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a Business Model

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Addressing Premature Reinforcement of Low-Voltage Distribution Infrastructure with Peak-Shaving and Power Curtailment: a Business Model

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***Abstract*—The uncontrolled inclusion of renewable energy sources in the distribution network causes severe overvoltages. Simultaneously, electrification strategies, such as heat pumps and electric vehicles, increase the peak demand, causing undervoltages. The combination of both phenomena has proven challenging for distributed system operators who are accountable for power quality and accessibility. System operators address those voltage issues with network reinforcements, but such projects are costly and time-consuming. We identified that the cost and qualified workforce availability are the main challenges of premature grid reinforcement. This paper evaluated peak-shaving and power curtailment at the low voltage distribution level as market-based alternatives to provide flexibility using the business model canvas. We identified the main actors that would benefit from peak-shaving and power curtailment at the residential level, their relationships, and the value proposition's challenges. We proposed a business model where residential prosumers receive compensation for supporting the network to prevent the distribution system from surpassing the projected power flows. Both alternatives offer system operators more control over the power flow to ensure power quality while decreasing costs, as fewer or no premature grid reinforcements might be needed. The business opportunity resources are categorized as technical and regulatory, highlighting the latter as the main challenge for the business model. We discussed two residential prosumer case scenarios for the Dutch context, one with a PV system and one with a PV and a heat pump. Our analysis suggests that the business models are technically possible for peak-shaving and power curtailment with existing technologies for the selected target. However, the former requires more complex activities and is limited to a narrower segment, as it requires prosumers with PV, storage and high-load devices, such as heat pumps.**

***Index Terms*—Ancillary Services, Business Model, Distribution System Operator, Peak-Shaving, Power Curtailment, Residential Energy Market**

I. Introduction

Energy transition has entailed changes in the energy mix and the transmission and distribution infrastructure. The intention is a generalized transition from fossil fuels to emission-free alternatives for generation, transportation and heating. From an infrastructure point of view, traditional energy systems are unidirectional; the power is generated in centralized power plants to be delivered to consumers through transmission and distribution networks. However, distributed renewable energy sources (DRES) introduce bidirectional energy flows in distribution systems. In this new scheme, prosumers consume power from the grid when their generators do not meet the local demand and inject power into the grid when the generation surpasses the demand. Since the distribution networks were not initially designed for distributed power injections, those power injections increase the voltage at the connection point, which can cause overvoltages beyond the voltage quality standards, such as EN 50160 in the European Union [1].

Heat and transport electrification also incorporate sudden high-power demands in the distribution network. Heat electrification at the residential level is mainly done by heat pumps (HPs). A characterization of the power consumption of HP in the Netherlands is provided in [2]. Their results suggest that a HP can consume between 18 and 35 kWh daily to provide space heating and domestic hot water, with powers eventually surpassing 3 kW. In contrast, during summer, the energy consumption for space cooling and domestic hot water decreases to around 10 kWh, but the power remains near 2.7 kW. Transport electrification at the residential level mainly comprises electric vehicles (EVs). The average battery capacity for EVs is around 35 kWh in Europe, but some vehicles can reach up to 90 kWh [3]. The power of the residential EV chargers is usually 11 kW; however, faster chargers' power is 22 kW [4]. Nevertheless, unlike the HPs, EVs can be charged using public infrastructure, but the usage and availability of public charging points largely depend on the country or region. For example, in the US, 80 % of EVs are charged at home [5], while only 46 % had private chargers at home in the Netherlands [6].

Literature provides numerous studies on the effect of the energy transition on electric networks. For example, [7] simulated Dutch residential apartment buildings with PV systems and HPs as loads in a CIGRE distribution network, demon-

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strating that, during summer, the power injection due to the PV can increase the voltage near 1.5 p.u., while, during winter, the voltage can drop below 0.9 p.u. Similarly, [4] studied the combined effect of HPs and EV chargers in German low-voltage distribution networks for different penetration levels using PowerFactory, concluding that the German infrastructure might not be prepared to supply the extra demand required for residential heating and private transport electrification.

