power Plant Concept: Economic Aspects.” *Energies (Basel)* 12.23 (2019): 4447-. Web.

[127] Z., Ullah, et al. “Virtual Power Plant: State of the Art Providing Energy Flexibility to Local Distribution Grids.” *E3S Web of Conferences* 231 (2021): 1002-. Web.

[128] D., Candra, et al. “Economic Optimal Implementation of Virtual Power Plants in the German Power Market.” *Energies (Basel)* 11.9 (2018): 2365-. Web.

[129] H., Wang, et al. “Integrated Techno-Economic Modeling, Flexibility Analysis, and Business Case Assessment of an Urban Virtual Power Plant with Multi-Market Co-Optimization.” *Applied energy* 259 (2020): 114142-. Web.

[130] Z., Ullah, et al. “Modelling and Analysis of Virtual Power Plants Interactive Operational Characteristics in Distribution Systems.” *Energy conversion and economics* 3.1 (2022): 11–19. Web.

[131] “Tesla Virtual Power Plant”, Online: https://arena.gov.au/projects/tesla-virtual-power-plant/ (Accessed on Jan. 12, 2024)

[132] “AGL Virtual Power Plant”, Online: https://arena.gov.au/projects/agl-virtual-power-plant/ (Accessed on Jan. 12, 2024)

[133] M. Lewis, “Two sides to the energy market?”, Energy Networks Australia, May 2020, Available Online: https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/two-sides-to-the-energy-market/ (Accessed on Jan. 5, 2024).

[134] “Heard of a two-sided energy market? Here’s how it works”, Synergy, Available Online: https://www.synergy.net.au/Blog/2022/01/Two-sided-energy-market (Accessed on Jan. 5, 2024).

[135] J. Stekli et. al, “Distributed energy resource participation in electricity markets: A review of approaches, modelling, and enabling information and communication technologies”, Energy Strategy Reviews, Elsevier, vol. 43, Sep. 2022, pp. 100940: 1-11, Available Online: https://www.sciencedirect.com/science/article/pii/S2211467X22001341 (Accessed on Jan. 5, 2024).

[136] E. Lannoye., “Activation of distributed energy resources in the energy market”, EPRI technical update, May 2019, Available Online: https://aemo.com.au/-/media/files/electricity/nem/der/2019/standards-protocols/epri-activation-of-der-in-the-energy-market-report.pdf?la=en (Accessed on Jan. 5, 2024).

[137] “Markets and framework”, AEMO, Available Online: https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/markets-and-framework (Accessed on Jan. 5, 2024).

[138] “Open Energy Network project”, Energy Networks Australia, Available Online: https://www.energynetworks.com.au/resources/reports/2020-reports-and-publications/open-energy-networks-project-energy-networks-australia-position-paper/ (Accessed on Jan. 5, 2024).

[139] “Post 2025 DER implementation plan – interoperability policy framework”, Energy and Climate Change Ministerial Council, Available Online: https://www.energy.gov.au/energy-and-climate-change-ministerial-council/working-groups/energy-transformation-enablers-working-group/post-2025-market-design/post-2025-der-implementation-plan-interoperability-policy-framework (Accessed on Jan. 5, 2024).

[140] “DER market integral trials – Summary report”, Distributed Energy Integration Program, Sep. 2022, Available Online: https://arena.gov.au/assets/2022/09/der-market-integration-trials-summary-report.pdf (Accessed on Jan. 5, 2024).

[141] “Local distributed energy resource network solutions”, RACE for 2030, Available Online: ttps://racefor2030.com.au/opportunity-assessment-reports/#2 (Accessed on Jan. 5, 2024).

[142] “DER standards and connections”, AEMO, Available Online: https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections (Accessed on Jan. 5, 2024).

[143] “DER roadmap: Distributed energy resources orchestration and responsibilities information paper - Summary”, Energy Policy WA, May. 2022, Available Online: https://www.wa.gov.au/system/files/2022-07/DER%20Orchestration%20Roles%20and%20Responsibilities%20information%20Paper%20-%20Summary.pdf (Accessed on Jan. 15, 2024).

[144] “Locational value of distributed energy resources”, Berkeley Lab, USA, Feb. 2021, Available Online:

https://eta-publications.lbl.gov/sites/default/files/lbnl_locational_value_der_2021_02_08.pdf (Accessed on Jan. 5, 2024).

