WP 1.5 Integrated MV-LV Network Studies to Assess Electrification Impact: Final Report

Milestone Report 4: 12/03/2025

Report for C4NET

Project Consortium

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Executive Summary

This report corresponds to Milestone 4 “Final Report” for Work Package 1.5 (WP1.5) "Integrated MV-LV Network Studies to Assess Electrification Impact " as part of the Centre for New Energy Technologies (C4NET)'s Enhanced System Planning (ESP) project.

Four MV-LV distribution networks (i.e., urban, Sub-Urban, short-rural, and long-rural) are assessed in this study to evaluate the impacts of electrification (considering rooftop PV systems, electric vehicles, and gas electrification). The simulation results are presented for two cases:

- Without DOEs: In this case, PV inverter functions (Volt-Watt and Volt-Var, following AS/NZS4777.2:2020 Australia A settings) are enabled, but DOEs are not implemented.
- With DOEs: In this case, PV inverter functions are still enabled, and DOEs are implemented.

Key findings from the simulations are presented below, along with **Recommendations** to advise Victorian distribution companies on network planning beyond 2030. These recommendations will ultimately help accelerate the electrification of distribution networks in alignment with Victoria’s goal of achieving net-zero emissions.

a. Key Findings (Without DOEs)

Voltage Assessment

1. In the next decade, PV penetration will keep growing steadily and voltage issues can emerge as a limiting factor for further PV uptake, typically for those networks less robust in voltage quality (i.e., urban network and short-rural network).
2. From 2033, the PV uptake slows down and net demand rises significantly due to the presence of increasing EV adoption and gas electrification, which further exacerbate voltage issues.
3. Since the voltage regulation devices in this study are operated to ensure equal voltage headroom and footroom, more voltage drop issues have emerged as a result of managing PV-related voltage rise issues. This indicates that voltage regulation devices (i.e., tap positions) have been exhausted to maintain customer voltages within both upper and lower limits.

Thermal Assessment

4. Due to the presence of increasing EV adoption and gas electrification, most networks (i.e., urban, sub-urban and long rural) observe a dramatic increase (up to 30%) in overloading distribution transformers from 2028 to 2033. And if network augmentation is not incorporated, more distribution transformers will be affected, and which could severely limit further DER uptake.

5. MV conductors may become constrained in the next few decades, earlier and more severe for those longer feeders (from 2033 for the long-rural feeder). Without network augmentation, more MV conductor will get overloaded and with higher utilisation level.
6. LV conductors generally remain within their thermal limits (only 1%-2% overloaded in the urban network). However, a modern design of LV conductors (i.e., featuring lower impedance and higher ampacity) is adopted in the MV-LV network model provided by WP1.4. This modelling choice may significantly underestimate LV conductor utilisation.

PV Curtailment

7. Given the high PV penetration across all the networks assessed, PV curtailment can be significant for some PV customers (up to 80% daily curtailment for the worst-case scenario) due to network-wide voltage rise issues
8. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters (resulting in maximum exports of 5kW, aligned with limits used by DNSPs), which can limit their export opportunities, thereby reducing aggregate PV export across the MV-LV network.

b. Key Findings (With DOEs)

Network Performance

1. Export DOEs effectively mitigate voltage rise issues caused by PV export once applied to all residential PV customers (by 2038). However, since PV inverters functions (i.e., Volt-Watt and Volt-Var) already enforce PV curtailment to help regulate voltages in the simulation Without DOEs, the additional benefits of export DOEs may be limited.
2. Since import DOEs are applied only to Level-2 EV charging, only a small fraction of the demand is managed (up to 30%). Over time, the demand from gas electrification (i.e., heating/cooling and hot water systems) becomes significant, resulting in more voltage drops and heavy asset utilisation. Consequently, managing Level-2 EV demand alone is insufficient to resolve both voltage and thermal l issues.

PV Curtailment

3. At the initial stage of export DOE implementation (i.e., 2028), total PV curtailment decreases across all assessed networks. This reduction occurs because only new PV customers begin adopting DOEs, and their inverters are upgraded to 10 kVA, unlocking greater PV potential.
4. When export DOEs are applied to more PV customers (i.e., from 2033), the impacts on PV curtailment vary among networks:
    a. In networks with severe voltage issues (i.e., urban and short-rural networks), total PV curtailment increases (by up to 24%) compared to the assessment without DOEs.

b. In networks with better voltage quality (i.e., sub-urban and long-rural networks), total PV curtailment remains consistently lower (by up to 7%) than in the assessment without DOEs.

This occurs due to the "Equal Allocation" strategy adopted in the DOE calculation (i.e., all flexible customers are given the same export limit during each time interval). By using this strategy, DOE values are constrained by the customer experiencing the most severe voltage issues (i.e., at end of the LV feeder), which negatively impacts all customers within the same LV network. As a result, in those networks with more significant voltage issues, total PV export can be greatly constrained.

EV Management

5. Among all the networks assessed, import DOEs will not cause EV charging delays exceeding an average of 6 hours. Furthermore, these delays will primarily occur at midnight, which is expected to cause minimal or no disruptions for EV users.

c. Key Findings (Considering Network Type)

The simulation results for the "Without DOEs" case indicate that the four assessed MV-LV networks (i.e., urban, sub-urban, short-rural, and long-rural) may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is implemented):

1. **Customer Voltage:** The urban and short-rural networks experience minor customer voltage issues from 2023, escalating to moderate by 2028 and severe after 2033. In contrast, the sub-urban and long-rural networks exhibit robust voltage quality, with minor voltage issues emerging in 2033 and 2028, respectively, and worsening gradually thereafter.
2. **MV Conductor:** Minor overloading of MV conductors occurs from 2033 in the long-rural network, 2038 in the urban network, 2048 in the sub-urban network, and 2053 in the short-rural network. Throughout the whole assessment period, overloaded conductors constitute no more than 10% of the total feeder length in any network.
3. **Distribution Transformer:** Minor overloading of several distribution transformers arises in 2023 for the short-rural and long-rural networks and in 2028 for the urban and sub-urban networks. This issue escalates significantly in the urban, sub-urban, and long-rural networks, affecting up to 50% of distribution transformers, whereas the impact remains less severe in the short-rural network (no more than 15% affected).
4. **LV Conductor:** LV conductors remain within their thermal ratings for most networks due to the modern design adopted. However, the urban network experiences very minor overloading in a small fraction of LV conductors after 2048. In reality, the utilisation of LV conductors is expected to be much higher with their actual conductor size.
5. **PV Curtailment:** Considerable aggregate PV curtailment occurs across all networks after 2028 and continues to increase over time.

With DOE implementation, the following key observations can be concluded:

1. **Customer Voltage:** Customer voltage issues are slightly reduced (up to 7%) across all networks. However, for the urban and short-rural networks, where voltage issues are more severe, this reduction may not be sufficient to meet the Australian standard for voltage non-compliance rate (i.e., <5%).
2. **MV Conductor:** Overloading of MV conductors persists in all networks, but the length of the overloaded segments decreases slightly.
3. **Distribution Transformer:** The number of overloaded distribution transformers is reduced slightly (up to 7%) across all networks, and the severity of overloading is significantly mitigated, thereby delaying the need for network augmentation.
4. **LV Conductor:** LV conductors remain within thermal limits for all networks throughout the analysis period.
5. **PV Curtailment:** In the urban and short-rural networks, total PV curtailment initially decreases in 2028 following DOE implementation. However, over time, the curtailment surpasses the amount observed in the "Without DOEs" case. In contrast, the sub-urban and long-rural networks experience a continuous reduction in PV curtailment, as these two networks are more robust in voltage quality.
6. **EV Charging Delays:** EV charging delays remain under 6 hours on average for all networks, primarily occurring at midnight, thereby minimizing disruptions for EV users.

d. General Recommendations

1. With high penetration of various DER technologies (i.e., PV, EVs, and gas electrification), both voltage rise and drop issues can emerge in MV-LV distribution networks. The results indicate that existing voltage regulation devices may soon be exhausted to maintain voltage within acceptable limits (from 2028). Therefore, it is recommended to:
   - **Upgrade voltage regulation devices** as soon as possible (e.g., expanding the tap range of OLTCs) to allow further DER uptake, particularly in networks more prone to voltage issues.
2. The surging demand from EV charging and gas electrification is expected to cause network-wide asset utilisation issues from 2028, primarily affecting distribution transformers. To prevent the escalation of asset overloading, it is recommended to
   - **Assess and evaluate asset utilisation** periodically (e.g., every five years) and **upgrade overloading assets** (i.e., transformers and conductors) as needed.
   - **Implement demand management strategies** (e.g., import DOEs, demand response) to mitigate excessive power flows.
3. The PV curtailment is found to be significant throughout the analysis period (up to 24% in 2053 when DOEs are not implemented). To unlock the full potential of PV generation, it is recommended to:

- **Improve network voltage quality**, thereby reducing PV curtailment caused by the Volt-Watt function.
- **Allow slightly larger export limits (greater than 5 kVA)**, providing more incentives for people to install larger PV inverters.

e. DOE Recommendations

1. **The adoption of DOEs is certainly recommended** to mitigate the impacts from the growing uptake of DERs (i.e., PV, EV and gas electrification). Since rooftop PV installations will plateau in the next few years, **focus should be given to import DOEs** as the new demand from the electrification of households will become the main challenge.
2. **Export DOEs** should continue be implemented **alongside existing PV inverter functions** (i.e., Volt-Watt and Volt-Var) to further alleviate network issues.
3. **Alternative DOE calculation strategies** (e.g., maximum services) that yield more PV generation for a community (i.e., a distribution transformer) should be explored while ensuring certain levels of fairness among solar PV customers.

The above recommendations will hopefully provide Victorian distribution companies with further insights on their network planning beyond 2030 and, ultimately, help accelerate electrification efforts towards the Victorian goal of net-zero emissions.

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Abbreviations and Acronyms

Abbreviation	Full Term
AEMO	Australian Energy Market Operator
C4NET	Centre for New Energy Technologies
DER	Distributed Energy Resource
DNSP	Distribution Network Service Provider
DOE	Dynamic Operating Envelope
ESP	Enhanced System Planning
EV	Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
OLTC	On-Load Tap Changer
PV	Photovoltaic
SWER	Single-Wire Earth Return
ZSS	Zone Substation
C&I	Commercial and Industrial
ADMD	After Diversity Maximum Demand

List of Considerations and Assumptions

1. The population growth in the assessed network area is not considered, meaning that the number of customers remains the same throughout the horizon (2023–2053).
2. Network augmentation or reconfiguration are not considered in this study, i.e., MV-LV networks are assumed to remain unchanged.
3. The effect of energy efficiency on residential demand is not considered (i.e., the same residential profiles apply to the 30-year analysis period).
4. Only peak demand days and shoulder days are considered in the impact assessment, while minimum demand days are out of the scope.
5. This study adopts a deterministic approach, meaning that only one possible case is studied and uncertainty is not considered.
6. Voltage measurements of residential customers (i.e., from smart meters) are assumed to be available to optimize voltage regulation operation.
7. The voltage at the head of the MV feeder (i.e., secondary bus of the zone substation) is assumed to remain constant at 1 pu.
8. Distribution transformers with a capacity smaller than 25 kVA are assumed to have 5 taps for off-load tap changers (off-LTC), while those above 25 kVA are assumed to have 7 taps for off-LTC.
9. The study assumes all the residential customer are either low-density or medium-density residential customers (i.e., detached houses or town houses), as no profiles are available for considering high-density residents (i.e., apartments).
10. Commercial and Industrial (C&I) customers are assumed to have the same type of profiles, with load operated for 24 hours and higher during the daytime (i.e., 9am-5pm)
11. For 2023, it is assumed that 30% of residential customers already have their heating device electrified and 50% of them having their cooling devices electrified.
12. The adoption of electrified heating, cooling, and hot water is assumed to reach 100% by 2053.
13. For base demand, a fixed power factor of 0.98 pu lagging is considered in modelling.
14. Each distributed energy resource (DER) technology adopts different power factors:
    - Rooftop PV: Volt-Watt and Volt-Var functions enabled, following AS/NZS4777.2:2020 Australia A settings.
    - EVs: 0.99 pu (lagging)
    - Hot Water and Heating/Cooling: 0.95 pu (lagging)
15. PV generation profiles are assumed to follow clear-sky irradiance conditions (i.e., no clouds).
16. Annual PV generation is calculated consideration a combination of 30 summer peak days, 30 winter peak days and 305 shoulder days.
17. Battery storage is assumed to be unavailable in this study.
18. The following assumptions are made for the adoption rate of export and import dynamic operating envelopes (DOEs)

- Export DOEs (including upgrades to 10 kVA PV inverters)
    - 2028: Applies to new PV customers.
    - 2033: Applies to 50% of existing PV customers.
    - 2038: Applies to 100% of existing PV customers.
- Import DOEs
    - 2033: Applies to new EV customers.
    - 2038: Applies to 100% of existing EV customers.

19. Both export and import DOEs are assumed to be calculated at the meter level (i.e., as a limit for the household net demand), and these DOEs are calculated for active power only, as reactive power is not considered controllable.
20. Perfect demand forecast is assumed available in DOE calculation, meaning the demand at the next time step is precisely known by distribution companies.
21. An equal allocation strategy is assumed for DOE implementation (i.e., all flexible customers within the same LV network adopt the same DOE values).
22. It is assumed that customers with PV systems or Level-2 EV chargers (7.4 kW) can be considered as flexible customers.
23. A flexible customer is assumed to receive both export DOEs and import DOEs, applied at the meter level (i.e., controlling household net demand).
24. Fixed customers with PV systems are assumed to install a 5 kVA PV inverter (i.e., net export no more than 5kVA), and flexible customers are assumed to upgrade their PV inverters to 10 kVA (i.e., net export no more than 10kVA).
25. When DOEs are implemented, PV inverter functions (i.e., Volt-Watt and Volt-Var) volt-watt are assumed to remain enabled.

Apart from the considerations and assumptions made in WP 1.5, **the assumptions in the input data from previous WPs** should also be taken into account in the results presented in WP 1.5. Key assumptions are summarized below, please refer to the relevant reports for more information.

26. Electrified heating/cooling profiles (WP1.1): The whole house is heated/cooled through a system of ducts as heat distribution system instead of zoning, and total number of bedrooms matches the household size [1].
27. Hot water profiles (WP1.1): It is assumed a shower duration of 7 min and a water consumption of 9 L/min [1].
28. EV profiles (Powercor): Only two EV charging levels are assumed available (2.3 kW and 7.4 kW), as no profiles are available for 3.7 kW charging.
29. MV-LV network modelling (WP1.4): Single-wire earth return (SWER) networks are not considered in rural feeders, and all LV conductors assume to adopt the modern design (i.e., lower impedance and larger ampacity) [2].

1. Project Overview

This section presents the Victorian context in terms of the uptake of Distributed Energy Resources (DERs), along with the key outcomes derived from WP1.5.

a. The Victorian Context

Hundreds of thousands of Australians (including Victorians) are embracing the use of DERs – seizing the opportunity to generate, store, manage or sell their own energy. These DERs include rooftop solar photovoltaics (PVs), electric vehicles (EVs), residential batteries as well as gas electrification (e.g., heat pumps). As shown in Fig. 1 [3], which is based on AEMO's forecast of DER installed capacity by 2050 [4], solar PVs will continue to be the prominent DER technology adopted in Australia. The uptake of batteries will also increase steadily, though not as significantly as solar PVs. However, EVs will emerge as a huge DER in the next few years.

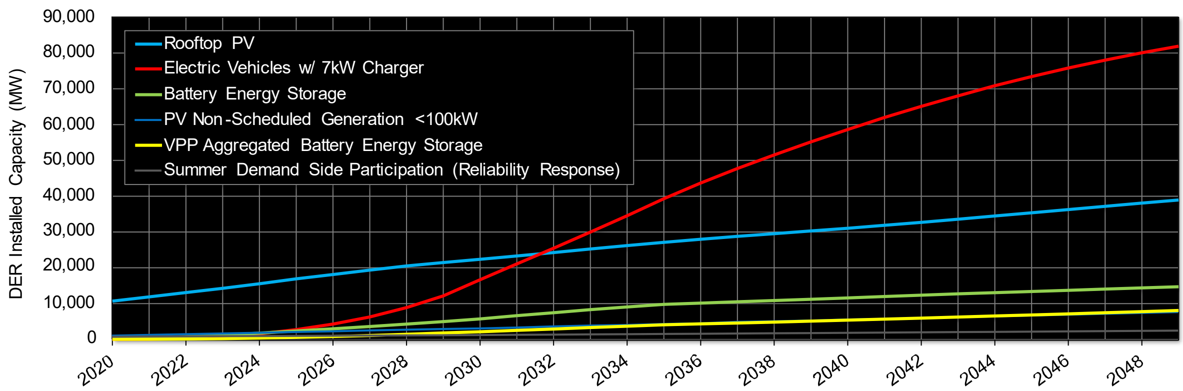

Figure 1. DER Installed Capacity Forecast [3]

In the context of Victoria, according to the State Government's vision [5], 1 in 3 households will have solar PVs installed by 2025, which can deliver up to 60% of our energy demand at times. A total of 740MWh of residential batteries will be available by 2025 (equivalent to the capacity of 25 Ballarat Energy Storage Systems [6]). 50% of all new light-duty vehicle sales are projected to be EVs by 2030. Moreover, a gas substitution roadmap was released in 2022 to speed up the home electrification. The rapid uptake of various DER technologies will help Victoria meet its legislated renewable energy targets of 40% by 2025, 50% by 2030, and ultimately net-zero emissions by 2050.

However, in the meantime, these DER technologies will potentially pose significant challenges to the power grid, particularly on the very infrastructure they are connected to: the distribution networks (the 'poles and wires'). Distribution networks were originally designed to cope with peak residential demand, and they are not engineered to host massive solar PV generation (which can lead to excessive voltage rise [7], [8]) and/or the additional EV demand (which can exacerbate voltage drops, also leading to asset congestion [9], [10]). According to the forecast daily load profile from the Victorian Annual Planning Report [11], shown in Fig. 2, a significant increase in both the reverse power flow during midday (11am-1pm) and peak demand during the night (6pm-8pm) is expected from the massive PV generation and EV demand, respectively. Given this, customer voltages can get close to both the upper and lower limits at different times of the day, posing larger challenges to distribution companies for voltage regulation. On the other hand, the initiative of gas electrification in Victoria will result in increased electricity demand, potentially exacerbating challenges similar to those observed with EVs, which requires further investigation for the network impacts.

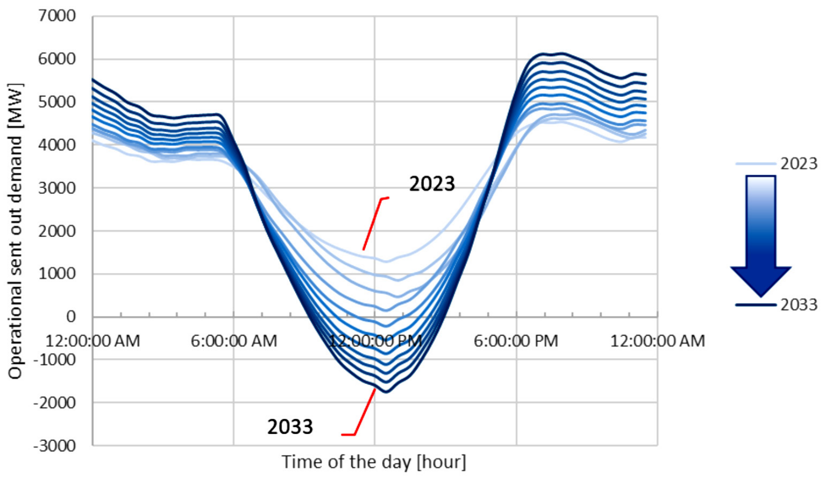

Figure 2. Victorian Daily Load Profile Forecast (2023-33) - Minimum Demand Day [11]

Consequently, to accommodate more DERs within Victorian distribution networks, it is critical for distribution companies to understand the potential challenges posed by a mix of DER technologies (e.g., voltage issues and/or asset congestion), as well as the solutions to address these technical barriers.

b. Key Outcomes

As part of "Work Package 1: Whole-Distribution Electrification Impact Assessment and Mitigation Options" within C4NET's Enhanced System Planning (ESP) collaborative research project, this study assessed the electrification impacts on Medium Voltage (MV) and Low Voltage (LV) distribution networks, spanning from 22kV feeders down to 230V single-phase customers. Key outcomes include:

1. **A literature review** summarizing the state-of-the-art in DER studies and identifying suitable methodologies for electrification impact assessment.
2. **A detailed assessment of electrification impacts** on the Victorian MV-LV network considering various scenarios (incorporating different DER technology mixes, network types as well as the use of dynamic operating envelopes). The following results are provided:
   - Impact Metrics Table: A table summarizing key metrics to assess network performance.
   - Aggregated Profiles: Aggregated active power (P), reactive power (Q), and apparent power (S) profiles at the head of the MV feeder. These profiles serve as inputs for WP1.6 to facilitate analysis at the sub-transmission level.

- Diversified Profiles: Diversified P and S profiles per residential customer, categorized by technology type (e.g., residential load, EV, hot water, heating/cooling, PV, and net demand).
- ADMD Table: Diversified P and S profiles per residential customer, categorized by technology type (e.g., residential demand, PV, EV, hot water, heating/cooling and net demand).

3. **A final report** consolidating findings, input data, assumptions, and case studies, providing a comprehensive reference for future planning and policy development.

Overall, WP1.5 provides valuable recommendations to Victorian distribution companies about network planning beyond 2030. These recommendations will ultimately help accelerate the electrification of distribution networks towards the Victorian goal of net-zero emissions.

2. Methodology

a. Multi-Scenario Electrification Impact Assessment

To assess impacts of electrification on MV-LV distribution networks over the next 30 years (i.e., 2023–2053), a multi-scenario impact analysis has been proposed based on power flow simulations, as illustrated in Figure 3.

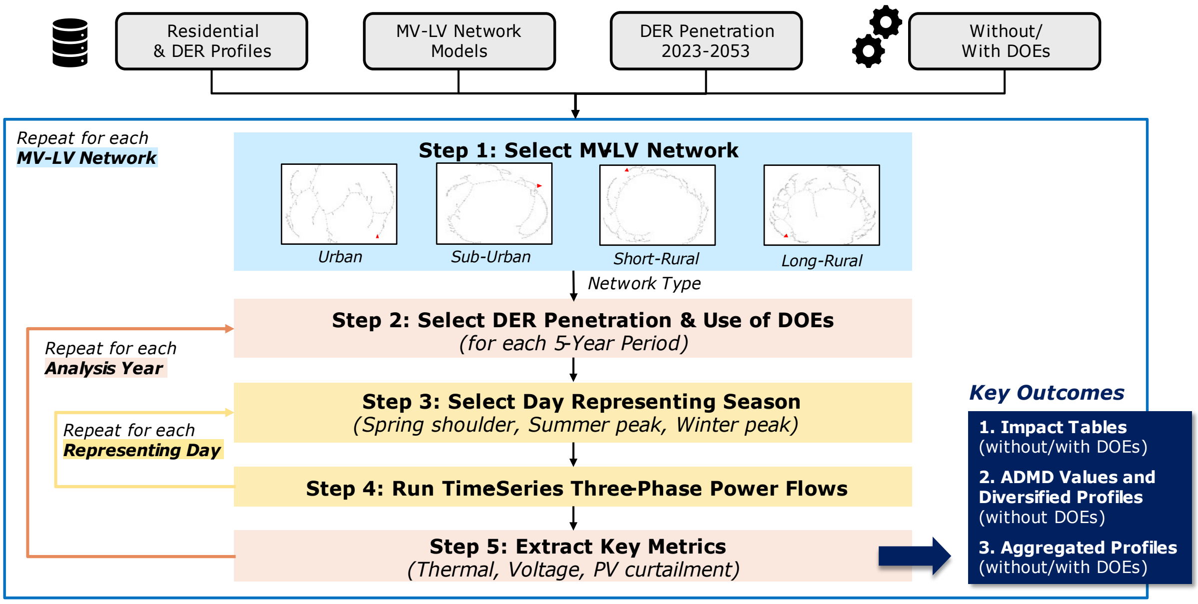

Figure 3. Overview of Multi-Scenario Electrification Impact Assessment

To capture various scenarios (with considering different DER technology mixes, network types as well as DER management strategies), the assessment incorporates the following key elements:

1. **MV-LV Network Types:** The study examines four MV-LV distribution networks, corresponding to four geographic areas: Urban, Sub-Urban, Short-Rural, and Long-Rural. The adopted network models, initially developed in WP1.4, are modified in WP1.5 for operational analysis. Details on each MV-LV network and their modifications are provided in *Section 3-a*.
2. **Analysis Year and DER Uptake:** The impact assessment is conducted every five years across the study horizon (i.e., 2023–2053), resulting in seven analysis years. For each analysis year, futuristic DER uptake data of PV, EV, gas electrification are sourced from the Scenario Planning conducted by C4NET, as detailed in *Section 3-b*.
3. **Representing Day:** For each analysis year, three representing days (from three seasons) are selected to capture demand and generation seasonality as well as different network challenges. These include a Spring Shoulder Day, a Summer Peak Day, and a Winter Peak Day. Different residential demand and DER profiles are applied to each representative day, as detailed in *Section 3-c* and *Section 3-e*.

4. **Use of Dynamic Operating Envelopes (DOEs)**: DOEs are emerging as a key strategy for managing DER while ensuring network integrity and is expected to be widely implemented across Victoria in the coming years. To evaluate its effectiveness and provide recommendations for implementation, this study compares the impacts of electrification under two scenarios: “Without DOEs” and “With DOEs”.
    - Scenario 1 (Without DOEs): Only embedded PV inverter functions (i.e., Volt-Watt and Volt-Var, following AS/NZS4777.2:2020 Australia A settings.) are implemented as non-network solutions to manage PV generation.
    - Scenario 2 (With DOEs): In addition to existing PV inverter functions, both Export DOEs and Import DOEs are introduced to manage PV generation and EV charging, respectively. Further details on DOE implementation (including its adoption rate, calculation and activation) are provided in *Section 2-c*.

1) Power Flow Simulations and Impact Metrics

Based on the scenarios developed considering the aforementioned elements, multiple time-series (24-hour, 30-minute interval) three-phase unbalanced power flow analyses are conducted using power flow software (e.g., OpenDSS) to evaluate the impacts of electrification on both thermal and voltage aspects.

Note that this study adopts a deterministic approach, which means that DER allocations to residential customers and their profile selections are randomized, thus uncertainty is not considered within the scope of this study.

The following metrics are derived from power flow simulation results (i.e., voltages, currents, and power) to assess various aspects, including voltage assessment, thermal assessment, PV curtailment, and EV management.

<u>Metrics - Overview</u>

1. **Maximum Absolute Power Flow (MVA):** The highest absolute power flow observed among the three representing days (i.e., spring shoulder day, summer peak day, and winter peak day).
2. **Increase of Maximum Absolute Power Flow (%):** The percentage increase in maximum power flow compared to the previous analysis year.

<u>Metrics - Voltage Assessment</u>

3. Voltage Rise/Drop Non-Compliance Rate (%):
4. The percentage of residential customers in the entire MV-LV network experiencing voltage rise issues (i.e., above 253V, 1.1 pu [12]) or voltage drop issues (i.e., below 216V, 0.94 pu [12]).
5. **Maximum/Minimum Customer Voltage (V):** The highest and lowest residential customer voltage observed across the MV-LV network.

6. **Ratio of LV Networks with Voltage Rise/Drop/Rise&Drop Issues (%):** The percentage of LV networks (associated with each distribution transformer) that have residential customers experiencing voltage rise issues, voltage drop issues, or both.

Metrics - Thermal Assessment

MV Feeder

7. **Overloaded Conductor Length (km):** The total length of overloaded MV conductors (i.e., utilisation above 100% for any time step).
8. **Max. Utilisation of the Worst Performing MV Segment (%):** The highest utilisation percentage (based on ampacity ratings) among all MV conductor segments.

Distribution Transformer

9. **Ratio of Distribution Transformer with Max. Utilisation within Each Range:** The percentage of distribution transformers with their peak one-time-step utilisation falling within different ranges (i.e., ≤100%, 100-110%, 110-150%, and >150%).
10. **Avg. Overloading Duration (hr):** The average number of hours that distribution transformers remain overloaded within each utilisation range.
11. **Max. Utilisation of the Worst Performing Transformer (%):** The highest utilisation percentage (based on kVA rating) among all distribution transformers.

