A Technology Assessment Approach for Achieving Sustainable Communities: An Energy Master Plan for a New Urban Development

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Featured Application: A technology assessment approach is proposed that is based on the triple bottom line framework for energy master planning for communities; A tool database and a technology database have been developed that include technical, social, environmental and economic parameters; The application of the framework is demonstrated through a case study of a new development; The connection between this approach and the UN SDGs, as well as state and national policies and regulations, is discussed.

Abstract: In the era of climate change and rapid urbanisation, communities and infrastructures need to be planned and designed in a way that promotes sustainable living. The provision of clean and affordable energy is a key to this aim. This paper proposes a technology assessment approach that is based on the triple bottom line (environmental, social and economic) sustainability framework. This approach can be employed in the technology screening that is involved in the early stages of the energy master planning process and can be applied to different community typologies in various locations and climates. The developed approach is demonstrated through a new urban renewal project case study in Fishermans Bend, Melbourne, in which a set of technological options were screened according to the project’s goals. The connection between the energy master plan and local and global sustainable development goals is discussed and policy interventions are proposed. The results show that the proposed approach could effectively enable the evaluation of the technological sustainability performance of the community by demonstrating the design trade-offs and the implementation of the sustainability objectives during the energy master planning process. Moreover, the proposed approach could provide guidance for effective policy making. It was found that government energy policies, regulations and incentives play a vital role in the feasibility of an energy master plan. Lastly, the proposed approach could facilitate the achievement of local and international targets, such as the UN SDGs, by 2050.

Keywords: energy master planning; technology screening; sustainable development goals; 3BL approach; community planning

1. Introduction

Despite the growing awareness of climate change, anthropogenic greenhouse gas (GHG) emissions are still set to increase [1], which is mainly due to rapid urbanisation coupled with increased migration, material production and energy consumption. If left unabated, the continuous warming of the earth could lead to catastrophic consequences. Alarmed by this present and future instability, many countries around the world are now pushing for sustainable design to be incorporated into new infrastructures. Moreover,
countries are gearing up for more ambitious environmental targets that are aimed at mitigating and adapting to the impacts of climate change by considering various dimensions of sustainability in the planning, design and assessment of infrastructures.

Sustainable solutions for meeting the net-zero emission targets include technologies that are used for renewable energy source capture and storage, energy efficiency measures and energy policies and frameworks. At present, the implementation of such solutions is primarily only concentrated and well adopted at an individual buildings/facilities/infrastructure level, in which technologies and measures are freely initiated by individual owners [2]. This approach may promote self-sustainability; however, there may be individual buildings that face design constraints that could limit their ability to contribute to and comply with overall sustainability targets. Instead of the individual buildings approach, a community/neighbourhood-level approach for energy master planning (EMP) could offer more benefits [2–4]. However, while there are existing methods for energy technology screening, most are not applied at the community level, the indicators or criteria are not usually utilised or regarded in EMP and there are limitations to the analysis of the technologies and policy linkages [3,5–8]. Integrated community EMP is not only crucial in the selection of appropriate renewable energy (RE) or energy-efficient (EE) technologies for implementation, but also in the mapping out of target achievements that are based on that community’s environmental, social and economic targets.

This study aimed to develop a structured technology assessment approach for an EMP and a conceptual design stage based on the triple bottom line (3BL) context. The suitability and perceived benefits of a standardised technology assessment approach were demonstrated through a case study on the residential precinct of Fishermans Bend (FB) Urban Renewal Project in Melbourne, Australia. Various supporting policies and incentives were also identified that could facilitate smooth and fast energy transition. Finally, the suitability of the recommended alternative scenarios and technologies for meeting both the goals of the city and the United Nations Sustainable Development Goals (UN SDGs) was explored.

The introduced approach could provide important guiding principles and a standard methodology for technology assessment that fulfils sustainability targets at the community level. Moreover, it could facilitate the achievement of energy and emission goals at the community level. The approach also allows for the analysis of the business as usual (BAU) model and other sustainability pillar scenarios. The results could inform the selection of the optimal RE and EE technology mix, which is expected to contribute towards achieving a greater sustainability goal for the city and the country. Furthermore, it could serve as a tool to help to prioritise and integrate sustainable initiatives into the development and policy plans of cities and countries across the globe. Specifically, the introduced approach could guide planners, decision makers, business owners and stakeholders in the early stages of energy master planning and design.

In the following section, the state-of-the-art EMP process is reviewed and current developments, existing gaps and potential future solutions are identified. Next, the Section 3 describes the construction of the proposed EMP framework and its application in the case study area. Sections 4 and 5 present the outcomes of the 3BL approach when used as part of the EMP framework in terms of the prioritisation of selected technologies. In the same section, a critical evaluation of SDG achievement, current knowledge and future research recommendations are also discussed. Finally, Section 6 provides a summary of the main points of the research. Full list of Abbreviations is provide in Appendix A.

2. Background

At the global level, the UN SDGs set ambitious goals and general guidelines for tackling the most pressing challenges that are facing humanity. It calls for collective and collaborative efforts from all countries to commit to and ramp up cross-cutting sustainable solutions into various issues that affect society, the environment and the economy. Aus-
Australia’s commitment to reducing its GHG emissions is in line with the UN SDGs, which are at the heart of the 2030 Agenda for Sustainable Development [9].

The reduction in GHG emissions through increasing the share of renewable sources in energy production is central to the SDGs. In a similar fashion, Australia is also moving forwards in terms of reducing the use of coal power plants for energy generation through the impositions of coal moratoriums and the retirement of old coal-fired power plants. As a result, coal-based energy generation is slowly being replaced by various RE technologies. Most of the efforts at the regional, state and national levels concentrate on putting policies, regulations and incentives in place to support and enable the transition from the outdated carbon economy into a sustainable energy economy.