[145] “Project EDGE final report”, Oct. 2023, Available Online: https://aemo.com.au/-/media/files/initiatives/der/2024/project-edge-final-report.pdf?la=en (Accessed on Jan. 5, 2024).

[146] “Project Symphony DER services report”, Available Online: https://arena.gov.au/assets/2022/03/project-symphony-der-services-report.pdf (Accessed on Jan. 5, 2024).

[147] “Project Edith”, Available Online: https://www.ausgrid.com.au/About-Us/Future-Grid/Project-Edith (Accessed on Jan. 15, 2024).

[148] “Project Converge”, Available Online: https://www.evoenergy.com.au/project-converge (Accessed on Jan. 5, 2024).

[149] “Demand response short notice trial RERT trial Year 3 report”, Oct. 2021, Available Online: https://arena.gov.au/assets/2021/10/demand-response-short-notice-rert-trial-year-3-report.pdf (Accessed on Jan. 5, 2024).

[150] “CONSORT Bruny Island Battery Trial”, Available Online: https://brunybatterytrial.org/ (Accessed on Jan. 5, 2024).

[151] “Networks Renewed”, Available Online: https://arena.gov.au/projects/networks-renewed/ (Accessed on Jan. 5, 2024).

[152] “Ausgrid’s Battery Virtual Power Plant final report”, Feb. 2023, Available Online: https://www.ausgrid.com.au/Industry/Demand-Management/Power2U-Progam/Battery-VPP-Trial (Accessed on Jan. 5, 2024).

[153] “Evolve DER Project”, Available Online: https://arena.gov.au/projects/evolve-der-project/ (Accessed on Jan. 5, 2024).

[154] “SA Power Networks Flexible Exports for Solar PV Trial”, Available Online: https://arena.gov.au/projects/sa-power-networks-flexible-exports-for-solar-pv-trial/ (Accessed on Jan. 5, 2024).

[155] “Advanced VPP grid integration”, Available Online: https://arena.gov.au/projects/advanced-vpp-grid-integration/ (Accessed on Jan. 5, 2024).

[156] “EWF and APG testing DER for frequency regulation on Austrian grid in new Flex-Hub concept”, Available Online: https://www.renewableenergyworld.com/storage/ewf-and-apg-testing-der-for-frequency-regulation-on-austrian-grid-in-new-flex-hub-concept/#gref (Accessed on Jan. 5, 2024).

[157] “Distributed ReStart”, Available Online: https://www.spenergynetworks.co.uk/pages/distributed_restart.aspx#tablist1-tab1 (Accessed on Jan. 5, 2024).

[158] “Power Potential”, Available Online: https://innovation.ukpowernetworks.co.uk/projects/power-potential (Accessed on Jan. 5, 2024).

[159] “Project PHOENIX”, Available Online: https://www.spenergynetworks.co.uk/pages/phoenix.aspx (Accessed on Jan. 5, 2024).

[160] “The Charge Project”, Available Online: https://www.spenergynetworks.co.uk/pages/charge.aspx#tablist1-tab1 (Accessed on Jan. 5, 2024).

[161] “Ming Yang unveils 1.3 GW wind-solar-battery hybrid plan”, Online: https://www.rechargenews.com/wind/ming-yang-unveils-1-3gw-wind-solar-battery-hybrid-plan/2-1-730650 (Accessed on Jan. 5, 2024).

[162] “Aggregate Distributed Energy Resources Pilot Project governing document”, Oct. 2022, Available Online: https://www.ercot.com/files/docs/2022/10/11/11.1%20Aggregate%20Distributed%20Energy%20Resource%20(DER)%20Pilot%20Project%20-%20Template.pdf (Accessed on Jan. 5, 2024).

[163] “DERMs technology allows grid connection even when grid is at full capacity”, Dec. 2021, Available Online: https://pv-magazine-usa.com/2021/12/08/derms-technology-allows-grid-connection-even-when-grid-is-at-full-capacity/ (Accessed on Jan. 5, 2024).

[164] “Pilot project to integrate decentralised energy resources in grid and system service”, Available Online: https://www.swissgrid.ch/en/home/newsroom/newsfeed/20230327-01.html (Accessed on Jan. 5, 2024).