Those scenarios are a reality already in many power systems worldwide, creating technical and, therefore, economic challenges, as infrastructure costs would constitute the most significant part of energy expenditures in the future [8]. At the European Union level, the GDP share for the energy transition is near 1 % annually from 2015-2050 [9]. In the Netherlands, the distribution system operator (DSO) Stedin has to reinforce numerous distribution stations and thousands of transformers, requiring approximately €1.8 billion in additional equity in the coming years [10]. Still, the tariffs for congestion management fees could increase to compensate for the introduction of renewables and the additional demand caused by heating and transport electrification.

This work studies how ancillary services in the residential energy market could be an alternative to reduce premature reinforcements in low-voltage residential distribution networks in the Netherlands. The scope for our analysis is: Dutch prosumers with a PV system and a HP, EV charging is excluded because, in the Netherlands, most EV owners use public infrastructure instead of charging at their own house [6], and existing energy tariff schemes for residential prosumers. The last point aims to recreate a more realistic analysis, as many works in the literature consider the wholesale energy market price for similar estimations, but the participation of individual residential prosumers would not fit the wholesale bid market in terms of capacity or reliability. This way, we first assessed relevant ancillary services at the residential low-voltage distribution networks to select the most suitable ones for residential prosumers. Then, an analysis of current market solutions will determine the technical feasibility of implementing those ancillary services in the short term. Finally, an analysis is provided to include feasible ancillary services in the energy market. The information is then summarized using the business model canvas, creating a framework for decision-makers to determine the value of ancillary services as an alternative to grid reinforcement in residential low-voltage distribution networks. Thus, the contributions of this paper can be summarized as follows:

1) proposing of a business model to provide value to Dutch DSOs and residential prosumers through peak-shaving and power curtailment, and
2) identifying peak-shaving and power curtailment opportunities in Dutch low-voltage residential networks.

II. Evaluation of Ancillary Services in LV Distribution Networks

System operators face challenges associated with the energy transition. They have to propose and realize solutions to ensure power delivery to a constantly changing network. Typically, those solutions involve reinforcing the grid, which is limited by the heavy financial burdens placed on governments by energy infrastructure deployments [11], the accuracy of former network planning models [11] and a shortage in the available qualified workforce could postpone such projects [12]. Given the challenges the energy transition causes to system operators in terms of infrastructure reinforcement, some authors have recommended different approaches. Reducing energy consumption (degrowth) was proposed by [13]. Based on two case studies in Spain and Greece, it was concluded that the strategy would not lead to considerable reductions in energy consumption. Creating new energy markets would have more realistic results [14], requiring still the inclusion of energy storage, handling of the variability in the final energy costs caused by the stochastic behaviour of DRES and evaluating the impact of high-voltage lines [11].

Ancillary services provide a collaboration framework between the system operators, generators, consumers and prosumers to ensure the operation of transmission or distribution systems [15]. Most current ancillary services in the Netherlands are at the high-voltage level [16]. However, if one considers the nature of the need for such services, it becomes apparent that the challenges once limited to transmission networks, are repeating in the distribution networks. Classifying the ancillary services in congestion management, voltage control, and frequency regulation or balancing reserves [17] allows us to correlate the objective of each group to the different challenges created by the energy transition. Including EV chargers and heat pumps in the distribution grid can considerably increase the power demand, depending on the penetration levels, thus creating congestion and leading to undervoltages, especially during winter. On the contrary, distributed renewable energy sources inject more power into the grid than can be consumed locally during summer, increasing the voltage and urging voltage regulation mechanisms in DRES-rich networks. Frequency regulation, nonetheless, is unlikely in distribution networks, as it would require a significant load or generation change in a short time, and individually, the prosumers cannot cause such power swings. These reasons lead recent literature to suggest that ancillary services are also attractive at the distribution level.