Although mechanisms for achieving the country-wide goals for energy transition seem to be the focus, there is still the need to strengthen collective efforts, especially within the cities and communities in which the most impacts can be made on climate change and potential sustainable changes. Cities are the greatest contributors to energy-related GHG emissions, which amount to around three quarters of total worldwide emissions [10]. Emissions from cities are largely driven by community activities, energy consumption or use and infrastructure development. Therefore, to mitigate and reduce city emissions, the focus needs to be on the decarbonisation of communities (i.e., neighbourhoods or districts) with the help of EMP.

EMP is a tool to aid and guide cities in the mapping of their energy sources, demands and consumptions and to initiate proper implementation processes [5]. The concept of EMP includes the selection of suitable technologies, policies and frameworks to effectively support not only local goals (e.g., council goals), but also global targets (e.g., UN SDGs). EMP at the community level is considered to achieve most of the national and subnational targets. Certain buildings within a neighbourhood can compensate for the failure of other individual buildings to comply with the targets [2]. Given that spatial planning has an influence on various urban development decisions (e.g., land use, mobility, infrastructure), the community-level application of EMP could be highly beneficial. It also allows EMP to explore different types of energy transition and different development strategies by leveraging energy-related technologies, policies and frameworks.

However, the use of EMP still presents several challenges. While EMP provides appropriate guidance for political institutions, businesses and individuals, it is still an uncommon practice both in general and especially within urban planning integration. Despite the awareness of the direct interrelationship between energy systems and the physical and functional aspects of urban development, a gap remains in terms of tying together these two approaches [11]. Mostly, if not always, energy-related planning and strategies are neglected in the process of spatial and urban planning. Another gap that has been identified is that the indicators or criteria that are utilised for EMP development vary on a case-by-case basis according to project goals, thus making it difficult to replicate in different projects or areas. The study of Neves and Leal [12] found that the identification and use of indicators as criteria for decision-making is not a common practice in many energy and climate action plans. For instance, the original EMP for Sicily was prepared in 2004 [13] and only consists of indicators that are focused on the economic aspects of the plan. This neglects other indicators and metrics that are crucial for achieving energy- and emissions-related targets; therefore, it is not ideal to adopt this approach in other EMPs. The inclusion, further analysis and evaluation of missing indicators is recommended to achieve a well-integrated EMP and a system that is sustainable overall [3]. Another challenge in EMP development is the lack of a single structured decision-making tool or model to guide planners in the selection of the best technologies or approaches for meeting energy and climate goals [14,15]. While there are methodologies and stages of EMP development that have been prescribed in the literature [2,7,8,15,16], they are often general in nature or lack integrated approaches. Specific steps, such as assessing BAU and other scenarios, have not been explicitly identified. Moreover, there are no existing works that provide discussions or methods regarding how EMPs could establish a link between achieving sustainable goals
at the community level within a set timeframe, supporting global SDGs and informing policy decisions in relation to the results of the approach.

2.1. Australian Policy and Regulation

This section provides the context of the existing national, state and municipal policies and regulations that apply to this case study. The discussion focuses on the policies and regulations that are related to GHG emissions, renewable energy and energy efficiency, as these themes are considered to be of greater relevance for EMP deployment.

2.1.1. GHG Emission Reduction

In the context of the Paris Agreement, Australia has set a national target of reducing GHG emissions to 26–28% below 2005 levels by 2030 [17] and reaching net-zero by 2050. Several Australian states have also taken the initiative to set their own net-zero GHG emissions targets. The Victorian Climate Change Act 2017, which has been in force since November 2017, established the long-term target of achieving net-zero GHG emissions by 2050 [18]. By means of its Climate Change Mitigation Strategy [19], the city of Melbourne committed to the same target of reaching net-zero emissions before 2050. However, Melbourne declared a climate and biodiversity emergency in 2019 and the net-zero target for the municipality was brought forward to 2040 [20]. Within this strategy, the development of zero-emissions buildings and precincts is considered a priority.

2.1.2. Renewable Energy

The Renewable Energy Target (RET) is an Australian Government scheme that was designed to encourage energy generation from renewable sources in order to achieve the national target of approximately 23.5% renewable energy generation by 2020 [21]. The RET is expected to be in force until 2030 and is divided into two core components: the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). RET participants who invest in or generate renewable energy may be eligible for financial incentives under the scheme [22]. All residential and commercial buildings that have PV systems with a 100 kW rating or less and an annual electricity output of no more than 250 MWh are eligible for the SRES [23]. In the case of FB, only PV systems that were installed before 2030 benefit from this scheme.

At the state level, Victoria currently has targets for the share of renewable electricity generation to be 25%, 40% and 50% by 2020, 2025 and 2030, respectively [24]. Victoria’s Renewable Energy Target (VRET) package includes the Solar Homes Program, which provides a rebate of up to AUD 1400 for solar panel (PV) system installation [25]. The Solar Homes Program also includes a solar battery rebate option of up to AUD 3500, which is available for all eligible households in Victoria that have solar panels [26,27].

The City of Melbourne’s Climate Change Mitigation Strategy [19] aspires to have the city being powered by 100% renewable energy by 2050 and is committed to facilitating Power Purchase Agreements (PPA) for businesses through the Melbourne Renewable Energy Project (MREP). To date, PPAs that were articulated by the MREP have enabled the development of two wind farms in Victoria [28]. A PPA is a long-term agreement between the seller and the purchaser of wind energy. Attaining a PPA is a key incentive for the development of wind farms because it secures a long-term revenue stream through the sale of energy and thus, is critical for managing risks and securing financing for the project [29].

