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CEREI: An open-source tool for Cost-Effective Renewable Energy Investments

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ABSTRACT

This paper presents the development of a tool that aims to help stakeholders make informed decisions to invest in renewable energy and understand the impact of different tariffs on the economic viability of renewable energy investments. This includes evaluating the costs and benefits, and assessing the impacts of different tariff structures on the economic feasibility of those options. Furthermore, the tool can help in identifying the potential risks and challenges associated with renewable energy integration projects, such as market and network charges fluctuations. Therefore, this tool provides various evaluations to inform users about their energy consumption in relation to sport market energy prices, network tariffs, and retailer charges. It enables the assessment of a site's economic operation over specific timeframes, calculates potential energy savings from on-site renewable sources, and determines economic indicators based on life-cycle cost analysis. The tool has been designed and validated with data from the Australian energy market, focusing on investment decisions for renewable energy projects in Victoria state. It adheres to the Australian Energy Market Regulations and incorporates feed-in tariff rates particular to the Victorian energy market and its regulatory framework.

Code metadata

Current code version	v1.0.0
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-23-00676
Permanent link to Reproducible Capsule	https://github.com/uts-isf/CEREI/blob/main/README.md
Legal Code License	MIT License
Code versioning system used	git
Software code languages, tools, and services used	Java 11 or higher
Compilation requirements, operating environments & dependencies	Open JDK, Apache Maven & Windows, macOS
If available Link to developer documentation/manual	https://github.com/uts-isf/CEREI/wiki
Support email for questions	ibrahim.ibrahim@uts.edu.au

Software metadata

Current software version	v1.0.0
Permanent link to executables of this version	https://github.com/uts-isf/CEREI/tree/main/app
Permanent link to Reproducible Capsule	https://github.com/uts-isf/CEREI/blob/main/README.md
Legal Software License	MIT License
Computing platforms/Operating Systems	Any modern platform that supports Java 18 or above/Windows & macOS
Installation requirements & dependencies	Java 11 or higher
If available, link to user manual - if formally published include a reference to the publication in the reference list	https://github.com/uts-isf/CEREI/wiki
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1. Motivation and significance

Governments around the world have taken some measures and climate action to reduce greenhouse gas (GHG) emissions. Several emission reduction strategies have been set for short-, medium- and long-term, to reach net-zero target. Green power is a clear path to decarbonisation of the energy sector, as it has the most affordable zero-emission solutions. In this context, the investment in renewable energy projects has been rapidly increased to reach zero emissions or to mitigate the emissions towards the net-zero targets. On-site renewable energy solutions (on-site renewable energy solutions involve generating renewable energy directly at the location where it is used, rather than relying on remote sources. These solutions allow for immediate use of the energy produced, reducing reliance on the traditional power grid and decreasing transmission losses), such as biomass energy systems, medium-scale solar photovoltaic (PV) systems and storage batteries are attracting industry to reduce the amount of non-green energy purchased from the grid [1]. Investment in on-site renewable energy solutions requires techno-economic studies to ensure reliability of power supply at an acceptable cost. Large-scale renewable energy integration requires a detailed life-cycle cost analysis to support the investment decision in terms of net present value, payback period, and levelised cost of energy. Furthermore, the selection of the right tariff structure and feed-in tariff rate are significantly influencing the economic results and the investment decision [2]. By assessing various tariffs and rates, investors can choose a network tariff that lowers energy bills and ensures cost-effective operations with on-site renewables as well selects a feed-in tariff rate that aligns with their targeted payback period or desired rate of return.

In recent years, the cost of renewable energy has been decreasing, making it a more feasible option for electricity generation. According to the study by the International Renewable Energy Agency (IRENA) [3], the cost of renewable energy has decreased significantly over the past decade and the decreasing trends continue in the current decade. This decrease in cost has made renewable energy more accessible to both developed and developing countries [3]. Shen et al. [4] argue that the cost of renewable energy must be reduced for the successful transition to clean energy. This requires a combination of technical, economic, and policy measures to promote the use of renewable energy technologies, such as wind, solar, biomass, and hydro power. In addition, government subsidies, and motives/support schemes are crucial to reducing the cost of renewable energy and increasing its uptake. Therefore, policy makers must ensure that subsidies, and motives/support schemes are effectively targeted, transparent, and well designed to achieve their desired outcomes [5].

Network tariffs significantly influence the viability and profitability of investments. These tariffs, levied by Distribution Network Service Providers (DNSPs), vary based on factors such as energy consumption, time of usage, and peak demand. They form a considerable portion of the total electricity costs for both residential and commercial users. Therefore, understanding how network tariffs affect renewable energy investments is crucial to encourage the adoption of these sustainable energy sources. Accordingly, a study by the European Commission in 2021 [6] highlights the importance of assessing the tariffs in the network to ensure that the costs of renewable energy are fairly distributed to achieve sustainable systems [6]. This involves evaluating the tariffs applied to renewable energy sources in the electrical network to ensure that the system is sustainable and cost-effective. In a study by Böhringer et al. in [7], the authors investigated the impact of different tariffs on renewable energy sources and found that feed-in tariffs were the most effective in promoting the development of renewable energy. They also found that a combination of feed-in tariffs and grid tariffs was more effective in promoting the uptake of renewable energy. As stated by Maldet et al. in [8], network tariffs are the charges that electricity customers pay to access the electrical grid, which play a crucial role in determining the feasibility of renewable energy projects and the overall cost of renewable energy. Similarly, Lin et al. [9] explore the impact of network tariffs on the cost of renewable energy. The authors argue that high network tariffs can reduce the competitiveness of renewable energy compared to conventional energy sources, such as fossil fuels. The authors suggest that network tariffs should be carefully structured to ensure fairness and transparency, as well as not overcharge renewable energy projects.

Recent developments in renewable energy cost reduction and network tariff assessment reveal a growing accessibility to renewable energy technologies in developing countries. Based on the literature, several research gaps have been identified as follows:

- Limited understanding about the impact of different network tariffs and assets' costs on the investment in renewable energy.
- Lack of data for detailed cost-benefit studies, making it difficult to accurately assess their potential for cost reduction.
- Limited knowledge of the technical and regulatory aspects of the integration of renewable energy for the investments behind-the-meter and front-the-meter.

In this context, the cost-effective long-term investment in renewable energy requires the analysis of the various scenarios, including the availability of generated energy and the realisation of the load profile. By assuming independence among short-term possibilities, the multihorizon structure has the advantage of reducing the computing challenge, while yet allowing for robust strategic planning judgements. Consequently, the increasing demand for renewable energy to reduce greenhouse gas emissions and mitigate climate change, the increasing costs of traditional energy sources, such as fossil fuels, and the government policies and incentives for the adoption of renewable energy sources are the main drivers for developing a tool for reducing the cost of renewable energy and assessing network tariffs.

Therefore, the motivation to develop this tool is to provide stakeholders with the information and analysis necessary to make informed decisions about the deployment and integration of renewable energy systems in the state of Victoria, Australia, conforming to the market regulations and feed-in tariff rates specific to Victoria's energy market regulations. This includes evaluating the costs and benefits of different renewable energy technologies, identifying potential barriers to deployment, and evaluating the impacts of different network tariffs on the economic viability of renewable energy projects. Additionally, it can help organisations and individuals make informed decisions about their energy usage and costs. This can include identifying cost-effective ways to reduce energy consumption, assessing the potential savings from implementing renewable energy sources, and evaluating the costs and benefits of different network tariffs. Therefore, the tool can help organisations and individuals make smarter decisions about their energy usage, ultimately leading to cost savings and a more sustainable energy future. In summary, the proposed tool can support the decisions in order:

- To help industrial and commercial customers in Australia to reduce their electrical energy bills and the distribution of the on-site generation behind-the-meter.
- To help decision makers within industrial and commercial organisations based on Victoria's energy market regulations identify cost-effective renewable energy solutions.
- To support the integration of renewable energy sources into existing power systems conforming to the market regulations and feed-in tariff rates specific to Victoria's energy market regulations and to facilitate the transition to a more sustainable energy system.

In the rapidly evolving landscape of energy management and sustainability, various tools have emerged as instrumental in aiding decision-makers. These tools differ in their capabilities and features, catering to a range of needs from energy flow modelling and optimisation to life-cycle cost assessment. Table 1 presents a comprehensive comparison

Table 1
Benchmarking CEREI against prominent energy modelling tools.