LV Circuit

12. **Ratio of LV Circuit with Max. Utilisation within Each Range**: The percentage of LV circuits with their peak one-time-step utilisation falling within different ranges (i.e., ≤100%, 100-110%, 110-150%, and >150%).
13. **Max. Utilisation of the Worst Performing LV Circuit (%):** The highest utilisation percentage (based on ampacity ratings) among all LV circuits.

Metrics - PV Curtailment Assessment

Per Customer

14. **Max. PV Curtailment (kWh):** The highest PV curtailment observed for any customer with a PV system in the MV-LV network.
15. **Ratio of Max. PV Curtailment (%):** The highest percentage of total PV curtailment relative to total PV generation, per PV customer.
16. **Ratio of PV Customers Curtailed (%):** he percentage of PV customers experiencing curtailment in the MV-LV network.

Aggregate Export

17. **PV Curtailment (MWh):** The total PV curtailment across the entire MV-LV network.
18. **Ratio of PV Curtailment (%):** The percentage of total PV curtailment relative to total PV generation in the MV-LV network.

Metrics - EV management Assessment *(Applicable to the "With DOEs" Scenario Only)*

19. **Ratio of EVs Affected (%):** The percentage of EVs subject to charging management via import DOEs (i.e., charging demand is reduced).
20. **Avg. EV Charging Delay (hrs):** The average charging delay for affected EVs across the MV-LV network.

2) Outcomes

Based on the power flow simulation results and the key metrics obtained, the following key outcomes are generated for each MV-LV network:

- **Impact Metrics Table:** A table summarizing key metrics to assess network performance.
- **Aggregated Profiles:** Aggregated active power (P), reactive power (Q), and apparent power (S) profiles at the head of the MV feeder. These profiles serve as inputs for WP1.6 to facilitate analysis at the sub-transmission level.
- **Diversified Profiles:** Diversified P and S profiles per residential customer, categorized by technology type (e.g., residential load, EV, hot water, heating/cooling, PV, and net demand).
- **ADMD Table:** Diversified P and S profiles per residential customer, categorized by technology type (e.g., residential demand, PV, EV, hot water, heating/cooling and net demand).

b. Operation of Voltage Regulation Devices

Voltage regulation devices (e.g., on-load/off-load tap changers, line voltage regulators, and line capacitor banks) serve as key network solutions for mitigating voltage issues and are actively considered in this study. At each time step of the power flow simulations, the settings of these devices are determined within different control cycles to maximize voltage headroom and footroom. This approach provides an optimal proxy for voltage performance, estimating the best possible voltage conditions these devices can achieve.

1) Control Principles

The following principles are followed in the operation of voltage regulation devices:

- **Prioritizing local voltage solutions:** Voltage regulation devices operate in a sequence that prioritizes the most localized solutions before broader network-wide solutions. This approach minimizes the number of customers affected by network operations. In this study, the priority sequence is as follows: off-load tap changer (at the distribution transformer) → line capacitor banks (at the end of the MV feeder) → line voltage regulators (at the middle of the MV feeder) → on-load tap changer (at the zone substation, i.e., the head of the MV feeder).

- **Ensuring equal voltage headroom and footroom:** With the increasing adoption of various technologies, both voltage rise (caused by net export) and voltage drop (caused by net import) issues can occur in LV networks. To address both voltage issues, this approach aims to maintain the median customer voltage (among all residential customers within the MV-LV network) at 1.02 pu, which is the midpoint of the compliance range (i.e., 0.94 pu to 1.1 pu [12]). By doing so, equal voltage headroom and footroom can be ensured across the entire MV-LV network. Note that this calculation assumes that voltage measurements from residential customers (i.e., from smart meters) are available in real-time.
- **Selecting the closest tap position to achieve the voltage target:** To model the discrete control nature of voltage regulation devices (i.e., tap adjustments), the closest tap position that brings the voltage within the compliance range is selected. For example, if the voltage target is calculated as 0.99 pu, the closest available tap at 1.0 pu is chosen.

Note that, in reality, distribution companies typically adopt a simpler approach to control voltage regulation devices (e.g., a droop curve or several setpoints related to loading levels), based on empirical experience regarding how the device settings can affect voltages.

The approach proposed in this study is a more advanced scheme, though the philosophy remains the same as the empirical strategy used in the industry (i.e., improving customer voltage as much as possible). By doing so, the potential of voltage regulation devices can be fully exploited (i.e., providing an optimal proxy for voltage performance). If voltage issues persist in this ideal case, it indicates that other network and non-network solutions should be considered to further address the voltage issues.

2) *Simulation Framework*

Compared to online voltage regulation devices (i.e., OLTC, line voltage regulators, and line capacitor banks), whose settings vary throughout the day, the settings of off-load tap changers are relatively fixed for medium-term operation (e.g., from several months to years). To model the "offline" operation of off-load tap changers, the simulations are carried out in two runs: first, the best off-LTC setting is calculated for each distribution transformer, and then online voltage regulation devices are operated in real-time, as shown in Figure 4.

- **First Run:** The first run is carried out assuming that off-LTCs of all distribution transformers are fixed at their nominal positions (i.e., 1 pu). For each time step, different control cycles are implemented for each voltage regulation device to avoid the hunting effect (i.e., re-running the power flow simulation after updating each device setting).
- **Second Run:** Based on the voltage profiles after the first run, the optimal off-LTC settings for each distribution transformer are then calculated and used in the simulations of the second run. This provides a 'fine-tuning' of the voltage profiles for each LV network (corresponding to each distribution transformer).

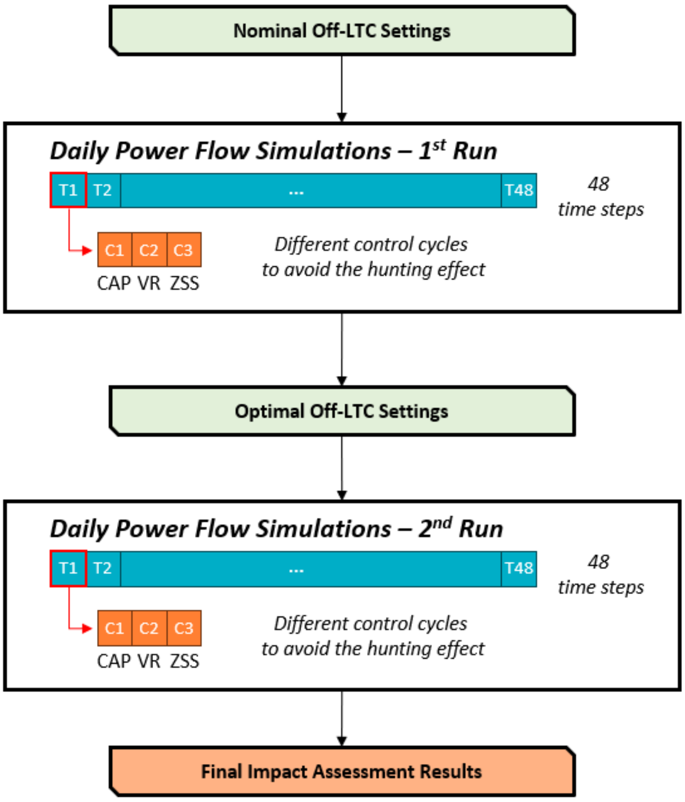

Figure 4. Steps to Operationalise Voltage Regulation Device

Figure 5 demonstrates the voltage profiles of all residential customers after each run of voltage regulation. It can be seen that the entire voltage spectrum decreases from 50 V to 40 V, with no further voltage rise issues present in this MV-LV network. Since the algorithm targets controlling the median customer voltage, it results in the median values being in the middle of the compliance range (216 V and 253 V).

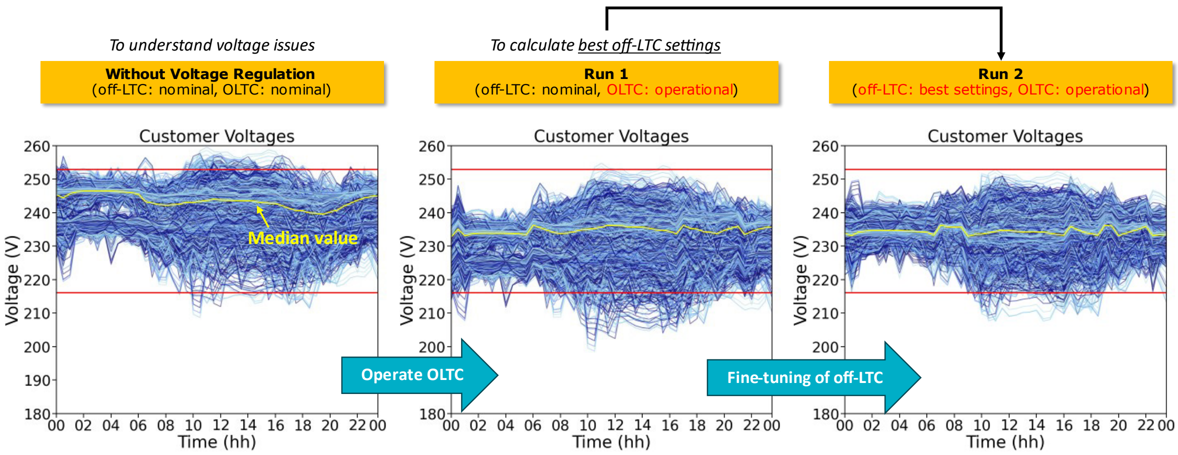

Figure 5. Examples of Voltage Profiles with Voltage Regulation

c. DOE Implementation

1) Concept

A concept of “flexible export limits”, as known as “export dynamic operating envelopes (DOEs)” has been published by Australian Energy Regulator in July 2023 [13], and started to be implemented in Victoria recently. Export DOE is defined as “a time-varying export limit” issued by a distribution company to aggregators, aimed at ensuring network integrity while facilitating residential DER services. Distribution companies only need to calculate and publish the time-varying export limits in advance (e.g., hours ahead, day ahead), while aggregators subscribe these limits to manage their DER portfolios. This clarifies the role of distribution companies in managing network assets without engaging in the control of behind-the-meter DERs, which adheres to the authority requirements in unbundled electricity markets (e.g., Australia) [14].

Apart from exports (from PVs), the increasing electrification of imports (from EVs and gas electrification) will also start to bring critical issues to distribution companies in the next decade. Therefore, it is believed that import DOEs (i.e., flexible import limit) will also need to be implemented in the future to manage household demand.

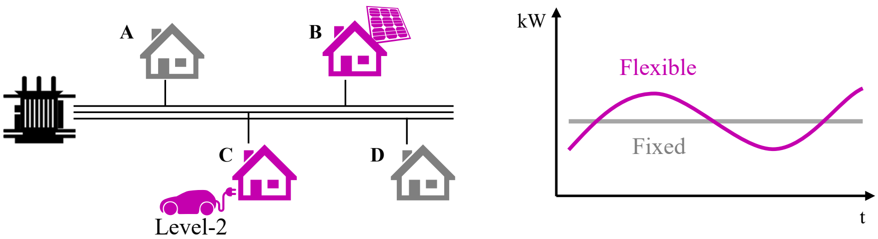

Figure 6. Illustration of Flexible Customer and Fixed Customer

The concepts are illustrated in Figure 6 using a demo LV feeder, where four single-phase customers are connected. In this study, both export and import DOEs are assumed to be calculated at the meter level (i.e., as a limit for the household net demand), and these DOEs are calculated for active power only, as reactive power is not considered controllable in this study.

The residential customers who adopt DOEs are randomly selected from those who have a PV system or Level-2 EV chargers installed, hereafter referred to as flexible customers (customer B and C as shown in Figure 6). This consideration is based on the fact that Level-1 chargers are designed simply to charge EVs, and only Level-2 chargers can provide monitoring and control functions [5]. For all other customers, referred to as fixed customers (customer A and D as shown in Figure 6), fixed power limits are applied (e.g., 5kw for export OE, 14kW for import OE), which are typically defined by the connection agreement (with distribution companies), local regulations, and/or the fuse rating (at the premise). Notably, the permitted range under the DOEs (purple line) can be either larger or smaller than the fixed limits (grey line), depending on the available capacity in the LV network at each time interval.

2) DOE Adoption Rate

In this context, both export and import DOEs are implemented in the impact assessment Scenario 2, "With DOEs," to understand their effectiveness in managing increasing DER penetration and mitigating potential network issues. The following adoption rates for export and import DOEs are considered in this study, with the timeline illustrated in Figure 7:

- ✓ Export OE (and upgrade to 10kVA PV inverter)
  - 2028 - apply to new PV customers.
  - 2033 - apply to 50% of existing PV customers.
  - 2038 - apply to 100% of existing PV customers.
- ✓ Import OE
  - 2033 - apply to new EV customers.
  - 2038 - apply to 100% of existing EV customers.
  - Only EV demand will be managed (I checked the hot water demand is not much)

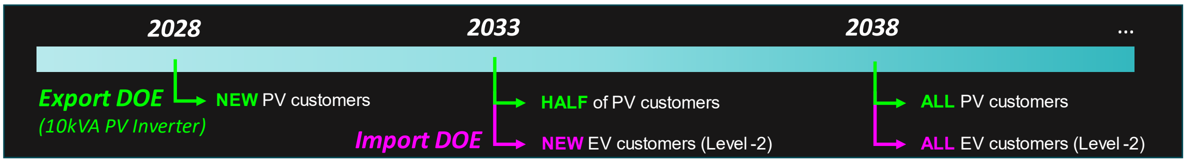

Figure 7. DOE Adoption Timeline

3) DOE Calculation

This study adopts a rule-based approach for calculating DOEs, which heuristically examines different limit values through power flow simulations at each time interval until it finds an adequate limit value that can maintain network integrity (i.e., complying with network constraints).

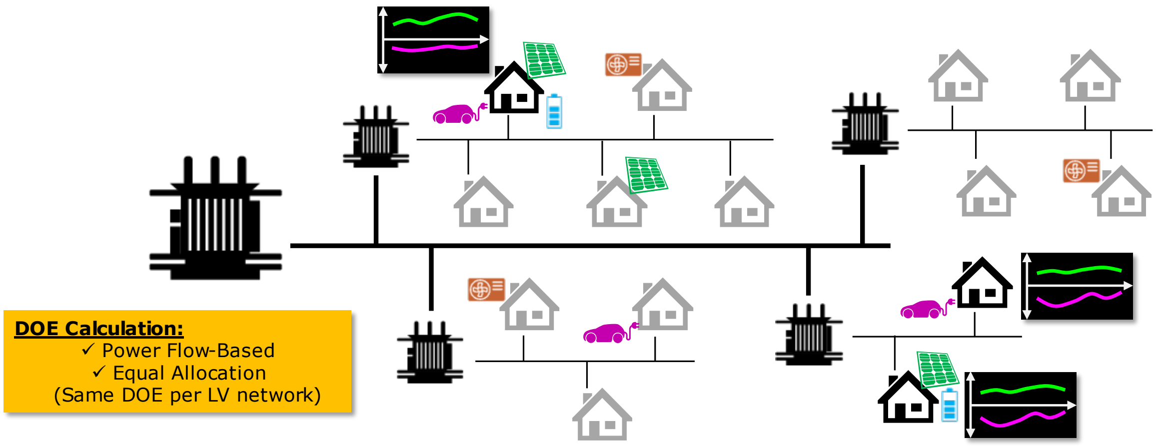

Figure 8. DOE Implementation in MV-LV Distribution Networks

An "Equal Allocation" strategy is assumed for DOE allocation, as shown in Figure 8, where all flexible customers within the same LV network (corresponding to the same distribution transformer) adopt the same DOE amount. This strategy helps ensure fairness among flexible customers but may constrain the total DER capacity (e.g., total PV generation, total EV charging demand), as customers at the end of the feeder can create voltage bottlenecks. According to the findings in the Project Edge [15], other strategies (e.g., Maximum Services) may be more beneficial in unlocking DER potential.

The generic architecture for the rule-based DOE calculation is shown in Figure 9. It requires static data (i.e., network model, thermal and voltage constraints, voltage regulation device settings, and upper DOE limits) and time-varying data (i.e., voltage at the head of the MV-LV feeder and forecast demand of both fixed and flexible customers). Each step is detailed below.

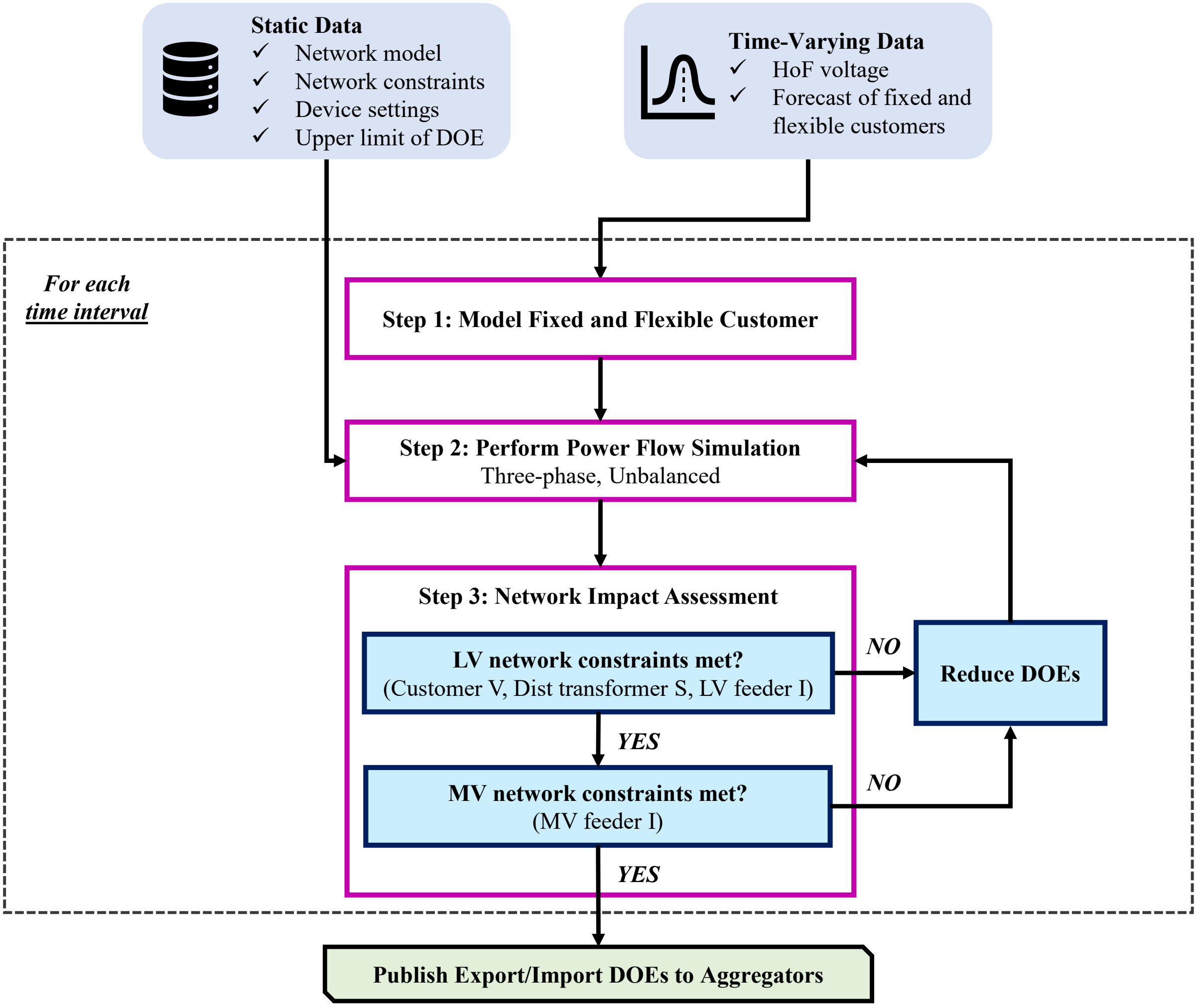

Figure 9. Generic Architecture of Flexible Import Limit Calculation

Step 1: Model Fixed and Flexible Customer

For fixed customers, whose demand is uncontrollable, their forecasted net active power and reactive power is directly used for demand modelling. The convention of power imports being positive and power exports being negative is adopted. Note that this study assumes a perfect forecast, meaning the demand at the next time step is precisely known by distribution companies.

For flexible customers, their active power (or part of it) is controllable while reactive power is assumed to remain uncontrollable. In this case, the forecasted net demand cannot be directly adopted in the modelling since control actions will change the profiles. Therefore, DOEs are used as a proxy for net active power, which represents the maximum a flexible customer can import/export. Given the “Equal Allocation” strategy adopted in this study, the DOE values are the same for flexible customers in the same LV network (i.e., connected to the same distribution transformer).

Step 2: Perform Power Flow Simulation

This rule-based DOE calculation requires power flow simulations to verify whether network constraints (i.e., thermal and voltage constraints) can be ensured under specific flexible import limits. At each time interval, the assessment begins with the upper limit of DOEs (e.g., 5kw for export OE, 14kW for import OE). Using both static data and time-varying, a three-phase unbalanced power flow analysis is performed using power flow equations or software (e.g., OpenDSS) to evaluate network performance.

Step 3: Network Impact Assessment

Based on the power flow simulation results (i.e., voltages, powers, currents), the network impacts are assessed in terms of both asset congestion and voltage issues, measured using the following performance metrics:

- **Utilisation level (%)**: Utilisation of transformers and feeders in both MV and LV parts with respect to their rated capacity.
- **Voltage Non-Compliance (%)**: Percentage of customers whose voltages do not meet the local requirements (e.g., 216V-253V as per Australian standard AS 61000.3.100 [12]).

Given the hierarchical structure of MV-LV distribution networks, the LV network is typically the bottleneck in accommodating additional demand. Therefore, as shown in Figure 9, the assessment is carried out in two stages: first at the LV level, and then at the MV level. At the LV level, if any thermal or voltage constraint are exceeded, the flexible import limit is reduced incrementally (e.g., by 1 kW) for the problematic LV network until all network constraints are resolved. Meanwhile, for LV networks that do not encounter any technical issues, DOEs remains unchanged. Once constraints are resolved for all LV networks, the assessment proceeds to the MV level. If congestion persists on the MV feeder after the LV-level demand adjustment, further reductions in the flexible import limit are applied across all LV networks to mitigate MV constraints. This bottom-up approach ensures that network issues are resolved locally first (for each LV network), preventing unnecessary curtailment of the import limit across the entire MV-LV network. After these two stages, the resulting DOEs ensure that all network constraints are met, and the available network capacity is fully exploited, which can then be published to aggregators and used for behind-the-meter DER management.

4) DER Management with DOEs

Once the DOEs are calculated and published by the distribution company, aggregators must adhere to these limits and manage customers' behind-the-meter devices accordingly. In this study, two types of DERs are managed using DOEs: PV systems and Level 2 EV chargers (i.e., 32A, 7.4kW).

At each time step, both export and import DOEs are calculated for flexible customers, defining the upper limits for their net export and import, respectively. For each flexible customer, if their real-time net demand exceeds the allocated DOEs, corresponding control actions must be implemented by aggregators, i.e., curtailing PV generation if net export exceeds the export DOEs or reducing EV charging demand if net import exceeds the import DOEs. Consequently, these control actions will result in PV curtailment or EV charging delays, which are assessed to understand their impact on customer comfort.

By controlling PV generation, customer net export is expected to remain within the export DOEs (i.e., at or below the limit), thereby ensuring network integrity. However, for import DOEs, the presence of uncontrollable appliances (i.e., residential demand, gas electrification demand) may lead to violations of the limits even if EV charging demand is entirely reduced. In such cases, network issues may still arise due to non-compliance with the import DOEs.

3. Input Data

This section introduces the MV-LV network model, scenario planning data, and profiles (for residential demand, C&I demand, and DERs) used in this study.

a. MV-LV Network Models and Modifications

This section outlines the modifications made in WP1.5 to adapt the network models for operational analysis. It also provides a comprehensive assessment of the synthetic LV network, evaluating its accuracy and potential impact on the assessment results.

Four MV feeders, provided by Victorian distribution companies (CitiPower, Powercor, United Energy, and Jemena), were modelled in WP1.4, with OpenDSS models supplied to WP1.5 for electrification impact assessment. Each feeder represents a distinct network type and geographic area, and their characteristics are introduced below, as summarized in Table 1.

Table 1. MV-LV Network Characteristics

Feeder Name	Geographic Area	Feeder Length	No. of Dist. Tx	No. of Cust.	No. of Cust. per km	No. of Cust. per Tx
Urban Feeder SBY32	Sunbury	19.8km	48	3,181 (91.7% RES, 8.3% C&I)	161	66
Sub-Urban Feeder WBE013	Werribee	33.1km	71	5,514 (96% RES, 4% C&I)	167	78
Short-Rural Feeder COO12	Coolaroo	93.1km	187	724 (89.5% RES, 10.5% C&I)	8	4
Long-Rural Feeder BAS033	Ballarat South	207.3km	877	3,924 (84% RES, 16% C&I)	19	5

- **Urban Feeder (SBY32, Sunbury)**: A 22 kV urban feeder acquired from Jemena, encompassing 48 distribution transformers over a 19.8 km distance. The feeder serves a total of 3,181 customers, with 91.7% residential and 8.3% commercial and industrial (C&I) customers.
- **Sub-Urban Feeder (WBE013, Werribee)**: A 22 kV sub-urban feeder from CitiPower, Powercor, and United Energy, consisting of 71 distribution transformers across a 33.14 km network. The feeder supplies 5,514 customers, with 96% residential and 4% C&I customers.
- **Short-Rural Feeder (COO12, Coolaroo)**: A 22 kV short-rural feeder provided by Jemena, spanning 93.1 km with 187 distribution transformers. The COO12 feeder supports 724 customers, with a breakdown of 89.5% residential and 10.5% C&I customers.
- **Long-Rural Feeder (BAS033, Ballarat South)**: A 22 kV long-rural feeder acquired from CitiPower, Powercor, and United Energy, extending over 207.3 km and incorporating 877 distribution transformers. It serves 3,942 customers, with 84% residential and 16% C&I and agricultural customers.

Overall, urban and sub-urban feeders are shorter and denser (serving more customers per unit of feeder length and per distribution transformer), whereas short-rural and long-rural feeders are longer and sparser.

Note that since LV network models were not available from distribution companies, WP1.4 adopted a pseudo-LV network modelling approach to generate synthetic LV network models. Further details on this methodology can be found in the WP1.4 Final Report [2]. There are some limitations presented in the network modelling which might affect the results of the impact assessment:

- A modern design of LV conductors (i.e., featuring lower impedance and higher ampacity) is adopted in the MV-LV network model provided by WP1.4. This modelling choice may significantly underestimate LV conductor utilisation.
- Single-wire earth return (SWER) networks are not considered in the MV-LV network models provided by WP1.4 for short-rural and long-rural feeders. Instead, these networks are modelled using a three-phase LV network as an alternative. This approach may lead to an underestimation of voltage issues.

1) Network Modifications Made for Operation

Several modifications have been made to the MV-LV network models provided by WP1.4 to better capture operational aspects:

1. **Increase in power factor of residential loads:** In the original OpenDSS files, the power factor of residential demand is fixed at 0.95 pu. Based on discussions with distribution companies, this value is increased to 0.98 pu to better reflect realistic usage patterns.
2. **Allocation of time-varying profiles instead of fixed demand:** In the original OpenDSS files, residential and commercial and industrial (C&I) loads are defined based on their ADMD values [2], with power flow results produced only for a single snapshot. To enable time-varying power

flow simulations, demand profiles are allocated to residential and C&I customers (further details on profiles are provided in Sections 3-c and 3-d). Notably, the random allocation of residential profiles can overload small distribution transformers, which is addressed by re-allocating profiles to ensure a problem-free base case scenario.

3. **Revision of tap modelling for voltage regulation devices:** In the original OpenDSS files, the tap modelling of voltage regulation devices (i.e., OLTC and off-LTC line voltage regulators) does not align with the device factsheets provided by distribution companies. Therefore, the number of taps and tap range are revised to ensure realistic modelling.
4. **Operationalization of voltage regulation devices:** In the original OpenDSS files, tap settings of voltage regulation devices (i.e., OLTC and line voltage regulators) are fixed values (e.g., 1.02 pu) set to address downstream voltage issues for a specific snapshot. In the time-varying power flow simulation of WP1.5, these voltage regulation devices are operationalized to dynamically address voltage issues at each timestep. The methodology for this operation is introduced in Section 2-b.
5. **Remove the 500 kVar capacitor modelled at the end of the long rural feeder:** The original OpenDSS files include a 500 kVar capacitor bank at the end of the long rural feeder. According to Powercor, this capacitor was installed to mitigate voltage drops caused by a nearby 2 MW quarry load. However, no such quarry load is identified in the network model provided to WP1.5. Therefore, the 500 kVar capacitor is removed to maintain voltage quality.