The electricity distributor in the FB area, CitiPower, supports the uptake of rooftop PV generation that can be interconnected with their network through a pre-approval process. Key requirements include the installation of “smart meters” that are in accordance with the National Electricity Rules and the use of “smart inverters” that are compliant with AS4777 [30]. Following the approval of an application and the subsequent connection to the grid, the user is able to export their surplus PV energy for a feed-in tariff (FiT), which is offered by the chosen retailer. The minimum FiT rates are defined annually by the Essential Services Commission (ESC) of the state of Victoria. The minimum flat rate FiT that is in
force for the 2020–21 financial year (starting 1 July 2020) is AUD 0.102/kWh [31]. However, the ability of the network to absorb the solar export can be limited in many areas, which can restrict the amount of energy that is exported by each system and therefore, the revenue from that energy [32]. This information must be considered in order to correctly size the PV systems prior to their purchase and installation. The future residents of FB could potentially benefit from the feed-in tariffs once their rooftop PV systems are operating and connected to the grid. It is important to note that the specifications of the small embedded generators must comply with the Electricity Distribution Code, which is set by the ESC [33].

2.1.3. Energy Efficiency

The National Energy Productivity Plan (NEPP) is a package of measures that aims to improve Australia’s energy productivity by 40% between 2015 and 2030 [34]. One of the key initiatives that addresses the NEPP target is provided in the Trajectory for Low Energy Buildings, which was released in 2019 and outlines policies that deliver cost-effective energy efficiency improvements for homes and businesses [35]. One of the proposed actions is to perform triennial revisions to the National Construction Code (NCC) requirements in order to incorporate measures for energy productivity. Several policy initiatives that support this activity are already underway.

The Victorian Energy Upgrades (VEU) program (formerly the “VEET scheme”), which was established under the Victorian Energy Efficiency Target Act 2007, helps Victoria residents to reduce their energy bills and GHG emissions by providing access to discounted energy-efficient products and services. Large energy retailers are required to acquire and surrender Victorian Energy Efficiency Certificates (VEECs) to meet the annual targets that are set in Victorian legislation [36]. The target that has been announced for 2021 is 6.5 million VEECs, progressively increasing to 7.3 million certificates by 2025 [37]. The targets for 2026 and beyond have not yet been defined. Each certificate represents one tonne of abated GHGs. The “accredited persons” who carry out the upgrade activities by installing energy-efficient products in residential or non-residential premises can create VEECs. The number of VEECs that are created depends on the GHG savings that are obtained from the upgrade. Activities that create VEECs include the installation of energy-efficient appliances (lamps, television, refrigerators, etc.), space conditioning services (window replacement/retrofit and weather sealing) and the installation of heat pumps, among others [38]. The VEU program has no stipulated end date, so it is assumed that it will remain in place throughout the whole duration of FB’s development.

New homes and significant home renovations in Victoria must meet minimum energy efficiency requirements that are mandated by the NCC. There are a few options for demonstrating compliance with these requirements, but by far the most popular pathway is by obtaining a 6-star rating via the Nationwide House Energy Rating Scheme (NatHERS) [39,40]. Under this scheme, houses are given a star rating from 0 to 10 that is based on the energy efficiency of their design. The rating considers many factors, including the building envelope (the roof, walls, floor and windows), the orientation and the type of glazing. The higher the star rating, the less energy is needed to heat and cool the home in order to keep it comfortable. For example, a 6-star NatHERS residential building in the Melbourne area requires a maximum thermal energy load of 114 MJ/m² per annum [41].

Office and commercial buildings, on the other hand, are assessed using the National Australian Built Environment Rating System (NABERS), which ranges from one to six stars [42]. This rating involves several parameters, including the intense energy load that is required by office equipment, lighting and computers. Australia’s Commercial Building Disclosure policy mandates all sellers/lessors of eligible commercial buildings to disclose information that is related to the building’s NABERS rating. This information-based policy intends to ensure that prospective buyers/tenants are informed about the building’s energy performance and to stimulate owners to make investments to improve the building’s energy efficiency [43].
3. Methods

In this section, the proposed EMP approach, assessment methods, modelling tool and case study are described.

3.1. EMP Framework

The EMP framework that was proposed in [3] was adapted and amended to satisfy the aim and objectives of this paper. The framework and steps are shown in the flowchart in Figure 1. The first step was to determine the client objectives and the project data (such as data regarding available technologies) with the required level of detail (Step A in Figure 1). Then, the proper planning approach and engineering formulations to be used in the planning and design of the energy system were employed (Step B in Figure 1). In this study, a top-down approach was followed. The triple bottom line criteria and metrics that are in line with the client and project goals needed to be set and then estimated for each alternative technology (steps C and D in Figure 1, respectively). The metrics that were used in this study are introduced in Section 4.2. These then needed to be compared to the client’s requirements; once the client goals were satisfied, the results could be presented in a decision matrix (Step E in Figure 1), which also included prioritising technologies and their supply mix as well as mapping the connections to the SDGs. If the client’s requirements were not met, all steps needed to be repeated with new inputs and/or scenarios. The output of the whole process formed the basis of the policy recommendations.

![Flowchart](Figure 1)

Figure 1. The main steps of the EMP framework, which was adopted from [3].

3.2. Assessment Metrics and Methods

In this section, the selected metrics and assessment methods are described. This paper analysed various development scenarios using the EMP framework, with a focus on the 3BL approach and highlighting the three pillars of sustainability: economic, environmental and social.