A detailed correlation between the specific ancillary services and different assets considered for the energy transition, such as DRES, battery energy storage systems (BESS), EVs and HPs, is provided in [18]. For the residential level, the ancillary services suggested are congestion management, voltage control, demand response, direct load control, peak-shaving, and power curtailment. A four-step approach to provide flexibility to DSOs through congestion management is studied in [19]. The proposed method includes acquiring voltage and current measurements on the transformer, feeders, and connection points with the prosumers so that the active and reactive powers throughout the network can be calculated. This data is then used to forecast the aggregated demand on the transformer, allowing an informed decision-making process and finishing with an interface for DSOs so they can request external stakeholders for flexibility. Other works suggest using the free capacity of microgrids [20] or multi-carrier energy hubs [21] within the network or using energy storage [22] or EVs [23] to dispatch power when needed. These approaches have in common a complex prediction-based control and the need for external assets, either storage systems or full microgrids, which are unlikely to be found in residential low-voltage distribution networks.

Voltage control using reactive power compensation in inverters is not allowed by the IEEE Standard 1547-2018 [24]. Instead, the technical standard indicates that the DSO are responsible for ensuring the voltage remains within the limits. In this sense, deploying such a service would require a technical framework. Demand response and direct load control aim to switch the load to meet the network requirements. Demand response is typically scheduled based on the predicted needs of the grid, whereas direct load control is performed in real-time based on the current needs of the grid [18]. The participation of small consumers and dispatchable DRES was proposed in [25] for low-voltage distribution networks, showing an improvement in the grid voltage and congestion. Still, demand response and direct load control would require robust communication with the DSO.

Peak-shaving is a well-known service in the literature that aims to reduce demand using local storage systems directly. Literature provides many examples of its deployment at the residential level. For instance, [26] used a PV-BESS system to reduce the demand peaks by up to 98 %, decreasing the yearly consumption by 15 % and the PV exports to the grid by 75 %. In [27], a 5 kW PV system was coupled with an 8 kWh BESS to provide peak-shaving to residential loads, reducing the demand by 47 %. Similar results were obtained by [28] and [29], demonstrating the solution's maturity. Similarly, power curtailment is commonly used in generation plants, and, recently, some local governments such as the United Kingdom (ENA EREC G100) [30] and Germany (EEG2012 70%) [31], have provided DSOs to enforce it at the low-voltage distribution network, which means the ancillary service is already part of the energy market. Peak-shaving and power curtailment have in common that they can follow either fixed or dynamic setpoints defined by the DSO at the connection point; the prosumer can manage the internal energy flow locally, thus reducing data privacy vulnerabilities and the complexity of the communication infrastructure required.

Based on the previous analysis, we will focus on peak-shaving and power curtailment, as they have already been implemented in some energy markets. Many inverters already have power limitation functionalities, enabling peak-shaving. For power curtailment, we evaluated the datasheets of five of the biggest residential inverter brands to determine their function capacities and limitations. We investigated whether power curtailment was possible at all, the curtailment range, and the type of curtailment control. Static control is a fixed power injection limit, after which the inverter would curtail the generation. Dynamic control allows communication with the DSO to define the maximum allowed power the grid can receive at any moment. Table I shows that all the brands studied can perform power curtailment in the whole generation range, from 0 to 100 %. However, dynamic control was not that common. Only SolarEdge inverters allow communications with the DSO to change the injection limit. The remaining brands require the user to define a fixed threshold. One interesting exception is Enphase, which, albeit not having communication functionalities, allows the user to set a setpoint profile for the curtailment, allowing a more flexible approach than a single value.

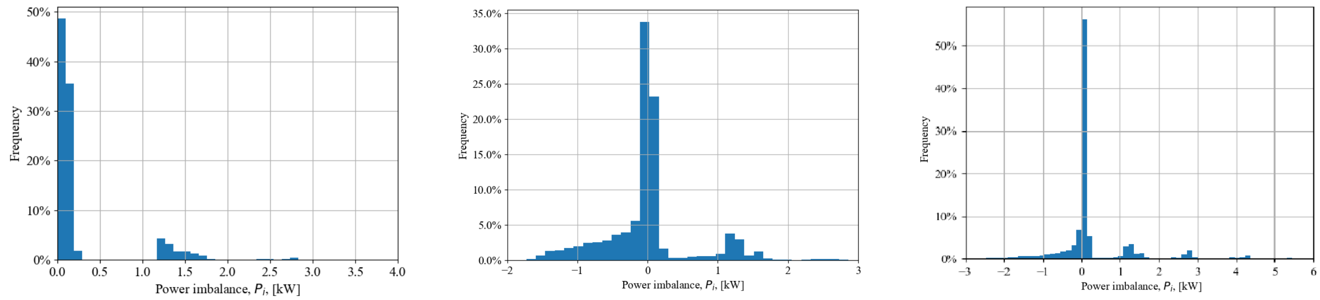
TABLE I: Power curtailment capabilities in inverter brands.