Feature/Tool	RETScreen [10]	HOMER Pro [11]	PVsyst [12]	AutoGrid [13]	openADR [14]	GridLAB-D [15]	CEREI
Behind-the-meter/Front-the-meter integration	Both	Both	Behind-the-meter	Both	Both	Both	Both
DER model	Yes	Yes	Limited	Yes	Yes	Yes	No
Dynamic/static tariff model	Both	Dynamic	Static	Dynamic	Dynamic	Both	Both
Monthly/yearly energy bill	Yearly	Both	Both	No	No	Both	Both
Energy savings	Yes	Yes	Yes	Yes	No	No	Yes
Price efficiency index (PEI)	No	No	No	No	No	No	Yes
Life cycle cost assessment	Yes	Yes	No	No	No	No	Yes

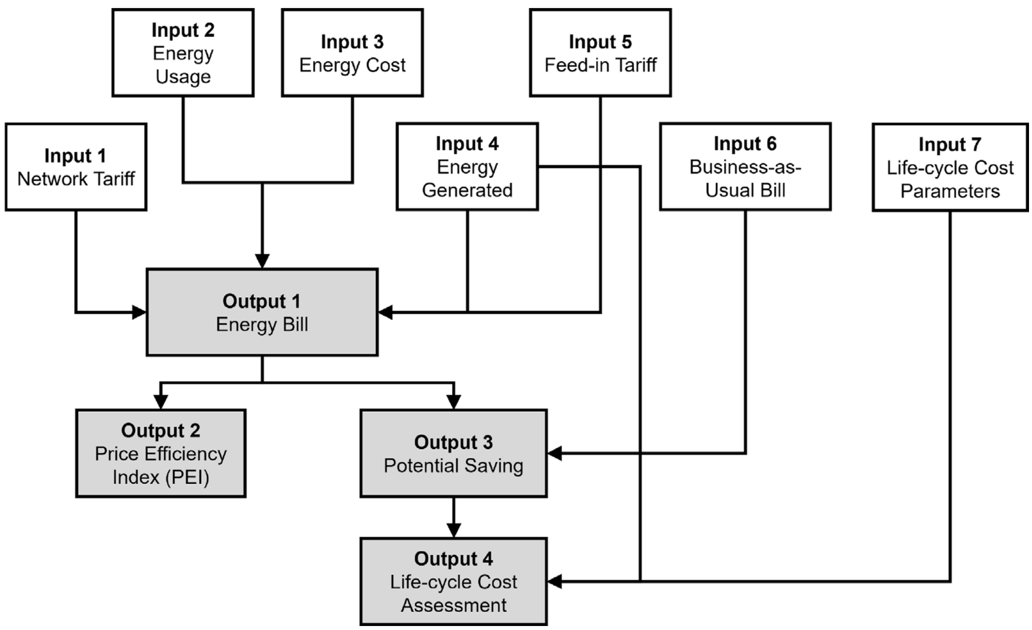


Fig. 1. Conceptual framework of CEREI.

of the CEREI tool with key energy modelling tools commonly used in the industry. This comparison highlights the unique features and capabilities of CEREI in the context of established tools, providing insights into its applications and advantages in the field of energy modelling and economic assessment.

2. Software description

The CEREI aims to aid in the decision-support process for industries that are looking to save energy, and transition to renewables while operationalising sustainability. This tool is developed in a JAVA environment, which provides stability in handling large volumes of data. The tool is single-threaded, which has just one primary thread of execution, handling tasks in a linear, sequential order. This straightforward approach to task processing, where each task is executed one after the other, lends itself well to simpler applications that do not demand much in terms of concurrent operations. Single-threaded programs are generally easier to understand and manage, making them a good fit for applications with basic concurrency needs.

2.1. Software architecture

The high-level conceptual framework of CEREI and its interface are illustrated in Fig. 1 and Fig. 2, respectively. CEREI can be used to assess the economic viability of investments in renewable energy generation on-site and different tariff structures. Economic viability is measured in the form of a new energy bill based on the nominated tariff structure, the price efficiency index (PEI), economic savings and the life-cycle cost assessment. Consequently, CEREI generates four outputs, highlighted by the green box as shown in Fig. 2. To generate the output(s), the tool allows for seven user inputs, which are highlighted by the red box as illustrated in Fig. 2. CEREI allows users to extract and save both summary and detailed results in the form of CSV files, which can be used for offline analysis and storage. The tool is developed with a data resolution of 30 min.

The seven user inputs, provided by CEREI and highlighted in the conceptual framework (see Fig. 1), are described as follows:

Input 1 – Network Tariff: The list of network parameters, including unit and time resolution, are listed in Table 2.

Input 2 – Energy Usage: The input provides the energy usage data in kWh of the grid, per meter. The data resolution is 30 min.

Input 3 – Energy Cost: The input provides the price data of the spot market in \$/kWh. In this study, Australian Energy Market Operator (AEMO) spot market price data were used with a 30 min time interval.

Input 4 - Energy generated: The input provides the on-site renewable energy generation data in kWh (the tool does not model the generation at this stage; however, the user should upload the generation file to the tool). The data resolution is 30 min.

Input 5 – Feed-in Tariff: The input provides the feed-in tariff rate data in \$/kWh. Here, a 30-minute resolution of the data is used.

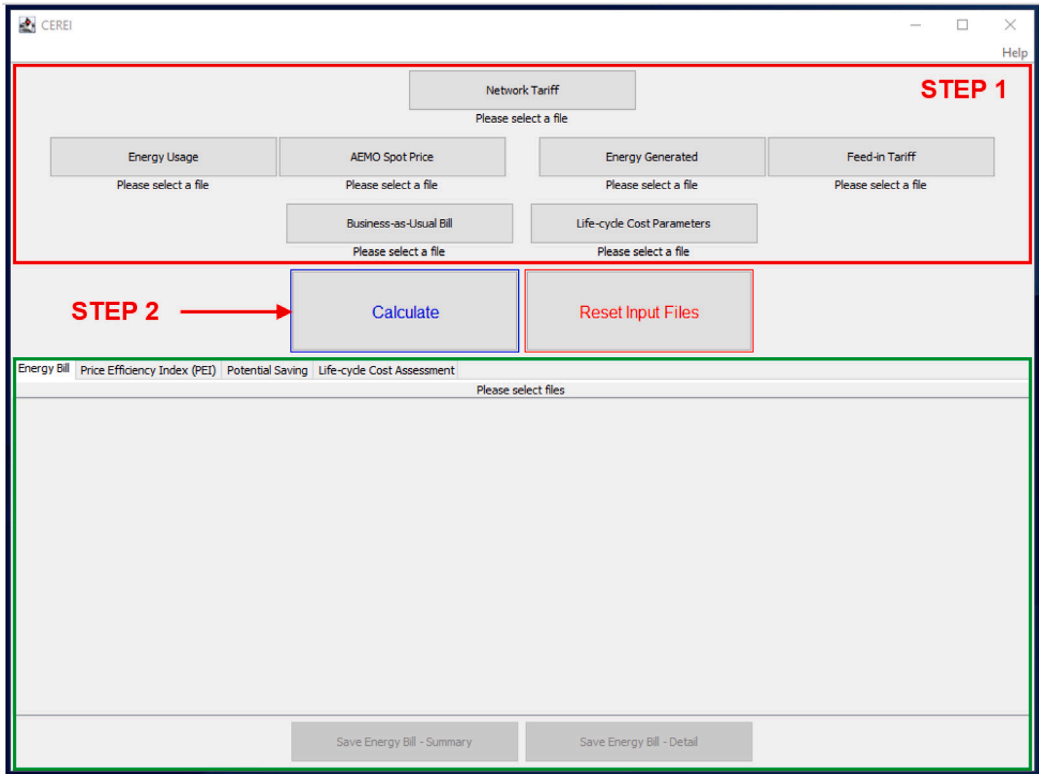


Fig. 2. CEREI interface.

Table 2
Network tariff parameters.