2) Synthetic LV network Assessment

Ten real LV networks (corresponding to ten sites), provided by Powercor (one of the Victorian distribution companies), are used to assess the accuracy of the pseudo-LV network models produced in WP1.4. For details on pseudo-LV network modelling, please refer to the WP1.4 final report. [2]

Both real and pseudo network models are delivered in OpenDSS files. Table 2 and Table 3 summarizes the characteristics of these real and corresponding pseudo-LV network models (e.g., transformer capacity, number of feeders, number of customers). The table is arranged in ascending order based on the number of residential customers at each site. Comparing both tables highlights the differences between the pseudo-LV network models and their real counterparts. This assessment examines how these differences affect the electrification assessment.

In this study, only networks with residential customers are considered; therefore, the Site 9 is disregarded (no residential customer). Furthermore, three load scenarios were considered to assess the behaviour of the pseudo-networks in different conditions.

- **Peak Load:** This scenario considers a load of 4.4 kW per residential customer (0.98 power factor, lagging), representing a high import condition.
- **Medium Load:** This scenario considers a load of 2.2 kW per residential customer (0.98 power factor, lagging), represents a medium import condition.

- **Peak Export:** This scenario represents high export conditions, where there is no residential load, and 5 kW export for each residential customer (e.g., PV).

Note that the load from C&I customers is not modified in none of these scenarios.

The assessment considered the following key metrics based on the described scenarios:

- **Customer voltage:** Represents the maximum, minimum, and average customer voltages.
- **Voltage at the furthest customer node:** Indicates the three-phase voltage at the most distant node with a connected customer.
- **Line utilisation at the head of the feeder:** Assesses the adequacy of conductor selection in the network.
- **Total active power losses:** Evaluate overall network efficiency.

Table 2. Summary of real LV network models

Site	Tx Rated Capacity (kVA)	No. Customers		No. Feeders	RES Customers per Phase		
		Residential	C & I		Ph A	Ph B	Ph C
9	500	0	24	2	0	0	0
5	10	1	0	1	1	0	0
10	500	1	9	3	1	0	0
6	315	2	14	5	1	1	0
3	315	2	14	5	1	1	0
7	1000	4	5	1	2	1	1
2	50	6	0	4	2	2	2
1	50	22	2	2	8	7	7
8	315	44	15	5	15	15	14
4	315	131	2	5	45	42	44

Table 3. Summary of pseudo-LV Network models

Site	Tx Rated Capacity (kVA)	No. Customers		No. Feeders	RES Customers per Phase		
		Residential	C & I		Ph A	Ph B	Ph C
9	500	0	1	0	0	0	0
5	10	1	0	1	1	0	0
10	500	1	1	1	1	0	0
6	315	2	1	1	1	1	0
3	315	2	1	1	1	1	0
7	1000	4	1	1	2	1	1
2	50	6	0	1	2	2	2
1	50	22	1	2	8	7	7
8	315	44	1	3	15	15	14
4	315	131	1	7	46	46	39

Site	Tx Rated Capacity (kVA)	Peak Load (kW) Residential	Peak Load (kW) Commercial	Scenario	Customer voltages Δ (%) Min	Customer voltages Δ (%) Max
5	10	4.4	0	Peak Load 4.4kW	0%	0%
				No Load + 100% PV	0%	0%
10	500	4.4	270	Peak Load 4.4kW	0%	0%
				No Load + 100% PV	1%	1%
6	315	8.8	252	Peak Load 4.4kW	2%	2%
				No Load + 100% PV	2%	1%
3	315	8.8	252	Peak Load 4.4kW	1%	1%
				No Load + 100% PV	1%	1%
7	1000	17.6	600	Peak Load 4.4kW	12%	9%
				No Load + 100% PV	10%	8%
2	50	26.4	0	Peak Load 4.4kW	-1%	0%
				No Load + 100% PV	0%	1%
1	50	96.8	20	Peak Load 4.4kW	14%	1%
				No Load + 100% PV	0%	-5%
8	315	193.6	120	Peak Load 4.4kW	5%	0%
				No Load + 100% PV	0%	-1%
4	315	576.4	20	Peak Load 4.4kW	8%	1%
				No Load + 100% PV	0%	-4%

Figure 10. Results of the Customer Voltage Comparison

Figure 10 summarises customer voltage results, which is the primary metric for assessing the performance of the pseudo-LV networks. Detailed results for other metrics are available in *Appendix-1*.

The primary metric-based findings of the comparison are presented in Figure 11, where the networks are categorised into three ranges based on their transformer rated capacity: A (up to 315 kV), B (between 315-500 kVA), and C (more than 500 kVA). Additionally, two subcategories are considered based on the proportion of residential customers: networks with more than 90% residential customers and those with less than 90%. Within each category range, the following conclusions can be drawn:

- **Range A (up to 315 kV):** In largely residential networks (more than 90%), pseudo-LV networks produce voltage results similar to the real networks.
- **Range B (between 315-500 kVA):** Pseudo-LV networks tends to underestimate voltage rises but overestimate voltage drops.
- **Range C (more than 500 kVA):** In mixed networks with less than 90% residential customers, pseudo-LV networks overestimated both voltage rises and drops.

Tx Rated Capacity	Largely RES (>90% Load RES)		Mixed with C&I (<90%. Load RES)	
	Voltage Rise	Voltage Drop	Voltage Rise	Voltage Drop
Range A: Up to 315 kVA	Overestimates ~1%	Underestimates ~1%	Underestimates ~5%	Overestimates ~14%
Range B: Between 315-500 kVA	Underestimates ~4%	Overestimates ~8%	Underestimates ~1%	Overestimates ~5%
Range C: More than 500 kVA	-	-	Overestimates ~9%	Overestimates ~12%

Figure 11. Summary of the conclusions

Applying these conclusions to the networks assessed in this project, the following points can be highlighted (Detailed statistics on the LV distribution transformers are available in *Appendix-1*):

- **Urban Network SBY32:** Around 20% of the pseudo-LV networks produce voltage results comparable to real networks, as they belong to Range A and are largely residential. However, the remaining 80% are more likely to underestimate voltage rises and overestimate voltage drops, given that the LV distribution transformers in this network mostly fall within Range B and C.

- **Su-burban Network WBE013:** Approximately 50% of the LV distribution transformers in this network fall within Range B, meaning the pseudo-LV networks tend to underestimate voltage rises and overestimate voltage drops.

- **Short-Rural COO012 and Long-Rural BAS033 Networks:** Pseudo-LV networks provide voltage results similar to real networks, as more than 80% of the LV distribution transformers in these networks fall within Range A and are largely residential.

b. Scenario Planning Data

The modelling of households and DERs for each analysis year is based on original scenario planning data provided by C4NET. The table of scenario data used in WP1.5 is provided in *Appendix-2* and is also available on C4NET SharePoint (WP1.5 Scenario Data.xlsx).

More specifically, the following data is adopted for each Network Type (i.e., urban, semi-urban, rural):

1. The proportion of each House Type (i.e., low-density, medium-density, and high-density).
2. The proportion of each House Size (i.e., 1-bed, 2-bed, 3-bed, 4-bed+) per House Type.
3. The proportion of each Efficiency Level (i.e., old, modern, new, efficient) per House Type.
4. PV: The average Panel Size and Uptake Rate per House Type.
5. EV: The proportion of each Charging Level (i.e., 2.3 kW, 3.7 kW, and 7.4 kW) and Uptake Rate per House Type.
6. Electrified Hot Water: The Uptake Rate per House Type.
7. Electrified Heating and Cooling: The Uptake Rate per House Type.

c. Residential Profiles

Anonymized Victorian smart meter data from AusNet in 2021 is used to model residential customers. Among the 1,472 recorded residential customers, data from 1,000 customers without PV installations is selected to represent the base demand as in the "without DER" case. The original half-hourly energy consumption data is converted into active power profiles, while reactive power is modelled in OpenDSS considering a fixed power factor of 0.95 pu (lagging).

Figure 12 presents the diversified residential demand profiles for 3 representing days assessed for this study (i.e., spring shoulder, summer peak, and winter peak days). Individual residential demand profiles for each calendar day are available on the C4NET SharePoint (WP1_5-Residential-Profiles).

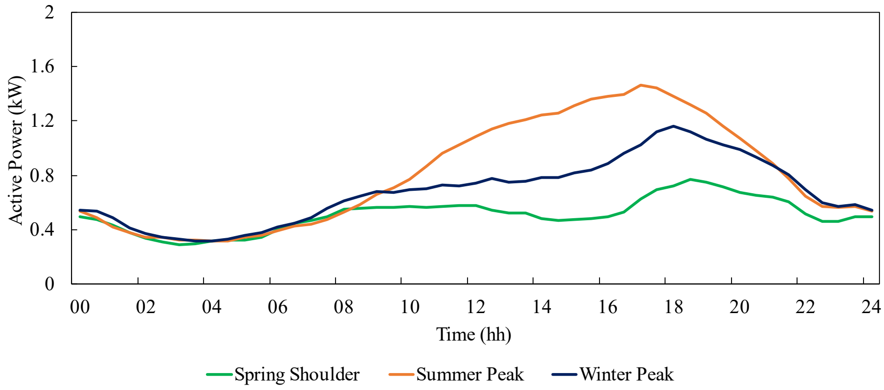

Figure 12. Diversified Residential Demand Profiles

d. C&I Profiles

All C&I loads are assumed to follow the same usage pattern, as shown in Figure 13 (per unit) with higher demand during the daytime (7 AM–5 PM) and lower demand overnight. The active power profile (in kW) for each C&I load is generated based on the peak demand provided in the OpenDSS model, while reactive power is modelled using a fixed power factor of 0.95 pu (lagging). This C&I demand profile is available on the C4NET SharePoint (WP1_5-Commercial-Profile).

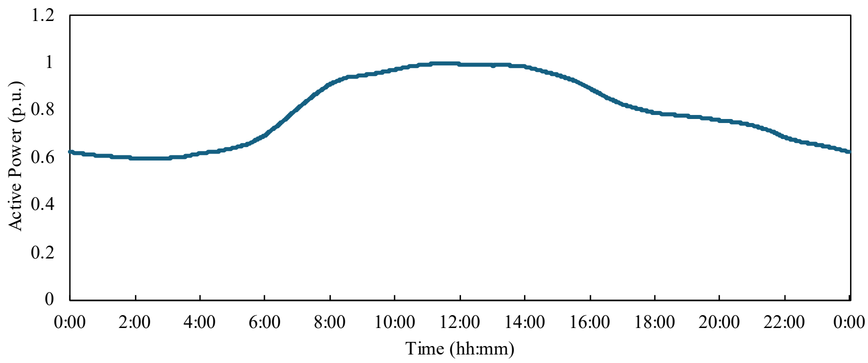

Figure 13. C&I Demand Profiles, Per Unit

e. DER Profiles

This section introduces the DER profiles adopted for each technology. The full set of individual demand profiles is available on the C4NET SharePoint (WP1_5-DER-profiles).

1) Heating and Cooling Profiles

A pool of electrified heating and cooling demand profiles from WP1.1 (considering different dwelling types, insulation types, building sizes, and climate zones) is adopted [1]. Figure 14 presents an example of the diversified cooling profiles for the following conditions: area (Melbourne), day type (summer peak), building size (3-bed), efficiency level (efficient), and house type (detached house). The reactive power is modelled in OpenDSS considering a fixed power factor of 0.95 pu (lagging).

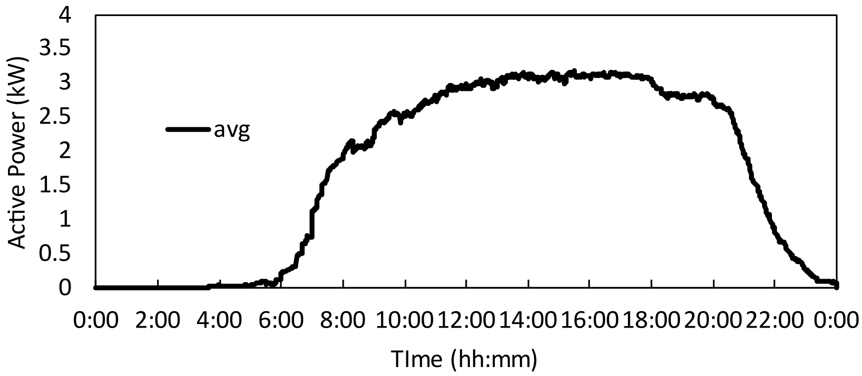

Figure 14. Diversified Heating/Cooling Demand Profiles

2) Hot Water Profiles

A pool of electrified hot water demand profiles from WP1.1 (considering different location, day type, technology) is adopted [1]. Figure 15 presents an example of the diversified cooling profiles for the following conditions: area (Melbourne), day type (summer peak), residents (3-occupant). The reactive power is modelled in OpenDSS considering a fixed power factor of 0.95 pu (lagging).

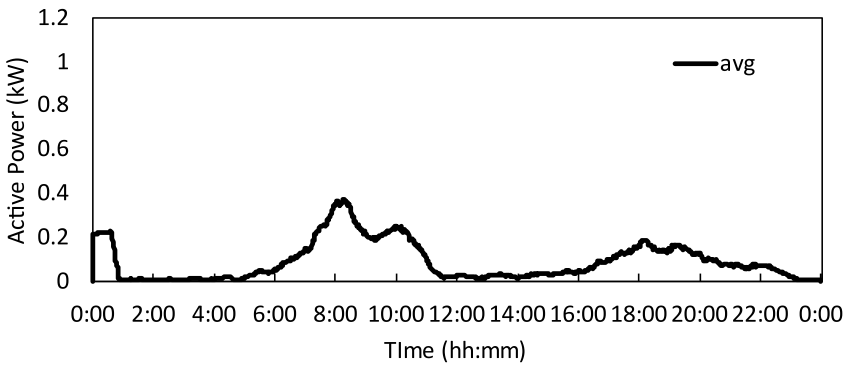

Figure 15. Diversified Hot Water Demand Profiles

3) EV Profiles

A pool of EV demand profiles from Powercor is adopted, considering different charging levels (i.e., 2.4 kW and 7.2 kW) and seasons (i.e., spring, summer, and winter). Figure 16 presents the diversified EV demand profiles for each charging level–season combination.

Since no profiles are available for 3.7 kW charging, this charging level is excluded from the study. When EV penetration exceeds 100%, some households are assumed to be allocated multiple EV chargers (with two EV demand profiles applied). Regarding charging frequency, EVs are assumed to charge no more than four days a week, with a daily plug-in factor of 70% [16].Reactive power is modelled in OpenDSS using a fixed power factor of 0.99 pu (lagging).

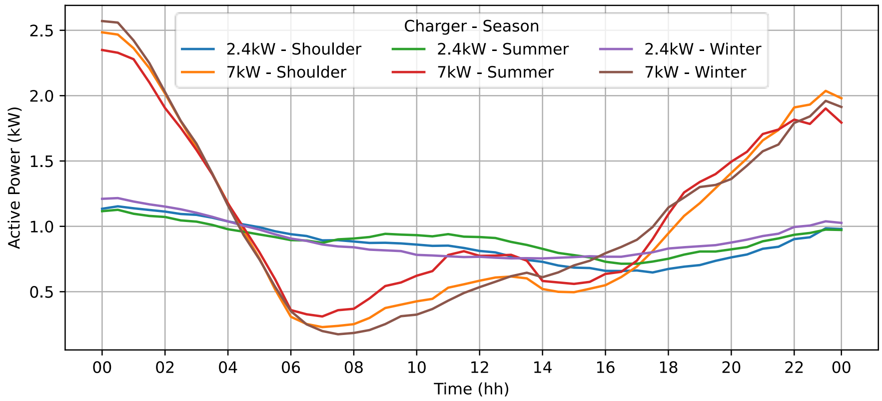

Figure 16. Diversified EV Demand Profiles

4) PV Profiles

A normalized, clear-sky PV generation profile [17] is used for each representative day analysed. Figure 16 presents an example of the PV generation profile on a Summer Peak Day with a PV panel size of 5 kW. Volt-Watt and Volt-Var inverter functions are enabled, following the AS/NZS 4777.2:2020 Australia A settings.

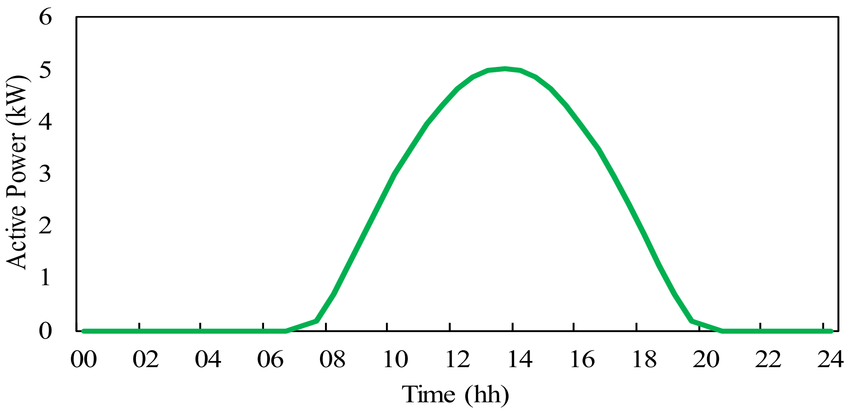

Figure 17. Clear-Sky PV Generation Profiles

4. Project Results

Four MV-LV distribution networks are assessed in this study for their electrification impacts (i.e., urban, sub-urban, short-rural and long-rural), and the simulation results are presented in two cases:

- **Without DOEs**: In this case, PV inverter functions (Volt-Watt and Volt-Var, following AS/NZS4777.2:2020 Australia A settings) are enabled, but DOEs are not implemented.
- **With DOEs**: In this case, PV inverter functions are still enabled, and DOEs are implemented based on the following adoption rates:
  - ✓ Export DOEs (and upgrade to 10kVA PV inverter)
    - 2028 - apply to new PV customers.
    - 2033 - apply to 50% of existing PV customers.
    - 2038 - apply to 100% of existing PV customers.
  - ✓ Import DOEs
    - 2033 - apply to new EV customers.
    - 2038 - apply to 100% of existing EV customers.
    - Only EV demand will be managed

For each case and each MV-LV network, a summary impact metrics table is provided analysing results from different perspectives (e.g., voltage, thermal, PV curtailment, and EV management). Full impact metrics tables, detailing the results for each representing day, are provided in the *Appendix*. Note that the following key assumptions or limitations need to be accounted for in the results:

1. The population growth in the assessed network area is not considered, meaning that the number of customers remains the same throughout the horizon (2023–2053).
2. Network augmentation or reconfiguration t is not considered in this study. That is, the assessed MV-LV networks are assumed to remain unchanged throughout the assessment period (2023–2053). Therefore, some voltage or thermal issues identified in this impact assessment should have been addressed before escalating to a severe level. However, changes in demand and the increase in network issues can still provide valuable insights for distribution network planning.
3. A modern design of LV conductors (i.e., featuring lower impedance and higher ampacity) is adopted in the MV-LV network model provided by WP1.4. This modelling choice may significantly underestimate LV conductor utilisation.
4. For short-rural and long-rural feeders, single-wire earth return (SWER) networks are not considered in the MV-LV network models provided by WP1.4. Instead, these networks are modelled using a three-phase LV network as an alternative. This approach may lead to an underestimation of voltage issues.
5. The size and adoption rate of DERs (i.e., PV, EVs, electrified heating/cooling, and hot water) are derived from scenario planning data provided by C4NET. Forecast assumptions in scenario planning may lead to underestimation or overestimation of the results.

a. Electrification Impact Assessment (Without DOEs)

1) Urban Network SBY32

Urban Network SBY32 (Without DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Overview										
Maximum Absolute Power Flow (MVA) [1]			9.7	8.9	10.2	12.1	14.0	16.1	18.3	19.9
Increase of Maximum Absolute Power Flow			/	/	15%	18%	18%	15%	13%	9%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0.1%	2%	5%	8%	15%	20%	24%
Voltage Drop Non-Compliance Rate			0.03%	3%	6%	17%	26%	34%	43%	45%
Maximum Customer Voltage (V) [2]			252	255	T	T	T	T	T	T
Minimum Customer Voltage (V)			216	207	197	179	181	169	172	174
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	2%	29%	48%	56%	58%	60%	60%
	Ratio of LV Networks with Voltage Drop Issues		2%	29%	52%	60%	63%	63%	65%	65%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	2%	29%	48%	56%	58%	60%	60%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.5	0.8	1.7	2.0
	Max. Utilisation of the Worst Performing MV Segment		76%	72%	83%	96%	110%	125%	140%	151%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	100%	94%	77%	56%	50%	44%	42%
		of 100-110%	0%	0%	6%	8%	6%	4%	6%	2%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	1.0	0.5	2.0	0.5	0.7	1.0
		of 110%-150%	0%	0%	0%	15%	25%	23%	13%	15%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	2.8	1.9	3.4	2.4	2.1
		of >150%	0%	0%	0%	0%	13%	23%	38%	42%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	0.0	1.8	3.3	4.2	4.9
	Max. Utilisation of the Worst Performing Transformer		71%	83%	109%	135%	173%	221%	254%	276%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	99%	98%
		of 100-110%	0%	0%	0%	0%	0%	0%	1%	1%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	1%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		32%	37%	60%	65%	70%	89%	104%	114%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	5.1	11.2	20.8	30.7	35.6	42.3	30.2
	Ratio of Max. PV Curtailment		/	11%	22%	39%	54%	59%	65%	45%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	722	1395	2140	3043	4140	5499	6821
	Ratio of PV Curtailment		/	6.1%	9.0%	11.8%	14.9%	17.9%	21.1%	23.7%

Table 4. Urban Network Impact Metrics Table (Without DOEs)

Overview

Urban Feeder (SBY32, Sunbury) is a 22 kV urban feeder acquired from Jemena, encompassing 48 distribution transformers over a 19.8 km distance. The feeder serves a total of 3,181 customers, with 91.7% residential and 8.3% C&I customers.

As shown in Table 4, the results indicate that this network may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is considered):

- Minor voltage issues arise from 2023, escalating to moderate by 2028 and severe after 2033.
- Minor overloading on MV conductors occurs from 2038, gradually increasing thereafter.
- Minor overloading on several distribution transformers begins in 2028, affecting a quarter of transformers by 2033 and more than half after 2043.
- Very minor overloading appears in a small fraction of LV conductors after 2048, given the modern design adopted.
- Considerable aggregate PV curtailment occurs after 2028 and continues to grow.

More detailed observations are provided below:

Voltage Assessment

In 2028, this urban feeder reaches a 33% PV penetration level and begins to experience moderate voltage issues, becoming a bottleneck for further PV uptake.

- Since the voltage regulation devices in this study are operated to ensure equal voltage headroom and footroom, more voltage drop issues have emerged as a result of managing PV-related voltage rise issues. This indicates that voltage regulation devices (i.e., tap positions) have been exhausted to maintain customer voltages within both upper and lower limits.
- Specifically, in 2028, 2% of the 3,181 residential customers will experience voltage rise issues, while 6% may encounter voltage drop issues, failing to comply with the distribution network's regulation (requiring voltage non-compliance to remain below 5%).
- Furthermore, the maximum customer voltage can exceed 253V, potentially leading to PV system tripping and resulting in customer complaints.

From 2028 to 2038, this urban feeder experiences a significant increase in EV uptake (rising from 14% to 86%) and gas electrification, while PV uptake grows more slowly (from 33% to 39%). As a result, net demand rises notably, which exacerbates voltage issues.

- More specifically, during 2028-2038, there is an 6% increase in voltage rise non-compliance and a 20% increase in voltage drop non-compliance. Once again, voltage regulation devices (i.e. taps) have been exhausted to keep customer voltages within both upper and lower limits. As a result, efforts to address demand-related voltage drop issues further exacerbate voltage rise problems.

Thermal Assessment

In this urban network, 6% of distribution transformers begin to experience minor overloading from 2028, and this issue can escalate rapidly if network augmentation is not considered. While MV conductors remain robust enough to accommodate the increasing demand until 2033, and LV conductors stay within their thermal ratings until 2043.

- More specifically, in 2028, 6% of the 48 distribution transformers may become slightly overloaded, experiencing a maximum utilisation below 110%, with an average overloading duration of 1 hour.
- Without network augmentation, by 2033, 23% of distribution transformers may be overloaded, with 15% experiencing utilisation above 110% for an average of 2.8 hours. The number of affected transformers increases to 44% by 2038, with 13% experiencing heavy loading above 150% for an average of 1.8 hours, which could severely limit further DER uptake.
- MV conductors remain robust enough to accommodate increasing demand until 2033. By 2038, 0.5 km of the 19.8 km feeder length may become overloaded, increasing to 2 km by 2053.
- Given the modern design adopted by LV network modelling (i.e., featuring lower impedance and higher ampacity), LV conductors remain within their thermal ratings until 2043, with 1% experiencing minor overloading by 2048.

PV Curtailment Assessment

Given the high PV penetration in 2028 (i.e., 33%), PV curtailment can be significant for some PV customers due to network-wide voltage rise issues. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters, which can limit their export opportunities, thereby reducing overall renewable energy penetration across the MV-LV network.

- All PV customers may experience curtailment to varying degrees. The most affected customers will face up to 22% PV curtailment in 2028, with this figure rising to 39% by 2033, significantly impacting customer benefits.
- The aggregated PV curtailment dramatically increases from 722 MWh (6.1%) in 2023 to 6,821 MWh (23.7%) in 2053. This curtailment is mainly due to the 5 kVA capacity limit of residential PV inverters, with further curtailment resulting from the PV Volt-Watt inverter function.

2) *Sub-Urban Network WBE013*

SubUrban Network WBE013 (Without DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Overview										
Maximum Absolute Power Flow (MVA) [1]			16.1	14.8	17.0	20.0	23.5	27.1	30.9	33.2
Increase of Maximum Absolute Power Flow			/	/	15%	21%	18%	15%	14%	8%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0%	0%	0%	0%	0.1%	1%	0.3%
Voltage Drop Non-Compliance Rate			0%	0%	0%	0.02%	0.1%	1%	1%	2%
Maximum Customer Voltage (V) [2]			246	249	249	251	251	255	258	256
Minimum Customer Voltage (V)			222	221	217	215	211	208	209	207
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	0%	0%	0%	0%	3%	6%	7%
	Ratio of LV Networks with Voltage Drop Issues		0%	0%	0%	1%	6%	20%	37%	41%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	0%	0%	0%	0%	1%	6%	7%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.5
	Max. Utilisation of the Worst Performing MV Segment		74%	73%	74%	75%	79%	94%	110%	124%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	100%	99%	69%	49%	41%	38%	38%
		of 100-110%	0%	0%	1%	13%	6%	4%	1%	1%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.5	0.8	1.1	1.3	1.0	1.5
		of 110%-150%	0%	0%	0%	18%	41%	25%	13%	8%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	1.1	3.3	4.1	4.0	4.8
		of >150%	0%	0%	0%	0%	4%	30%	48%	52%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	0.0	0.7	2.7	3.9	5.1
	Max. Utilisation of the Worst Performing Transformer		93%	93%	102%	131%	164%	194%	238%	256%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		29%	25%	36%	46%	59%	65%	72%	76%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	4.2	6.4	8.9	11.5	14.6	18.7	20.8
	Ratio of Max. PV Curtailment		/	9%	13%	17%	20%	24%	29%	31%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	1293	2504	3837	5456	7402	9834	12230
	Ratio of PV Curtailment		/	6.1%	8.9%	11.7%	14.7%	17.7%	20.8%	23.4%

Table 5. Sub-Urban Network Impact Metrics Table (Without DOEs)

Overview

Sub-Urban Feeder (WBE013, Werribee) is a 22 kV sub-urban feeder from CitiPower, Powercor, and United Energy, consisting of 71 distribution transformers across a 33.14 km network. The feeder supplies 5,514 customers, with 96% residential and 4% C&I customers.

As shown in Table 5, the results indicate that this network may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is considered):

- Minor voltage issues arise from 2033, slightly increasing thereafter.
- Minor overloading on MV conductors occurs from 2048, gradually increasing thereafter.
- Minor overloading on several distribution transformers begins in 2028, affecting a third of transformers by 2033 and more than half after 2038.
- LV conductors remain within their thermal ratings throughout the analysis period, given the modern design adopted.
- Considerable aggregate PV curtailment occurs after 2028 and continues to grow.