The set of indicators was chosen by considering the goals of FB and through the suggested and acceptable reference sets of indicators from existing studies. Thus, expert judgement was employed in the selection of the indicators. Nevertheless, the values of each indicator were gathered from and cross-checked by extensive research of the literature and open access publications from both Australia and other comparable countries. The selected indicators are listed in Table 1.


Table 1. A list of indicators for the triple bottom line (3BL).

| Bottom Lines (Level 1) | Indicators (Level 2)                                      |
|------------------------|----------------------------------------------------------|
| Environmental          | Capital costs                                            |
|                        | Annual operations and maintenance costs                  |
| Social                 | Job creation                                             |
|                        | Social acceptance                                        |
| Economic               | Embodied GHG emissions                                   |
|                        | Cumulative avoided GHG emissions                         |

3.2.1. Environmental Metrics

Melbourne has ambitious environmental targets, specifically for the reduction in GHG emissions. GHG emissions are usually expressed in carbon dioxide equivalent (\(\text{CO}_{2e}\)). All gaseous substances that the Intergovernmental Pollution Prevention and Control (IPCC) has defined as having a global warming potential (GWP) coefficient are considered as GHGs [1]. The GWP expresses the contribution of specific greenhouse gases to global warming in relation to \(\text{CO}_2\) [44]. The major GHGs include carbon dioxide (\(\text{CO}_2\)), methane (\(\text{CH}_4\)), nitrous oxide (\(\text{N}_2\text{O}\)), as well as several types of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) [45].

The selected performance indicators under the environmental metric were embodied GHG emissions and cumulative avoided GHG emissions. Embodied GHG emissions, which are measured in kg\(\text{CO}_{2e}/\text{kWh}\), pertain to the \(\text{CO}_{2e}\) of GHG emissions from the manufacturing, transport and construction of materials and equipment that are needed to produce and install technologies for energy production. This performance indicator is also often called upfront embodied carbon [46] and does not account for emissions that may be present during the operations and maintenance of RE and EE technologies. The estimation of embodied GHG emissions is not straightforward and may vary between RE and EE technologies. On the other hand, cumulative avoided GHG emissions (kg\(\text{CO}_{2e}/\text{kWh}\)) pertain to the lifecycle emissions that would be produced should the city still generate electricity from fossil fuels, not from renewable energy and energy-efficient technologies. This is often expressed as the difference between the actual GHG emissions that are produced by the proposed technologies and the current or baseline GHG emissions.

3.2.2. Social Metrics

The impact of the implementation of the technologies on the community is also important to assess for energy master planning. To measure the impact of the technologies on local communities and society as a whole, the most common social indicators, such as job creation and social acceptability, were selected [47]. Job creation (number of jobs per year/MW) refers to the estimated total number of jobs that would be created over the lifecycle of the system or technology. In this paper, the number of jobs created per technology employed only considered the construction and installation (C&I) and operations and maintenance (O&M) [48] of the technology and was expressed through Equation (1). The number of jobs created is an important criterion as it provides benefits for nearby residents in terms of uplifting their socioeconomic status.

\[
\text{Jobs Created} = \text{C&I} + \text{O&M}
\]  

where C&I refers to the jobs that are created during the construction and installation period only. O&M refers to created jobs that are associated with operating and maintaining the technology throughout its operational lifetime.

Social acceptability is a qualitative performance indicator that is evaluated based on the typical opinions or preferences of local populations in many developed countries regarding the hypothesised realisation of technology projects that are under review [8]. Public opinion is crucial and needs consideration as it may influence the time that is required to proceed with and complete an energy project. The qualitative description of
social acceptability that was used in this study is shown below. For quantitative values, a conversion was assumed and set as a qualitative scale:

- High (100%): the majority of the local community highly accepts that the project is beneficial;
- Moderate (50%): half of the local community accepts the project but believes that it does not necessarily provide maximum benefits;
- Low (0%): the local community does not accept the project.

3.2.3. Economic Metrics

Financial sustainability was measured through performance indicators that fall under the economic metric and was also relevant in decision-making. Capital costs (AUD/kW) and annual O&M costs (AUD/kW/year) were the selected typical performance indicators in this study [3,49]. “Capital costs” refers to the estimated total of the initial one-time expenses that are necessary for buying and setting up the system or technology. The estimation of capital costs may vary depending on the type of technology, geographical location, system size and project lifetime [50]. The typical calculation can be expressed as Equation (2):

\[ \text{Capital Costs} = \frac{\text{Cost of technology (AUD)}}{\text{Capacity of technology (kW)}} \] (2)

“Annual O&M costs”, on the other hand, refers to the estimated total annual expenses for the energy that is required to operate and maintain the service (i.e., system or technology). It can be generally calculated from Equation (3):

\[ \text{Annual Energy Cost} = \frac{\text{Cost of electricity (AUD/year)}}{\text{Capacity of technology (kW)}} \] (3)

3.3. Decision-Making Methods

Figure 2 shows a summary of steps that were used to assess the technologies for EMPs.

![Decision-Making Methods Diagram]

Once the metrics and required data are obtained, the second step in the assessment is the normalisation of the collected performance indicators data. Normalisation transforms the raw data into non-dimensional numerical values from 0 to 10, with 10 being the highest and 0 being the lowest.