Brand	Power curtailment	Range	Control	Ref
Enphase	Enabled	0-100	Static (profile)	[32]
Growatt	Enabled	0-100	Static	[33]
SMA	Enabled	0-100	Static	[34]
SolarEdge	Enabled	0-100	Static/Dynamic	[35]
Victron	Enabled	0-100	Static	[36]

III. Business model

We will focus on two groups of residential prosumers: those with a PV system and those with a PV system and a HP. PV systems are expected to have powers between 1.5 kW to 2.5 kW, and HP are expected to have powers below 3 kW. We assume that EVs would be connected to public charging points controlled by the DSO; thus, they are excluded. We used the model in [7] to create a representative yearly power imbalance profile between the PV generation and the house power demand, both with and without the heat pump. Fig. 1a shows the power distribution for the loads, Fig. 1b shows the distribution of power demanded from and injected into the grid (imbalance) for prosumers only with the PV system, and Fig. 1c shows the case for prosumers with PV and HP. Power consumed from the grid is represented as a positive power imbalance, whereas negative power imbalances are power injected back into the grid.

Fig. 1 illustrate why DRES and HP create challenges for DSOs and their opportunities for peak-shaving and power curtailment. The base case shows that, typically, the grid expects powers below 0.5 kW from households, separated into groups spread based on the power used by different high-power appliances (e.g., the microwave, kettle, or induction kitchen) which, in very infrequent cases, they can reach 4 kW when several of such appliances are used simultaneously. Adding a PV system reduces the probability of high power being demanded as the maximum power is below 3 kW. However, the effect is visible mainly in the lower power range, as the probability of powers between 0 and 0.5 kW is approximately halved. However, a considerable amount of power is injected into the grid, in ranges between 1.8 kW with lower probabilities and near 0 kW with higher probabilities. Adding the heat pump would require a bigger PV system to compensate for the increased energy consumption, leading to a higher maximum injected power and keeping the probability behaviour of the case with only the PV. Small groups created



(a) (b) (c)

Fig. 1: Power demanded from the grid with (a) no PV or HP, (b) a 2 kW PV, and (c) a 2.5 kW PV and a 3 kW HP.

by high-power appliances still characterize the demand, which has increased to maximum powers near 6 kW [37].

The low probability of high power injection for both cases (with and without) into the grid would suggest that power curtailment below a specific threshold would not considerably affect the prosumers' revenue due to feed-in. Nonetheless, fixing a curtailment threshold to limit the power injection into the grid would greatly benefit DSOs. Such an injection limit would allow more controlled power injections into the grid, providing more certainty for design scenarios. Similarly, the discrete demand groups are a promising scenario for peak-shaving, as the higher the power, the lower the occurrence probability. Thus, BESS can be sized based on demand limits to avoid affecting the grid. Note that the base case has most of the demand below 2 kW, and the probability of powers above that threshold is almost neglectable in the case without HP, making it less attractive. The case with HP, on the other hand, has low-probability demand groups above 2 kW, which are more promising for peak-shaving. Still, peak-shaving would be a more complex business case, as it requires prosumers to purchase BESSs, increasing their costs and urging a more generous compensation to at least reach the balance point.

Establishing the power imbalance behaviours allowed us to determine the business opportunities for both scenarios (with and without HP). Consequently, analyzing the actors involved allows us to create a business model that provides value for prosumers and the DSOs by enabling peak-shaving and power curtailment. Following the approach proposed in [38] to simplify the canvas analysis, we divided it into three sections: value proposition, value creation and delivery and value capture. The first includes the value proposition, customer relationships and segments; the second includes resources, activities, partners and channels; and the last includes the cost structure and revenue streams.