More detailed observations are provided below:

Voltage Assessment

This sub-urban network is relatively robust in terms of voltage quality, with only minor voltage issues arising from 2033 and slightly increasing thereafter. Overall, the voltage non-compliance rate remains within the distribution network's regulatory limit (i.e., 5%).

- Since the voltage regulation devices in this study are operated to ensure equal voltage headroom and footroom, more voltage drop issues have emerged as a result of managing PV-related voltage rise issues. This indicates that voltage regulation devices (i.e., tap positions) have been exhausted to maintain customer voltages within both upper and lower limits.
- Specifically, 0.02% of the 5,293 residential customers begin to experience voltage drop issues from 2033, and 0.1% of residential customers start to experience voltage rise issues from 2043. By 2053, the voltages still comply with the distribution network's regulation (requiring voltage non-compliance to remain below 5%).

Thermal Assessment

In this sub-urban network, 1% of distribution transformers begin to experience minor overloading from 2028, and this issue can escalate rapidly if network augmentation is not considered. While MV conductors remain robust enough to accommodate the increasing demand until 2043, and LV conductors stay within their thermal ratings throughout the analysis period.

- More specifically, in 2028, 1% of the 48 distribution transformers may become slightly overloaded, experiencing a maximum utilisation below 110%, with an average overloading duration of 0.5 hour.

- Without network augmentation, by 2033, a third of distribution transformers may be overloaded, with 18% experiencing utilisation above 110%. By 2038, more than half of transformers will be affected, with 4% experiencing heavy loading above 150%, and 41% experiencing moderate loading above 110%, which could severely limit further DER uptake.
- MV conductors remain robust enough to accommodate increasing demand until 2043. By 2048, 0.4 km of the 33.14 km feeder length may become overloaded, increasing to 2.5 km by 2053.
- Given the modern design adopted by LV network modelling (i.e., featuring lower impedance and higher ampacity), LV conductors remain within their thermal ratings throughout the analysis period.

PV Curtailment Assessment

Given the high PV penetration in 2028 (i.e., 33%), PV curtailment can be significant for some PV customers due to network-wide voltage rise issues. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters, which can limit their export opportunities, thereby reducing overall renewable energy penetration across the MV-LV network.

- All PV customers may experience curtailment to varying degrees. The most affected customers will face up to 13% PV curtailment in 2028, with this figure rising to 17% by 2033, slightly impacting customer benefits.
- The aggregated PV curtailment dramatically increases from 1,293 MWh (6.1%) in 2023 to 12,230 MWh (23.4%) in 2053. This curtailment is mainly due to the 5 kVA capacity limit of residential PV inverters, with further curtailment resulting from the PV Volt-Watt inverter function.

3) *Short-Rural Network COO012*

Short-Rural Network COO012 (Without DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Overview										
Maximum Absolute Power Flow (MVA) [1]			3.5	3.0	3.4	3.8	4.2	4.7	5.1	5.5
Increase of Maximum Absolute Power Flow			/	/	11%	14%	14%	10%	11%	6%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			3%	1%	5%	10%	16%	19%	19%	24%
Voltage Drop Non-Compliance Rate			1%	3%	9%	11%	14%	18%	22%	28%
Maximum Customer Voltage (V) [2]			254	258	T	T	T	T	T	T
Minimum Customer Voltage (V)			214	206	190	173	174	175	169	166
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		1%	1%	3%	5%	6%	6%	7%	9%
LV Network Voltages	Ratio of LV Networks with Voltage Drop Issues		2%	3%	6%	8%	11%	16%	20%	25%
LV Network Voltages	Ratio of LV Networks with Both Voltage Rise&Drop Issues		1%	1%	3%	5%	6%	6%	7%	7%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
MV Feeder	Max. Utilisation of the Worst Performing MV Segment		64%	57%	61%	70%	81%	90%	99%	105%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	99%	98%	98%	95%	93%	87%	85%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of 100-110%	0%	0%	1%	0%	2%	2%	1%	2%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	Avg. Overloading Duration (hr) [3]	0.0	0.0	0.5	0.0	0.7	0.6	0.8	0.8
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of 110%-150%	0%	1%	1%	2%	3%	4%	8%	7%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	Avg. Overloading Duration (hr) [3]	0.0	0.5	1.5	1.7	2.2	1.3	1.6	1.5
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of >150%	0%	0%	1%	1%	1%	1%	4%	5%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	Avg. Overloading Duration (hr) [3]	0.0	0.0	1.5	1.5	1.5	1.5	1.5	1.4
Distribution Transformer	Max. Utilisation of the Worst Performing Transformer		75%	114%	170%	203%	205%	193%	210%	210%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of >150%	0%	0%	0%	0%	0%	0%	0%	0%
LV Circuit	Max. Utilisation of the Worst Performing LV Circuit		33%	36%	40%	51%	64%	71%	85%	87%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	11.7	10.5	39.5	44.7	44.2	50.2	53.2
Per Customer	Ratio of Max. PV Curtailment		/	12%	21%	74%	78%	73%	78%	78%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	160	310	480	685	922	1220	1517
Aggregate Export [4]	Ratio of PV Curtailment		/	6.1%	8.9%	11.9%	15.1%	18.0%	21.0%	23.7%

Table 6. Short-Rural Network Impact Metrics Table (Without DOEs)

Overview

Short-Rural Feeder (COO12, Coolaroo) is a 22 kV feeder provided by Jemena, spanning 93.1 km with 187 distribution transformers. The COO12 feeder supports 724 customers, with a breakdown of 89.5% residential and 10.5% C&I customers.

As shown in Table 6, the results indicate that this network may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is considered):

- Minor voltage issues arise from 2023, escalating to moderate by 2028 and severe after 2033.
- Minor overloading on MV conductors occurs from 2053.
- Minor overloading on several distribution transformers begins in 2023, gradually increasing thereafter.
- LV conductors remain within their thermal ratings throughout the analysis period, given the modern design adopted.
- Considerable aggregate PV curtailment occurs after 2028 and continues to grow.

More detailed observations are provided below:

Voltage Assessment

In 2028, this short-rural feeder reaches a 29% PV penetration level and begins to experience significant voltage issues, becoming a bottleneck for further PV uptake.

- Since the voltage regulation devices in this study are operated to ensure equal voltage headroom and footroom, more voltage drop issues have emerged as a result of managing PV-related voltage rise issues. This indicates that voltage regulation devices (i.e., taps) have been exhausted to maintain customer voltages within both upper and lower limits.
- Specifically, 5% of the 648 residential customers will experience voltage rise issues, while 9% may encounter voltage drop issues, failing to comply with the distribution network's regulation (requiring voltage non-compliance to remain below 5%).
- Furthermore, the maximum customer voltage can exceed 253V, potentially leading to PV system tripping and resulting in customer complaints.

From 2028 to 2038, this short-rural feeder experiences a significant increase in EV uptake (rising from 14% to 87%) and gas electrification, while PV uptake grows more slowly (from 37% to 43%). As a result, net demand rises notably, which exacerbates voltage issues.

- More specifically, there is an 11% increase in voltage rise non-compliance and a 5% increase in voltage drop non-compliance. Once again, voltage regulation devices (i.e. tap positions) have been exhausted to keep customer voltages within both upper and lower limits. As a result, efforts to address demand-related voltage drop issues further exacerbate voltage rise problems.

Thermal Assessment

In this short-rural network, 2% of distribution transformers begin to experience moderate to severe overloading from 2028, and this issue can escalate rapidly if network augmentation is not considered. While MV conductors remain robust enough to accommodate the increasing demand until 2048, and LV conductors stay within their thermal ratings throughout the whole analysis period.

- More specifically, in 2028, 1% of the 187 distribution transformers may become heavily overloaded, experiencing a maximum utilisation above 150%, with an average overloading duration of 1.5 hours.
- Without network augmentation, by 2038, 5% of distribution transformers may be overloaded, with 4% experiencing utilisation above 110% for more than 2 hours in average. From 2043 to 2048, the number of overloaded transformers increases significantly (from 7% to 13%), which could severely limit further DER uptake.
- MV conductors remain robust enough to accommodate increasing demand until 2048. By 2053, 2.8 km of the 93.71 km feeder length may become overloaded.
- Given the modern design adopted by LV network modelling (i.e., featuring lower impedance and higher ampacity), LV conductors remain within their thermal ratings throughout the analysis period.

PV Curtailment Assessment

Given the high PV penetration in 2028 (i.e., 37%), PV curtailment can be significant for some PV customers due to network-wide voltage rise issues. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters, which can limit their export opportunities, thereby reducing overall renewable energy penetration across the MV-LV network.

- All PV customers may experience curtailment to varying degrees. The most affected customers will face up to 12% PV curtailment in 2028, with this figure rising to 74% by 2033, significantly impacting customer benefits.
- The aggregated PV curtailment dramatically increases from 722 MWh (6.1%) in 2023 to 6,821 MWh (23.7%) in 2053. This curtailment is partly due to the PV Volt-Watt inverter function and partly due to the 5 kVA capacity limit of residential PV inverters.

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4) Long-Rural Network BAS033

RuralLong Network BAS033 (Without DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Overview										
Maximum Absolute Power Flow (MVA) [1]			16.9	14.9	17.0	19.9	22.8	25.9	29.3	31.9
Increase of Maximum Absolute Power Flow			/	/	14%	17%	15%	14%	13%	9%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0%	0%	0%	1%	1%	4%	21%
Voltage Drop Non-Compliance Rate			0.21%	0%	0.1%	0.1%	0.2%	2%	3%	23%
Maximum Customer Voltage (V) [2]			250	245	249	252	256	256	T	T
Minimum Customer Voltage (V)			215	221	216	213	210	208	199	184
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	0%	0%	0%	0.5%	1%	3%	16%
	Ratio of LV Networks with Voltage Drop Issues		0.3%	0%	0.1%	0.2%	0.5%	3%	5%	23%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	0%	0%	0%	0%	0.3%	1%	12%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	6.7	9.2	17.7	20.4
	Max. Utilisation of the Worst Performing MV Segment		81%	71%	80%	102%	126%	155%	178%	196%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	97%	91%	83%	76%	68%	63%	59%
		of 100-110%	0.1%	2%	2%	4%	4%	5%	5%	5%
		Avg. Overloading Duration (hr) [3]	1.0	0.8	0.9	0.9	1.0	0.8	1.0	1.0
		of 110%-150%	0.2%	1%	6%	8%	11%	12%	13%	14%
		Avg. Overloading Duration (hr) [3]	0.5	1.6	1.5	1.5	1.5	1.6	1.5	1.7
		of >150%	0%	0%	1%	5%	9%	15%	20%	22%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	1.4	1.9	2.5	2.8	3.3	3.7
	Max. Utilisation of the Worst Performing Transformer		115%	146%	196%	294%	297%	346%	388%	428%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		24%	23%	32%	50%	55%	65%	78%	78%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	4.1	6.1	8.2	11.1	13.7	16.8	19.7
	Ratio of Max. PV Curtailment		/	9%	12%	15%	19%	23%	26%	29%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	808	1563	2397	3405	4621	6134	7632
	Ratio of PV Curtailment		/	6.0%	8.8%	11.6%	14.7%	17.6%	20.7%	23.3%

Table 7. Long-Rural Network Impact Metrics Table (Without DOEs)

Overview

Long-Rural Feeder (BAS033, Ballarat South) is a 22 kV long-rural feeder acquired from CitiPower, Powercor, and United Energy, extending over 207.3 km and incorporating 877 distribution transformers. It serves 3,942 customers, with 84% residential and 16% C&I and agricultural customers.

As shown in Table 7, the results indicate that this network may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is considered):

- Minor voltage issues arise from 2028, escalating to severe by 2053.
- Minor overloading on MV conductors occurs from 2033, escalating to moderate by 2038.
- Minor overloading on several distribution transformers begins in 2023, affecting a quarter of transformers by 2038.
- LV conductors remain within their thermal ratings throughout the analysis period, given the modern design adopted.
- Considerable aggregate PV curtailment occurs after 2028 and continues to grow.

More detailed observations are provided below:

Voltage Assessment

This long rural network is relatively robust in terms of voltage quality, with only minor voltage issues arising from 2028 and gradually increasing thereafter. However, from 2048 to 2053, there is a dramatic rise in the voltage non-compliance rate.

- Specifically, in 2028, 0.1% of the 3,311 residential customers experience voltage drop issues. This increases to 3% by 2048, along with 4% of residential customers experiencing voltage rise issues, which is still within the distribution network's regulatory limit (requiring voltage non-compliance to remain below 5%).
- However, from 2048 to 2053, voltage non-compliance increases sharply, with a 17% increase in voltage rise issues and a 20% increase in voltage drop issues. This indicates that voltage regulation devices (e.g., tap positions) have been exhausted, making it impossible to maintain customer voltages within both upper and lower limits.

Thermal Assessment

In this long-rural network,3% of distribution transformers begin to experience minor overloading from 2023, and this issue can escalate rapidly if network augmentation is not considered. A small segment of MV conductors begin to experience overloading from 2033 as well, escalating to moderate by 2038. LV conductors remain within their thermal ratings throughout the analysis period

- More specifically, in 2023, 3% of the 877 distribution transformers may become slightly overloaded, experiencing a maximum utilisation below 150%, with an average overloading duration of 1.6 hour.
- Without network augmentation, by 2028, 9% of distribution transformers may be overloaded, with 1% experiencing utilisation above 150% for an average of 2.8 hours. The number of affected transformers increases to 17% by 2033, with 5% experiencing heavy loading above 150% for an average of 1.9 hours, which could severely limit further DER uptake.
- MV conductors remain robust enough to accommodate increasing demand until 2028. By 2033, 0.04 km of the 207.3 km feeder length may become overloaded, increasing to 9.2 km by 2043 and 20.4 km by 2053.
- Given the modern design adopted by LV network modelling (i.e., featuring lower impedance and higher ampacity), LV conductors remain within their thermal ratings throughout the assessment period.

PV Curtailment Assessment

Given the high PV penetration in 2028 (i.e., 33%), PV curtailment can be significant for some PV customers due to network-wide voltage rise issues. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters, which can limit their export opportunities, thereby reducing overall renewable energy penetration across the MV-LV network.

- All PV customers may experience curtailment to varying degrees. The most affected customers will face up to 12% PV curtailment in 2028, with this figure rising to 15% by 2033, slightly impacting customer benefits.
- The aggregated PV curtailment dramatically increases from 808 MWh (6.0%) in 2023 to 7,632 MWh (23.3%) in 2053. This curtailment is mainly due to the 5 kVA capacity limit of residential PV inverters, with further curtailment resulting from the PV Volt-Watt inverter function.

b. Electrification Impact Assessment (With DOEs)

1) Urban Network SBY32

Urban Network (With DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Houses with PV, EV and DOEs										
Houses with PV			0%	27%	33%	36%	39%	41%	44%	47%
Houses with PV + Export DOE			0%	0%	6%	18%	39%	41%	44%	47%
Houses with EV			0%	1%	14%	50%	86%	119%	147%	155%
Houses with EV + Import DOE (Level-2 EV)			0%	0%	0%	5%	15%	27%	43%	54%
Overview										
Maximum Absolute Power Flow (MVA) [1]			9.7	8.9	10.2	11.8	13.6	15.6	17.2	18.4
Increase of Maximum Absolute Power Flow			/	/	15%	16%	16%	14%	10%	7%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0.1%	2%	3%	5%	6%	8%	5%
Voltage Drop Non-Compliance Rate			0.03%	3%	6%	14%	22%	28%	37%	43%
Maximum Customer Voltage (V) [2]			252	255	T	T	T	T	T	T
Minimum Customer Voltage (V)			216	207	197	192	180	182	176	177
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	2%	25%	40%	42%	38%	42%	42%
	Ratio of LV Networks with Voltage Drop Issues		2%	29%	50%	60%	60%	60%	63%	63%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	2%	25%	40%	42%	38%	42%	42%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.5	0.7	1.1	1.7
	Max. Utilisation of the Worst Performing MV Segment		76%	72%	83%	94%	109%	121%	134%	143%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	100%	94%	83%	56%	54%	50%	42%
		of 100-110%	0%	0%	6%	2%	15%	4%	6%	8%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	1.0	0.5	1.1	1.3	2.7	0.8
		of 110%-150%	0%	0%	0%	15%	23%	25%	15%	15%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	2.0	2.9	3.5	4.1	2.7
		of >150%	0%	0%	0%	0%	6%	17%	29%	35%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	0.0	2.0	3.1	3.6	4.4
	Max. Utilisation of the Worst Performing Transformer		71%	83%	109%	132%	165%	202%	228%	249%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		33%	37%	60%	62%	68%	81%	89%	94%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	5.1	33.4	53.4	56.9	60.1	64.6	66.9
	Ratio of Max. PV Curtailment		/	11%	66%	100%	100%	99%	100%	98%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	722	1353	3673	7224	9473	11894	13551
	Ratio of PV Curtailment		/	6.1%	8.7%	20.5%	35.9%	41.6%	46.0%	47.4%
EV Management Assessment										
Ratio of EVs Affected			/	/	/	10%	13%	16%	21%	24%
Avg. EV Charging Delay (hrs)			/	/	/	4.8	6.0	6.0	5.9	5.6

Table 8. Urban Network Impact Metrics Table (With DOEs)

Overview

Urban Feeder (SBY32, Sunbury) is a 22 kV urban feeder acquired from Jemena, encompassing 48 distribution transformers over a 19.8 km distance. The feeder serves a total of 3,181 customers, with 91.7% residential and 8.3% C&I customers.

As shown in Table 8, the results of the electrification impact assessment (With DOEs) indicate that implementing DOEs effectively eliminates both voltage and thermal issues, helping to delay the need for network augmentation. However, due to a significant portion of demand being uncontrollable (i.e., Level-1 EV charging, electrified heating/cooling and hot water), the effectiveness of DOEs can be largely limited.

More detailed observations are provided below:

Voltage Assessment

With DOE implementation, customer voltage non-compliance rates decrease slightly. However, this reduction may not be sufficient to meet distribution network regulations, which require non-compliance to remain below 5%.

- As DOEs are gradually rolled out to PV and Level-2 EV customers (from 2028 to 2038), customer voltage rise and drop non-compliance rates decrease by 5%-7% (among 2,917 residential customers in this urban network).
- Beyond 2043, the effectiveness of OE in reducing voltage non-compliance becomes more pronounced, leading to a 16%–21% decrease compared to the assessment without DOEs.
- However, the non-compliance rate remains above 5% beyond 2028, necessitating additional DER management strategies.

Thermal Assessment

Once DOEs are implemented (i.e. from) 2028, fewer distribution transformers will experience overloading, helping to delay network augmentation. The length of overloaded MV conductors decreases, and LV conductors remain within their thermal ratings throughout the analysis period.

- From 2033 to 2053, the number of overloaded distribution transformers decreases by 4%–6% (among 48 transformers in this urban network).
- Between 2038 and 2053, the severity of overloading is significantly reduced, with 6%–9% fewer transformers exceeding 150% loading compared to the assessment without DOEs.
- Overloading of MV conductors persists beyond 2038; however, compared to the assessment without DOEs, the overloading length is slightly reduced by 0.1 km–0.6 km (out of 19.8 km) between 2043 and 2053.
- Overloading of LV conductors is fully addressed with DOE implementation, remaining within their thermal ratings throughout the analysis period.

PV Curtailment Assessment

At the initial stage of DOE implementation (i.e., 2028), total PV curtailment decreases. However, over time, curtailment increases and surpasses the amount observed in the assessment without DOEs. This occurs because DOEs impose additional constraints on existing PV inverter functions (i.e., Volt-Watt and Volt-Var). Furthermore, due to the "Equal Allocation" strategy adopted in this study (i.e., all flexible customers are given the same export limit during the corresponding time interval), aggregate PV generation is not maximized.

- All PV customers experience some degree of curtailment, with the most affected facing up to 66% PV curtailment in 2028, higher than 22% as observed in the assessment without DOEs. This figure rises to 100% by 2033, higher than 39% as observed in the assessment without DOEs.
- In 2028, aggregate PV curtailment is 8.7%, which is less compared to 9% without DOEs. This reduction occurs because a small fraction of PV systems begins adopting DOEs, and their inverters are upgraded to 10 kVA, unlocking greater PV potential.
- However, as DOE adoption increases, the limitations of the "Equal Allocation" strategy become evident. Since DOE values are constrained by the customer with the most severe voltage issues, this negatively impacts all customers within the same LV network. Consequently, PV curtailment is 8%-24% higher than in the assessment without DOEs.

EV Management Assessment

When DOEs are applied to Level-2 EVs (starting in 2033), their impact on EV charging is a critical factor to assess. The analysis shows that EV charging delays remain under 6 hours on average throughout the analysis horizon. Moreover, these delays primarily occur at midnight, minimizing disruptions for EV users.

2) *Sub-Urban Network WBE013*

Suburban Network (With DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Houses with PV, EV and DOEs										
Houses with PV			0%	28%	35%	38%	41%	44%	47%	49%
Houses with PV + Export DOE			0%	0%	7%	19%	41%	44%	47%	49%
Houses with EV			0%	1%	14%	50%	87%	119%	148%	156%
Houses with EV + Import DOE (Level-2 EV)			0%	0%	0%	5%	16%	28%	43%	54%
Overview										
Maximum Absolute Power Flow (MVA) [1]			16.1	14.8	17.0	19.9	23.0	25.7	28.9	30.9
Increase of Maximum Absolute Power Flow			/	/	15%	19%	15%	12%	12%	7%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0%	0%	0%	0%	0%	0.3%	0%
Voltage Drop Non-Compliance Rate			0%	0%	0%	0.02%	0.1%	0.4%	1%	1%
Maximum Customer Voltage (V) [2]			246	249	249	249	250	252	257	252
Minimum Customer Voltage (V)			222	221	217	216	212	210	212	208
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	0%	0%	0%	0%	0%	1%	0%
	Ratio of LV Networks with Voltage Drop Issues		0%	0%	0%	1%	3%	13%	13%	23%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	0%	0%	0%	0%	0%	0%	0%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9
	Max. Utilisation of the Worst Performing MV Segment		74%	73%	74%	74%	76%	89%	103%	114%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	100%	99%	73%	52%	42%	39%	39%
		of 100-110%	0%	0%	1%	10%	4%	6%	3%	0%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.5	0.9	0.7	2.0	2.0	0.0
		of 110%-150%	0%	0%	0%	17%	42%	31%	20%	15%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	0.9	3.0	3.6	4.9	4.6
		of >150%	0%	0%	0%	0%	1%	21%	38%	45%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	0.0	0.5	1.6	2.8	3.8
	Max. Utilisation of the Worst Performing Transformer		93%	93%	102%	131%	164%	183%	212%	230%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		29%	25%	36%	43%	52%	59%	64%	69%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	4.2	6.4	19.5	44.9	57.4	63.4	67.1
	Ratio of Max. PV Curtailment		/	9%	13%	36%	79%	94%	98%	99%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	1293	2000	1605	2890	5123	8873	11774
	Ratio of PV Curtailment		/	6.1%	7.1%	4.9%	7.8%	12.4%	18.9%	22.8%
EV Management Assessment										
Ratio of EVs Affected			/	/	/	9%	12%	16%	21%	24%
Avg. EV Charging Delay (hrs)			/	/	/	3.4	5.3	5.3	5.5	5.5

Table 9. Sub-Urban Network Impact Metrics Table (With DOEs)

Overview

Sub-Urban Feeder (WBE013, Werribee) is a 22 kV sub-urban feeder from CitiPower, Powercor, and United Energy, consisting of 71 distribution transformers across a 33.14 km network. The feeder supplies 5,514 customers, with 96% residential and 4% C&I customers.

As shown in Table 9, the results of the electrification impact assessment (With DOEs) indicate that implementing DOEs effectively eliminates both voltage and thermal issues, helping to delay the need for network augmentation. However, due to a significant portion of demand being uncontrollable (i.e., Level-1 EV charging, electrified heating/cooling and hot water), the effectiveness of DOEs can be largely limited.

More detailed observations are provided below:

Voltage Assessment

This Sub-Urban network is relatively robust in terms of voltage quality, with voltage non-compliance remaining below 5% in the assessment without DOEs. Nonetheless, DOEs help further improve voltage quality.

- After DOEs are rolled out to PV and Level-2 EV customers (after 2038), customer voltage rise and drop non-compliance rates decrease by 0.7%–1.3% among 5,293 residential customers in this Sub-Urban network. Additionally, voltage non-compliance remains below 5%, complying with distribution network regulations.
- Notably, voltage drop non-compliance in LV networks (corresponding to 71 distribution transformers) decreases by 7%–18%, and no LV networks experience both voltage rise and drop issues. Thus, DOEs effectively improve voltage quality.

Thermal Assessment

Once DOEs are implemented (i.e. from 2028), fewer distribution transformers will experience overloading, helping to delay network augmentation. The length of overloaded MV conductors decreases, and LV conductors remain within their thermal ratings throughout the analysis period.

- From 2033 to 2053, the number of overloaded distribution transformers decreases by 1%–4% (among 71 transformers in this sub-urban network).
- Between 2038 and 2053, the severity of overloading is significantly reduced, with 3%–10% fewer transformers exceeding 150% loading compared to the assessment without DOEs.
- Overloading of MV conductors persists beyond 2048; however, compared to the assessment without DOEs, the overloading length is slightly reduced by 0.1 km–1.6 km (out of 33.14 km) in 2048 and 2053.

PV Curtailment Assessment

In this Sub-Urban network, total PV curtailment decreases With DOE implementation throughout the analysis period. This is because upgraded PV inverter sizes (from 5 kVA to 10 kVA) unlock more PV potential. However, due to the "Equal Allocation" strategy adopted in this study (i.e., all flexible customers are given the same export limit during the corresponding time interval), aggregate PV generation is not maximized. Alternative allocation strategies could further enhance PV generation.

- All PV customers experience some degree of curtailment, with the most affected facing up to 13% PV curtailment in 2028. This figure rises to 36% by 2033, which is higher than the 17% observed in the assessment without DOEs.
- With DOE implementation from 2023, aggregate PV curtailment in this Sub-Urban network decreases by 0.6%–6.8%. Notably, this is the one of the two networks (the other is long-rural network) that consistently experiences a reduction in PV curtailment. This is because the network has robust voltage quality, preventing voltage constraints from the most affected customers under the "Equal Allocation" strategy from significantly impacting aggregate PV curtailment.

EV Management Assessment

When DOEs are applied to Level-2 EVs (starting in 2033), their impact on EV charging is a critical factor to assess. The analysis shows that EV charging delays remain under 6 hours on average throughout the analysis horizon. Moreover, these delays primarily occur at midnight, minimizing disruptions for EV users.

3) Short-Rural Network COO012

Short-Rural Network (With DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Houses with PV, EV and DOEs										
Houses with PV			0%	29%	37%	41%	43%	46%	49%	52%
Houses with PV + Export DOE			0%	0%	8%	20%	43%	46%	49%	52%
Houses with EV			0%	1%	14%	50%	87%	120%	149%	157%
Houses with EV + Import DOE (Level-2 EV)			0%	0%	0%	7%	16%	28%	43%	55%
Overview										
Maximum Absolute Power Flow (MVA) [1]			3.5	3.0	3.4	3.8	4.3	4.6	5.0	5.3
Increase of Maximum Absolute Power Flow			/	/	11%	14%	12%	10%	8%	6%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			3%	1%	4%	9%	14%	14%	14%	20%
Voltage Drop Non-Compliance Rate			1%	3%	8%	9%	12%	15%	21%	25%
Maximum Customer Voltage (V) [2]			254	258	T	T	T	T	T	T
Minimum Customer Voltage (V)			214	206	190	188	189	182	180	175
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		1%	1%	3%	4%	5%	5%	7%	7%
	Ratio of LV Networks with Voltage Drop Issues		2%	3%	5%	6%	10%	12%	21%	25%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		1%	1%	3%	4%	4%	5%	6%	6%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	Max. Utilisation of the Worst Performing MV Segment		64%	57%	61%	70%	80%	89%	97%	100%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	99%	98%	98%	97%	95%	91%	89%
		of 100-110%	0%	0%	1%	0%	0%	2%	3%	3%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	0.5	0.0	0.0	0.7	0.6	0.9
		of 110%-150%	0%	1%	1%	2%	3%	3%	5%	5%
		Avg. Overloading Duration (hr) [3]	0.0	0.5	1.5	1.7	2.1	1.1	1.6	1.7
		of >150%	0%	0%	1%	1%	1%	1%	1%	2%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	1.5	1.5	1.5	1.5	1.8	1.3
	Max. Utilisation of the Worst Performing Transformer		75%	114%	170%	202%	205%	193%	210%	210%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		33%	36%	40%	51%	62%	67%	78%	81%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	5.9	40.7	51.8	57.1	60.2	64.1	66.9
	Ratio of Max. PV Curtailment		/	12%	81%	97%	100%	99%	99%	98%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	160	252	519	1107	1378	1622	1959
	Ratio of PV Curtailment		/	6.1%	7.3%	13.1%	24.8%	27.3%	28.3%	30.9%
EV Management Assessment										
Ratio of EVs Affected			/	/	/	8%	12%	16%	20%	23%
Avg. EV Charging Delay (hrs)			/	/	/	3.1	4.4	4.2	4.0	4.0

Table 10. Short-Rural Network Impact Metrics Table (With DOEs)

Overview

Short-Rural Feeder (COO12, Coolaroo) is a 22 kV feeder provided by Jemena, spanning 93.1 km with 187 distribution transformers. The COO12 feeder supports 724 customers, with a breakdown of 89.5% residential and 10.5% C&I customers.