The general formula that is used to normalise datasets is presented in Equation (4). This equation is appropriate for raw dataset values that are beneficial when they are high; thus, resulting in a high normalised score. For example, higher cumulative avoided GHG emissions values correspond to higher normalised scores. On the other hand, when the
value of the indicator suggests that it is less beneficial when raw dataset value is high, Equation (5) is used instead:

\[
z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)} \times Q
\]

\[
z_i = Q - \left( \frac{x_i - \min(x)}{x_i - \min(x)} \times Q \right)
\]

where \(z_i\) is the \(i^{th}\) normalised value, \(x_i\) is the \(i^{th}\) value, \(\min(x)\) is the minimum value, \(\max(x)\) is the maximum value and \(Q\) is the maximum number of normalised values.

The third step was the application of the analytic hierarchy process (AHP) [51] to calculate weights. The weights were calculated from pairwise matrices, which were established using Saaty’s rating scale, as shown in Table 2.

Table 2. Saaty’s rating scale.

| Intensity of Importance | Definition | Explanation |
|-------------------------|------------|-------------|
| 1                       | Equal importance | Two factors contribute equally to the objective |
| 3                       | Somewhat more important | Experience and judgement slightly favour one over the other |
| 5                       | Much more important | Experience and judgement strongly favour one over the other |
| 7                       | Very much more important | Experience and judgement very strongly favour one over the other and its importance is demonstrated in practice |
| 9                       | Absolutely more important | The evidence favouring one over the other is of the highest possible validity |
| 2, 4, 6, 8              | Intermediate values | When compromise is needed |

Saaty’s rating scale is based on expert opinions on the perceived difference between the importance of each performance indicator. For the fourth step, the additive aggregation method was applied to the weights to calculate an aggregated score. Equation (6) is the general equation that is used to calculate the aggregated score [52]:

\[
SI_i = (\omega_1 I_1 + \omega_2 I_2 + \ldots + \omega_n I_n) = \sum_{i=1}^{n} \omega_i I_i
\]

where \(SI_i\) is the overall score of the \(i^{th}\) alternative, \(\omega_i\) is the importance (weight) of the criterion (i.e., indicators, metrics, scenarios) and \(I_i\) is the relative score of the criterion.

In Step 4, the aggregated scores were dependent on the weights that were calculated for each of the performance indicators without considering the scenarios, such as base (or neutral), pro-economic, pro-environmental and pro-social. To analyse each of the scenarios, the fifth step was to use the AHP again to determine the weight of each 3BL metric. The calculated weights of the 3BL metrics were multiplied by the aggregated scores from Step 4 to obtain the scenario scores (Step 5). A spider diagram was generated to visualise the scores for each of the scenarios (Step 6). Finally, based on the aggregated scores, the technology share or portfolio was assessed to match the energy demand of an area with a goal to reduce GHG emissions to net-zero. The input data (i.e., electricity demand and current/projected GHG emissions) were needed to determine the percentage share of the technology that is required for the development. A decision could then be drawn from the result and the SDGs that are met by these priority technologies could be mapped.

3.4. Modelling Tool

A spreadsheet-based modelling tool was developed by incorporating the framework and assessment methods described above, which enabled the technology screening/assessment in the early stages of the design. Within the modelling tool, three bottom
lines were considered with two indicators (outputs) for each, which were used to assess their competitiveness using the input data from the literature. The model inputs, outputs and their associated assumptions/limitations are described in Table 3. The developed model is explored in a case study in the next section.

| Bottom Line | Inputs | Outputs | Assumptions/Limitations |
|-------------|--------|---------|-------------------------|
| Economic    | Cost of the technology (AUD) | Annual maintenance costs (AUD/kW/year): the O&M costs divided by the capacity of the technology | An assumption was made that capital costs were a one-off and that installed technologies do not require replacement before 2051 |
|             | Capacity of the technology (kW) | Capital costs (AUD/kW): the cost of the technology divided by the capacity of the technology | Net cash, though not assessed as an indicator, takes the factor mentioned above into account, based on the input of an estimated lifecycle of the technology; it also incorporates input costs and profits from the generated electricity for a wholistic value |
|             | O&M costs (AUD/Year) | | Limitation of accuracy: any cost inputs were not adjusted for inflation, particularly for projects proposed in the future |
|             | Price of electricity ($/kWh) | | For cases where energy savings were measured, an assumption was made that average apartment households of today are representative of those in the future |
|             | | | For energy efficiency technologies, only the effects of installing wall/ceiling insulation and the resulting energy savings in heating and cooling were studied |
| Environment | Capacity of technology energy savings (kW) | Embodied carbon (kgCO₂e/kWh) | There was a limitation in the measurement of social acceptability as it is an objective indicator that was used for the purpose of comparison between specified technologies |
|             | Capacity factor (%): the percentage of the theoretical installed capacity (rated capacity) multiplied such that the average capacity is obtained | Cumulative avoided GHG (kgCO₂e/kWh): GHG emissions that are avoided throughout the entire lifecycle of the technology, including operation | |
|             | GHG emissions of technology per kWh (kgCO₂e/kWh): the amount of GHG emissions produced in kg per kWh | | |
|             | GHG emissions per kWh BAU (kgCO₂e/kWh): the amount of GHG emissions based on current average for Australia, used as reference for comparison | | |
| Social      | Jobs created during the construction and maintenance of the technologies | Job creation (jobs/year/MW) | |
|             | Public attitudes and acceptance of technologies | Social acceptability (%) | |

3.5. Case Study Description

The FB urban renewal precinct was selected as the case study for the demonstration of the approach that was developed in this study and is described in this section. FB is a district within the City of Melbourne and the City of Port Phillip, which is located near Melbourne’s Central Business District (CBD). FB was traditionally dominated by low-scale industrial and warehousing buildings but is now Australia’s largest urban renewal project and covers approximately 480 hectares, which is more than twice the size of Melbourne’s current CBD [53]. By 2050, FB is expected to house 80,000 residents and host 80,000 jobs, distributed across five linked precincts: Montague, Lorimer, Sandridge, Wirraway and the employment precinct. Whereas the former four precincts are destined for medium-to high-density mixed-use commercial and residential development, it is planned for the
latter to become a National Employment and Innovation Cluster (NEIC) that can host up to 40,000 jobs in the design, engineering and manufacturing sectors.