Category	Parameter (Unit, Resolution)
Tariff structure and meter configuration	1. Tariff Name 2. Peak, Shoulder, and Off-peak Periods 3. Meter Configuration
Energy charges	1. Loss Ratio - Spot Price (c/kWh, monthly) 2. Loss Ratio - Feed-in Tariff (c/kWh, monthly) 3. Service and Admin Charge ($/Day, monthly)
Network charges	1. Standing Charge ($/Year, monthly) 2. Peak Rate (c/kWh, monthly) 3. Shoulder Rate (c/kWh, monthly) 4. Off-peak Rate (c/kWh, monthly) 5. Demand Critical Peak Rate ($/kVA/month, monthly) 6. Demand Critical Peak (kVA, monthly) 7. Demand Capacity Rate ($/kVA/month, monthly) 8. Demand Capacity (kVA, monthly)
Market charges (these charges are applicable in Australia. If your region does not have equivalent charges, please assign a value of 0 to those that do not exist)	1. Victorian Energy Efficiency Target (VEET) Charge (c/kWh, monthly) 2. VEET Loss Ratio (c/kWh, monthly) 3. Small-scale Renewable Energy Scheme (SRES) Charge (c/kWh, monthly) 4. SRES Loss Ratio (c/kWh, monthly) 5. Large-scale Renewable Energy Target (LRET) Charge (c/kWh, monthly) 6. LRET Loss Ratio (c/kWh, monthly) 7. Australian Energy Market Operator (AEMO) Pool and Reliability and Emergency Reserve Trader (RERT) Charge (GST Exempt) (c/kWh, monthly) 8. AEMO and RERT Loss Ratio (c/kWh, monthly) 9. Ancillary Services (c/kWh, monthly) 10. Ancillary Services Loss Ratio (c/kWh, monthly)
Other charges	1. Meter Charge ($/Year, monthly) 2. CT Compliance Testing Levey ($/Yr, monthly)

Input 6 – Business-as-Usual Bill: The input provides the summary of the reference energy bill (business-as-usual bill) for the entire year, the basis of which all economic savings would be calculated.

Input 7 – Life-cycle Cost Parameter: The input provides the essential parameters for the life-cycle cost assessment. The list of parameters required for this is listed in Table 3.

Table 3
Life-cycle cost parameters.

Category	Parameter
Default parameters applicable to all components	1. Lifetime 2. Real discount rate (%) 3. General inflation rate (%) 4. Degradation rate (%)
Component specific parameters	1. Component name 2. Cost code 3. Number of units 4. Capital cost ($) 5. Installation cost ($) 6. Fixed operation and maintenance (O&M) cost ($) 7. Replacement cost ($) 8. Future cost ($) 9. Discount rate (%) 10. Inflation rate (%)

CEREI produces four outputs (See Fig. 1), each of which are briefly discussed below. The outputs can be separately generated by CEREI based on the inputs provided by the user. Here, Fig. 3 illustrates the required inputs for calculating each output.

Output 1 - Energy Bill: It provides the detailed and summary of annual energy bill. To calculate the energy bill, three inputs (i.e., Input 1, Input 2, and Input 3) are necessary under the grid import of energy, without factoring in on-site renewable energy generation. However, two more inputs (i.e., Input 4 and Input 5) are required in addition to those three inputs for on-site renewable energy generations.

Output 2 - Price Efficiency Index (PEI): PEI values are calculated for each meter and summarised for an entire year. The values reflect the economic operation of an individual site within a specific time period. The PEI values are always generated together with Output 1. Therefore, the input file requirements for PEI are identical to those of Output 1.

Output 3 - Potential Saving: This output displays the annual economic savings by comparing the summary energy bills from Output 1 and the energy bill provided by the user (Input 6).

Output 4 - Life-cycle Cost Assessment: The life-cycle cost assessment is performed here to provide economic assessment of the investment, including the levelised cost of energy (LCOE) and simple payback period. To generate Output 4, the user needs to upload all seven inputs. In the event without investment in on-site renewable energy generator and the user only aims to evaluate the feasibility of a different tariff structures, Input 4 and Input 5 can be skipped.

2.2. Software features

The calculation of the outputs can widely vary depending on the interconnection of the meters as well as the existence of the on-site renewable energy generation. The tool has been developed based on four scenarios, with and without on-site renewable energy generation. These scenarios are described below and graphically presented in Table 4.

Scenario 1: There is no on-site generation. In this scenario, the user can use the tool to calculate and analyse the monthly, quarterly, and yearly energy cost based on the new nominated tariff structure.

Scenario 2: There is an on-site generation but the energy produced is not consumed on-site. In this scenario, the user can consider that the distributed energy resource (DER) is connected to the grid through its own meter, known as front-the-meter. In this case, all the energy generated by the DER will be exported to the grid based on the feed-in tariff rate.

Scenario 3: There is an on-site generation, and it is connected to one existing meter (i.e., behind-the-meter). In this scenario, the energy generated can be consumed by the loads connected to the selected meter only and the remaining energy will be exported to the grid based on the feed-in tariff rate.

Scenario 4: There is on-site generation, and it is distributed among the existing meters (i.e., behind-the-meter). In this scenario, the energy generated will be consumed by the load in the selected meters and the remaining energy will be exported to the grid based on the feed-in tariff rate. The selection of the meters should be specified by the user in the Input 1 file. Accordingly, there are three different meter selection options as follows:

- The energy generated is distributed among the existing meters based on the priority order provided by the user.
- If Input 6 is provided, the energy generated is automatically distributed among the existing meters based on the priority created by highest to lowest annual cost of the meter from Input 6.
- Otherwise, the energy generated is distributed among the existing meters automatically based on the priority obtained from the order of the meters' appearance in Input 2.

3. Illustrative examples

The CEREI tool has been rigorously tested with 15 different case studies simulating using the possible real world scenarios. We developed 15 case studies, which are set in the "sample_data" folder in GitHub CEREI repository. In addition, blank input file templates are available in repository for the user to test and try the case studies and/or set a new case study. As part of development, real world industry data was collected and processed. The NSP83 tariff architecture (i.e., Tariff G2) was chosen in this example. The data was collected for the entire year (i.e., 2020). The site included six energy meters (i.e., NMI1 to NMI6) and a single on-site renewable energy generation.

In this paper, the results from case study 15 are presented, analysed, and discussed. The case study 15 considers Scenario 4 from Table 4, where CEREI generates all four outputs (see Fig. 1) considering on-site renewable energy generation. For this particular case, Fig. 3 dictates that CEREI needs all seven inputs (see Fig. 1) to generate the outputs.

The on-site renewable energy generator is connected to all existing meters (Case Study 15). The energy generated on-site is distributed among all existing meters, to be consumed by on-site loads, based on the priority ranking of meters obtained from the highest to lowest annual energy cost obtained from Input 6.

The annual energy bill summary from Output 1 (i.e., Energy Bill) of case study 15 by CEREI is presented in Fig. 4. It shows the summary of energy bill across each meter, per month, and per quarter. It also shows the yearly, quarterly and monthly total for individual meters and all meters combined. The positive $ values indicate cost, and the negative $ value indicates credit. This summary of the energy bill can be exported and saved as CSV file by clicking the "Save Energy Bill - Summary" button in Fig. 4.

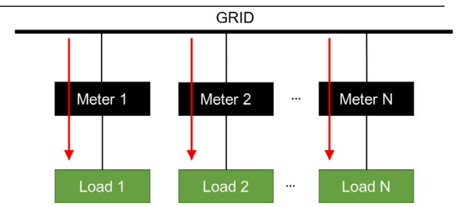
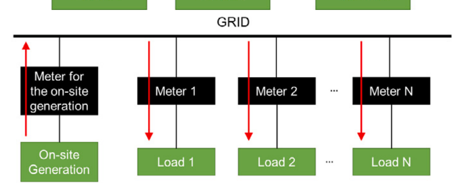
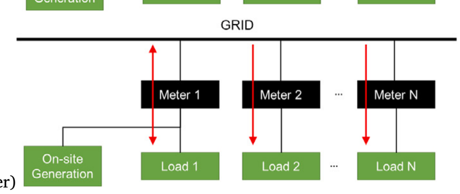
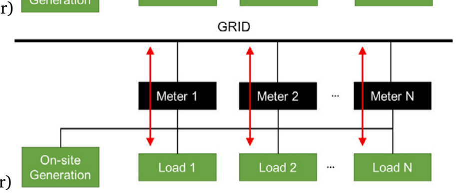
The Output 2 (i.e., Price Efficiency Index (PEI)) from case study 15 has been calculated for each meter per month, quarter and annually, which can be shown in the second tab in CEREI.