As shown in Table 10, the results of the electrification impact assessment (With DOEs) indicate that implementing DOEs effectively eliminates both voltage and thermal issues, helping to delay the need for network augmentation. However, due to a significant portion of demand being uncontrollable (i.e., Level-1 EV charging, electrified heating/cooling and hot water), the effectiveness of DOEs can be largely limited.

More detailed observations are provided below:

Voltage Assessment

With DOE implementation, customer voltage non-compliance rates decrease slightly. However, this reduction may not be sufficient to meet distribution network regulations, which require non-compliance to remain below 5%.

- As DOEs are gradually rolled out to PV and Level-2 EV customers (from 2028 to 2038), customer voltage rise and drop non-compliance rates decrease by 2%-4% (among 648 residential customers in this short-rural network). However, the non-compliance rate remains above 5% beyond 2028, necessitating additional DER management strategies.
- Notably, voltage rise non-compliance in LV networks (corresponding to 187 distribution transformers) remains below 5% until 2043, compared to 2033 in the assessment without DOEs.

Thermal Assessment

Once DOEs are implemented (i.e., 2028), fewer distribution transformers will experience overloading, helping to delay network augmentation. The length of overloaded MV conductors decreases, and LV conductors remain within their thermal ratings throughout the analysis period.

- More specifically, in 2038 and 2043, the number of overloaded distribution transformers decreases by 2% (4 out of 187).
- In 2048 and 2053, the number of overloaded distribution transformers decreases by 4%. Additionally, the severity of overloading is significantly reduced, with 3% fewer transformers exceeding 150% loading.
- Overloading of MV conductors persists in 2053. However, compared to the assessment without DOEs, the overloading length is reduced by 2 km (out of 93.1 km).

PV Curtailment Assessment

At the initial stage of DOE implementation (i.e., 2028), total PV curtailment decreases. However, over time, curtailment increases and surpasses the amount observed in the assessment without DOEs.

This occurs because DOEs impose additional constraints on existing PV inverter functions (i.e., Volt-Watt and Volt-Var). Furthermore, due to the "Equal Allocation" strategy adopted in this study (i.e., all flexible customers are given the same export limit during the corresponding time interval), aggregate PV generation is not maximized.

- All PV customers experience some degree of curtailment, with the most affected facing up to 12% PV curtailment in 2028. This figure rises to 97% by 2033, which is 20% higher than in the assessment without DOEs.
- In 2028, aggregate PV curtailment is 7.3%, which is less compared to 8.9% without DOEs. This reduction occurs because a small fraction of PV systems begins adopting DOEs, and their inverters are upgraded to 10 kVA, unlocking greater PV potential.
- However, as DOE adoption increases, the limitations of the "Equal Allocation" strategy become evident. Since DOE values are constrained by the customer with the most severe voltage issues, this negatively impacts all customers within the same LV network. Consequently, PV curtailment is 3%-10% higher than in the assessment without DOEs.

EV Management Assessment

When DOEs are applied to Level-2 EVs (starting in 2033), their impact on EV charging is a critical factor to assess. The analysis shows that EV charging delays remain under 5 hours on average throughout the analysis horizon. Moreover, these delays primarily occur at midnight, minimizing disruptions for EV users.

4) Long-Rural Network BAS033

Long-Rural Network (With DOEs)										
Year			Base Demand (No DER)	2023	2028	2033	2038	2043	2048	2053
Houses with PV, EV and DOEs										
Houses with PV			0%	29%	37%	41%	43%	46%	49%	52%
Houses with PV + Export DOE			0%	0%	8%	20%	43%	46%	49%	52%
Houses with EV			0%	1%	14%	50%	87%	120%	149%	157%
Houses with EV + Import DOE (Level-2 EV)			0%	0%	0%	7%	16%	28%	43%	55%
Overview										
Maximum Absolute Power Flow (MVA) [1]			16.9	14.9	17.0	20.0	22.9	25.7	28.4	30.2
Increase of Maximum Absolute Power Flow			/	/	14%	18%	14%	12%	11%	6%
Voltage Assessment										
Voltage Rise Non-Compliance Rate			0%	0%	0%	0%	0%	0.2%	0.2%	19%
Voltage Drop Non-Compliance Rate			0.2%	0%	0%	0.1%	0.4%	1%	2%	22%
Maximum Customer Voltage (V) [2]			250	245	247	247	250	255	256	256
Minimum Customer Voltage (V)			215	221	218	213	210	209	201	197
LV Network Voltages	Ratio of LV Networks with Voltage Rise Issues		0%	0%	0%	0%	0%	0.1%	0.2%	14%
	Ratio of LV Networks with Voltage Drop Issues		0.3%	0%	0%	0.2%	1%	2%	3%	22%
	Ratio of LV Networks with Both Voltage Rise&Drop Issues		0%	0%	0%	0%	0%	0%	0%	11%
Thermal Assessment										
MV Feeder	Overloaded Conductor Length (km)		0.0	0.0	0.0	0.04	6.6	9.2	12.9	18.9
	Max. Utilisation of the Worst Performing MV Segment		81%	71%	81%	101%	123%	151%	170%	186%
Distribution Transformer	Ratio of Transformer with Max. Utilisation	of <=100%	100%	97%	91%	86%	79%	74%	68%	66%
		of 100-110%	0%	2%	1%	3%	3%	4%	5%	5%
		Avg. Overloading Duration (hr) [3]	1.0	0.8	0.8	0.8	0.7	0.8	0.9	0.8
		of 110%-150%	0%	1%	6%	6%	9%	11%	12%	13%
		Avg. Overloading Duration (hr) [3]	0.5	1.6	1.5	1.5	1.3	1.6	1.7	1.8
		of >150%	0%	0%	1%	5%	8%	12%	15%	17%
		Avg. Overloading Duration (hr) [3]	0.0	0.0	1.3	1.6	2.4	2.6	3.3	3.5
	Max. Utilisation of the Worst Performing Transformer		115%	146%	196%	277%	264%	291%	340%	367%
LV Circuit	Ratio of LV Circuits with Max. Utilisation	of <=100%	100%	100%	100%	100%	100%	100%	100%	100%
		of 100-110%	0%	0%	0%	0%	0%	0%	0%	0%
		of 110%-150%	0%	0%	0%	0%	0%	0%	0%	0%
		of >150%	0%	0%	0%	0%	0%	0%	0%	0%
	Max. Utilisation of the Worst Performing LV Circuit		24%	23%	32%	42%	51%	61%	64%	71%
PV Curtailment Assessment										
Per Customer	Max. PV Curtailment (kWh)		/	4.1	32.9	53.0	51.2	60.7	63.6	66.9
	Ratio of Max. PV Curtailment		/	9%	71%	99%	99%	100%	98%	99%
Ratio of PV Customers Curtailed			/	100%	100%	100%	100%	100%	100%	100%
Aggregate Export [4]	PV Curtailment (MWh)		/	808	1321	1475	2483	3613	5366	6635
	Ratio of PV Curtailment		/	6.0%	7.5%	7.3%	10.9%	14.1%	18.4%	20.6%
EV Management Assessment										
Ratio of EVs Affected			/	/	/	8%	13%	16%	21%	24%
Avg. EV Charging Delay (hrs)			/	/	/	2.8	3.5	3.7	3.9	4.1

Table 11. Long-Rural Network Impact Metrics Table (With DOEs)

Overview

Long-Rural Feeder (BAS033, Ballarat South) is a 22 kV long-rural feeder acquired from CitiPower, Powercor, and United Energy, extending over 207.3 km and incorporating 877 distribution transformers. It serves 3,942 customers, with 84% residential and 16% C&I and agricultural customers.

As shown in Table 11, the results of the electrification impact assessment (With DOEs) indicate that implementing DOEs effectively eliminates both voltage and thermal issues, helping to delay the need for network augmentation. However, due to a significant portion of demand being uncontrollable (i.e., Level-1 EV charging, electrified heating/cooling and hot water), the effectiveness of DOEs can be largely limited.

More detailed observations are provided below:

Voltage Assessment

Until 2048, this long-rural network remains relatively robust in terms of voltage quality, with voltage non-compliance staying below 5% in the assessment without DOEs. However, by 2053, the voltage non-compliance rate increases dramatically, and DOEs provide only a slight improvement in mitigating voltage issues.

- After DOEs are rolled out to PV and Level-2 EV customers (after 2038), despite customer voltage rise and drop non-compliance rates decrease by 0.8%–4.8% among 3,311 residential customers in this long-rural network.
- By 2048, voltage non-compliance remains below 5% until 2048, complying with distribution network regulations. However, in 2053, the non-compliance rate rises sharply (i.e., both voltage rise and drop non-compliance exceed 20%), and DOEs only slightly mitigate the issue (by 2%), failing to bring it within regulatory limits.

Thermal Assessment

Once DOEs are implemented (i.e. from 2028), fewer distribution transformers will experience overloading, helping to delay network augmentation. The length of overloaded MV conductors decreases, and LV conductors remain within their thermal ratings throughout the analysis period.

- From 2033 to 2053, the number of overloaded distribution transformers decreases by 3%–7% (among 877 transformers in this long-rural network).
- Between 2038 and 2053, the severity of overloading is significantly reduced, with 1%–5% fewer transformers exceeding 150% loading compared to the assessment without DOEs.
- Overloading of MV conductors persists beyond 2033. However, compared to the assessment without DOEs, the overloading length is slightly reduced by 0.1 km–4.8 km (out of 207.3 km) within 2033-2053.

PV Curtailment Assessment

In this long-rural network, total PV curtailment decreases With DOE implementation throughout the analysis period. This is because upgraded PV inverter sizes (from 5 kVA to 10 kVA) unlock more PV potential. However, due to the "Equal Allocation" strategy adopted in this study (i.e., all flexible customers are given the same export limit during the corresponding time interval), aggregate PV generation is not maximized. Alternative allocation strategies could further enhance PV generation.

- All PV customers experience some degree of curtailment, with the most affected facing up to 71% PV curtailment in 2028, which is higher than the 12% observed in the assessment without DOEs. This figure rises to 99% by 2033, which is higher than the 15% observed in the assessment without DOEs.
- With DOE implementation from 2023, aggregate PV curtailment in this Sub-Urban network decreases by 1.4%–3.7%. Notably, this is the one of the two networks (the other is sub-urban network) that consistently experiences a reduction in PV curtailment. This is because the network has robust voltage quality, preventing voltage constraints from the most affected customers under the "Equal Allocation" strategy from significantly impacting aggregate PV curtailment.

EV Management Assessment

When DOEs are applied to Level-2 EVs (starting in 2033), their impact on EV charging is a critical factor to assess. The analysis shows that EV charging delays remain under 4 hours on average throughout the analysis horizon. Moreover, these delays primarily occur at midnight, minimizing disruptions for EV users.

5. Key Findings

Based on DER scenarios developed by C4NET in collaboration with participating DNSPs, and assuming no population growth or network upgrades (e.g., network augmentation), the key findings from the electrification impact assessment in MV-LV distribution networks are as follows for both the "Without DOEs" and "With DOEs" cases:

a. Key Findings (Without DOEs)

Voltage Assessment

1. In the next decade, PV penetration will keep growing steadily and voltage issues can emerge as a limiting factor for further PV uptake, typically for those networks less robust in voltage quality (i.e., urban network and short-rural network).
2. From 2033, the PV uptake slows down and net demand rises significantly due to the presence of increasing EV adoption and gas electrification, which further exacerbate voltage issues.
3. Since the voltage regulation devices in this study are operated to ensure equal voltage headroom and footroom, more voltage drop issues have emerged as a result of managing PV-related voltage rise issues. This indicates that voltage regulation devices (i.e., tap positions) have been exhausted to maintain customer voltages within both upper and lower limits.

Thermal Assessment

4. Due to the presence of increasing EV adoption and gas electrification, most networks (i.e., urban, sub-urban and long rural) observe a dramatic increase (up to 30%) in overloading distribution transformers from 2028 to 2033. And if network augmentation is not incorporated, more distribution transformers will be affected, and which could severely limit further DER uptake.
5. MV conductors may become constrained in the next few decades, earlier and more severe for those longer feeders (from 2033 for the long-rural feeder). Without network augmentation, more MV conductor will get overloaded and with higher utilisation level.
6. LV conductors generally remain within their thermal limits (only 1%-2% overloaded in the urban network). However, a modern design of LV conductors (i.e., featuring lower impedance and higher ampacity) is adopted in the MV-LV network model provided by WP1.4. This modelling choice may significantly underestimate LV conductor utilisation.

PV Curtailment

7. Given the high PV penetration across all the networks assessed, PV curtailment can be significant for some PV customers (up to 80% daily curtailment for the worst-case scenario) due to network-wide voltage rise issues

8. In the simulations, residential PV systems are assumed to be equipped with 5 kVA inverters (resulting in maximum exports of 5kW, aligned with limits used by DNSPs), which can limit their export opportunities, thereby reducing aggregate PV export across the MV-LV network.

b. Key Findings (With DOEs)

Network Performance

1. Export DOEs effectively mitigate voltage rise issues caused by PV export once applied to all residential PV customers (by 2038). However, since PV inverters functions (i.e., Volt-Watt and Volt-Var) already enforce PV curtailment to help regulate voltages in the simulation Without DOEs, the additional benefits of export DOEs may be limited.
2. Since import DOEs are applied only to Level-2 EV charging, only a small fraction of the demand is managed (up to 30%). Over time, the demand from gas electrification (i.e., heating/cooling and hot water systems) becomes significant, resulting in more voltage drops and heavy asset utilisation. Consequently, managing Level-2 EV demand alone is insufficient to resolve both voltage and thermal I issues.

PV Curtailment

3. At the initial stage of export DOE implementation (i.e., 2028), total PV curtailment decreases across all assessed networks. This reduction occurs because only new PV customers begin adopting DOEs, and their inverters are upgraded to 10 kVA, unlocking greater PV potential.
4. When export DOEs are applied to more PV customers (i.e., from 2033), the impacts on PV curtailment vary among networks:
    a. In networks with severe voltage issues (i.e., urban and short-rural networks), total PV curtailment increases (by up to 24%) compared to the assessment without DOEs.
    b. In networks with better voltage quality (i.e., sub-urban and long-rural networks), total PV curtailment remains consistently lower (by up to 7%) than in the assessment without DOEs.

    This occurs due to the "Equal Allocation" strategy adopted in the DOE calculation (i.e., all flexible customers are given the same export limit during each time interval). By using this strategy, DOE values are constrained by the customer experiencing the most severe voltage issues (i.e., at end of the LV feeder), which negatively impacts all customers within the same LV network. As a result, in those networks with more significant voltage issues, total PV export can be greatly constrained.

EV Management

5. Among all the networks assessed, import DOEs will not cause EV charging delays exceeding an average of 6 hours. Furthermore, these delays will primarily occur at midnight, which is expected to cause minimal or no disruptions for EV users.

c. Key Findings (Considering Network Type)

The simulation results for the "Without DOEs" case indicate that the four assessed MV-LV networks (i.e., urban, sub-urban, short-rural, and long-rural) may experience the following technical issues during the analysis period (if no network augmentation or reconfiguration is implemented):

1. **Customer Voltage:** The urban and short-rural networks experience minor customer voltage issues from 2023, escalating to moderate by 2028 and severe after 2033. In contrast, the sub-urban and long-rural networks exhibit robust voltage quality, with minor voltage issues emerging in 2033 and 2028, respectively, and worsening gradually thereafter.
2. **MV Conductor:** Minor overloading of MV conductors occurs from 2033 in the long-rural network, 2038 in the urban network, 2048 in the sub-urban network, and 2053 in the short-rural network. Throughout the whole assessment period, overloaded conductors constitute no more than 10% of the total feeder length in any network.
3. **Distribution Transformer:** Minor overloading of several distribution transformers arises in 2023 for the short-rural and long-rural networks and in 2028 for the urban and sub-urban networks. This issue escalates significantly in the urban, sub-urban, and long-rural networks, affecting up to 50% of distribution transformers, whereas the impact remains less severe in the short-rural network (no more than 15% affected).
4. **LV Conductor:** LV conductors remain within their thermal ratings for most networks due to the modern design adopted. However, the urban network experiences very minor overloading in a small fraction of LV conductors after 2048. In reality, the utilisation of LV conductors is expected to be much higher with their actual conductor size.
5. **PV Curtailment:** Considerable aggregate PV curtailment occurs across all networks after 2028 and continues to increase over time.

With DOE implementation, the following key observations can be concluded:

1. **Customer Voltage:** Customer voltage issues are slightly reduced (up to 7%) across all networks. However, for the urban and short-rural networks, where voltage issues are more severe, this reduction may not be sufficient to meet the Australian standard for voltage non-compliance rate (i.e., <5%).
2. **MV Conductor:** Overloading of MV conductors persists in all networks, but the length of the overloaded segments decreases slightly.
3. **Distribution Transformer:** The number of overloaded distribution transformers is reduced slightly (up to 7%) across all networks, and the severity of overloading is significantly mitigated, thereby delaying the need for network augmentation.
4. **LV Conductor:** LV conductors remain within thermal limits for all networks throughout the analysis period.
5. **PV Curtailment:** In the urban and short-rural networks, total PV curtailment initially decreases in 2028 following DOE implementation. However, over time, the curtailment

surpasses the amount observed in the "Without DOEs" case. In contrast, the sub-urban and long-rural networks experience a continuous reduction in PV curtailment, as these two networks are more robust in voltage quality.

6. **EV Charging Delays:** EV charging delays remain under 6 hours on average for all networks, primarily occurring at midnight, thereby minimizing disruptions for EV users.

6. Recommendations

The following recommendations, based on the findings from the electrification impact assessment, are intended to help Victorian distribution companies in network planning beyond 2030.

a. General Recommendations

1. With high penetration of various DER technologies (i.e., PV, EVs, and gas electrification), both voltage rise and drop issues can emerge in MV-LV distribution networks. The results indicate that existing voltage regulation devices may soon be exhausted to maintain voltage within acceptable limits (from 2028). Therefore, it is recommended to:
   - **Upgrade voltage regulation devices** as soon as possible (e.g., expanding the tap range of OLTCs) to allow further DER uptake, particularly in networks more prone to voltage issues.
2. The surging demand from EV charging and gas electrification is expected to cause network-wide asset utilisation issues from 2028, primarily affecting distribution transformers. To prevent the escalation of asset overloading, it is recommended to
   - **Assess and evaluate asset utilisation** periodically (e.g., every five years) and **upgrade overloading assets** (i.e., transformers and conductors) as needed.
   - **Implement demand management strategies** (e.g., import DOEs, demand response) to mitigate excessive power flows.
3. The PV curtailment is found to be significant throughout the analysis period (up to 24% in 2053 when DOEs are not implemented). To unlock the full potential of PV generation, it is recommended to:
   - **Improve network voltage quality**, thereby reducing PV curtailment caused by the Volt-Watt function.
   - **Allow slightly larger export limits (greater than 5 kVA)**, providing more incentives for people to install larger PV inverters.

b. DOE Recommendations

1. **The adoption of DOEs is certainly recommended** to mitigate the impacts from the growing uptake of DERs (i.e., PV, EV and gas electrification). Since rooftop PV installations will plateau in the next few years, **focus should be given to import DOEs** as the new demand from the electrification of households will become the main challenge.
2. **Export DOEs** should continue be implemented **alongside existing PV inverter functions** (i.e., Volt-Watt and Volt-Var) to further alleviate network issues.
3. **Alternative DOE calculation strategies** (e.g., maximum services) that yield more PV generation for a community (i.e., a distribution transformer) should be explored while ensuring certain levels of fairness among solar PV customers.

7. Appendix

Appendix 1: Synthetic LV Network Assessment Results

Value in red are greater than 253V and less than 216V

Value in red bold are greater than 263V and less than 206V

Site	No. Customers		Scenario	Customer Voltages (V)						Furthest 3-Phase Voltage (V)						Line Util HoF						Total Losses (kW)	
				Real			Synthetic			Real			Synthetic			Real			Synthetic				
	Residential	Commercial		Min	Max	Avg	Min	Max	Avg	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C	Real	Synthetic
9	0	24	**No Res load**	-	-	-	-	-	-	-	-	-	-	-	-	121%	121%	121%	-	-	-	16.301	7.537
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1	0	**Peak Load** 4.4kW	227.2	227.2	227.2	228.4	228.4	228.4	227.2	238.3	238.0	228.4	238.5	238.3	6%	0%	0%	8%	0%	0%	0.194	0.169
			Medium Load 2.2kW	233.0	233.0	233.0	233.6	233.6	233.6	233.0	238.4	238.2	233.6	238.5	238.4	3%	0%	0%	4%	0%	0%	0.060	0.054
			No Load + 100% PV	247.3	247.3	247.3	246.1	246.1	246.1	247.3	238.8	238.7	246.1	238.4	238.5	6%	0%	0%	8%	0%	0%	0.202	0.180
10	1	9	**Peak Load** 4.4kW	232.2	232.2	232.2	233.3	233.3	233.3	232.2	232.4	232.4	233.3	234	233.8	73%	73%	73%	8%	0%	0%	7.290	4.710
			Medium Load 2.2kW	232.4	232.4	232.4	233.6	233.6	233.6	232.3	232.4	232.4	233.6	233.9	233.9	73%	73%	73%	4%	0%	0%	7.202	4.642
			No Load + 100% PV	233.1	233.1	233.1	234.6	234.6	234.6	232.6	232.4	232.4	234.6	233.9	234.0	73%	73%	73%	9%	0%	0%	6.954	4.469
6	2	14	**Peak Load** 4.4kW	226.6	226.9	226.8	232.2	232.2	232.2	226.4	226.5	227.6	232.3	232.2	233.1	72%	72%	64%	8%	8%	0%	7.487	6.141
			Medium Load 2.2kW	227.5	227.9	227.7	232.5	232.5	232.5	227.1	227.1	227.7	232.6	232.5	233.0	68%	68%	64%	4%	4%	0%	7.112	5.943
			No Load + 100% PV	229.8	230.6	230.2	233.5	233.6	233.6	228.9	228.8	227.9	233.5	233.5	232.7	56%	56%	64%	9%	9%	0%	6.156	5.406
3	2	14	**Peak Load** 4.4kW	228.1	228.3	228.2	231.0	231.1	231.1	225.3	225.2	225.9	231.2	231.0	231.9	76%	84%	76%	8%	8%	0%	10.090	6.140
			Medium Load 2.2kW	228.6	228.8	228.7	231.4	231.4	231.4	225.6	225.5	225.8	231.5	231.4	231.9	76%	80%	76%	4%	4%	0%	9.778	5.943
			No Load + 100% PV	230	230.2	230.1	232.4	232.4	232.4	226.2	226.3	225.7	232.3	232.4	231.6	76%	84%	76%	9%	9%	0%	8.919	5.406
7	4	5	**Peak Load** 4.4kW	207.6	212.8	209.7	232.2	232.8	232.5	212.8	213.8	212.8	232.2	233.1	232.6	83%	81%	81%	15%	8%	8%	51.271	11.599
			Medium Load 2.2kW	209.6	213.6	211.0	232.7	233.0	232.8	213.6	214.1	213.6	232.7	233.1	232.9	81%	80%	80%	8%	4%	4%	49.144	11.299
			No Load + 100% PV	212.7	215.8	214.6	233.5	234.0	233.8	215.7	214.9	215.8	234.0	233.2	233.7	73%	76%	76%	17%	9%	9%	43.310	10.504
2	6	0	**Peak Load** 4.4kW	234.3	234.5	234.4	233.7	234.4	234	234.4	234.5	234.4	234.7	233.8	233.7	5%	5%	5%	15%	15%	15%	0.459	0.486
			Medium Load 2.2kW	236.4	236.5	236.4	236.1	236.4	236.3	236.4	236.5	236.4	236.6	236.2	236.1	2%	3%	2%	7%	7%	7%	0.180	0.187
			No Load + 100% PV	241.8	241.9	241.9	241.8	242.4	242.1	241.9	241.8	241.9	241.5	242.3	242.3	5%	6%	5%	16%	16%	16%	0.520	0.549
1	22	2	**Peak Load** 4.4kW	**187.5**	217.7	**198.7**	214.3	220.1	216.4	**187.5**	**192.1**	**194.2**	214.8	214.6	214.3	54%	48%	48%	49%	49%	49%	18.562	8.815
			Medium Load 2.2kW	211.8	227.3	217.5	225.4	228.1	226.4	211.8	214.3	215.4	225.7	225.5	225.4	30%	27%	27%	23%	23%	23%	5.459	2.746
			No Load + 100% PV	245.7	**263.2**	255.9	245.6	250	248.1	**263.2**	260.7	258.7	248.9	249.9	249.4	33%	33%	34%	47%	47%	47%	7.469	4.427
8	44	15	**Peak Load** 4.4kW	214.6	231.1	221.1	226.1	231.4	228.7	216.6	216.2	215.2	228.6	226.2	226.3	139%	131%	148%	46%	46%	46%	21.480	10.499
			Medium Load 2.2kW	224	233.8	227.9	231.4	234	232.7	225.1	224.9	224.5	232.6	231.5	231.5	100%	96%	104%	23%	23%	23%	9.475	4.756
			No Load + 100% PV	240.5	249	245.4	240.4	244.9	242.5	247.5	248.1	248.6	242.4	244.8	244.1	65%	57%	72%	49%	48%	48%	6.022	3.542
4	131	2	**Peak Load** 4.4kW	**200.8**	222.4	214.4	216.2	224.5	219.8	**201.2**	213.6	208.8	216.4	216.4	222.5	125%	107%	132%	56%	56%	47%	55.546	39.989
			Medium Load 2.2kW	221.0	230.7	226.9	227.7	231.5	229.4	221.1	226.4	224.4	227.8	227.8	230.5	60%	56%	68%	27%	27%	23%	13.360	10.086
			No Load + 100% PV	248.4	**264.7**	255.0	247.6	254.1	251.0	**264.4**	256.9	260.1	253.9	253.2	249.7	118%	103%	109%	54%	55%	47%	44.089	34.337

Appendix 1: Synthetic LV Network Assessment Results (Continued)