[165] “Local energy markets theory & practice”, Trade RES 2nd Public Workshop, Nov. 2022, Available Online: https://traderes.eu/wp-content/uploads/2022/12/4.-TradeRES_Local-Energy-Markets-Theory-and-Practice_EshtherMengelkamp.pdf (Accessed on Jan. 5, 2024).

[166] "Local energy market", Available Online: https://es.catapult.org.uk/tools-and-labs/our-place-net-zero-toolkit/smart-local-energy-systems/local-energy-market/ (Accessed on Jan. 5, 2024).

[167] "What is peer-to-peer energy trading", Mar. 2020, Available Online: https://www.infiniteenergy.com.au/peer-to-peer-energy-trading/ (Accessed on Jan. 5, 2024).

[168] "The distributed energy resources revolution: A roadmap for Australia's enormous rooftop solar and battery potential", Clean Energy Council, Available Online: https://assets.cleanenergycouncil.org.au/documents/advocacy-initiatives/the-distributed-energy-resources-revolution-paper.pdf (Accessed on Jan. 5, 2024).

[169] M. I. Azim et. al, "Peer-to-peer kilowatt and negawatt trading: A review of challenges and recent advances in distribution networks", Renewable and Sustainable Energy Reviews, vol. 169, Nov. 2022, pp. 112908: 1-23, Available Online: https://www.sciencedirect.com/science/article/abs/pii/S1364032122007894 (Accessed on Jan. 5, 2024).

[170] O. Valarezo et. al, "Analysis of new flexibility market models in Europe", Energies, vol. 14, no. 12, Jun. 2021, pp. 3521: 1-24, Available Online:

https://www.mdpi.com/1996-1073/14/12/3521 (Accessed on Jan. 15, 2024).

[171] F. Charbonnier et. al, "Coordination of resources at the edge of the electricity grid: Systematic review and taxonomy", Applied Energy, vol. 318, May. 2022, pp. 119188: 1-18, Available Online: https://www.sciencedirect.com/science/article/pii/S030626192200558X (Accessed on Jan. 5, 2024).

[172] "The potential of blockchain for peer-to-peer energy trading", Reintech, Available Online: https://reintech.io/blog/blockchain-potential-peer-to-peer-energy-trading (Accessed on Jan. 5, 2024).

[173] "Types of blockchain: Public, private, or something in between", Foley, Available Online: https://www.foley.com/insights/publications/2021/08/types-of-blockchain-public-private-between/ (Accessed on Jan. 5, 2024).

[174] W. Tushar et. al, "Peer-to-peer trading in electricity networks: An overview", IEEE Transactions on Smart Grid, vol. 11, no. 4, Jul. 2020, pp. 3185-3200, Available Online: https://ieeexplore.ieee.org/abstract/document/8972609 (Accessed on Jan. 5, 2024).

[175] M. I. Azim, "Peet-to-peer energy trading in low-voltage distribution networks", PhD Thesis, The University of Queensland, Apr. 2022, Available Online: https://espace.library.uq.edu.au/view/UQ:d3d1e7e (Accessed on Jan. 5, 2024).

[176] C. Long et. al, "Peer-to-peer energy trading in a community microgrid", Proc. of the IEEE Power & Energy Society General Meeting, Chicago, USA, Jul. 2017, pp. 1-5, Available Online: https://ieeexplore.ieee.org/document/8274546 (Accessed on Jan. 5, 2024).

[177] "Local energy markets and fairness: Insights for smart local energy systems (SLES)", Catapult energy systems, Available Online: https://esc-production-2021.s3.eu-west-2.amazonaws.com/wp-content/uploads/2022/03/17112202/Local-Energy-Markets-and-Fairness-Insights-for-Smart-Local-Energy-Systems.pdf (Accessed on Jan. 5, 2024).

[178] M. Dynge et. al, "Evaluating fairness indicators for local energy markets", TechRxiv, May 2024, Available Online:

https://www.techrxiv.org/doi/full/10.36227/techrxiv.22736996.v1 (Accessed on Jan. 5, 2024).

[179] V. Dudjak et. al, "Impact of local energy markets integration in power systems layer: A comprehensive review", IEA, Nov. 2021, Available Online: https://userstcp.org/wp-content/uploads/2021/11/GO-P2P-ST1-Literature-Review.pdf (Accessed on Jan. 5, 2024).