The actual values of potential savings, across each meter, per year, month, and quarter, is exclusively presented in Output 3 (i.e., Potential Saving) by CEREI. This is shown in Fig. 5. The positive $ values indicate

Outputs	Inputs						
	Input 1: Network Tariff	Input 2: Energy Usage	Input 3: AEMO Spot Price	Input 4: Energy Generated	Input 5: Feed-in Tariff	Input 6: Business-as - Usual Bill	Input 7: Life-cycle Cost Parameters
Output 1 Energy Bill	Needed	Needed	Needed	*Needed if there is an on-site generation*			
Output 2 Price Efficiency Index (PEI)	Needed	Needed	Needed	*Needed if there is an on-site generation*			
Output 3 Potential Saving	Needed	Needed	Needed	*Needed if there is an on-site generation*		Needed	
Output 4 Life-cycle Cost Assessment	Needed	Needed	Needed	*Needed if there is an on-site generation*		Needed	Needed

Fig. 3. Required inputs to generate desired output(s).

Table 4
On-site generation configuration.

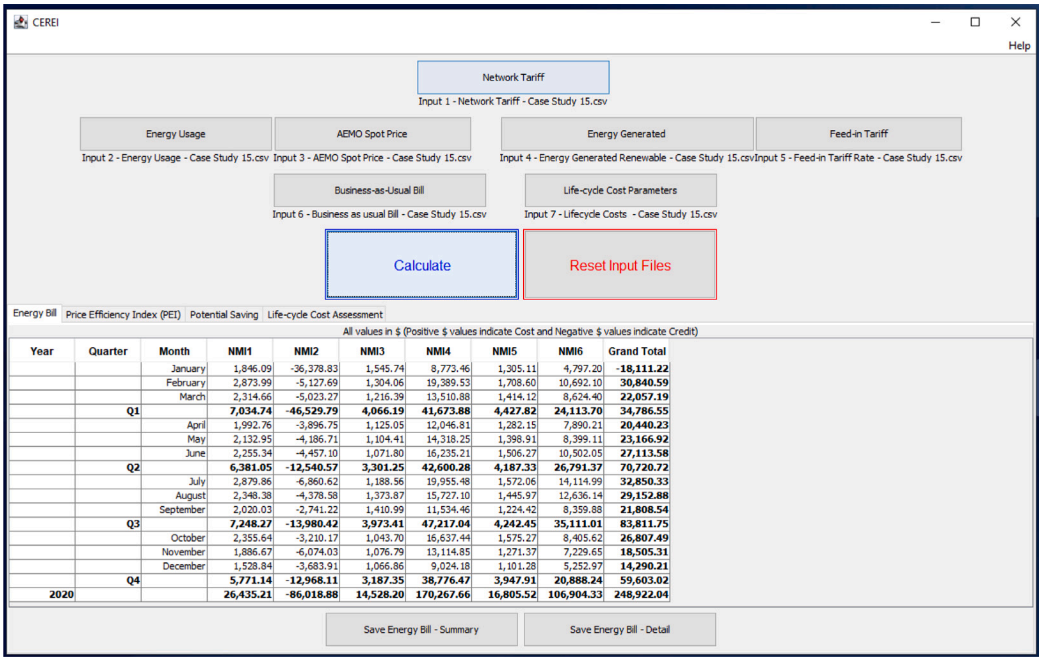
Scenario	On-site generation connection
Scenario 1 - No generation	
Scenario 2 - On-site generation connected to a separate meter (Front-the-meter)	
Scenario 3 - On-site generation connected with one existing meter (Behind-the-meter)	
Scenario 4 - On-site generation connected with all existing meters (Behind-the-meter)	

saving and the negative $ value indicates extra costs over the BAU energy bill. This result summary can be exported and saved as CSV file by clicking the “Save Potential Saving - Summary” button in Fig. 5.

The Output 4 (i.e., Life-cycle Cost Assessment) by CEREI is shown in Fig. 6. Given the new tariff structure and the existing level of consumption and generation, the payback period for investment on 10 different components across the industry, would be 14.77 years with a LCOE of 0.43 $\ kWh. This results summary can be exported and saved as CSV file by clicking the “Save Life-cycle Cost Assessment - Summary” button in Fig. 6, while the detailed assessment results can also be exported by clicking “Save Life-cycle Cost Assessment - Detail” button as shown in Fig. 6.

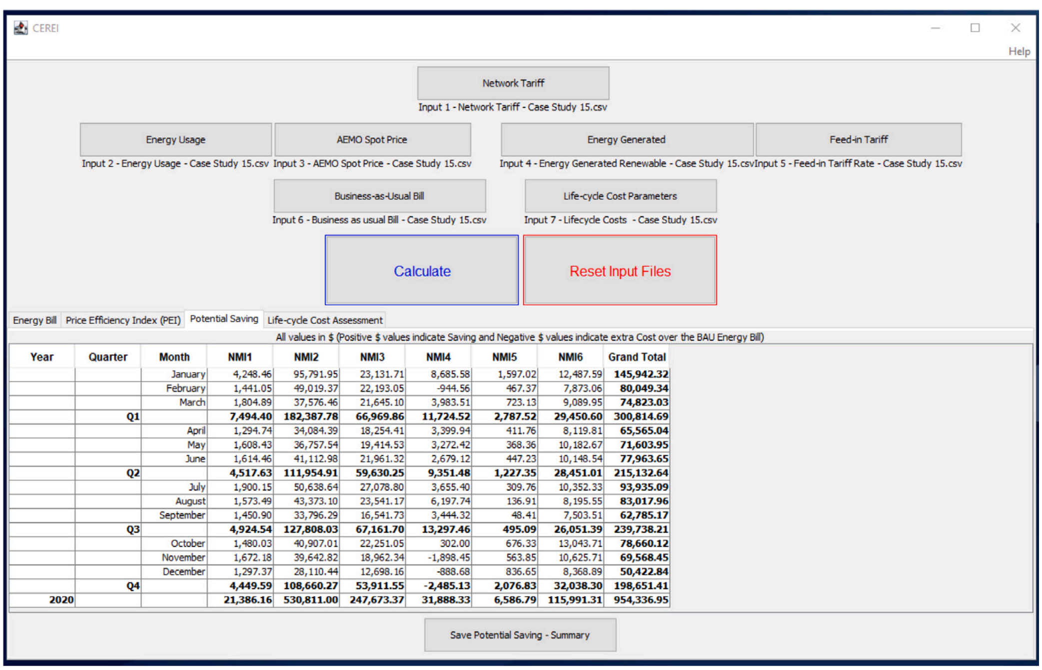
4. Impact

CEREI tool would help the users to evaluate the cost-benefits of different renewable energy options, and assess the impact of different network tariffs on the economical feasibility of those options. It would likely include features such as data input and analysis capabilities, visualisation tools, and reporting functionality to help users make informed decisions about their renewable energy investments, other on-site generation, or storage, and demand response. The tool could be used by utilities, governments, businesses, and individuals to evaluate the feasibility and cost-effectiveness of different renewable energy projects. This information can help decision makers make informed decisions about how to invest in renewable energy, identify potential