The general *value proposition* of the business model is to reduce LV distribution infrastructure reinforcement costs for DSOs due to the energy transition by enabling peak-shaving and power curtailment participation at the residential level. Naturally, to create a business, the prosumers should also benefit from it. Therefore, determining the cost associated with premature infrastructure reinforcement would allow DSOs to set a maximum budget to compensate the prosumers who provide those ancillary services. Once DSOs set the boundaries for power exchange (maximum allowed injection for power curtailment and maximum power demand for peak-shaving), they will be communicated to the prosumers. Thus, *customer relationships* are from DSOs to the prosumers through the utility providers. The setpoints prosumers must follow to support the grid can be static, i.e., fixed limits for power exchange, or dynamic, based on the network status or predicted status at any particular point. Each ancillary service would have its own *customer segment*, as both have different hardware requirements. On the one hand, the power curtailment segment includes prosumers with solar systems, whose inverters can receive and execute power curtailment setpoints, which most commercially available solar inverters can do. On the other hand, the peak-shaving segment requires prosumers with short power peaks in their consumption profile. Heat pumps are characterized by having such behaviour [2]; thus, prosumers with HP meet this requirement, as normal residential loads are not as frequent nor have such high power demand. However, peak-shaving would require prosumers to acquire a BESS with an energy management system (EMS) capable of receiving peak-shaving signals to charge and discharge the batteries accordingly, as they would unlikely have one already.

The *resources* required to implement any ancillary service can be categorized into technical and regulatory requirements. Technical requirements include the technology and infrastructure (including software and hardware, e.g., communication protocols and cybersecurity). Regulatory requirements refer to the legal and policy frameworks. For this reason, DSO would need *partners* throughout the energy supply chain, with different *activities*. The DSOs should determine the maximum costs they would pay for the ancillary services. Those costs are associated with the network modifications (reinforcement and operation) caused by the energy transition. The estimations should be presented to policymakers and regulatory authorities, enabling the legal framework to be updated based on the market's results and changes. Utility companies should facilitate communication between the DSO and the prosumers, which would also require a part of the compensation. Finally, prosumers should evaluate whether providing ancillary services to the DSO would be more profitable than the current tariffs, risking less cooperative schemes in the future. There should be clear communication *channels* between the partners. Based on its surveys, [38] recommends newsletters and websites as the most accepted channels for energy business models.

The value proposition is based on a collaborative approach; thus, the *cost structure* is divided among the different partners. From a CAPEX perspective, it relies on the prosumers, as they require a specific system to participate in the ancillary service market (PV alone for power curtailment and PV+BESS for peak-shaving). On the other hand, DSOs and energy utility companies would require lower initial investments, as the business model's value is precisely the reduction or absence of infrastructure reinforcement. Their investment would rely on the communication infrastructure, which could be purchased or subcontracted, in which case, part of those costs are transferred to the OPEX. From the OPEX perspective, the prosumers do not have any additional costs as they currently do, aside from penalties for not complying with the ancillary service contract. DSOs and utility companies, however, do have operational expenses, as they are to compensate the prosumers for the usage of their assets to support the grid. In this sense, there would be profit if the compensation costs were below the projected grid infrastructure costs. For the DSO, the *revenue* would come from the difference between the infrastructure reinforcement costs and the compensation for providing ancillary services to the prosumers and utility companies. For prosumers, peak-shaving and power curtailment would have different revenue structures. The former requires them to purchase a BESS and use it to keep their demanded power below a threshold set by the DSO; thus, they should be compensated for the purchase and availability of the storage unit. Power curtailment is more straightforward, as the compensation should equal or exceed the earnings lost due to energy curtailment under a feed-in tariff. DSOs would profit as intermediaries between the DSOs and prosumers.

IV. Discussion

Power curtailment presents the most straightforward implementation; the technology is available, and minimum infrastructure is required for static conditions. This enables different compensation schemes, such as a fixed amount to ensure the limit, based on the curtailed energy, or both. If a feed-in tariff is considered, there would be no cost difference for either the prosumer or the DSO to pay the curtailed energy the same price as if the energy had been injected into the grid. The difference would be from a resilience perspective, as the energy is no longer injected, thus avoiding the challenges associated with DRES penetration. Using fixed amounts would be attractive for prosumers only if the compensation is equal to or exceeds the revenue not received due to curtailment, and it might be challenging for DSOs to define a value that would fit all prosumers.