The Victorian State Government has launched the FB Framework [53], which sets out the long-term strategic plan for the development of FB up to 2050. The following eight sustainability goals have been set for FB:

- A connected and liveable community;
- A prosperous community;
- An inclusive and healthy community;
- A climate resilient community;
- A water sensitive community;
- A biodiverse community;
- A low-carbon community;
- A low-waste community.

Each of these goals unfolds into several objectives for FB’s development, totalling 43 objectives, from which the following stand out as relevant for this EMP:

- Achieve net-zero GHG emissions by 2050 (Note 1);
- Maximise renewable energy generation, storage and distribution;
- Requirement for all new buildings to meet a minimum Green Star—Design & As Built (or equivalent) rating standard of five stars for buildings over 5000 m$^2$ and four stars for smaller buildings (Note 2);
- Be a climate resilient community, with engineered resilience to changing climate events, such as heatwaves, storms and sea level rise;
- Facilitate job growth, hosting 80,000 jobs by 2050.

(Note 1) Although the project’s net-zero strategy stipulates that FB’s GHG inventory comprises all emissions from transport, waste, water and energy consumption [54], this study assumed a simplified goal of net-zero emissions for the electricity supply only. Therefore, GHG emissions from other sectors within FB were not considered.

(Note 2) Green Star—Design & As Built is a rating standard that assesses the sustainability outcomes of the design and construction of new buildings or major refurbishments across nine holistic impact categories: management; indoor environment quality; energy; transport; water; materials; land use and ecology; emissions; and innovation [55]. Although notably the most holistic, Green Star is not the only tool that is available for rating the sustainability performance of buildings in Australia. Other available rating tools include NatHERS (for homes) and NABERS (for offices larger than 2000 m$^2$), but their assessment is limited to environmental performance (comprising energy, waste, water and indoor environment) and energy only in the case of NatHERS [56].

The FB urban renewal project was used as a case study to demonstrate the technology assessment approach that is proposed in this paper. Hence, the EMP needed to fulfil the aforementioned goals and objectives as best as possible. Moreover, in this study, we limited our scope to the residential neighbourhoods and therefore, the employment precinct was excluded. The four precincts under consideration are predicted to experience expressive growth in terms of population and the number of households and jobs according to the interim (year 2025) and final (year 2050) projections, which are presented in Table 4 [53]. An enterprise of this magnitude provided an unparalleled opportunity to demonstrate the best practices of urban planning being supported by state-of-the-art technology, thereby setting a global benchmark for sustainable and resilient urban transformation.
Table 4. The projection of population growth in FB’s residential precincts [53].

| Precinct | Area (ha) | Population | Number of Households | Jobs |
|----------|-----------|------------|----------------------|------|
|          | 2018      | 2025       | 2050                 | 2018 | 2025 | 2050 | 2018 | 2025 | 2050 |
| Montague | 43        | 280        | 4450                 | 23,200 | 155  | 2450 | 10,311 | 3240 | 3400 | 4000 |
| Lorimer  | 25        | 280        | 3440                 | 12,000 | 0    | 1900 | 5882  | 1820 | 2290 | 6000 |
| Sandridge| 86        | 520        | 880                  | 27,200 | 287  | 487  | 13,737 | 5200 | 11,080 | 26,000 |
| Wirraway | 94        | 200        | 360                  | 17,600 | 155  | 200  | 6822  | 2410 | 2740 | 4000 |
| Total    | 248       | 1280       | 9130                 | 80,000 | 597  | 5037 | 36,752 | 12,670 | 19,510 | 40,000 |

4. Results

The key results of the tool’s application are presented in this section and show the performance of the technologies across multiple indicators and different preferences, which were aggregated into a score for decision-making. Though both the indicators and technologies assessed were limited in this case study, the competitiveness of the technologies across any number of indicators can be determined and compared by utilising this framework, based on pairwise comparisons. These pairwise comparisons can quantify the subjective opinions of potential stakeholders or decision-makers, based on simple surveys or polls, and produce weights to accurately assess the competitiveness of technologies or policies according to their preferences. Using FB as a case study, this approach is outlined below.

4.1. 3BL Assessment Technology Screening

In the 3BL assessment, six different technologies (including BAU) were screened. These included:

- Rooftop PV, assuming 1.5 kW capacity per household;
- Offsite wind energy (onshore), 2 MW through PPA;
- Heat pump with 10kW system, which is able to provide approximately 2.7 MWh of energy for heating;
- Energy efficiency from wall and ceiling insulation that is installed in a typical Australian apartment, with savings of 20% on energy consumption for heating;
- BAU, assuming energy is taken from the grid using data from most recent estimates.

There were four scenarios that were considered, including neutral, pro-economic, pro-social and pro-environmental cases. All bottom lines were rated equally in the neutral case; however, for each “pro” scenario, the corresponding bottom line was attributed more weight, as determined through pairwise comparisons. As such, the technologies were expected to differ in competitiveness depending on the scenario, despite the fact that the underlying indicators that were being assessed remained unchanged.