Year	Quarter	Month	NMI1	NMI2	NMI3	NMI4	NMI5	NMI6	Grand Total
		January	1,846.09	-36,378.83	1,545.74	8,773.46	1,305.11	4,797.20	**-18,111.22**
		February	2,873.99	-5,127.69	1,304.06	19,389.53	1,708.60	10,692.10	**30,840.59**
		March	2,314.66	-5,023.27	1,216.39	13,510.88	1,414.12	8,624.40	**22,057.19**
	Q1		**7,034.74**	**-46,529.79**	**4,066.19**	**41,673.88**	**4,427.82**	**24,113.70**	**34,786.55**
		April	1,992.76	-3,896.75	1,125.05	12,046.81	1,282.15	7,890.21	**20,440.23**
		May	2,132.95	-4,186.71	1,104.41	14,318.25	1,398.91	8,399.11	**23,166.92**
		June	2,255.34	-4,457.10	1,071.80	16,235.21	1,506.27	10,502.05	**27,113.58**
	Q2		**6,381.05**	**-12,540.57**	**3,301.25**	**42,600.28**	**4,187.33**	**26,791.37**	**70,720.72**
		July	2,879.86	-6,860.62	1,188.56	19,955.48	1,572.06	14,114.99	**32,850.33**
		August	2,348.38	-4,378.58	1,373.87	15,727.10	1,445.97	12,636.14	**29,152.88**
		September	2,020.03	-2,741.22	1,410.99	11,534.46	1,224.42	8,359.88	**21,808.54**
	Q3		**7,248.27**	**-13,980.42**	**3,973.41**	**47,217.04**	**4,242.45**	**35,111.01**	**83,811.75**
		October	2,355.64	-3,210.17	1,043.70	16,637.44	1,575.27	8,405.62	**26,807.49**
		November	1,886.67	-6,074.03	1,076.79	13,114.85	1,271.37	7,229.65	**18,505.31**
		December	1,528.84	-3,683.91	1,066.86	9,024.18	1,101.28	5,252.97	**14,290.21**
	Q4		**5,771.14**	**-12,968.11**	**3,187.35**	**38,776.47**	**3,947.91**	**20,888.24**	**59,603.02**
2020			**26,435.21**	**-86,018.88**	**14,528.20**	**170,267.66**	**16,805.52**	**106,904.33**	**248,922.04**

Fig. 4. Annual summary energy bill as part of Output 1 (Energy Cost) from Case Study 15.



Year	Quarter	Month	NMI1	NMI2	NMI3	NMI4	NMI5	NMI6	Grand Total
		January	4,248.46	95,791.95	23,131.71	8,685.58	1,597.02	12,487.59	**145,942.32**
		February	1,441.05	49,019.37	22,193.05	-944.56	467.37	7,873.06	**80,049.34**
		March	1,804.89	37,576.46	21,645.10	3,983.51	723.13	9,089.95	**74,823.03**
	Q1		**7,494.40**	**182,387.78**	**66,969.86**	**11,724.52**	**2,787.52**	**29,450.60**	**300,814.69**
		April	1,294.74	34,084.39	18,254.41	3,399.94	411.76	8,119.81	**65,565.04**
		May	1,608.43	36,757.54	19,414.53	3,272.42	368.36	10,182.67	**71,603.95**
		June	1,614.46	41,112.98	21,961.32	2,679.12	447.23	10,148.54	**77,963.65**
	Q2		**4,517.63**	**111,954.91**	**59,630.25**	**9,351.48**	**1,227.35**	**28,451.01**	**215,132.64**
		July	1,900.15	50,638.64	27,078.80	3,655.40	309.76	10,352.33	**93,935.09**
		August	1,573.49	43,373.10	23,541.17	6,197.74	136.91	8,195.55	**83,017.96**
		September	1,450.90	33,796.29	16,541.73	3,444.32	48.41	7,503.51	**62,785.17**
	Q3		**4,924.54**	**127,808.03**	**67,161.70**	**13,297.46**	**495.09**	**26,051.39**	**239,738.21**
		October	1,480.03	40,907.01	22,251.05	302.00	676.33	13,043.71	**78,660.12**
		November	1,672.18	39,642.82	18,962.34	-1,898.45	563.85	10,625.71	**69,568.45**
		December	1,297.37	28,110.44	12,698.16	-888.68	836.65	8,368.89	**50,422.84**
	Q4		**4,449.59**	**108,660.27**	**53,911.55**	**-2,485.13**	**2,076.83**	**32,038.30**	**198,651.41**
2020			**21,386.16**	**530,811.00**	**247,673.37**	**31,888.33**	**6,586.79**	**115,991.31**	**954,336.95**

Fig. 5. Output 3 - Potential Savings from Case Study 15.

cost savings and cost-effective solutions, and assess the potential impact of different network tariffs on the overall cost and performance of renewable energy projects. Additionally, the tool can help decision makers identify and address potential risks and challenges associated with renewable energy projects, such as regulatory or policy changes, market fluctuations, and technical challenges. Ultimately, the tool can help decision makers make more informed, effective decisions about renewable energy integration projects, which can lead to cost savings, increased efficiency, and improved environmental outcomes.

5. Extensibility

The extensibility of CEREI tool would refer to the ability to expand and adapt the tool to different scenarios and contexts. This could include the ability to add new data sources, integrate with other systems, and customise the tool for specific user needs. Additionally, CEREI tool includes the ability to easily update and improve the tool as new technologies and regulations evolve. Overall, the extensibility of CEREI makes it a flexible and adaptable tool for organisations aiming

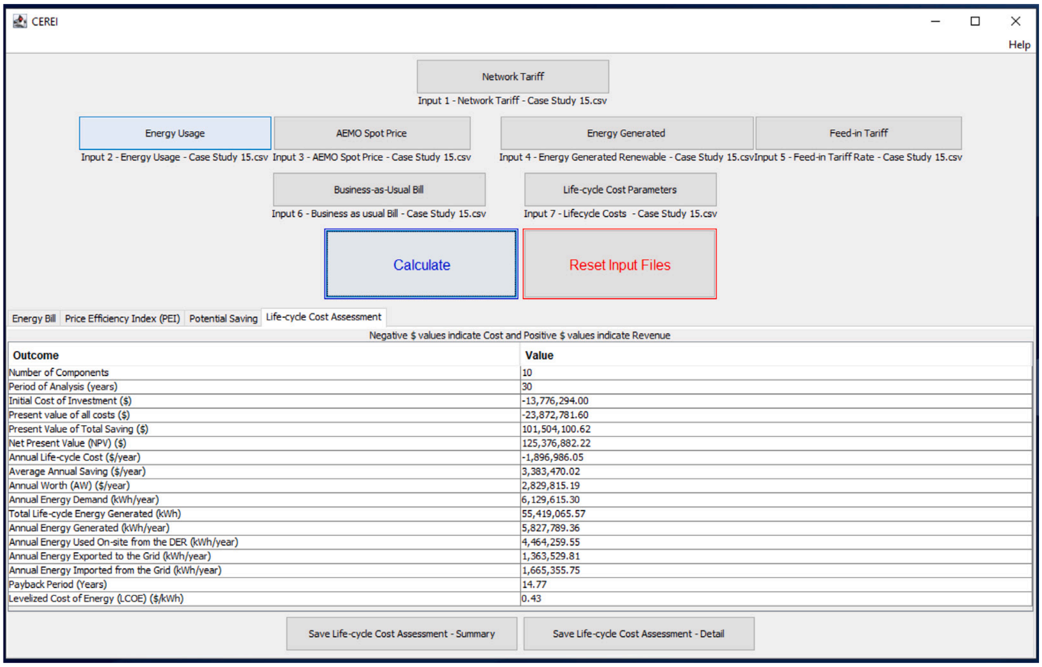


Fig. 6. Output 4 - Life-cycle cost analysis summary from Case Study 15.

to reduce their energy costs and economically assess the feasibility of on-site renewable energy sources.

CEREI tool can be considered at this stage as an energy calculation tool for the energy flow behind the meter including the life-cycle calculation assessment. Therefor, the tool has some limitations, which are considered as the future steps to extend the functionality of CEREI tool. These limitations can be summarised as follows:

- The tool, designed and rigorously tested using data from the Australian energy market, incorporates a feed-in tariff model that aligns with the unique characteristics of this market. This specificity in design means the tool's outputs are highly relevant and customised for users operating within the Australian context. The tool's architecture is flexible, allowing it to be adapted and scaled up to accommodate different parameters and tariff models from other regions, enhancing its applicability in diverse energy markets.
- The tool was developed using 30-minute time interval and then converting the data to be hourly. Therefore, the energy usage, spot market price, and FIT should be imported with 30-minute time interval. The tool can be extended to standardise the time interval based on a certain reference.
- The tool does not support the modelling of the energy source. The user should use other modelling tool to generate the time-series energy output with a timeframe matches the demand.
- The tool has been developed and tested using industrial tariff structures including TOU tariff structure (e.g., peak, shoulder, off-peak tariffs). Accordingly, it is not including flat tariffs at this stage.
- The tool is not supporting the network reliability, stability, and constraints analysis. Therefore, it considers that all of the excess energy can be exported to the grid without any curtailment, which needs to be updated in the later version.