Peak-shaving has a more complex scenario. First, the prosumer must purchase a BESS to support the grid. In markets such as the Dutch, where there are no noticeable changes between hourly residential tariffs and small prosumers cannot participate in the day-ahead or intraday markets [16], the revenue comes from the reduced energy purchased based on a feed-in tariff scheme. Therefore, the compensation for providing peak-shaving should be at least equal to the cost associated with the degradation of the battery, as energy arbitrage at this scale is unlikely to be profitable.

Dynamic tariffs would be a more flexible approach for both ancillary services, giving DSOs more control over the power flows. However, its deployment is more challenging. The DSOs would need full observability over the system, information on which customers are located in specific network regions, and the capability of sending information in real-time to the customers. Likewise, the customers should follow the DSO setpoints, requiring a more complex and robust communication infrastructure and regulatory framework. Either way, dialogue is required among all the actors to understand the opportunities and risks involved in peak-shaving and power curtailment markets. Most of the framework exists as it applies to other actors in the energy supply chain. Thus, the fastest solution would be to estimate fixed power thresholds for each ancillary service and compensate prosumers who meet these targets provided they were not met before. In the case of power curtailment, the easiest compensation would be based on the amount of energy curtailed. The fastest implementation route for peak-shaving would be a fixed amount for storage availability. Then, the main challenge for DSOs would be to set the peak-shaving and power curtailment thresholds that allow them to minimize the infrastructure reinforcement. Once this framework is established, the operation includes a regular evaluation of the distribution network to assess the effectiveness of the used setpoints.

V. Conclusions

This paper evaluated the feasibility of peak-shaving and power curtailment to reduce premature reinforcement in low-voltage residential distribution networks in the Netherlands due to the energy transition. It was determined that prosumers with PV systems could provide power curtailment without affecting their revenue if their compensation is similar to the energy tariff, as the residential market uses a feed-in scheme. For peak shaving, prosumers should have a heat pump, a PV system and a BESS to provide the ancillary service. The DSO should estimate the power demand limit for peak-shaving and the reinforcement costs associated with those power ranges to propose compensation to the prosumers. A static setpoint is preferred over a dynamic one, albeit less flexible, as existing technologies would allow immediate adoption, and the regulatory frameworks would require minimum changes.

References

[1] "EN Standard 50160 - Voltage characteristics of electricity supplied by public electricity networks," 2010.

[2] N. Damianakis, G. C. R. Mouli, and P. Bauer, "Risk-averse estimation of electric heat pump power consumption," in *2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, 2023, pp. 1–6.