[180] M. I. Azim et. al, "Investigating the impact of power losses on grid-connected networks with prosumers", Applied Energy, Elsevier, vol. 263, Apr. 2020, pp. 1-12, Available Online: https://www.sciencedirect.com/science/article/pii/S0306261920301999 (Accessed on Jan. 5, 2024).

[181] M. I. Azim et. al, "Regulated P2P energy trading: A typical Australian distribution network case study", IEEE PES General Meeting, Montreal, Canada, Aug. 2-6, 2020, pp. 1-5, Available Online: https://ieeexplore.ieee.org/document/9282128 (Accessed on Jan. 5, 2024).

[182] K. Petrou et. al, "Ensuring distribution network integrity using dynamic operating limits for prosumers", IEEE Transactions on Smart Grid, vol. 12, no. 4, Sep. 2021, pp. 3877-3888, Available Online: https://ieeexplore.ieee.org/document/9432974 (Accessed on Jan. 15, 2024).

[183] "AGL virtual trial of peer-to-peer energy trading", Available Online: https://arena.gov.au/projects/agl-virtual-trial-peer-to-peer-trading/ (Accessed on Jan. 5, 2024).

[184] "CUB, Australia", Available Online: https://www.powerledger.io/clients/cub-australia (Accessed on Jan. 5, 2024).

[185] "Evermore, Australia", Available Online: https://www.powerledger.io/clients/evermore-australia (Accessed on Jan. 5, 2024).

[186] "Wongan-Ballidu, Australia", Available Online: https://www.powerledger.io/clients/wongan-ballidu-australia (Accessed on Jan. 5, 2024).

[187] "RENeW Nexus, Australian Government, Australia", Available Online: https://www.powerledger.io/clients/renew-nexus-australian-government-australia (Accessed on Jan. 5, 2024).

[188] "East Village, Australia", Available Online: https://www.powerledger.io/clients/east-village-australia (Accessed on Jan. 5, 2024).

[189] "T77 & 077-BCPG, Thailand", Available Online: https://www.powerledger.io/clients/t77-bcpg-and-mea-thailand-thailand (Accessed on Jan. 5, 2024).

[190] "SEDA, Malaysia", Available Online: https://www.powerledger.io/clients/seda-malaysia (Accessed on Jan. 5, 2024).

[191] "BSES Rajdhani", Available Online: https://www.powerledger.io/clients/bses-rajdhani-india (Accessed on Jan. 5, 2024).

[192] "KEPCO, Japan", Available Online: https://www.powerledger.io/clients/kepco-japan (Accessed on Jan. 5, 2024).

[193] "Brooklyn Microgrid", Available Online: https://www.brooklyn.energy/ (Accessed on Jan. 5, 2024).

[194] “American PowerNet, United States”, Available Online: https://www.powerledger.io/clients/american-powernet (Accessed on Jan. 5, 2024).

[195] “The SOLGRID”, Available Online: https://solshare.com/solgrid/ (Accessed on Jan. 5, 2024).

[196] “P2P-SmartTest”, Available Online: https://cordis.europa.eu/project/id/646469 (Accessed on Jan. 5, 2024).

[197] “Vandebron”, Available Online: https://www.dcbel.energy/blog/2021/05/07/the-internet-of-energy-three-paths-towards-peer-to-peer-electricity/ (Accessed on Jan. 5, 2024).

[198] “Piclo Peer-to-Peer Energy Trading Platform”, Available Online: https://mission-innovation.net/our-work/mission-innovation-breakthroughs/piclo-peer-to-peer-energy-trading-platform/ (Accessed on Jan. 4, 2024).

[199] “Pebbles”, Available Online: https://pebbles-projekt.de/en/project/ (Accessed on Jan. 5, 2024).

[200] “Peer Energy Cloud”, Available Online: https://software-cluster.org/projects/peer-energy-cloud/ (Accessed on Jan. 5, 2024).

[201] “Kiplo”, Available Online: https://cleanwatts.energy/kiplo/ (Accessed on Jan. 5, 2024).

[202] “BEST”, Available Online: https://www.my-oli.com/en/projects (Accessed on Jan. 5, 2024).