6. Conclusions

In light of our rapidly changing energy landscape, the introduction of the CEREI tool marks a significant step forward for organisations and individuals alike. The tool has been engineered and subjected to trials utilising data from the energy sector in Australia. It aims to facilitate investment choices for renewable energy initiatives in the state of Victoria, conforming to the market regulations and feed-in tariff rates specific to Victoria's energy market regulations. The tool offers invaluable insights into energy usage and costs and serves as an essential bridge to understanding the intricacies of renewable energy investments and tariff structures. Its user-friendly interface and robust analytical capacities ensure that users receive actionable, precise, and relevant data. These insights can empower users to make strategic decisions, ensuring environmental sustainability and cost-effectiveness.

One of the notable strengths of CEREI is its ability to strike a balance between energy demand, generation, demand response, and wholesale balancing energy. This equilibrium is crucial as the world leans towards integrating renewable energy sources and phasing out traditional, non-renewable ones. Moreover, by providing a comprehensive overview of various tariff structures and renewable energy investment alternatives, CEREI aids in simplifying complex decisions, making the path to a green energy future more accessible.

Furthermore, the tool's potential extends beyond just decision-making. By allowing users to anticipate and address challenges tied to renewable energy projects, such as fluctuations in market and network charges, CEREI ensures that projects are initiated and seen through to successful completion. The importance of such a tool in today's world cannot be overstated. As we stand on the precipice of a global shift towards renewable energy, tools like CEREI will undoubtedly play a pivotal role in shaping a sustainable, cost-effective energy future.

CRediT authorship contribution statement

Ibrahim Anwar Ibrahim: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tanveer Choudhury:** Writing – original draft, Visualization, Software, Data curation. **James Sargeant:** Writing – review & editing, Visualization, Software, Data curation. **Rakibuzzaman Shah:** Writing – review & editing, Resources, Project administration, Funding acquisition. **Md. Jahangir Hossain:** Project administration, Funding acquisition. **Syed Islam:** Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data used in developing CEREI tool is located in CEREI repository, which can be accessed via the link:https://github.com/uts-isf/CEREI/tree/main/sample_data.

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Appendix. Software functionalities

CEREI performs all its calculation in logical sequence in seven steps, explained below. The first three steps involve data processing and manipulation. Once data is ready to be used, Step 4 - Step 7 are followed to calculate the four outputs associated with the required inputs based on the scenario (see Fig. 1).

Step 1. Incorporation of loss ratio: This step involves incorporation of relevant loss ratio to: (i) spot market price (obtained via Input 3 from Fig. 1), (ii) feed-in tariff (obtained via Input 5 from Fig. 1), and (iii) market charges (obtained via Input 1 from Fig. 1 that includes VEET charge, SRES charge, LRET charge, AEMO and RERT charge, and ancillary services - details of which are provided in Table 2). The loss ratios are obtained from Input 1 (see Fig. 1 and Table 2).

Therefore, the calculation flowchart for Step 1 is presented in Figs. A.1 and A.2. All loss ratios (for spot price, feed-in tariff and market charges) are in the monthly interval (in c/kWh). To calculate the monthly market charges, which account for the loss ratio, the two values are directly combined. Subsequently, it is converted into daily 30-minute interval data, given in Fig. A.1. Conversely, the spot price and feed-in tariff are recorded as 30-minute interval daily data. For this reason, the relevant loss ratios are initially converted to daily 30-minute interval data before being incorporated into the spot price and feed-in tariff values. This results in spot price and feed-in tariff values with loss ratio as given in Fig. A.2.

Step 2. Calculation of net energy: The aim of this step is to calculate the net energy imported from the grid and/or exported to the grid, considering the energy usage reading from meters (i.e., National Metering Identifier (NMI)) provided by the user (Input 2 in Fig. 1) and on-site renewable energy generation values provided by the user (i.e., Input 4 in Fig. 1). The calculation flowchart is presented in Fig. A.3. The net energy is calculated by subtracting the value of on-site renewable energy generated from the energy usage value from the on-site electrical meters. A positive net energy value shows that energy have been imported from the grid. A negative net energy value means that there has been no energy import from the grid, and the excess energy coming from the on-site renewable energy generation is being exported to the grid.

Step 3. Finding time of use energy during peak/off-peak/shoulder: This step finds the net energy imported from the grid during the peak time (peak energy usage), off-peak time (off-peak energy usage) and shoulder time (shoulder energy usage) based on the chosen tariff structure by the user, and the "Net Energy Imported from the Grid" from Step 2 (daily 30-minutes interval data measured in kWh). From the obtained daily 30-minutes data, CEREI calculates the aggregate peak, off-peak, and shoulder energy usage in kWh for the entire month. CEREI also calculates the aggregate net energy imported from the grid for the entire month. The calculation flowchart is presented in Fig. A.4. The tariffs considered for the development of CEREI are: (i) Tariff G1 (e.g., NSP81); and (ii) Tariff G2 (e.g., NSP82, and NSP83), which are structured as follows:

Tariff G1: The components within this tariff structure are:

- Standing charge ($/year)
- Peak rate (c/kWh) is considered between 7am to 11pm, Monday to Friday
- Off-peak rate (c/kWh) is considered at all other times
- Capacity ($/KVA/year)
- Critical peak demand ($/KVA/year)

Tariff G2: The components within this tariff structure are:

- Standing charge ($/year)
- Peak rate (c/kWh) is considered between 7am to 10am and 4pm to 11pm, Monday to Friday
- Shoulder rate (c/kWh) is considered between 10am to 4pm, Monday to Friday
- Off-peak rate (c/kWh) is considered at all other times

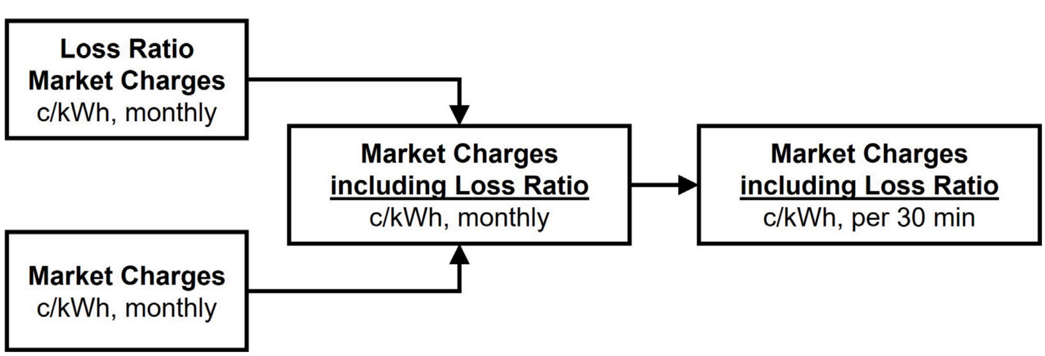

Fig. A.1. Flowchart for calculation of market charges with loss ratio.

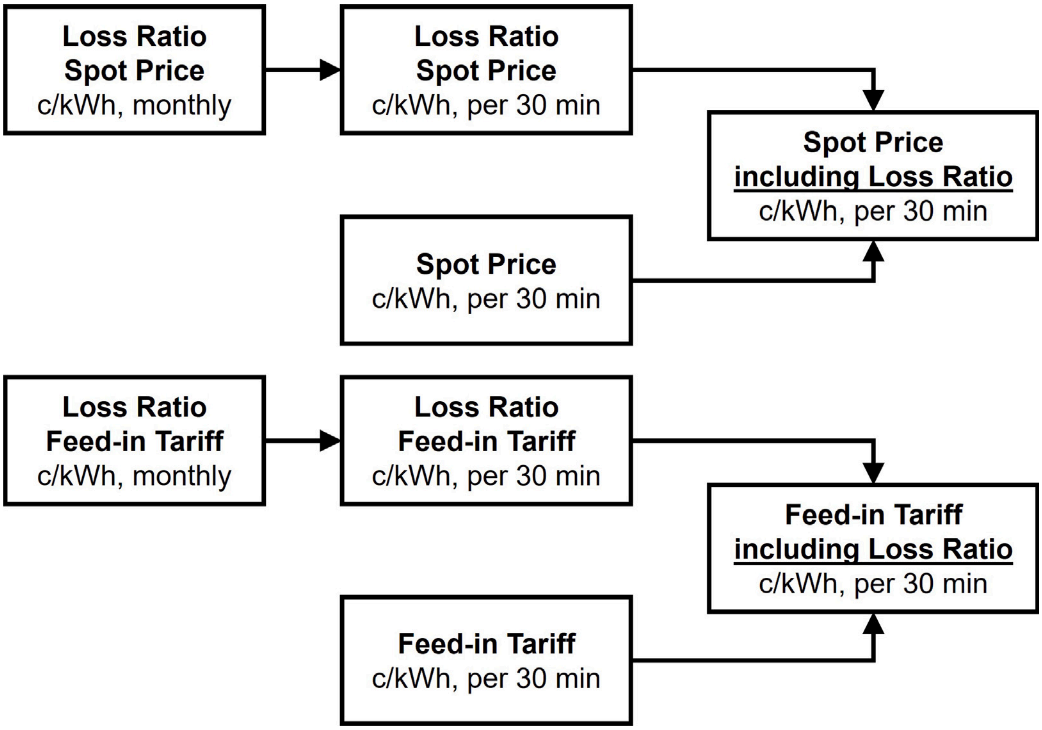

Fig. A.2. Flowchart for calculation of spot price and feed-in tariff with loss ratio.