[3] "Global EV Outlook 2023: Trends in electric light-duty vehicles," 2023. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2023/trends-in-electric-light-duty-vehicles
[4] P. Fakhrooeian, V. Pitz, and B. Scheppat, "Systematic evaluation of possible maximum loads caused by electric vehicle charging and heat pumps and their effects on common structures of german low-voltage grids," *World Electric Vehicle Journal*, vol. 15, no. 2, 2024.
[5] "Charging at home," 2020. [Online]. Available: https://www.energy.gov/eere/electricvehicles/charging-home
[6] B. Wolterman, T. Duurkoop, A. Haarhuis, M. Zweistra, E. Hiep, and M. van Biezen, "Laden van elektrische auto's in Nederland: Ervaringen en meningen van EV-rijders," 2023. [Online]. Available: https://elaad.nl/wp-content/uploads/downloads/Nationaal-Laadonderzoek-2023-Rapport.pdf
[7] J. Alpízar-Castillo, L. Ramírez-Elizondo, and P. Bauer, "The effect of non-coordinated heating electrification alternatives on a low-voltage distribution network with high pv penetration," in *2023 IEEE 27th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG)*, June 2023.
[8] D. Bogdanov, M. Ram, A. Aghahosseini, A. Gulagi, A. S. Oyewo, M. Child, U. Caldera, K. Sadovskaia, J. Farfan, L. De Souza Noel Simas Barbosa, M. Fasihi, S. Khalili, T. Traber, and C. Breyer, "Low-cost renewable electricity as the key driver of the global energy transition towards sustainability," *Energy*, vol. 227, p. 120467, 2021.
[9] P. D'Aprile, H. Engel, G. van Gendt, S. Helmcke, S. Hieronimus, T. Nauclér, D. Pinner, D. Walter, and M. Witteveen, "Net-zero europe decarbonization pathways and socioeconomic implications," McKinsey Company, Tech. Rep., 2020. [Online]. Available: https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20the%20european%20union%20could%20achieve%20net%20zero%20emissions%20at%20net%20zero%20cost/net-zero-europe-vf.pdf
[10] "Integraleinfrastructuurverkenning2030-2050," Netbeheer Nederland, Tech. Rep., October 2023. [Online]. Available: https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2023-10/II3050_Eindrapport.pdf
[11] E. Hache and A. Palle, "Renewable energy source integration into power networks, research trends and policy implications: A bibliometric and research actors survey analysis," *Energy Policy*, vol. 124, p. 23 – 35, 2019.
[12] W. Bai, L. Zhang, S. Lu, J. Ren, and Z. Zhou, "Sustainable energy transition in southeast asia: Energy status analysis, comprehensive evaluation and influential factor identification," *Energy*, vol. 284, p. 128670, 2023.
[13] M. Tsagkari, J. Roca, and G. Kallis, ""from local island energy to degrowth? exploring democracy, self-sufficiency, and renewable energy production in greece and spain"," *Energy Research Social Science*, vol. 81, p. 102288, 2021.
[14] Y. Zhou and P. D. Lund, "Peer-to-peer energy sharing and trading of renewable energy in smart communities trading pricing models, decision-making and agent-based collaboration," *Renewable Energy*, vol. 207, p. 177 – 193, 2023.
[15] "Directive 2009/72/ec of the european parliament and of the council of 13 july 2009 concerning common rules for the internal market in electricity and repealing directive 2003/54/ec," July 2009. [Online]. Available: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0055:0093:en:PDF
[16] "Dutch ancillary services," TenneT, Tech. Rep. [Online]. Available: https://www.tennet.eu/markets/dutch-ancillary-services
[17] G. C. Kryonidis, E. O. Kontis, T. A. Papadopoulos, K. D. Pippi, A. I. Nousdilis, G. A. Barzegkar-Ntovom, A. D. Boubaris, and N. P. Papanikolaou, "Ancillary services in active distribution networks: A review of technological trends from operational and online analysis perspective," *Renewable and Sustainable Energy Reviews*, vol. 147, 9 2021.
[18] J. Alpízar-Castillo, L. Ramirez-Elizondo, and P. Bauer, "Assessing the role of energy storage in multiple energy carriers toward providing ancillary services: A review," *Energies*, vol. 16, no. 1, 2023.
[19] R. Fonteijn, P. H. Nguyen, J. Morren, and J. G. Slootweg, "Demonstrating a generic four-step approach for applying flexibility for congestion management in daily operation," *Sustainable Energy, Grids and Networks*, vol. 23, 9 2020.
[20] M. Babagheibi, S. Jadid, and A. Kazemi, "An incentive-based robust flexibility market for congestion management of an active distribution system to use the free capacity of microgrids," *Applied Energy*, vol. 336, p. 120832, 2023.