Site	No. Customers		Scenario	Customer Voltages						Furthest 3-Phase Voltage						Line Util HoF1			Total Losses	
	Residential	Commercial		Δ (V)			Δ (%)			Δ (V)			Δ (%)			Δ (%)			Δ (kW)	Δ (%)
				Min	Max	Avg	Min	Max	Avg	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C		
9	0	24	No Res load	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.8	-54%
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1	0	**Peak Load** 4.4kW	1.3	1.3	1.3	1%	1%	1%	1.3	0.3	0.3	1%	0%	0%	2%	0%	0%	0.0	-13%
			Medium Load 2.2kW	0.6	0.6	0.6	0%	0%	0%	0.6	0.1	0.2	0%	0%	0%	1%	0%	0%	0.0	-9%
			No Load + 100% PV	-1.1	-1.1	-1.1	0%	0%	0%	-1.1	-0.4	-0.2	0%	0%	0%	2%	0%	0%	0.0	-11%
10	1	9	**Peak Load** 4.4kW	1.0	1.0	1.0	0%	0%	0%	1.1	1.6	1.4	0%	1%	1%	-65%	-73%	-73%	-2.6	-35%
			Medium Load 2.2kW	1.2	1.2	1.2	0%	0%	0%	1.3	1.6	1.5	1%	1%	1%	-69%	-73%	-73%	-2.6	-36%
			No Load + 100% PV	1.5	1.5	1.5	1%	1%	1%	2.0	1.5	1.7	1%	1%	1%	-64%	-73%	-73%	-2.5	-36%
6	2	14	**Peak Load** 4.4kW	5.5	5.3	5.4	2%	2%	2%	5.9	5.6	5.4	3%	2%	2%	-65%	-65%	-64%	-1.3	-18%
			Medium Load 2.2kW	5.1	4.7	4.9	2%	2%	2%	5.5	5.4	5.3	2%	2%	2%	-64%	-64%	-64%	-1.2	-16%
			No Load + 100% PV	3.7	3.0	3.3	2%	1%	1%	4.5	4.7	4.9	2%	2%	2%	-47%	-47%	-64%	-0.8	-12%
3	2	14	**Peak Load** 4.4kW	2.9	2.8	2.8	1%	1%	1%	5.8	5.9	6.1	3%	3%	3%	-69%	-76%	-76%	-3.9	-39%
			Medium Load 2.2kW	2.8	2.6	2.7	1%	1%	1%	5.9	5.9	6.0	3%	3%	3%	-73%	-76%	-76%	-3.8	-39%
			No Load + 100% PV	2.5	2.2	2.3	1%	1%	1%	6.2	6.1	5.9	3%	3%	3%	-68%	-76%	-76%	-3.5	-39%
7	4	5	**Peak Load** 4.4kW	24.6	19.9	22.7	12%	9%	11%	19.4	19.3	19.8	9%	9%	9%	-68%	-73%	-73%	-39.7	-77%
			Medium Load 2.2kW	23.1	19.4	21.8	11%	9%	10%	19.1	19.1	19.3	9%	9%	9%	-73%	-76%	-76%	-37.8	-77%
			No Load + 100% PV	20.8	18.2	19.1	10%	8%	9%	18.3	18.2	17.9	8%	8%	8%	-57%	-67%	-67%	-32.8	-76%
2	6	0	**Peak Load** 4.4kW	-0.6	-0.1	-0.4	0%	0%	0%	0.3	-0.6	-0.7	0%	0%	0%	10%	10%	10%	0.0	6%
			Medium Load 2.2kW	-0.3	-0.1	-0.2	0%	0%	0%	0.1	-0.3	-0.3	0%	0%	0%	5%	5%	5%	0.0	4%
			No Load + 100% PV	0.1	0.5	0.2	0%	0%	0%	-0.4	0.6	0.4	0%	0%	0%	11%	10%	11%	0.0	6%
1	22	2	**Peak Load** 4.4kW	26.8	2.4	17.7	14%	1%	9%	27.3	22.5	20.1	15%	12%	10%	-5%	0%	0%	-9.7	-53%
			Medium Load 2.2kW	13.6	0.8	9.0	6%	0%	4%	13.9	11.2	10.1	7%	5%	5%	-7%	-4%	-3%	-2.7	-50%
			No Load + 100% PV	-0.1	-13.2	-7.8	0%	-5%	-3%	-14.3	-10.8	-9.3	-5%	-4%	-4%	14%	14%	14%	-3.0	-41%
8	44	15	**Peak Load** 4.4kW	11.5	0.3	7.6	5%	0%	3%	12.0	10.0	11.1	6%	5%	5%	-93%	-84%	-102%	-11.0	-51%
			Medium Load 2.2kW	7.4	0.2	4.8	3%	0%	2%	7.5	6.6	7.0	3%	3%	3%	-77%	-73%	-81%	-4.7	-50%
			No Load + 100% PV	-0.2	-4.2	-3.0	0%	-2%	-1%	-5.0	-3.3	-4.5	-2%	-1%	-2%	-16%	-9%	-24%	-2.5	-41%
4	131	2	**Peak Load** 4.4kW	15.3	2.1	5.4	8%	1%	3%	15.2	2.8	13.7	8%	1%	7%	-69%	-51%	-84%	-15.6	-28%
			Medium Load 2.2kW	6.7	0.9	2.4	3%	0%	1%	6.7	1.4	6.1	3%	1%	3%	-33%	-29%	-45%	-3.3	-25%
			No Load + 100% PV	-0.7	-10.6	-4.0	0%	-4%	-2%	-10.5	-3.7	-10.4	-4%	-1%	-4%	-64%	-48%	-62%	-9.8	-22%

Highest positive value (Over-estimation)

0

Lowest negative value (Under-estimation)

Appendix 1: Synthetic LV Network Assessment Results (Continued)

Table A-1. Statistics for Urban Network SBY32

Item	No. Dist Tx	Percentage
Without RES	8	17%
Range A	10	21%
Range B	5	10%
Range C	25	52%
Total	48	100%

Table A-2. Statistics for Suburban Network WBE013

Item	No. Dist Tx	Percentage
Without RES	20	28%
Range A	4	6%
Range B	3	4%
Range C	44	62%
Total	71	100%

Table A-3. Statistics for Short-Rural Network COO012

Item	No. Dist Tx	Percentage
Without RES	13	7%
Range A	161	86%
Range B	12	6%
Range C	1	1%
Total	187	100%

Table A-4. Statistic for Long-Rural Network BAS033

Item	No. Dist Tx	Percentage
Without RES	112	13%
Range A	709	81%
Range B	48	5%
Range C	8	1%
Total	877	100%

Appendix 2: Scenario Planning Data

2023

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
	low-density	63.43%	73.92%	0.68%	8.10%	46.55%	44.67%	52.93%	27.08%	6.66%	13.33%	6.20	30.60%		5.10	11.00	1.78%		1.07%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
Urban	medium-density	22.38%	26.08%	9.64%	43.13%	36.77%	10.46%	42.81%	14.96%	14.63%	27.61%	4.00	15.00%	26.53%	5.10	11.00	1.10%	1.60%	1.03%	80.00%	15.00%	5.00%	1.06%	68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
	high-density	14.19%	0.00%	32.74%	56.86%	9.63%	0.77%	/	/	/	/	1.00	0.50%		5.10	11.00	-		0.72%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
	low-density	80.93%	83.22%	0.74%	7.96%	44.32%	46.99%	46.30%	23.40%	9.32%	20.98%	6.20	30.60%		5.10	11.00	1.48%		1.07%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
Semi-Urban	medium-density	16.31%	16.78%	8.30%	45.37%	36.87%	9.46%	42.81%	14.96%	14.63%	27.61%	4.00	15.00%	27.98%	5.10	11.00	1.10%	1.41%	1.03%	80.00%	15.00%	5.00%	1.07%	68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
	high-density	2.76%	0.00%	36.18%	56.47%	6.02%	1.33%	/	/	/	/	1.00	0.50%		5.10	11.00	-		0.72%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
	low-density	91.57%	92.14%	1.55%	11.69%	49.59%	37.18%	55.15%	24.01%	6.28%	14.56%	6.20	30.60%		5.10	11.00	1.41%		1.07%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
Rural	medium-density	7.81%	7.86%	17.91%	57.31%	22.12%	2.66%	42.81%	14.96%	14.63%	27.61%	4.00	15.00%	29.37%	5.10	11.00	1.10%	1.38%	1.03%	80.00%	15.00%	5.00%	1.07%	68.00%	10.00%	20.00%	2.00%	50.00%	30.00%
	high-density	0.62%	0.00%	45.24%	33.40%	14.12%	7.25%	/	/	/	/	1.00	0.50%		5.10	11.00	-		0.72%	80.00%	15.00%	5.00%		68.00%	10.00%	20.00%	2.00%	50.00%	30.00%

2028

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
	low-density	61.91%	73.39%	0.65%	7.56%	44.31%	47.47%	46.51%	23.79%	6.31%	23.39%	6.60	38.59%		5.51	12.14	8.58%		14.00%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
Urban	medium-density	22.45%	26.61%	9.03%	41.66%	37.82%	11.49%	36.60%	12.79%	13.48%	37.13%	4.26	17.60%	33.01%	5.51	12.14	5.18%	7.67%	13.36%	72.50%	20.00%	7.50%	13.83%	56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
	high-density	15.65%	0.00%	32.71%	57.08%	9.50%	0.71%	/	/	/	/	1.06	0.59%		5.51	12.14	-		9.35%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
	low-density	80.21%	82.69%	0.70%	7.42%	41.92%	49.96%	39.28%	19.85%	8.52%	32.35%	6.60	38.59%		5.51	12.14	6.99%		14.00%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
Semi-Urban	medium-density	16.79%	17.31%	7.50%	44.29%	38.06%	10.15%	34.97%	12.22%	12.88%	39.93%	4.26	17.60%	34.96%	5.51	12.14	5.18%	6.67%	13.36%	72.50%	20.00%	7.50%	13.89%	56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
	high-density	3.00%	0.00%	36.05%	57.40%	5.52%	1.03%	/	/	/	/	1.06	0.59%		5.51	12.14	-		9.35%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
	low-density	91.91%	92.28%	1.55%	11.38%	47.89%	39.18%	48.02%	20.91%	5.89%	25.18%	6.60	38.59%		5.51	12.14	0.07		14.00%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
Rural	medium-density	7.69%	7.72%	17.46%	56.57%	23.35%	2.63%	38.00%	13.28%	14.00%	34.73%	4.26	17.60%	36.97%	5.51	12.14	0.05	6.50%	13.36%	72.50%	20.00%	7.50%	13.95%	56.67%	8.33%	16.67%	18.33%	58.33%	41.67%
	high-density	0.40%	0.00%	46.66%	35.21%	10.96%	7.17%	/	/	/	/	1.06	0.59%		5.51	12.14	-		9.35%	72.50%	20.00%	7.50%		56.67%	8.33%	16.67%	18.33%	58.33%	41.67%

2033

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
	low-density	60.59%	72.92%	0.64%	7.08%	42.30%	49.98%	40.98%	20.96%	6.00%	32.07%	7.02	42.48%		6.44	13.41	17.05%		50.66%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
Urban	medium-density	22.50%	27.08%	8.52%	40.40%	38.71%	12.36%	31.48%	11.00%	12.51%	45.01%	4.53	19.67%	36.31%	6.44	13.41	10.08%	15.16%	48.17%	65.00%	25.00%	10.00%	49.99%	45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
	high-density	16.90%	0.00%	32.70%	57.21%	9.43%	0.67%	/	/	/	/	1.13	0.65%		6.44	13.41	-		33.72%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
	low-density	79.61%	82.25%	0.66%	6.96%	39.92%	52.46%	33.56%	16.96%	7.85%	41.63%	7.02	42.48%		6.44	13.41	13.65%		50.66%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
Semi-Urban	medium-density	17.18%	17.75%	6.87%	43.43%	39.00%	10.70%	28.97%	10.12%	11.51%	49.39%	4.53	19.67%	38.43%	6.44	13.41	10.08%	13.01%	48.17%	65.00%	25.00%	10.00%	50.22%	45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
	high-density	3.21%	0.00%	35.97%	58.00%	5.19%	0.84%	/	/	/	/	1.13	0.65%		6.44	13.41	-		33.72%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
	low-density	92.14%	92.40%	1.56%	11.11%	46.39%	40.95%	41.97%	18.27%	5.56%	34.20%	7.02	42.48%		6.44	13.41	0.13		50.66%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
Rural	medium-density	7.58%	7.60%	17.02%	55.87%	24.51%	2.60%	33.79%	11.81%	13.43%	40.98%	4.53	19.67%	40.75%	6.44	13.41	0.10	12.63%	48.17%	65.00%	25.00%	10.00%	50.47%	45.33%	6.67%	13.33%	34.67%	66.67%	53.33%
	high-density	0.28%	0.00%	48.38%	37.42%	7.10%	7.10%	/	/	/	/	1.13	0.65%		6.44	13.41	-		33.72%	65.00%	25.00%	10.00%		45.33%	6.67%	13.33%	34.67%	66.67%	53.33%

2038

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
	low-density	59.41%	72.44%	0.62%	6.65%	40.49%	52.25%	36.19%	18.51%	5.71%	39.59%	7.47	45.21%		7.20	14.80	25.43%		87.73%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
Urban	medium-density	22.60%	27.56%	8.07%	39.32%	39.48%	13.12%	27.14%	9.48%	11.63%	51.75%	4.82	21.72%	38.73%	7.20	14.80	14.75%	22.49%	83.09%	57.50%	30.00%	12.50%	86.45%	34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
	high-density	17.99%	0.00%	32.69%	57.29%	9.37%	0.64%	/	/	/	/	1.20	0.72%		7.20	14.80	-		58.16%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
	low-density	79.09%	81.87%	0.63%	6.57%	38.20%	54.59%	28.85%	14.58%	7.28%	49.28%	7.47	45.21%		7.20	14.80	20.05%		87.73%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
Semi-Urban	medium-density	17.51%	18.13%	6.36%	42.74%	39.76%	11.14%	24.28%	8.48%	10.41%	56.83%	4.82	21.72%	40.95%	7.20	14.80	14.75%	19.09%	83.09%	57.50%	30.00%	12.50%	86.88%	34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
	high-density	3.40%	0.00%	35.91%	58.41%	4.97%	0.70%	/	/	/	/	1.20	0.72%		7.20	14.80	-		58.16%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
	low-density	92.29%	92.51%	1.56%	10.86%	45.05%	42.52%	36.80%	16.02%	5.25%	41.92%	7.47	45.21%		7.20	14.80	0.19		87.73%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
Rural	medium-density	7.47%	7.49%	16.61%	55.19%	25.62%	2.58%	30.09%	10.52%	12.90%	46.49%	4.82	21.72%	43.45%	7.20	14.80	0.15	18.49%	83.09%	57.50%	30.00%	12.50%	87.38%	34.00%	5.00%	10.00%	51.00%	75.00%	65.00%
	high-density	0.24%	0.00%	50.52%	40.16%	2.34%	6.98%	/	/	/	/	1.20	0.72%		7.20	14.80	-		58.16%	57.50%	30.00%	12.50%		34.00%	5.00%	10.00%	51.00%	75.00%	65.00%

Appendix 2: Scenario Planning Data (Continued)

2043

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
Urban	low-density	58.37%	72.00%	0.60%	6.25%	38.83%	54.31%	32.04%	16.39%	5.45%	46.13%	7.95	48.10%		8.21	16.35	29.64%		120.44%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	medium-density	22.69%	28.00%	7.69%	38.38%	40.15%	13.78%	23.51%	8.22%	10.87%	57.41%	5.13	23.98%	41.35%	8.21	16.35	16.91%	26.08%	113.69%	50.00%	35.00%	15.00%	118.55%	22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	high-density	18.94%	0.00%	32.68%	57.36%	9.34%	0.63%	/	/	/	/	1.28	0.79%		8.21	16.35	-		79.58%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
Semi-Urban	low-density	78.64%	81.55%	0.61%	6.24%	36.73%	56.43%	24.94%	12.60%	6.79%	55.67%	7.95	48.10%		8.21	16.35	23.05%		120.44%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	medium-density	17.80%	18.45%	5.94%	42.17%	40.38%	11.51%	20.54%	7.18%	9.49%	62.79%	5.13	23.98%	43.65%	8.21	16.35	16.91%	21.92%	113.69%	50.00%	35.00%	15.00%	119.19%	22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	high-density	3.56%	0.00%	35.88%	58.72%	4.80%	0.61%	/	/	/	/	1.28	0.79%		8.21	16.35	-		79.58%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
Rural	low-density	92.41%	92.61%	1.56%	10.65%	43.85%	43.94%	32.36%	14.09%	4.98%	48.56%	7.95	48.10%		8.21	16.35	0.22		120.44%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	medium-density	7.38%	7.39%	16.21%	54.55%	26.68%	2.56%	26.85%	9.38%	12.41%	51.36%	5.13	23.98%	46.32%	8.21	16.35	0.17	21.18%	113.69%	50.00%	35.00%	15.00%	119.94%	22.67%	3.33%	6.67%	67.33%	83.33%	76.67%
	high-density	0.21%	0.00%	51.33%	42.10%	0.00%	6.57%	/	/	/	/	1.28	0.79%		8.21	16.35	-		79.58%	50.00%	35.00%	15.00%		22.67%	3.33%	6.67%	67.33%	83.33%	76.67%

2048

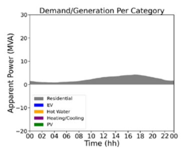
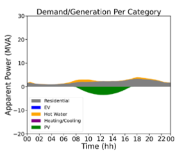
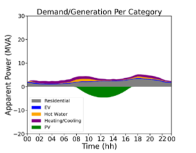
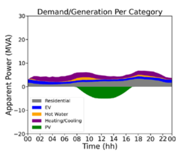
Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
Urban	low-density	57.45%	71.61%	0.59%	5.89%	37.33%	56.20%	28.42%	14.54%	5.22%	51.83%	8.46	51.19%		9.09	18.05	32.87%		149.53%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	medium-density	22.77%	28.39%	7.35%	37.55%	40.74%	14.35%	20.45%	7.15%	10.20%	62.20%	5.46	26.47%	44.17%	9.09	18.05	18.47%	28.78%	140.71%	42.50%	40.00%	17.50%	147.03%	11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	high-density	19.78%	0.00%	32.67%	57.41%	9.31%	0.61%	/	/	/	/	1.36	0.87%		9.09	18.05	-		98.50%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
Semi-Urban	low-density	78.26%	81.27%	0.58%	5.95%	35.44%	58.03%	21.65%	10.94%	6.36%	61.05%	8.46	51.19%		9.09	18.05	25.24%		149.53%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	medium-density	18.04%	18.73%	5.59%	41.69%	40.91%	11.81%	17.51%	6.12%	8.73%	67.65%	5.46	26.47%	46.56%	9.09	18.05	18.47%	23.97%	140.71%	42.50%	40.00%	17.50%	147.88%	11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	high-density	3.70%	0.00%	35.84%	58.96%	4.67%	0.53%	/	/	/	/	1.36	0.87%		9.09	18.05	-		98.50%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
Rural	low-density	92.52%	92.70%	1.57%	10.45%	42.77%	45.21%	28.54%	12.43%	4.74%	54.30%	8.46	51.19%		9.09	18.05	0.23		149.53%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	medium-density	7.29%	7.30%	15.83%	53.93%	27.70%	2.53%	23.98%	8.38%	11.96%	55.68%	5.46	26.47%	49.38%	9.09	18.05	0.18	23.13%	140.71%	42.50%	40.00%	17.50%	148.88%	11.33%	1.67%	3.33%	83.67%	91.67%	88.33%
	high-density	0.19%	0.00%	50.90%	43.19%	0.00%	5.91%	/	/	/	/	1.36	0.87%		9.09	18.05	-		98.50%	42.50%	40.00%	17.50%		11.33%	1.67%	3.33%	83.67%	91.67%	88.33%

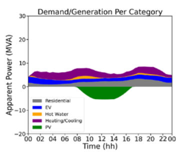
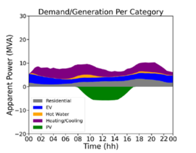
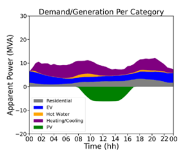
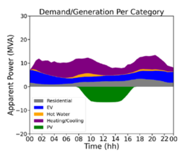
2053

Network Type	House Type	Proportion	Re-Proportion	House Size				Efficiency				PV			BES				EV					Hot Water				Cooling	Heating
				1-bed	2-bed	3-bed	4-bed+	Old	Modern	New	Efficient	Avg. Size (kW)	Uptake		Avg. Size (kW)	Avg. Size (kWh)	Uptake		Uptake	2.3kW	3.7kW	7.4kW		Gas	Solar	Resistive	Heat pump	Electric	Electric
Urban	low-density	56.79%	71.33%	0.58%	5.69%	36.49%	57.25%	25.85%	13.22%	5.04%	55.89%	8.89	53.79%		10.01	19.53	33.42%		157.80%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	medium-density	22.83%	28.67%	7.16%	37.11%	41.06%	14.67%	18.35%	6.41%	9.72%	65.52%	5.73	28.66%	46.59%	10.01	19.53	18.58%	29.17%	148.16%	36.50%	44.00%	19.50%	155.04%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	high-density	20.38%	0.00%	32.67%	57.43%	9.29%	0.61%	/	/	/	/	1.43	0.94%		10.01	19.53	-		103.71%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
Semi-Urban	low-density	77.99%	81.07%	0.57%	5.79%	34.75%	58.89%	19.40%	9.80%	6.05%	64.75%	8.89	53.79%		10.01	19.53	25.44%		157.80%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	medium-density	18.21%	18.93%	5.40%	41.44%	41.18%	11.97%	15.48%	5.41%	8.20%	70.91%	5.73	28.66%	49.04%	10.01	19.53	18.58%	24.14%	148.16%	36.50%	44.00%	19.50%	155.98%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	high-density	3.80%	0.00%	35.83%	59.07%	4.61%	0.49%	/	/	/	/	1.43	0.94%		10.01	19.53	-		103.71%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
Rural	low-density	92.60%	92.76%	1.57%	10.34%	42.18%	45.91%	25.85%	11.26%	4.56%	58.33%	8.89	53.79%		10.01	19.53	0.24		157.80%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	medium-density	7.23%	7.24%	15.61%	53.58%	28.29%	2.52%	21.93%	7.67%	11.62%	58.78%	5.73	28.66%	51.97%	10.01	19.53	0.19	23.26%	148.16%	36.50%	44.00%	19.50%	157.10%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
	high-density	0.17%	0.00%	50.59%	43.96%	0.00%	5.45%	/	/	/	/	1.43	0.94%		10.01	19.53	-		103.71%	36.50%	44.00%	19.50%		0.00%	0.00%	0.00%	100.00%	100.00%	100.00%

Appendix 3: Full Impact Metrics Table (Without DOEs) – Urban Network

Urban Network SBY32 (Without DOEs)

Year	Base Demand (No DER)				2023				2028				2033			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																
Maximum Absolute Power Flow (MVA) [1]	8.3	9.7	7.8	**9.7**	8.9	8.4	7.7	**8.9**	10.2	9.7	7.9	**10.2**	12.1	11.4	8.8	**12.1**
Increase of Maximum Absolute Power Flow	/	/	/	/	/	/	/	/	15%	15%	3%	**15%**	18%	18%	12%	**18%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																
Voltage Assessment																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	2%	1%	0.4%	**2%**	5%	2%	1%	**5%**
Voltage Drop Non-Compliance Rate	0%	0.03%	0%	**0%**	1%	3%	0.5%	**3%**	6%	6%	2%	**6%**	17%	12%	6%	**17%**
Maximum Customer Voltage (V) [2]	252	252	248	**252**	254	252	255	**255**	264	262	259	**264**	274	264	263	**274**
Minimum Customer Voltage (V)	218	216	221	**216**	210	207	213	**207**	197	200	205	**197**	184	179	202	**179**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	2%	0%	2%	**2%**	29%	25%	10%	**29%**	48%	29%	33%	**48%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	2%	0%	**2%**	15%	29%	15%	**29%**	50%	52%	31%	**52%**	60%	58%	48%	**60%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	2%	0%	0%	**2%**	29%	25%	6%	**29%**	48%	29%	31%	**48%**
Thermal Assessment																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	65%	76%	61%	**76%**	72%	68%	63%	**72%**	83%	78%	64%	**83%**	96%	92%	71%	**96%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	94%	96%	100%	**94%**	77%	85%	100%	**77%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	6%	2%	0%	**6%**	8%	6%	0%	**8%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.0	0.5	0.0	**1.0**	0.5	1.3	0.0	**0.5**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	2%	0%	**0%**	15%	8%	0%	**15%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.5	0.0	**0.0**	2.8	1.8	0.0	**2.8**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	71%	99%	70%	**71%**	83%	89%	70%	**83%**	109%	113%	76%	**109%**	135%	130%	86%	**135%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	27%	32%	20%	**32%**	37%	34%	32%	**37%**	60%	41%	32%	**60%**	64%	65%	35%	**65%**
PV Curtailment Assessment																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	/	0.4	5.1	4.2	**5.1**	1.3	11.2	6.3	**11.2**	2.4	20.8	8.7	**20.8**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	/	2%	11%	10%	**11%**	4%	22%	14%	**22%**	7%	39%	18%	**39%**
Ratio of PV Customers Curtailed	/	/	/	/	0%	100%	85%	**100%**	86%	100%	86%	**100%**	85%	100%	85%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	/	0.0	2.6	2.1	**722**	0.1	4.8	4.1	**1395**	0.7	7.3	6.2	**2140**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	/	0%	7%	7%	**6%**	0%	10%	10%	**9%**	2%	13%	13%	**12%**

Year	2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																
Maximum Absolute Power Flow (MVA) [1]	14.0	13.4	10.0	**14.0**	16.1	15.4	11.5	**16.1**	18.3	17.3	12.8	**18.3**	19.9	18.6	13.7	**19.9**
Increase of Maximum Absolute Power Flow	16%	18%	14%	**18%**	15%	14%	14%	**15%**	13%	12%	12%	**13%**	9%	8%	7%	**9%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																
Voltage Assessment																
Voltage Rise Non-Compliance Rate	8%	3%	2%	**8%**	15%	6%	7%	**15%**	20%	8%	10%	**20%**	24%	10%	12%	**24%**
Voltage Drop Non-Compliance Rate	26%	16%	11%	**26%**	34%	24%	21%	**34%**	43%	31%	27%	**43%**	45%	34%	32%	**45%**
Maximum Customer Voltage (V) [2]	271	271	268	**271**	276	272	276	**276**	278	271	271	**278**	275	274	270	**275**
Minimum Customer Voltage (V)	183	182	181	**181**	178	169	182	**169**	175	172	180	**172**	174	175	185	**174**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	56%	40%	33%	**56%**	58%	46%	44%	**58%**	60%	50%	48%	**60%**	60%	56%	48%	**60%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	63%	63%	58%	**63%**	63%	60%	60%	**63%**	63%	65%	60%	**65%**	65%	63%	63%	**65%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	56%	40%	33%	**56%**	58%	46%	44%	**58%**	60%	50%	48%	**60%**	60%	56%	48%	**60%**
Thermal Assessment																
MV Feeder – Overloaded Conductor Length (km)	0.5	0.3	0.0	**0.5**	0.8	0.7	0.0	**0.8**	1.7	1.4	0.1	**1.7**	2.0	2.0	0.3	**2.0**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	110%	106%	81%	**110%**	125%	120%	91%	**125%**	140%	134%	102%	**140%**	151%	143%	108%	**151%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of <=100%	56%	69%	94%	**56%**	50%	56%	83%	**50%**	44%	44%	71%	**44%**	42%	44%	63%	**42%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 100-110%	6%	4%	6%	**6%**	4%	8%	4%	**4%**	6%	13%	4%	**6%**	2%	4%	6%	**2%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	2.0	1.5	0.5	**2.0**	0.5	1.5	0.5	**0.5**	0.7	1.0	0.5	**0.7**	1.0	1.3	0.5	**1.0**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 110%-150%	25%	21%	0%	**25%**	23%	17%	13%	**23%**	13%	17%	21%	**13%**	15%	19%	25%	**15%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	1.9	2.4	0.0	**1.9**	3.4	2.8	0.5	**3.4**	2.4	2.9	1.3	**2.4**	2.1	2.5	1.9	**2.1**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of >150%	13%	6%	0%	**13%**	23%	19%	0%	**23%**	38%	27%	4%	**38%**	42%	33%	6%	**42%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	1.8	1.0	0.0	**1.8**	3.3	2.2	0.0	**3.3**	4.2	3.2	0.5	**4.2**	4.9	3.4	0.7	**4.9**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	173%	166%	105%	**173%**	221%	192%	131%	**221%**	254%	220%	156%	**254%**	276%	244%	170%	**276%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	99%	100%	100%	**99%**	98%	100%	100%	**98%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	1%	0%	0%	**1%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	70%	68%	47%	**70%**	89%	86%	60%	**89%**	104%	87%	73%	**104%**	114%	98%	75%	**114%**
PV Curtailment Assessment																
Per Customer – Max. PV Curtailment (kWh)	5.6	30.7	12.3	**30.7**	8.5	35.6	14.8	**35.6**	12.1	42.3	17.7	**42.3**	17.4	30.2	22.7	**30.2**
Per Customer – Ratio of Max. PV Curtailment	16%	54%	23%	**54%**	23%	59%	26%	**59%**	31%	65%	30%	**65%**	42%	45%	36%	**45%**
Ratio of PV Customers Curtailed	85%	100%	85%	**100%**	84%	100%	100%	**100%**	83%	100%	100%	**100%**	83%	100%	100%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	1.7	10.1	8.8	**3043**	3.1	13.6	11.9	**4140**	5.0	17.8	15.8	**5499**	6.8	21.8	19.5	**6821**
Aggregate Export [4] – Ratio of PV Curtailment	5%	17%	16%	**15%**	7%	20%	19%	**18%**	10%	23%	22%	**21%**	13%	25%	25%	**24%**