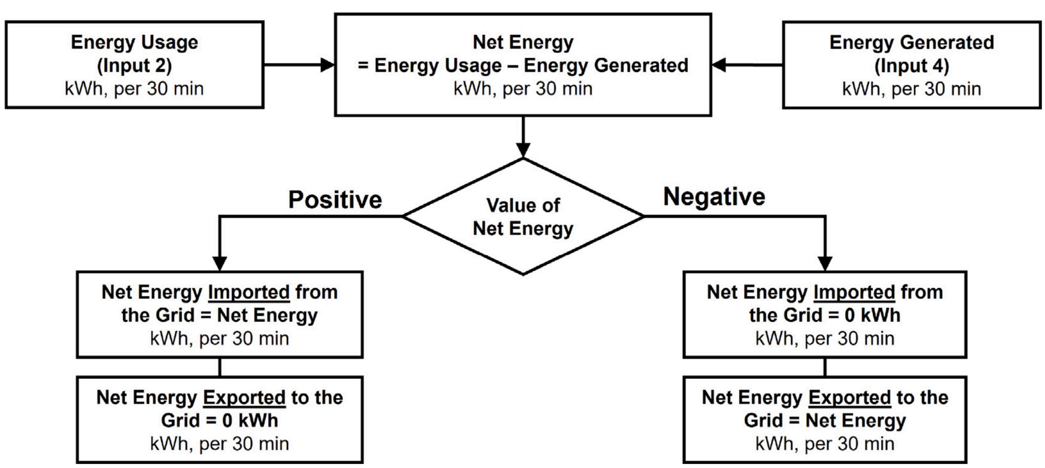

Fig. A.3. Flowchart for calculation of net energy.

- Capacity ($/KVA/year)
- Critical peak demand ($/KVA/year)

Step 4. Calculation of Output 1 - New Energy Bill: The total monthly energy bill is calculated by summing the following individual sub-categories: (i) energy charges, (ii) network charges, (iii) market charges, (iv) other charges. In this context, the energy charge calculation flowchart is presented in Fig. A.5. In addition, the network charge calculation flowchart is illustrated in Fig. A.6. Moreover, the market charge calculation flowchart is given in Fig. A.7. Finally, the other charge calculation flowchart is presented in Fig. A.8. From the monthly bill, the quarterly and annual bill can be calculated, which forms Output 1 (Fig. 1).

Step 5. Calculation of Output 2 - PEI: Using spot price (including loss ratio), total network and market charges, along with net energy imported from the grid, monthly, quarterly, and yearly PEI parameter are calculated, which forms Output 2 (Fig. 1). In this context, the PEI calculation flowchart is presented in Fig. A.9.

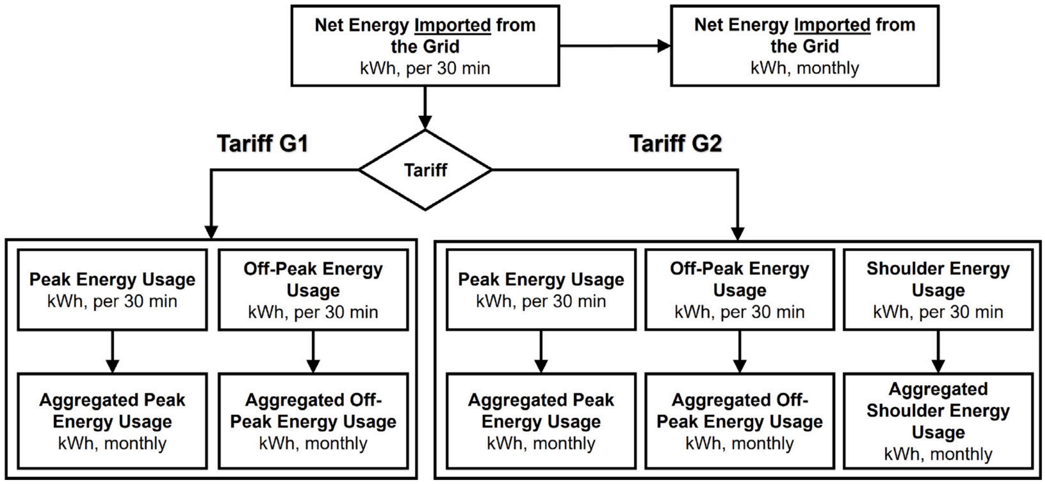

Fig. A.4. Flowchart to calculate net and aggregate energy usage during peak, off-peak, and shoulder time.

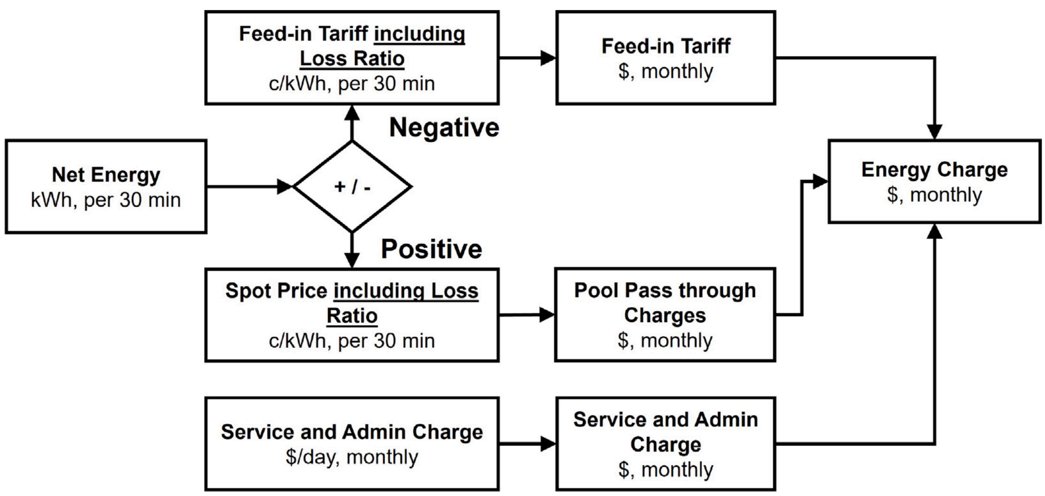

Fig. A.5. Flowchart for calculation of energy charges as part of Output 1.