[21] A. Hosseini, A. Mirzapour-Kamanaj, R. Kazemzadeh, K. Zare, and B. Mohammadi-Ivatloo, "Congestion management for coordinated electricity and gas grids in the presence of multi-energy hubs: A risk-based optimal scheduling," *Sustainable Energy, Grids and Networks*, vol. 36, p. 101153, 2023.
[22] F. H. Aghdam, M. W. Mudiyanselage, B. Mohammadi-Ivatloo, and M. Marzband, "Optimal scheduling of multi-energy type virtual energy storage system in reconfigurable distribution networks for congestion management," *Applied Energy*, vol. 333, p. 120569, 2023.
[23] F. Noori, M. Korani, V. Farrokhikia, and F. Faghihi, "Evaluating the impact of integrating cryogenic energy storage and electric vehicles on congestion management in reconfigurable distribution networks considering conditional value-at-risk index," *Energy Reports*, vol. 11, pp. 1979–1992, 2024.
[24] "IEEE standard 1547-2018 - for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces," 2018.
[25] B. Canizes, V. Silveira, and Z. Vale, "Demand response and dispatchable generation as ancillary services to support the low voltage distribution network operation," *Energy Reports*, vol. 8, pp. 7–15, 2022, the 8th International Conference on Energy and Environment Research –"Developing the World in 2021 with Clean and Safe Energy".
[26] C. Jankowiak, A. Zacharopoulos, C. Brandoni, P. Keatley, P. MacArtain, and N. Hewitt, "Assessing the benefits of decentralised residential batteries for load peak shaving," *Journal of Energy Storage*, vol. 32, 12 2020.
[27] V. K. Teki, M. K. Maharana, and C. K. Panigrahi, "Study on home energy management system with battery storage for peak load shaving," *Materials Today: Proceedings*, vol. 39, pp. 1945–1949, 2021, 3rd International Conference on Solar Energy Photovoltaics.
[28] Y. Zhou, H. Obeid, S. Laghrouche, M. Hilairet, and A. Djerdir, "A novel second-order sliding mode control of hybrid fuel cell/super capacitors power system considering the degradation of the fuel cell," *Energy Conversion and Management*, vol. 229, 2 2021.
[29] L. Chen, Q. Xu, Y. Yang, and J. Song, "Optimal energy management of smart building for peak shaving considering multi-energy flexibility measures," *Energy and Buildings*, vol. 241, p. 110932, 2021.
[30] "Technical requirements for customers' export and import limitation schemes," Energy Networks Association, Engineering Recommendation G100 Issue 2 2022 Amendment 2, April 2023. [Online]. Available: https://www.energynetworks.org/assets/images/ENA_EREC_G100_Issue_2_Amendment_2_(2023).pdf
[31] "Export limitation," SolarEdge, Application Note Version 2.8, March 2022. [Online]. Available: https://knowledge-center.solaredge.com/sites/kc/files/feed-in_limitation_application_note.pdf
[32] "Pcs integration in enphase energy system," Enphase, TECHNICAL BRIEF – North America TEB-00049-2.0, September 2023. [Online]. Available: https://enphase.com/download/pcs-integration-enphase-energy-system-tech-brief
[33] "Growatt export limitation guide," Growatt, Tech. Rep., 2020. [Online]. Available: https://growatt.pl/wp-content/uploads/2020/01/Growatt-Export-Limitation-Guide.pdf
[34] "Sma export control solution," SMA Solar Technology, Manufacturer's Declaration HK_ENA_EREC_G100_en_11, April 2018. [Online]. Available: https://s3.amazonaws.com/ecodirect_docs/SMA/EDMM-US-10/SMA-EDMM-US-10-Export-Control-Solution-HK_ENA_EREC_G100_en_11.pdf
[35] "Solaredge inverters, power control options," SolarEdge, Application Note Version 9, March 2023. [Online]. Available: https://knowledge-center.solaredge.com/sites/kc/files/application_note_power_control_configuration.pdf
[36] "Ess design and installation manual," Victron, Tech. Rep. Rev. 10, September 2023. [Online]. Available: https://www.victronenergy.com/media/pg/Energy_Storage_System/en/configuration.html#UUID-42f56b22-76b3-0c69-57c2-3e54b2e0df4e
[37] J. Alpízar-Castillo, L. M. Ramírez-Elizondo, and P. Bauer, "Modelling and evaluating different multi-carrier energy system configurations for a dutch house," *Applied Energy*, vol. 364, p. 123197, 2024.
[38] A. Teladia, E. van der Waal, J. Brouwer, and H. van der Windt, "From kilowatts to cents: Financial inclusion of citizens through dutch community energy business model configurations," *Energy Research Social Science*, vol. 106, p. 103322, 2023.