The indicator data and the linearly normalised scores of between 0 (worst) and 10 (best) are presented in Table 5. The accuracy of the data was limited due to the use of single references to determine the inputs and the differing studies (and as a result, differing methodologies) for most indicators. However, for the purposes of highlighting the framework in this study, the data, while limited, were assumed to be within a realistic range.
Table 5. The indicator outputs and normalisation.

| Technology Raw Values          | Economic | Environmental | Social |
|--------------------------------|----------|---------------|--------|
|                                | O&M Costs (AUD/kWh/Year) | Capital Costs (AUD/kW) | Embodied Carbon (kgCO$_2$e/kWh) | Cumulative Avoided GHG (kgCO$_2$e/kWh) | Job Creation | Social Acceptability |
| Rooftop PV (1.5 kW per household) | 10       | 2143.33       | 0.03   | 0.58 | 2.4 | 1 |
| Offsite Wind Energy (2 MW)     | 45       | 6000          | 0.01   | 0.64 | 3   | 0.5 |
| Heat Pump (All households)     | 100      | 2000          | 0.02   | 0.65 | 3   | 0.5 |
| Energy Efficiency (All households) | 0.54     | 8685.08       | 2.46   | 0.66 | 26  | 1 |
| BAU                            | 55       | 0             | 0.656  | 0   | 0   | 0 |

Key observations included:
- Energy efficiency had the lowest O&M costs, as little maintenance is needed after installing the insulation, though it had the highest capital costs;
- Capital costs were the lowest for BAU, with the assumption that the BAU case used existing energy generation from the National Electric Market (NEM);
- Energy efficiency performed the worst for the embodied carbon indicator. For insulation, kgCO$_2$e is typically measured per area rather than per kWh, as in energy generation methods. The value for kgCO$_2$e/kWh was obtained by calculating the average embodied carbon associated with installing insulation in a typical apartment divided by the kWh that would be saved over a year. Since the savings would benefit the user for much longer than a year, this value could be much larger in real life.

The weights that were obtained through subjective pairwise comparisons using Saaty’s rating scale are shown in Tables 6–8. It can be observed that the values were uniform for both indicator and scenario weights.

Table 6. The indicator outputs and normalisation.

| Technology Normalised Scores | O&M Costs | Capital Costs | Embodied Carbon | Cumulative Avoided GHG | Job Creation | Social Acceptability |
|-----------------------------|-----------|---------------|-----------------|-------------------------|--------------|----------------------|
| Rooftop PV                  | 9         | 7.5           | 9.9             | 8.9                     | 0.9          | 10                   |
| Wind Energy                 | 5.5       | 3.1           | 10              | 9.8                     | 1.2          | 5                    |
| Heat Pump                   | 0         | 7.7           | 9.9             | 9.9                     | 1.2          | 5                    |
| Energy Efficiency           | 9.9       | 0             | 0               | 10                      | 10           | 10                   |
| BAU                         | 4.5       | 10            | 7.3             | 0                       | 0            | 0                    |

Table 7. The indicator weights.

| Indicators                  | Weight |
|-----------------------------|--------|
| Maintenance Costs           | 25%    |
| Capital Costs               | 75%    |
| Embodied Carbon             | 25%    |
| Cumulative Avoided GHGs     | 75%    |
| Job Creation                | 50%    |
| Social Acceptability        | 50%    |
Table 8. The scenario weights.

| Scenarios            | Economic Weight | Environmental Weight | Social Weight |
|----------------------|-----------------|-----------------------|---------------|
| Neutral              | 33%             | 33%                   | 33%           |
| Pro-economic         | 50%             | 25%                   | 25%           |
| Pro-environmental    | 25%             | 50%                   | 25%           |
| Pro-social           | 25%             | 25%                   | 50%           |

Based on the Equation (6), an aggregation of the technologies’ performance across all indicators and corresponding weights was calculated, with the results shown by the scenario spider diagrams in Figure 3 and Table 9. It can be observed that BAU performed the worst in all scenarios, while rooftop PV performed better in all scenarios, excluding pro-social in which it ranked second to energy efficiency. Otherwise, the technologies varied in scores across the different scenarios, reflecting the impact of the pairwise comparisons.
Figure 3. The scenario spider diagrams showing the aggregated scores.

Table 9. The technology aggregated scores.

| Technology     | Neutral | Pro-Economic | Pro-Environmental | Pro-Social |
|----------------|---------|--------------|--------------------|------------|
| Rooftop PV     | 7.88    | 8.17         | 8.18               | 7.27       |
| Wind Turbine   | 3.22    | 3.28         | 3.64               | 2.72       |
| Heat Pump      | 6.61    | 6.67         | 7.43               | 5.73       |
| Energy Efficiency | 6.67  | 5.63         | 6.88               | 7.50       |
| BAU            | 3.49    | 4.77         | 3.07               | 2.61       |

4.2. Assessing the Technology Portfolio EMP

Following the 3BL assessment, the most competitive technologies were identified as stated in Section 4.1. From the RE technology scores for each of the scenarios that were analysed in this paper, the optimal percentage shares of the technologies for FB residential precinct were determined. Table 10 shows the shares of RE technologies with the goal
of meeting electricity demand for the FB residential precincts, thereby transitioning to renewable energy and energy efficiency and achieving net-zero GHG emissions in the energy sector by 2050. The pro-social scenario best satisfied the goal of the FB framework.