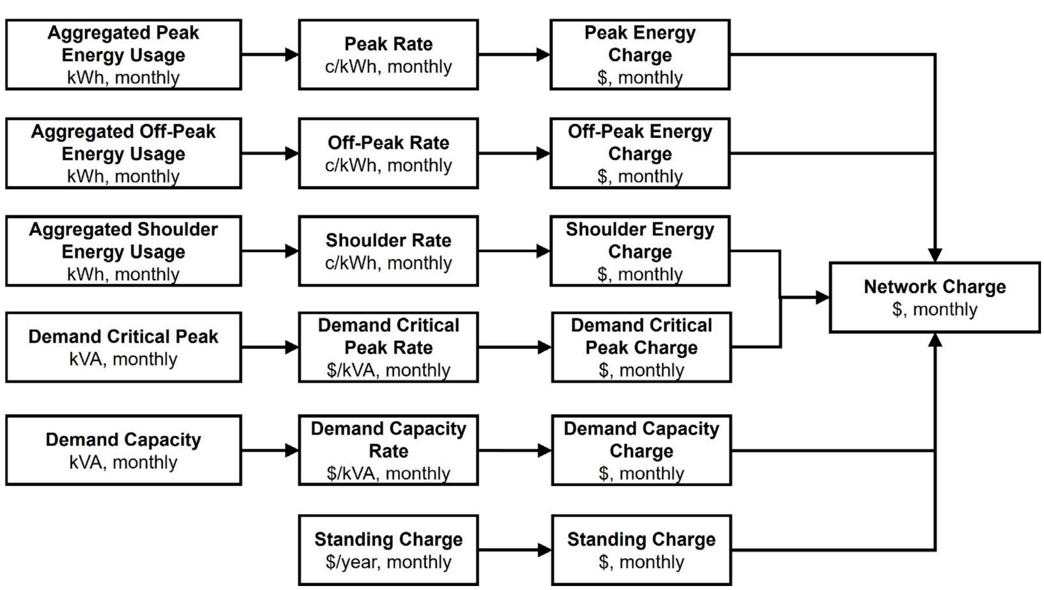

Fig. A.6. Flowchart for calculation of network charges as part of Output 1.

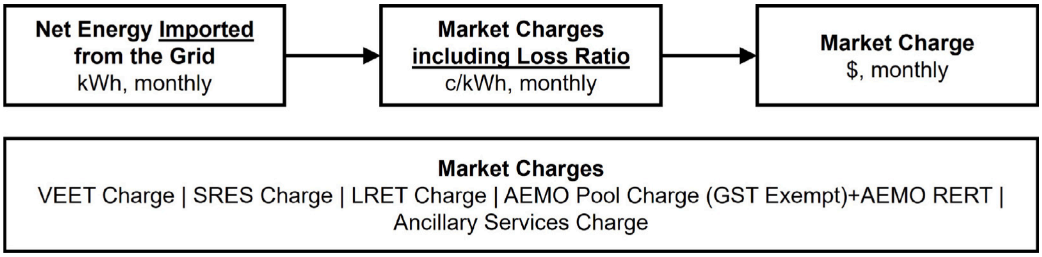

Fig. A.7. Flowchart for calculation of market charges as part of Output 1.

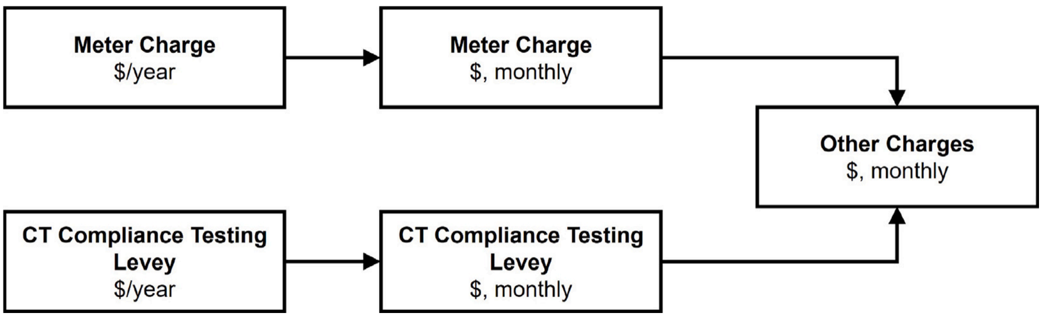

Fig. A.8. Flowchart for calculation of other charges as part of Output 1.

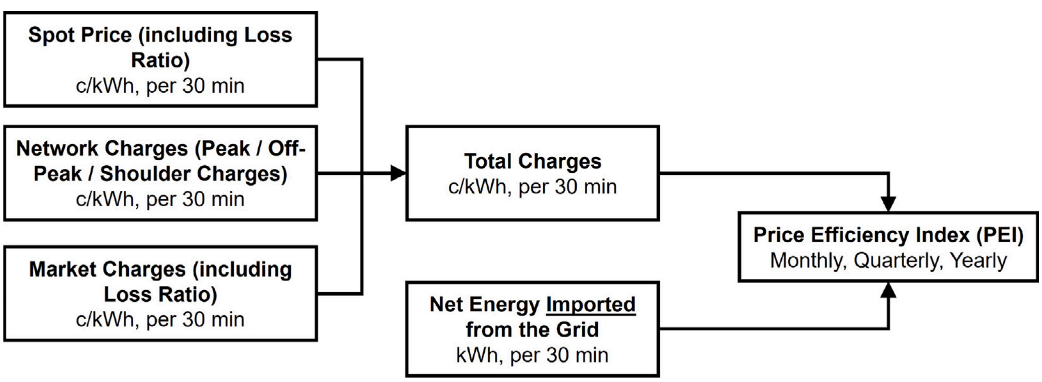

Fig. A.9. Flowchart for calculation of Price Efficiency Index (PEI).

Step 6. Calculation of Output 3 - Savings in Energy Bill: Comparing the annual summary energy bill from Output 1 and user provided business-as-usual (BAU) bill (Input 6 in Fig. 1), the annual savings in energy bill are calculated, which forms Output 3 (Fig. 1).

Step 7: Calculation of Output 4 - Life-cycle cost assessment: Using Input 7, along with all the other inputs (this could exclude Input 4 and Input 5 in case of no on-site renewable generation investment option), the tool performs life-cycle cost assessment for the capital investments (relating to capital, installation, replacement, future, and operational and maintenance costs) considering BAU energy bill, potential savings, lifetime, discount rate, inflation rate, and degradation rate, which forms Output 4 (see Fig. 1).

References

[1] Ahmed A, Ge T, Peng J, Yan W-c, Tuan B, You S. Assessment of the renewable energy generation towards net-zero energy buildings : A review. Energy Build 2022;256:111755. http://dx.doi.org/10.1016/j.enbuild.2021.111755.

[2] Sadiq R, Karunathilake H, Hewage K. Renewable energy selection for net-zero energy communities : Life cycle based decision making under uncertainty. Renew Energy 2019;130:558–73. http://dx.doi.org/10.1016/j.renene.2018.06.086.

[3] IRENA. Renewable power generation costs in 2019. Tech. rep., IRENA; 2020, p. 144, URL www.irena.org.

[4] Shen W, Chen X, Qiu J, Hayward JA, Sayeef S, Osman P. A comprehensive review of variable renewable energy levelized cost of electricity. Renew Sustain Energy Rev 2020;133(August):110301. http://dx.doi.org/10.1016/j.rser.2020.110301.

[5] Zhang W, Chiu Y-b. Country risks, government subsidies, and Chinese renewable energy firm performance: New evidence from a quantile regression. Energy Econ 2023;106540. http://dx.doi.org/10.1016/j.eneco.2023.106540.

[6] European Commission. Renewable energy. 2023, URL https://energy.ec.europa.eu/topics/renewable-energy_en.

[7] Böhringer C, Cuntz A, Harhoff D, Asane-otoo E. The impact of the german feed-in tariff scheme on innovation : Evidence based on patent fi lings in renewable energy technologies. Energy Econ 2017;67:545–53. http://dx.doi.org/10.1016/j.eneco.2017.09.001.

[8] Maldet M, Huglen F, Schwabeneder D, Lettner G, Crespo P, Saif A, et al. Trends in local electricity market design : Regulatory barriers and the role of grid tariffs. J Clean Prod 2022;358(September 2021):131805. http://dx.doi.org/10.1016/j.jclepro.2022.131805.

[9] Lin B, Chen J, Wesseh Jr PK. Peak-valley tariffs and solar prosumers : Why renewable energy policies should target local electricity markets. Energy Policy 2022;165(March):112984. http://dx.doi.org/10.1016/j.enpol.2022.112984.

[10] RETScreen Innovation Lab. RETScreen clean energy management software. 2023, URL https://natural-resources.canada.ca/maps-tools-and-publications/tools/modelling-tools/retscreen/7465.

[11] HOMER Energy. HOMER energy. 2023, URL https://www.homerenergy.com/.

[12] PVsyst SA. Pvsyst. 2023, URL https://www.pvsyst.com/features/.

[13] AutoGrid System. AutoGrid. 2023, URL https://www.auto-grid.com/.

[14] OpenADR Alliance. openADR. 2023, URL https://www.openadr.org/.

[15] Battelle Memorial Institute. GridLAB-D. 2023, URL https://www.gridlabd.org/.