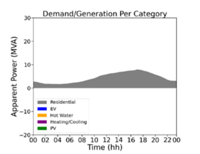
Appendix 4: Full Impact Metrics Table (Without DOEs) – Sub-Urban Network

SubUrban Network WBE013 (Without DOEs)

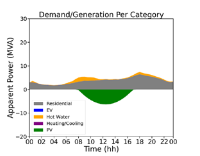
Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																																
Maximum Absolute Power Flow (MVA) [1]	13.7	16.1	12.2	**16.1**	14.8	14.0	12.4	**14.8**	17.0	16.1	12.8	**17.0**	20.0	19.4	14.7	**20.0**	23.5	22.6	17.4	**23.5**	27.1	26.0	20.0	**27.1**	30.9	29.2	22.5	**30.9**	33.2	31.6	24.1	**33.2**
Increase of Maximum Absolute Power Flow	/	/	/	**/**	/	/	/	**/**	15%	15%	3%	**15%**	18%	21%	15%	**21%**	17%	16%	18%	**18%**	15%	15%	15%	**15%**	14%	12%	12%	**14%**	8%	8%	7%	**8%**

Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day

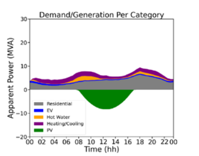
Base Demand (No DER):



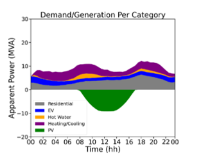
2023:



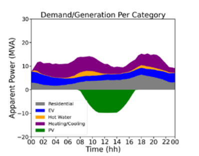
2028:



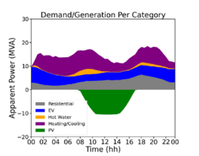
2033:



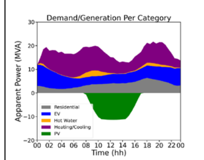
2038:



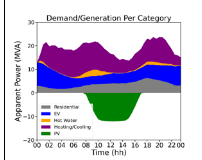
2043:



2048:



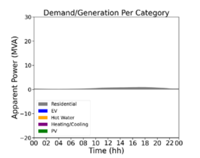
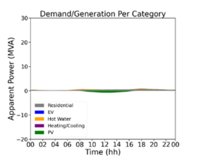
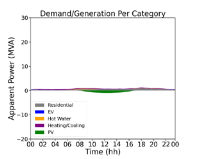
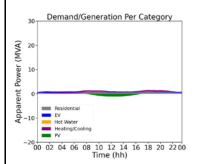
2053:

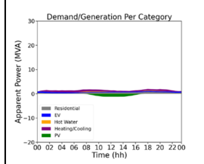
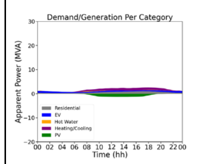
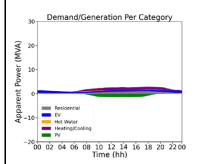
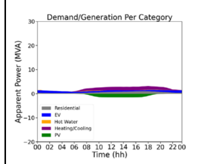


Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.1%	0%	0%	**0.1%**	1%	0.02%	0%	**1%**	0.3%	0.02%	0.1%	**0.3%**
Voltage Drop Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0.02%	0%	**0.02%**	0.1%	0.1%	0%	**0.1%**	0.4%	1%	0.1%	**1%**	1%	1%	0.2%	**1%**	2%	2%	0.4%	**2%**
Maximum Customer Voltage (V) [2]	241	246	242	**246**	245	249	245	**249**	246	249	248	**249**	251	249	247	**251**	249	251	249	**251**	255	251	252	**255**	258	253	253	**258**	256	253	255	**256**
Minimum Customer Voltage (V)	224	222	227	**222**	223	221	223	**221**	217	217	222	**217**	217	215	217	**215**	213	211	219	**211**	214	208	213	**208**	211	212	209	**209**	207	209	212	**207**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	3%	0%	0%	**3%**	6%	1%	0%	**6%**	7%	1%	6%	**7%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	1%	0%	**1%**	6%	4%	0%	**6%**	14%	20%	1%	**20%**	37%	30%	8%	**37%**	41%	31%	15%	**41%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	6%	1%	0%	**6%**	7%	1%	4%	**7%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.4	0.4	0.0	**0.4**	2.5	2.0	0.0	**2.5**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	72%	74%	72%	**74%**	73%	73%	72%	**73%**	73%	74%	71%	**74%**	74%	75%	72%	**75%**	79%	77%	72%	**79%**	94%	90%	72%	**94%**	110%	104%	75%	**110%**	124%	117%	83%	**124%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	99%	100%	100%	**99%**	69%	83%	100%	**69%**	49%	49%	94%	**49%**	41%	42%	72%	**41%**	38%	41%	55%	**38%**	38%	39%	48%	**38%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	13%	10%	0%	**13%**	6%	14%	3%	**6%**	4%	1%	14%	**4%**	1%	1%	8%	**1%**	1%	0%	7%	**1%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.5	0.0	0.0	**0.5**	0.8	0.9	0.0	**0.8**	1.1	1.3	0.5	**1.1**	1.3	1.5	0.5	**1.3**	1.0	0.5	0.5	**1.0**	1.5	0.0	0.7	**1.5**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	18%	7%	0%	**18%**	41%	35%	3%	**41%**	25%	39%	14%	**25%**	13%	18%	34%	**13%**	8%	10%	39%	**8%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.1	1.4	0.0	**1.1**	3.3	2.3	0.5	**3.3**	4.1	3.0	0.6	**4.1**	4.0	3.4	0.8	**4.0**	4.8	2.5	1.5	**4.8**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	4%	1%	0%	**4%**	30%	17%	0%	**30%**	48%	39%	3%	**48%**	52%	51%	6%	**52%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.7	0.5	0.0	**0.7**	2.7	1.8	0.0	**2.7**	3.9	2.3	0.5	**3.9**	5.1	2.8	0.5	**5.1**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	93%	93%	93%	**93%**	93%	93%	93%	**93%**	102%	93%	93%	**102%**	131%	122%	93%	**131%**	164%	152%	120%	**164%**	194%	173%	143%	**194%**	238%	212%	166%	**238%**	256%	239%	175%	**256%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	22%	29%	18%	**29%**	25%	25%	25%	**25%**	36%	34%	28%	**36%**	46%	44%	34%	**46%**	59%	54%	40%	**59%**	63%	65%	47%	**65%**	71%	72%	57%	**72%**	76%	76%	68%	**76%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	**/**	0.0	4.2	3.4	**4.2**	0.2	6.4	5.6	**6.4**	1.1	8.9	7.5	**8.9**	2.1	11.5	10.2	**11.5**	3.9	14.6	12.7	**14.6**	5.7	18.7	15.8	**18.7**	6.5	20.8	18.3	**20.8**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	**/**	0%	9%	8%	**9%**	1%	13%	12%	**13%**	3%	17%	15%	**17%**	6%	20%	19%	**20%**	10%	24%	23%	**24%**	14%	29%	27%	**29%**	16%	31%	29%	**31%**
Ratio of PV Customers Curtailed	/	/	/	**/**	0%	100%	85%	**100%**	86%	100%	86%	**100%**	85%	100%	85%	**100%**	85%	100%	85%	**100%**	84%	100%	100%	**100%**	83%	100%	100%	**100%**	82%	100%	100%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	**/**	0.0	4.6	3.8	**1293**	0.1	8.6	7.4	**2504**	1.2	12.9	11.2	**3837**	3.0	18.0	15.8	**5456**	5.4	24.1	21.4	**7402**	8.7	31.6	28.3	**9834**	11.9	39.0	35.1	**12230**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	**/**	0%	7%	7%	**6%**	0%	10%	10%	**9%**	2%	13%	12%	**12%**	4%	16%	16%	**15%**	7%	19%	19%	**18%**	10%	22%	22%	**21%**	12%	25%	24%	**23%**

Appendix 5: Full Impact Metrics Table (Without DOEs) – Short-Rural Network

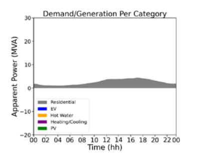
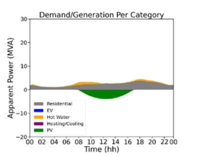
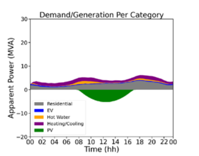
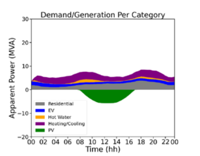
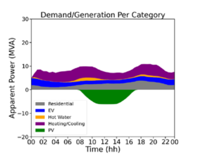
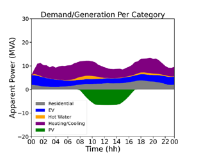
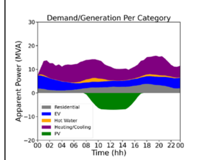
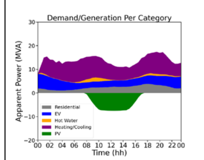
Short-Rural Network COO012 (Without DOEs)

Year	Base Demand (No DER)				2023				2028				2033			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																
Maximum Absolute Power Flow (MVA) [1]	3.1	3.5	3.0	**3.5**	3.0	2.9	2.6	**3.0**	3.4	3.3	2.7	**3.4**	3.8	3.7	3.0	**3.8**
Increase of Maximum Absolute Power Flow	/	/	/	/	/	/	/	/	10%	11%	3%	**11%**	14%	14%	10%	**14%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																
Voltage Assessment																
Voltage Rise Non-Compliance Rate	0%	3%	0%	**3%**	1%	0.5%	0%	**1%**	4%	5%	0.5%	**5%**	10%	7%	4%	**10%**
Voltage Drop Non-Compliance Rate	0%	1%	0%	**1%**	1%	3%	1%	**3%**	9%	5%	3%	**9%**	11%	8%	8%	**11%**
Maximum Customer Voltage (V) [2]	250	254	249	**254**	258	253	252	**258**	264	275	255	**275**	270	277	259	**277**
Minimum Customer Voltage (V)	218	214	222	**214**	211	206	214	**206**	194	190	209	**190**	194	173	200	**173**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	1%	0%	**1%**	1%	1%	0%	**1%**	3%	2%	1%	**3%**	5%	3%	3%	**5%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	2%	0%	**2%**	2%	3%	2%	**3%**	6%	6%	4%	**6%**	6%	8%	5%	**8%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	1%	0%	**1%**	1%	1%	0%	**1%**	3%	2%	1%	**3%**	5%	3%	3%	**5%**
Thermal Assessment																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	56%	64%	54%	**64%**	57%	54%	48%	**57%**	61%	59%	49%	**61%**	70%	67%	56%	**70%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	100%	100%	100%	**100%**	99%	99%	100%	**99%**	99%	98%	100%	**98%**	99%	98%	99%	**98%**
Distribution Transformer – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	1%	0%	**1%**	0%	0%	1%	**0%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.5	0.0	**0.5**	0.0	0.0	0.5	**0.0**
Distribution Transformer – of 110%-150%	0%	0%	0%	**0%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	0%	2%	1%	**2%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.5	0.5	0.0	**0.5**	2.5	1.5	0.0	**1.5**	0.0	1.7	0.5	**1.7**
Distribution Transformer – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.0	1.5	0.0	**1.5**	1.0	1.5	0.0	**1.5**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	75%	99%	70%	**75%**	114%	125%	93%	**114%**	196%	170%	95%	**170%**	222%	203%	114%	**203%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	21%	33%	17%	**33%**	36%	31%	30%	**36%**	38%	40%	31%	**40%**	49%	51%	31%	**51%**
PV Curtailment Assessment																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	/	1.4	11.7	7.8	**11.7**	3.5	10.5	6.2	**10.5**	4.9	39.5	10.2	**39.5**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	/	2%	12%	9%	**12%**	11%	21%	13%	**21%**	15%	74%	21%	**74%**
Ratio of PV Customers Curtailed	/	/	/	/	2%	100%	85%	**100%**	86%	100%	86%	**100%**	86%	100%	86%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	/	0.0	0.6	0.5	**160**	0.0	1.1	0.9	**310**	0.2	1.7	1.4	**480**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	/	0%	7%	7%	**6%**	0%	11%	10%	**9%**	2%	14%	13%	**12%**

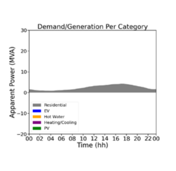
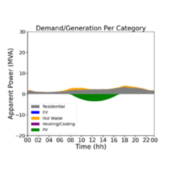
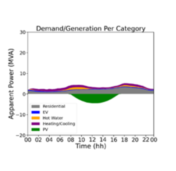
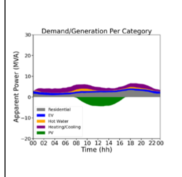
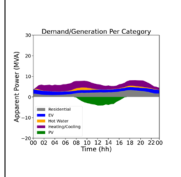
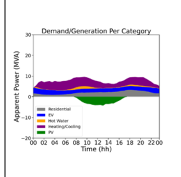
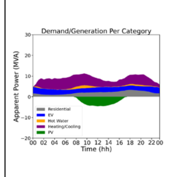
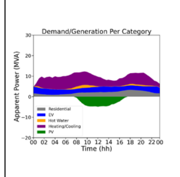
Year	2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																
Maximum Absolute Power Flow (MVA) [1]	4.2	4.2	3.3	**4.2**	4.6	4.7	3.6	**4.7**	5.0	5.1	4.0	**5.1**	5.3	5.5	4.3	**5.5**
Increase of Maximum Absolute Power Flow	11%	14%	10%	**14%**	9%	10%	10%	**10%**	9%	11%	11%	**11%**	5%	6%	6%	**6%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																
Voltage Assessment																
Voltage Rise Non-Compliance Rate	16%	10%	11%	**16%**	19%	13%	13%	**19%**	19%	17%	18%	**19%**	24%	18%	22%	**24%**
Voltage Drop Non-Compliance Rate	14%	13%	12%	**14%**	18%	18%	16%	**18%**	22%	22%	20%	**22%**	28%	24%	22%	**28%**
Maximum Customer Voltage (V) [2]	279	293	269	**293**	277	279	274	**279**	292	287	289	**292**	302	279	287	**302**
Minimum Customer Voltage (V)	192	174	198	**174**	181	175	187	**175**	179	169	171	**169**	167	166	171	**166**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	5%	6%	4%	**6%**	6%	6%	5%	**6%**	7%	7%	5%	**7%**	8%	6%	9%	**9%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	11%	11%	7%	**11%**	15%	16%	10%	**16%**	18%	20%	13%	**20%**	25%	21%	17%	**25%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	5%	6%	4%	**6%**	6%	6%	5%	**6%**	7%	7%	5%	**7%**	7%	6%	5%	**7%**
Thermal Assessment																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.8	2.8	0.0	**2.8**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	81%	78%	60%	**81%**	90%	89%	69%	**90%**	97%	99%	76%	**99%**	103%	105%	80%	**105%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	97%	95%	97%	**95%**	94%	93%	94%	**93%**	87%	89%	91%	**87%**	85%	87%	89%	**85%**
Distribution Transformer – of 100-110%	1%	2%	1%	**2%**	2%	2%	2%	**2%**	1%	3%	2%	**1%**	2%	4%	2%	**2%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.5	0.7	2.5	**0.7**	0.6	0.6	1.5	**0.6**	0.8	0.6	0.8	**0.8**	0.8	0.6	0.5	**0.8**
Distribution Transformer – of 110%-150%	1%	3%	2%	**3%**	3%	4%	4%	**4%**	8%	5%	6%	**8%**	7%	5%	7%	**7%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	1.0	2.2	0.7	**2.2**	1.3	1.3	0.8	**1.3**	1.6	1.2	1.1	**1.6**	1.5	2.0	1.1	**1.5**
Distribution Transformer – of >150%	1%	1%	1%	**1%**	1%	1%	1%	**1%**	4%	3%	2%	**4%**	5%	4%	2%	**5%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	1.0	1.5	0.5	**1.5**	1.8	1.5	0.5	**1.5**	1.5	3.0	1.2	**1.5**	1.4	2.6	1.3	**1.4**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	240%	205%	168%	**205%**	210%	193%	168%	**193%**	210%	244%	186%	**210%**	210%	318%	205%	**210%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	59%	64%	40%	**64%**	71%	71%	50%	**71%**	75%	85%	60%	**85%**	87%	86%	67%	**87%**
PV Curtailment Assessment																
Per Customer – Max. PV Curtailment (kWh)	13.1	44.7	15.2	**44.7**	9.0	44.2	16.4	**44.2**	7.9	50.2	19.1	**50.2**	12.6	53.2	22.4	**53.2**
Per Customer – Ratio of Max. PV Curtailment	38%	78%	29%	**78%**	24%	73%	29%	**73%**	20%	78%	32%	**78%**	31%	78%	36%	**78%**
Ratio of PV Customers Curtailed	84%	100%	84%	**100%**	84%	100%	100%	**100%**	83%	100%	100%	**100%**	82%	100%	100%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	0.4	2.4	2.0	**685**	0.7	3.1	2.6	**922**	1.1	4.1	3.5	**1220**	1.5	5.0	4.3	**1517**
Aggregate Export [4] – Ratio of PV Curtailment	5%	17%	16%	**15%**	8%	20%	19%	**18%**	10%	23%	22%	**21%**	13%	26%	25%	**24%**

Appendix 6: Full Impact Metrics Table (Without DOEs) – Long-Rural Network

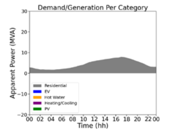
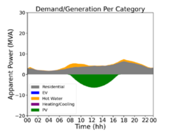
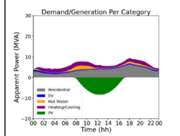
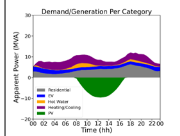
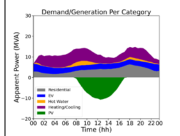
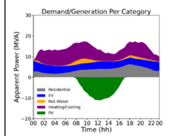
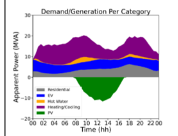
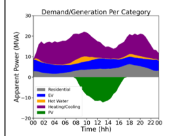
RuralLong Network BAS033 (Without DOEs)

Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Overview																																
Maximum Absolute Power Flow (MVA) [1]	15.5	16.9	14.6	**16.9**	14.9	13.9	13.3	**14.9**	17.0	15.5	14.2	**17.0**	19.9	17.6	15.6	**19.9**	22.8	19.9	17.0	**22.8**	25.9	22.2	18.5	**25.9**	29.3	24.6	19.9	**29.3**	31.9	26.3	20.7	**31.9**
Increase of Maximum Absolute Power Flow	/	/	/	**/**	/	/	/	**/**	14%	11%	7%	**14%**	17%	14%	10%	**17%**	15%	13%	9%	**15%**	14%	12%	9%	**14%**	13%	11%	8%	**13%**	9%	7%	4%	**9%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																																
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	1%	0%	0%	**1%**	4%	0%	0%	**4%**	21%	0%	0%	**21%**
Voltage Drop Non-Compliance Rate	0%	0.2%	0%	**0.2%**	0%	0%	0%	**0%**	0%	0%	0.1%	**0.1%**	0.1%	0%	0%	**0.1%**	0.2%	0.1%	0%	**0.2%**	2%	1%	0%	**2%**	3%	0.4%	0.2%	**3%**	23%	4%	1%	**23%**
Maximum Customer Voltage (V) [2]	247	250	247	**250**	244	244	245	**245**	247	248	249	**249**	252	248	247	**252**	256	248	250	**256**	256	251	251	**256**	258	251	252	**258**	267	251	251	**267**
Minimum Customer Voltage (V)	221	215	223	**215**	221	223	224	**221**	218	218	216	**216**	213	219	220	**213**	210	216	216	**210**	208	213	217	**208**	199	209	209	**199**	184	204	206	**184**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.5%	0%	0%	**0.5%**	1%	0%	0%	**1%**	3%	0%	0%	**3%**	16%	0%	0%	**16%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	0.3%	0%	**0.3%**	0%	0%	0%	**0%**	0%	0%	0.1%	**0.1%**	0.2%	0%	0%	**0.2%**	0.5%	0.2%	0%	**0.5%**	3%	1%	0%	**3%**	5%	1%	1%	**5%**	23%	5%	1%	**23%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.3%	0%	0%	**0.3%**	1%	0%	0%	**1%**	12%	0%	0%	**12%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	6.7	0.3	0.0	**6.7**	9.2	6.1	0.0	**9.2**	17.7	9.5	0.7	**17.7**	20.4	12.0	1.0	**20.4**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	74%	81%	70%	**81%**	71%	66%	66%	**71%**	80%	75%	67%	**80%**	102%	90%	75%	**102%**	126%	107%	87%	**126%**	155%	123%	97%	**155%**	178%	140%	106%	**178%**	196%	153%	115%	**196%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	100%	100%	100%	**100%**	97%	97%	97%	**97%**	91%	92%	94%	**91%**	83%	87%	88%	**83%**	76%	80%	83%	**76%**	68%	75%	77%	**68%**	63%	70%	72%	**63%**	59%	69%	70%	**59%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 100-110%	0%	0.1%	0%	**0.1%**	1%	2%	1%	**2%**	2%	3%	2%	**2%**	4%	3%	3%	**4%**	4%	5%	4%	**4%**	5%	5%	4%	**5%**	5%	5%	5%	**5%**	5%	4%	4%	**5%**
Avg. Overloading Duration (hr) [3]	0.0	1.0	0.0	**1.0**	0.9	0.8	0.9	**0.8**	0.9	0.9	0.6	**0.9**	0.9	1.1	0.8	**0.9**	1.0	0.9	0.9	**1.0**	0.8	1.0	0.8	**0.8**	1.0	1.1	0.8	**1.0**	1.0	1.0	0.8	**1.0**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 110%-150%	0%	0.2%	0%	**0.2%**	2%	1%	1%	**1%**	6%	4%	3%	**6%**	8%	7%	7%	**8%**	11%	10%	9%	**11%**	12%	13%	11%	**12%**	13%	14%	11%	**13%**	14%	13%	12%	**14%**
Avg. Overloading Duration (hr) [3]	0.0	0.5	0.0	**0.5**	0.9	1.6	1.0	**1.6**	1.5	1.7	1.1	**1.5**	1.5	1.9	1.2	**1.5**	1.5	2.2	1.1	**1.5**	1.6	2.1	1.1	**1.6**	1.5	1.9	1.1	**1.5**	1.7	2.1	1.0	**1.7**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of >150%	0%	0%	0%	**0%**	0.1%	0%	0.1%	**0%**	1%	0.5%	1%	**1%**	5%	2%	2%	**5%**	9%	4%	4%	**9%**	15%	7%	8%	**15%**	20%	11%	12%	**20%**	22%	14%	15%	**22%**
Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.5	0.0	1.5	**0.0**	1.4	3.8	0.9	**1.4**	1.9	2.3	0.9	**1.9**	2.5	2.5	1.1	**2.5**	2.8	3.0	1.2	**2.8**	3.3	3.0	1.3	**3.3**	3.7	3.0	1.3	**3.7**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	99%	115%	90%	**115%**	166%	146%	154%	**146%**	196%	213%	165%	**196%**	294%	236%	219%	**294%**	297%	272%	233%	**297%**	346%	347%	276%	**346%**	388%	403%	339%	**388%**	428%	403%	350%	**428%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	19%	24%	15%	**24%**	23%	22%	20%	**23%**	31%	32%	25%	**32%**	50%	38%	29%	**50%**	55%	44%	38%	**55%**	65%	46%	41%	**65%**	78%	55%	50%	**78%**	78%	58%	50%	**78%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	**/**	0.0	4.1	3.2	**4.1**	0.1	6.1	5.3	**6.1**	1.0	8.2	7.2	**8.2**	2.2	11.1	9.5	**11.1**	3.4	13.7	12.2	**13.7**	5.0	16.8	15.0	**16.8**	6.4	19.7	17.5	**19.7**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	**/**	0%	9%	7%	**9%**	0%	12%	12%	**12%**	3%	15%	15%	**15%**	6%	19%	18%	**19%**	9%	23%	22%	**23%**	13%	26%	25%	**26%**	15%	29%	28%	**29%**
Ratio of PV Customers Curtailed	/	/	/	**/**	0%	100%	85%	**100%**	86%	100%	86%	**100%**	85%	100%	85%	**100%**	85%	100%	85%	**100%**	84%	100%	100%	**100%**	83%	100%	100%	**100%**	82%	100%	100%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	**/**	0.0	2.9	2.4	**808**	0.1	5.4	4.6	**1563**	0.8	8.1	7.0	**2397**	1.9	11.2	9.9	**3405**	3.4	15.1	13.3	**4621**	5.5	19.8	17.6	**6134**	7.5	24.4	21.9	**7632**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	**/**	0%	7%	7%	**6%**	0%	10%	10%	**9%**	2%	13%	12%	**12%**	4%	16%	16%	**15%**	7%	19%	18%	**18%**	10%	22%	22%	**21%**	12%	25%	24%	**23%**

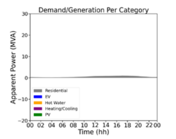
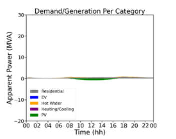
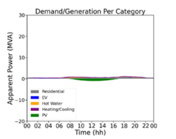
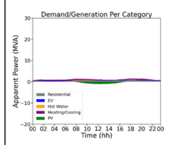
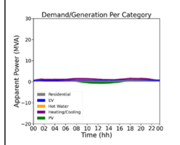
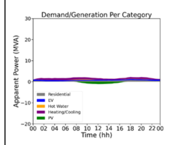
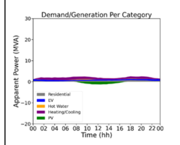
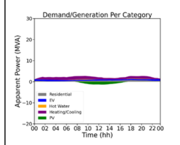
Appendix 7: Full Impact Metrics Table (With DOEs) – Urban Network

Urban Network (With DOEs)																																
Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Houses with PV, EV and DOEs																																
Houses with PV	0%				27%				33%				36%				39%				41%				44%				47%			
Houses with PV + Export DOE	0%				0%				6%				18%				39%				41%				44%				47%			
Houses with EV	0%				1%				14%				50%				86%				119%				147%				155%			
Houses with EV + Import DOE (Level-2 EV)	0%				0%				0%				5%				15%				27%				43%				54%			
Overview																																
Maximum Absolute Power Flow (MVA) [1]	8.3	9.7	7.8	**9.7**	8.9	8.4	7.7	**8.9**	10.2	9.7	7.9	**10.2**	11.8	11.2	8.7	**11.8**	13.6	12.9	10.1	**13.6**	15.6	14.5	11.5	**15.6**	17.2	16.0	12.3	**17.2**	18.4	17.0	12.8	**18.4**
Increase of Maximum Absolute Power Flow	/	/	/	/	/	/	/	/	15%	15%	3%	**15%**	15%	16%	10%	**16%**	15%	15%	16%	**16%**	14%	12%	14%	**14%**	10%	10%	7%	**10%**	7%	6%	4%	**7%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																																
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	2%	0.5%	0.3%	**2%**	3%	1%	1%	**3%**	5%	1%	1%	**5%**	6%	1%	2%	**6%**	8%	2%	2%	**8%**	5%	1%	1%	**5%**
Voltage Drop Non-Compliance Rate	0%	0.03%	0%	**0.03%**	1%	3%	0.5%	**3%**	6%	6%	2%	**6%**	14%	9%	4%	**14%**	22%	9%	6%	**22%**	28%	13%	12%	**28%**	37%	18%	17%	**37%**	43%	19%	20%	**43%**
Maximum Customer Voltage (V) [2]	252	252	248	**252**	254	252	255	**255**	264	261	259	**264**	267	262	263	**267**	267	266	262	**267**	272	266	263	**272**	278	265	264	**278**	272	263	258	**272**
Minimum Customer Voltage (V)	218	216	221	**216**	210	207	213	**207**	197	199	205	**197**	192	192	202	**192**	180	195	202	**180**	182	187	195	**182**	176	184	191	**176**	177	189	189	**177**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	2%	0%	2%	**2%**	25%	13%	8%	**25%**	40%	19%	21%	**40%**	42%	13%	19%	**42%**	38%	21%	25%	**38%**	42%	19%	27%	**42%**	42%	15%	21%	**42%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	2%	0%	**2%**	15%	29%	15%	**29%**	50%	48%	29%	**50%**	60%	56%	46%	**60%**	60%	60%	52%	**60%**	60%	60%	54%	**60%**	63%	60%	60%	**63%**	63%	60%	60%	**63%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	2%	0%	0%	**2%**	25%	13%	4%	**25%**	40%	19%	19%	**40%**	42%	13%	17%	**42%**	38%	21%	21%	**38%**	42%	19%	27%	**42%**	42%	15%	21%	**42%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.5	0.1	0.0	**0.5**	0.7	0.7	0.0	**0.7**	1.1	0.8	0.0	**1.1**	1.7	1.1	0.1	**1.7**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	65%	76%	61%	**76%**	72%	68%	63%	**72%**	83%	78%	64%	**83%**	94%	91%	70%	**94%**	109%	103%	81%	**109%**	121%	114%	91%	**121%**	134%	125%	98%	**134%**	143%	130%	102%	**143%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	94%	98%	100%	**94%**	83%	92%	100%	**83%**	56%	71%	96%	**56%**	54%	60%	90%	**54%**	50%	56%	77%	**50%**	42%	52%	75%	**42%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	6%	2%	0%	**6%**	2%	4%	0%	**2%**	15%	4%	4%	**15%**	4%	8%	4%	**4%**	6%	4%	13%	**6%**	8%	4%	10%	**8%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.0	0.5	0.0	**1.0**	0.5	2.0	0.0	**0.5**	1.1	1.3	0.8	**1.1**	1.3	2.0	1.3	**1.3**	2.7	1.5	0.6	**2.7**	0.8	0.8	0.8	**0.8**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	15%	4%	0%	**15%**	23%	23%	0%	**23%**	25%	23%	6%	**25%**	15%	21%	10%	**15%**	15%	19%	15%	**15%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	2.0	1.8	0.0	**2.0**	2.9	2.7	0.0	**2.9**	3.5	3.9	1.2	**3.5**	4.1	4.3	1.9	**4.1**	2.7	4.7	1.9	**2.7**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	6%	2%	0%	**6%**	17%	8%	0%	**17%**	29%	19%	0%	**29%**	35%	25%	0%	**35%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	2.0	0.5	0.0	**2.0**	3.1	2.5	0.0	**3.1**	3.6	3.5	0.0	**3.6**	4.4	3.3	0.0	**4.4**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	71%	99%	70%	**71%**	83%	89%	70%	**83%**	109%	101%	76%	**109%**	132%	125%	86%	**132%**	165%	151%	103%	**165%**	202%	171%	121%	**202%**	228%	192%	137%	**228%**	249%	210%	145%	**249%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	27%	32%	20%	**32%**	37%	34%	32%	**37%**	60%	41%	35%	**60%**	62%	57%	37%	**62%**	68%	65%	47%	**68%**	81%	70%	56%	**81%**	89%	77%	58%	**89%**	94%	82%	60%	**94%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	/	0.4	5.1	4.2	**5.1**	16.5	33.4	20.8	**33.4**	29.5	53.4	42.1	**53.4**	33.3	56.9	39.3	**56.9**	36.4	60.1	54.8	**60.1**	38.7	64.6	57.5	**64.6**	39.6	66.9	59.5	**66.9**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	/	2%	11%	10%	**11%**	54%	66%	45%	**66%**	90%	100%	85%	**100%**	96%	100%	75%	**100%**	98%	99%	98%	**99%**	99%	100%	97%	**100%**	96%	98%	95%	**98%**
Ratio of PV Customers Curtailed	/	/	/	/	0%	100%	85%	**100%**	77%	100%	80%	**100%**	86%	100%	89%	**100%**	93%	100%	98%	**100%**	94%	100%	98%	**100%**	92%	100%	97%	**100%**	92%	100%	98%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	/	0.0	2.6	2.1	**722**	0.5	5.2	3.9	**1353**	4.5	14.5	10.2	**3673**	11.4	25.1	20.1	**7224**	15.5	29.0	26.7	**9473**	17.4	31.1	34.2	**11894**	19.9	33.2	39.2	**13551**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	/	0%	7%	7%	**6%**	2%	11%	9%	**9%**	14%	27%	21%	**21%**	31%	41%	36%	**36%**	37%	42%	42%	**42%**	37%	40%	48%	**46%**	38%	38%	49%	**47%**
EV Management Assessment																																
Ratio of EVs Affected	/	/	/	/	/	/	/	/	/	/	/	/	9%	10%	9%	**10%**	13%	13%	12%	**13%**	16%	16%	16%	**16%**	21%	20%	20%	**21%**	24%	24%	24%	**24%**
Avg. EV Charging Delay (hrs)	/	/	/	/	/	/	/	/	/	/	/	/	4.2	3.6	4.8	**4.8**	4.9	4.6	6.0	**6.0**	4.4	4.7	6.0	**6.0**	4.4	4.9	5.9	**5.9**	4.5	4.8	5.6	**5.6**

Appendix 8: Full Impact Metrics Table (With DOEs) – Sub-Urban Network

Suburban Network (With DOEs)																																
Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Houses with PV, EV and DOEs																																
Houses with PV	0%				28%				35%				38%				41%				44%				47%				49%			
Houses with PV + Export DOE	0%				0%				7%				19%				41%				44%				47%				49%			
Houses with EV	0%				1%				14%				50%				87%				119%				148%				156%			
Houses with EV + Import DOE (Level-2 EV)	0%				0%				0%				5%				16%				28%				43%				54%			
Overview																																
Maximum Absolute Power Flow (MVA) [1]	13.7	16.1	12.2	**16.1**	14.8	14.0	12.4	**14.8**	17.0	16.1	12.8	**17.0**	19.9	19.1	14.6	**19.9**	23.0	21.9	16.8	**23.0**	25.7	24.7	18.8	**25.7**	28.9	27.1	20.4	**28.9**	30.9	28.7	21.4	**30.9**
Increase of Maximum Absolute Power Flow	/	/	/	/	/	/	/	/	15%	15%	3%	**15%**	17%	19%	14%	**19%**	15%	15%	15%	**15%**	12%	12%	12%	**12%**	12%	10%	9%	**12%**	7%	6%	5%	**7%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																																
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.3%	0%	0%	**0.3%**	0%	0%	0%	**0%**
Voltage Drop Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0.02%	0%	**0.02%**	0%	0.1%	0%	**0.1%**	0.4%	0.3%	0.1%	**0.4%**	1%	0.1%	0%	**1%**	1%	0.5%	0.02%	**1%**
Maximum Customer Voltage (V) [2]	241	246	242	**246**	245	249	245	**249**	246	249	248	**249**	248	248	249	**249**	249	250	248	**250**	252	249	248	**252**	257	249	249	**257**	252	249	248	**252**
Minimum Customer Voltage (V)	224	222	227	**222**	223	221	223	**221**	217	217	222	**217**	216	216	221	**216**	217	212	219	**212**	212	210	214	**210**	213	212	217	**212**	210	208	216	**208**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	0%	0%	0%	**0%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	1%	0%	**1%**	0%	3%	0%	**3%**	13%	8%	1%	**13%**	13%	6%	0%	**13%**	23%	10%	1%	**23%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.3	0.0	0.0	**0.3**	0.9	0.3	0.0	**0.9**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	72%	74%	72%	**74%**	73%	73%	72%	**73%**	73%	74%	71%	**74%**	74%	74%	71%	**74%**	76%	76%	71%	**76%**	89%	86%	71%	**89%**	103%	96%	73%	**103%**	114%	105%	74%	**114%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	99%	100%	100%	**99%**	73%	90%	100%	**73%**	52%	56%	97%	**52%**	42%	44%	89%	**42%**	39%	42%	66%	**39%**	39%	41%	58%	**39%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	10%	6%	0%	**10%**	4%	11%	1%	**4%**	6%	6%	7%	**6%**	3%	1%	18%	**3%**	0%	1%	17%	**0%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.5	0.0	0.0	**0.5**	0.9	1.1	0.0	**0.9**	0.7	1.4	0.5	**0.7**	2.0	1.5	0.5	**2.0**	2.0	2.5	0.5	**2.0**	0.0	1.0	0.7	**0.0**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	17%	4%	0%	**17%**	42%	32%	1%	**42%**	31%	42%	4%	**31%**	20%	32%	15%	**20%**	15%	24%	25%	**15%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.9	0.7	0.0	**0.9**	3.0	1.9	0.5	**3.0**	3.6	3.1	0.5	**3.6**	4.9	3.8	0.7	**4.9**	4.6	3.9	0.8	**4.6**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	0%	0%	**1%**	21%	8%	0%	**21%**	38%	24%	0%	**38%**	45%	34%	0%	**45%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.5	0.0	0.0	**0.5**	1.6	1.5	0.0	**1.6**	2.8	2.2	0.0	**2.8**	3.8	2.5	0.0	**3.8**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	93%	93%	93%	**93%**	93%	93%	93%	**93%**	102%	93%	93%	**102%**	131%	115%	93%	**131%**	164%	144%	110%	**164%**	183%	161%	126%	**183%**	212%	188%	138%	**212%**	230%	212%	142%	**230%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation – of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	22%	29%	18%	**29%**	25%	25%	25%	**25%**	36%	34%	29%	**36%**	43%	43%	35%	**43%**	52%	51%	38%	**52%**	57%	59%	41%	**59%**	64%	62%	46%	**64%**	69%	64%	50%	**69%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	/	0.0	4.2	3.4	**4.2**	0.2	6.4	5.5	**6.4**	4.9	19.5	7.6	**19.5**	24.7	44.9	30.6	**44.9**	29.0	57.4	36.5	**57.4**	37.5	63.4	41.1	**63.4**	38.1	67.1	44.6	**67.1**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	/	0%	9%	8%	**9%**	1%	13%	12%	**13%**	15%	36%	15%	**36%**	71%	79%	58%	**79%**	78%	94%	65%	**94%**	95%	98%	69%	**98%**	92%	99%	71%	**99%**
Ratio of PV Customers Curtailed	/	/	/	/	0%	100%	85%	**100%**	69%	100%	69%	**100%**	36%	100%	46%	**100%**	50%	100%	69%	**100%**	71%	100%	80%	**100%**	84%	100%	88%	**100%**	86%	100%	92%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	/	0.0	4.6	3.8	**1293**	0.1	6.9	5.9	**2000**	0.5	6.3	4.6	**1605**	2.9	12.4	8.0	**2890**	8.5	23.8	13.6	**5123**	16.1	38.7	23.7	**8873**	21.5	47.0	31.9	**11774**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	/	0%	7%	7%	**6%**	0%	8%	8%	**7%**	1%	6%	5%	**5%**	4%	11%	8%	**8%**	11%	19%	12%	**12%**	19%	27%	18%	**19%**	23%	30%	22%	**23%**
EV Management Assessment																																
Ratio of EVs Affected	/	/	/	/	/	/	/	/	/	/	/	/	9%	8%	9%	**9%**	12%	12%	12%	**12%**	16%	16%	15%	**16%**	21%	21%	20%	**21%**	24%	24%	23%	**24%**
Avg. EV Charging Delay (hrs)	/	/	/	/	/	/	/	/	/	/	/	/	3.4	2.2	1.9	**3.4**	5.3	4.4	4.5	**5.3**	5.2	4.9	5.3	**5.3**	4.8	5.0	5.5	**5.5**	4.5	5.0	5.5	**5.5**

Appendix 9: Full Impact Metrics Table (With DOEs) – Short-Rural Network

Short-Rural Network (With DOEs)																																
Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Houses with PV, EV and DOEs																																
Houses with PV	0%				29%				37%				41%				43%				46%				49%				52%			
Houses with PV + Export DOE	0%				0%				8%				20%				43%				46%				49%				52%			
Houses with EV	0%				1%				14%				50%				87%				120%				149%				157%			
Houses with EV + Import DOE (Level-2 EV)	0%				0%				0%				7%				16%				28%				43%				55%			
Overview																																
Maximum Absolute Power Flow (MVA) [1]	3.1	3.5	3.0	**3.5**	3.0	2.9	2.6	**3.0**	3.4	3.3	2.7	**3.4**	3.8	3.7	3.0	**3.8**	4.3	4.1	3.4	**4.3**	4.6	4.6	3.6	**4.6**	5.0	4.9	3.9	**5.0**	5.3	5.2	4.1	**5.3**
Increase of Maximum Absolute Power Flow	/	/	/	**/**	/	/	/	**/**	10%	11%	3%	**11%**	14%	14%	12%	**14%**	12%	12%	12%	**12%**	9%	10%	6%	**10%**	8%	8%	8%	**8%**	6%	5%	5%	**6%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																																
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	3%	0%	**3%**	1%	0.5%	0%	**1%**	4%	4%	0.3%	**4%**	9%	5%	2%	**9%**	14%	7%	6%	**14%**	14%	8%	6%	**14%**	14%	9%	9%	**14%**	20%	7%	8%	**20%**
Voltage Drop Non-Compliance Rate	0%	1%	0%	**1%**	1%	3%	1%	**3%**	8%	5%	2%	**8%**	9%	6%	6%	**9%**	12%	10%	9%	**12%**	15%	11%	9%	**15%**	21%	13%	12%	**21%**	25%	15%	12%	**25%**
Maximum Customer Voltage (V) [2]	250	254	249	**254**	258	253	252	**258**	264	274	255	**274**	270	265	259	**270**	279	267	264	**279**	273	274	271	**274**	276	274	277	**277**	280	274	278	**280**
Minimum Customer Voltage (V)	218	214	222	**214**	211	206	214	**206**	194	190	209	**190**	194	188	201	**188**	193	189	198	**189**	182	187	187	**182**	180	182	186	**180**	175	181	182	**175**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	1%	0%	**1%**	1%	1%	0%	**1%**	3%	2%	1%	**3%**	4%	2%	3%	**4%**	5%	4%	3%	**5%**	5%	4%	5%	**5%**	7%	4%	4%	**7%**	7%	4%	4%	**7%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	2%	0%	**2%**	2%	3%	2%	**3%**	5%	5%	3%	**5%**	6%	6%	5%	**6%**	10%	10%	6%	**10%**	12%	12%	6%	**12%**	21%	15%	7%	**21%**	25%	17%	10%	**25%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	1%	0%	**1%**	1%	1%	0%	**1%**	3%	1%	1%	**3%**	4%	2%	3%	**4%**	4%	4%	3%	**4%**	5%	4%	4%	**5%**	6%	4%	4%	**6%**	6%	4%	4%	**6%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.8	0.0	0.0	**0.8**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	56%	64%	54%	**64%**	57%	54%	48%	**57%**	61%	59%	49%	**61%**	70%	67%	56%	**70%**	80%	75%	62%	**80%**	89%	86%	69%	**89%**	97%	92%	75%	**97%**	100%	98%	77%	**100%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	100%	100%	100%	**100%**	99%	99%	100%	**99%**	99%	98%	100%	**98%**	99%	98%	99%	**98%**	97%	97%	98%	**97%**	96%	95%	96%	**95%**	91%	93%	96%	**91%**	89%	92%	94%	**89%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	1%	0%	**1%**	0%	0%	1%	**0%**	1%	0%	0%	**0%**	1%	2%	2%	**2%**	3%	3%	2%	**3%**	3%	4%	2%	**3%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.5	0.0	**0.5**	0.0	0.0	0.5	**0.0**	0.5	0.0	0.0	**0.0**	0.5	0.7	0.8	**0.7**	0.6	1.0	0.8	**0.6**	0.9	0.7	0.5	**0.9**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	0%	2%	0%	**2%**	1%	3%	2%	**3%**	2%	3%	2%	**3%**	5%	3%	3%	**5%**	5%	3%	3%	**5%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.5	0.5	0.0	**0.5**	2.5	1.5	0.0	**1.5**	0.0	1.7	0.0	**1.7**	1.0	2.1	1.2	**2.1**	1.5	1.1	1.0	**1.1**	1.6	1.1	1.0	**1.6**	1.7	2.9	0.7	**1.7**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	1%	1%	0%	**1%**	2%	1%	1%	**2%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	1.0	1.5	0.0	**1.5**	1.0	1.5	0.0	**1.5**	1.0	1.5	0.0	**1.5**	1.8	1.5	0.0	**1.5**	1.8	4.5	0.0	**1.8**	1.3	4.5	1.5	**1.3**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	75%	99%	70%	**75%**	114%	125%	93%	**114%**	196%	170%	95%	**170%**	222%	202%	100%	**202%**	240%	205%	133%	**205%**	210%	193%	138%	**193%**	210%	203%	142%	**210%**	210%	203%	205%	**210%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	21%	33%	17%	**33%**	36%	31%	30%	**36%**	38%	40%	34%	**40%**	46%	51%	30%	**51%**	56%	62%	40%	**62%**	64%	67%	45%	**67%**	78%	78%	51%	**78%**	81%	78%	56%	**81%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	**/**	0.7	5.9	3.9	**5.9**	6.1	40.7	6.1	**40.7**	28.7	51.8	41.0	**51.8**	33.2	57.1	48.3	**57.1**	34.2	60.2	51.5	**60.2**	35.4	64.1	54.6	**64.1**	37.4	66.9	56.0	**66.9**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	**/**	2%	12%	9%	**12%**	20%	81%	13%	**81%**	88%	97%	83%	**97%**	96%	100%	92%	**100%**	93%	99%	92%	**99%**	90%	99%	92%	**99%**	90%	98%	90%	**98%**
Ratio of PV Customers Curtailed	/	/	/	**/**	2%	100%	85%	**100%**	72%	100%	70%	**100%**	64%	100%	63%	**100%**	62%	100%	58%	**100%**	68%	100%	65%	**100%**	72%	100%	69%	**100%**	73%	100%	73%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	**/**	0.0	0.6	0.5	**160**	0.0	1.0	0.7	**252**	0.8	1.9	1.4	**519**	1.8	3.7	3.1	**1107**	2.4	4.1	3.9	**1378**	2.8	4.7	4.6	**1622**	3.1	5.3	5.6	**1959**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	**/**	0%	7%	7%	**6%**	1%	10%	8%	**7%**	11%	16%	13%	**13%**	22%	27%	25%	**25%**	25%	27%	28%	**27%**	26%	27%	29%	**28%**	26%	27%	32%	**31%**
EV Management Assessment																																
Ratio of EVs Affected	/	/	/	**/**	/	/	/	**/**	/	/	/	**/**	8%	8%	6%	**8%**	11%	12%	9%	**12%**	15%	16%	14%	**16%**	20%	20%	18%	**20%**	23%	23%	21%	**23%**
Avg. EV Charging Delay (hrs)	/	/	/	**/**	/	/	/	**/**	/	/	/	**/**	2.0	2.6	3.1	**3.1**	4.1	3.3	4.4	**4.4**	4.2	4.2	4.2	**4.2**	3.7	4.0	3.9	**4.0**	3.3	3.8	4.0	**4.0**

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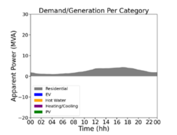
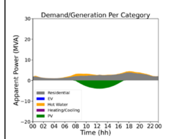
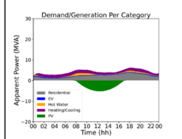
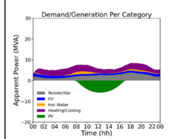
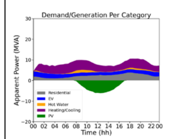
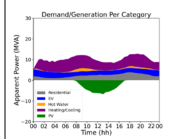
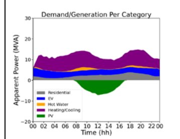
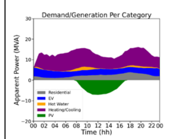
Appendix 10: Full Impact Metrics Table (With DOEs) – Long-Rural Network

Long-Rural Network (With DOEs)																																
Year	Base Demand (No DER)				2023				2028				2033				2038				2043				2048				2053			
Day Type	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long	Winter Peak	Summer Peak	Spring Shoulder	Year Long
Houses with PV, EV and DOEs																																
Houses with PV	0%				29%				37%				41%				43%				46%				49%				52%			
Houses with PV + Export DOE	0%				0%				8%				20%				43%				46%				49%				52%			
Houses with EV	0%				1%				14%				50%				87%				120%				149%				157%			
Houses with EV + Import DOE (Level-2 EV)	0%				0%				0%				7%				16%				28%				43%				55%			
Overview																																
Maximum Absolute Power Flow (MVA) [1]	15.5	16.9	14.6	**16.9**	14.9	13.9	13.3	**14.9**	17.0	15.3	14.2	**17.0**	20.0	17.3	15.5	**20.0**	22.9	19.5	17.2	**22.9**	25.7	21.4	19.1	**25.7**	28.4	23.3	20.5	**28.4**	30.2	24.5	21.3	**30.2**
Increase of Maximum Absolute Power Flow	/	/	/	/	/	/	/	/	14%	10%	7%	**14%**	18%	14%	9%	**18%**	14%	12%	11%	**14%**	12%	10%	11%	**12%**	11%	9%	7%	**11%**	6%	6%	4%	**6%**
Aggregated Demand/Generation Per Technology (MVA) During the Peak Demand Day																																
Voltage Assessment																																
Voltage Rise Non-Compliance Rate	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0.0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.2%	0%	0%	**0.2%**	0.2%	0%	0%	**0.2%**	19.3%	0%	0%	**19%**
Voltage Drop Non-Compliance Rate	0%	0.2%	0%	**0.2%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.1%	0%	0%	**0.1%**	0.4%	0%	0%	**0.4%**	1%	0%	0%	**1%**	2%	0%	0.2%	**2%**	22%	3%	0.2%	**22%**
Maximum Customer Voltage (V) [2]	247	250	247	**250**	244	244	245	**245**	246	246	247	**247**	247	245	247	**247**	250	246	246	**250**	255	247	248	**255**	256	248	248	**256**	256	248	249	**256**
Minimum Customer Voltage (V)	221	215	223	**215**	221	223	224	**221**	218	221	221	**218**	213	220	217	**213**	210	218	217	**210**	209	215	220	**209**	201	216	214	**201**	197	208	206	**197**
LV Network Voltages – Ratio of LV Networks with Voltage Rise Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.1%	0%	0%	**0%**	0.2%	0%	0%	**0%**	14%	0%	0%	**14%**
LV Network Voltages – Ratio of LV Networks with Voltage Drop Issues	0%	0.3%	0%	**0.3%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0.2%	0%	0%	**0.2%**	1%	0%	0%	**1%**	2%	0.3%	0%	**2%**	3%	0.1%	0.2%	**3%**	22%	3%	1%	**22%**
LV Network Voltages – Ratio of LV Networks with Both Voltage Rise&Drop Issues	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	11%	0%	0%	**11%**
Thermal Assessment																																
MV Feeder – Overloaded Conductor Length (km)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.04	0.0	0.0	**0.04**	6.6	0.04	0.0	**6.6**	9.2	3.4	0.04	**9.2**	12.9	7.3	0.04	**12.9**	18.9	8.2	1.7	**18.9**
MV Feeder – Max. Utilisation of the Worst Performing MV Segment	74%	81%	70%	**81%**	71%	66%	66%	**71%**	81%	75%	67%	**81%**	101%	86%	74%	**101%**	123%	106%	85%	**123%**	151%	117%	105%	**151%**	170%	131%	112%	**170%**	186%	138%	119%	**186%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of <=100%	100%	100%	100%	**100%**	97%	97%	97%	**97%**	91%	94%	94%	**91%**	86%	91%	91%	**86%**	79%	87%	87%	**79%**	74%	82%	83%	**74%**	68%	80%	78%	**68%**	66%	77%	76%	**66%**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 100-110%	0%	0.1%	0%	**0.1%**	1%	2%	1%	**2%**	1%	3%	2%	**1%**	3%	3%	3%	**3%**	3%	5%	4%	**3%**	4%	5%	4%	**4%**	5%	5%	5%	**5%**	5%	5%	5%	**5%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	1.0	0.0	**1.0**	0.9	0.8	0.9	**0.8**	0.8	0.7	0.6	**0.8**	0.8	0.8	0.6	**0.8**	0.7	0.7	0.7	**0.7**	0.8	0.8	0.6	**0.8**	0.9	0.9	0.6	**0.9**	0.8	0.8	0.6	**0.8**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of 110%-150%	0%	0.2%	0%	**0.2%**	2%	1%	1%	**1%**	6%	3%	3%	**6%**	6%	5%	5%	**6%**	9%	7%	7%	**9%**	11%	9%	8%	**11%**	12%	11%	11%	**12%**	13%	12%	10%	**13%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.5	0.0	**0.5**	0.9	1.6	1.0	**1.6**	1.5	1.4	0.8	**1.5**	1.5	1.3	0.7	**1.5**	1.3	1.7	0.8	**1.3**	1.6	1.5	0.8	**1.6**	1.7	1.8	0.8	**1.7**	1.8	2.0	0.7	**1.8**
Distribution Transformer – Ratio of Transformer with Max. Utilisation of >150%	0%	0%	0%	**0%**	0.1%	0%	0.1%	**0%**	1%	0%	1%	**1%**	5%	1%	2%	**5%**	8%	2%	3%	**8%**	12%	3%	5%	**12%**	15%	5%	7%	**15%**	17%	5%	9%	**17%**
Distribution Transformer – Avg. Overloading Duration (hr) [3]	0.0	0.0	0.0	**0.0**	0.5	0.0	1.5	**0.0**	1.3	4.0	0.8	**1.3**	1.6	2.5	0.7	**1.6**	2.4	2.5	0.8	**2.4**	2.6	2.5	0.8	**2.6**	3.3	2.5	0.9	**3.3**	3.5	2.8	0.9	**3.5**
Distribution Transformer – Max. Utilisation of the Worst Performing Transformer	99%	115%	90%	**115%**	166%	146%	154%	**146%**	196%	212%	165%	**196%**	277%	236%	203%	**277%**	264%	272%	227%	**264%**	291%	347%	250%	**291%**	340%	358%	292%	**340%**	367%	358%	298%	**367%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of <=100%	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 100-110%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of 110%-150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Ratio of LV Circuits with Max. Utilisation of >150%	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**
LV Circuit – Max. Utilisation of the Worst Performing LV Circuit	19%	24%	15%	**24%**	23%	22%	20%	**23%**	31%	32%	28%	**32%**	42%	34%	30%	**42%**	51%	41%	35%	**51%**	61%	43%	38%	**61%**	64%	48%	43%	**64%**	71%	54%	46%	**71%**
PV Curtailment Assessment																																
Per Customer – Max. PV Curtailment (kWh)	/	/	/	/	0.0	4.1	3.2	**4.1**	20.3	29.0	32.9	**32.9**	32.2	53.0	32.7	**53.0**	34.3	51.2	42.0	**51.2**	36.5	60.7	52.2	**60.7**	37.6	63.6	55.8	**63.6**	40.1	66.9	58.8	**66.9**
Per Customer – Ratio of Max. PV Curtailment	/	/	/	/	0%	9%	7%	**9%**	66%	58%	71%	**71%**	99%	99%	66%	**99%**	99%	90%	80%	**99%**	99%	100%	93%	**100%**	96%	98%	94%	**98%**	97%	99%	94%	**99%**
Ratio of PV Customers Curtailed	/	/	/	/	0%	100%	85%	**100%**	70%	100%	72%	**100%**	49%	100%	50%	**100%**	52%	100%	48%	**100%**	71%	100%	61%	**100%**	80%	100%	69%	**100%**	85%	100%	77%	**100%**
Aggregate Export [4] – PV Curtailment (MWh)	/	/	/	/	0.0	2.9	2.4	**808**	0.1	4.5	3.9	**1321**	1.7	4.8	4.2	**1475**	4.9	8.0	6.9	**2483**	8.5	12.2	9.8	**3613**	11.6	18.5	14.6	**5366**	14.5	24.5	17.9	**6635**
Aggregate Export [4] – Ratio of PV Curtailment	/	/	/	/	0%	7%	7%	**6%**	0%	9%	8%	**7%**	5%	8%	7%	**7%**	12%	12%	11%	**11%**	18%	16%	14%	**14%**	22%	21%	18%	**18%**	24%	25%	20%	**21%**
EV Management Assessment																																
Ratio of EVs Affected	/	/	/	/	/	/	/	/	/	/	/	/	8%	8%	7%	**8%**	12%	13%	12%	**13%**	16%	16%	16%	**16%**	20%	20%	21%	**21%**	23%	24%	24%	**24%**
Avg. EV Charging Delay (hrs)	/	/	/	/	/	/	/	/	/	/	/	/	2.7	2.8	2.6	**2.8**	3.3	3.4	3.5	**3.5**	3.4	3.7	3.7	**3.7**	3.5	3.9	3.8	**3.9**	3.4	4.1	3.7	**4.1**

8. References

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