Table 10. The RE technology share options.

| Scenarios               | Technologies (% Share) | Electricity Demand Satisfied by 2050? | Net-Zero GHG Emissions Achieved by 2050? |
|-------------------------|-------------------------|--------------------------------------|----------------------------------------|
|                         | Rooftop PV              | Wind Turbine                        | Heat Pump                               | Energy Efficiency                     |                                      |
| Neutral (Option 1)      | 32%                     | 13%                                  | 27%                                    | 27%                                   | No                                    |
| Pro-economic (Option 2) | 34%                     | 14%                                  | 28%                                    | 24%                                   | No                                    |
| Pro-environmental (Option 3) | 31%                 | 14%                                  | 28%                                    | 26%                                   | No                                    |
| Pro-social (Option 4)   | 31%                     | 12%                                  | 25%                                    | 32%                                   | Yes                                   |

Initially, the technologies were modelled to meet FB’s residential electricity demand and net-zero GHG emissions by 2050 in order to ensure that Melbourne’s emission target would be met. Thus, this paper also attempted to assess three time horizons (i.e., 2030, 2040 and 2050) for implementation to aid in policy and decision-making. Varying the target completion year for installing and implementing RE technologies is a common practice in energy planning [57,58]. Figure 4 shows that the suggested technology mix for Option 4 could be optimised further by implementing the technologies earlier than 2050. When the implementation of Option 4 was set to timeframe A (2030) and timeframe B (2040), the goals could be met as early as 2028 and 2032, respectively.

![Figure 4](image_url)  
Figure 4. The timeline for technologies to achieve electricity demand and net-zero GHG emissions.

The results show that Option 4 was the optimal technology share. As the electricity demand from the grid is replaced by RE technologies over the years, net-zero GHG emissions would also be achieved. The targets of Victoria and the City of Melbourne for the RE share of electricity generation would also be met and even surpassed. Victoria is only aiming for a 50% RE share by 2030, while the City of Melbourne is targeting a 100% RE share by 2040. Option 4 could provide 100% RE as early as 2028, depending on the implementation pace and the enabling policies that are in place.

Option 4 recommended prioritising energy efficiency implementation, since it had the biggest share in EMP. Energy efficiency measures, such as the installation of wall insulation, could cut 32% of total electricity use compared to not having energy efficiency measures. Rooftop PVs ranked a very close second behind energy efficiency, with a percentage value of 31%. Ground source heat pumps ranked third, while wind energy technology came last with a very small share in the technology mix.
4.3. SDG Connections

To evaluate the different contributions of the technologies in the EMP to the UN SDGs [59] (Table 11), the driving forces of the shared socioeconomic pathways (SSPs: the scenarios of projected socioeconomic global changes up to 2100) that are related to the SDGs were considered following the approach in [60]. The SSPs include six driving forces: demographics; economy and lifestyle; technology; environment and natural resources; human development; and policies and institutions. Following the methodology proposed in [60], the two driving forces that were most relevant to the paper were selected; namely, technology and environment and natural resources. The relationship between the technologies in the EMP and the SDGs were mapped based on the SSP driving forces (Figure 5). By matching the SDGs to the technologies, policy makers can align the sustainable development of FB with the UN’s standards and proposals.

Table 11. The UN SDGs.

| SDG  | Description/Title               |
|------|---------------------------------|
| Goal 1 | No Poverty                     |
| Goal 2 | Zero Hunger                    |
| Goal 3 | Good Health and Well-Being     |
| Goal 4 | Quality Education              |
| Goal 5 | Gender Equality                |
| Goal 6 | Clean Water and Sanitation     |
| Goal 7 | Affordable and Clean Energy    |
| Goal 8 | Decent Work and Economic Growth|
| Goal 9 | Industry, Innovation and Infrastructre |
| Goal 10 | Reduced Inequalities           |
| Goal 11 | Sustainable Cities and Communities |
| Goal 12 | Responsible Consumption and Production |
| Goal 13 | Climate Action                |
| Goal 14 | Life Below Water               |
| Goal 15 | Life on Land                   |
| Goal 16 | Peace, Justice and Strong Institutions |
| Goal 17 | Partnership for the Goals      |

The development and implementation of the technologies that were identified through the process of EMP related to the local driving forces of the technology and environment and natural resources SSPs. In particular, the relevant driving forces that were considered when mapping the SDGs were: development and transfer; carbon intensity and energy intensity; fossil constraints; and environment and resilience against climate change impacts. Each of the technologies in the selected case study were analysed against the driving forces. Figure 5 shows that the implementation of the technologies that were identified and prioritised in the EMP and also satisfied the performance objectives, thereby contributing to the achievement of some global SDGs (Table 11).
5. Discussion

In this section, the results of the application of the EMP framework to the case study are analysed and discussed.

5.1. Analysis of the 3BL Results

The weights of the indicators and scenarios seem to be uniform due to the small number of expert opinions that were gathered and the limited number of criteria that were being compared in each matrix (for example, the matrices for the pairwise comparisons of indicators were two by two, while those for the scenarios were three by three). Averaging scores for pairwise comparisons from a larger pool of people and increasing the number of indicators can be easily accommodated by this framework and may increase the accuracy of the model for future studies.

From an environmental lens, the country’s reliance on fossil fuels for its energy supply further exacerbates environmental quality degradation, which agrees with the study of [61]. The new development of coal-fired power plants in Victoria is at a halt with existing facilities being retired; thus, there are no expected capital costs. On the other hand, the operating costs of these facilities appear to be less competitive than the RE and EE technologies that were introduced in this paper. It can also be observed that there may be external costs that are related to GHG emissions, which are likely to further reduce the BAU model’s environmental and economic performance. While these were not included in the analysis under economic indicators, their impact spills over and was considered in the evaluation of the social indicators. The expert judgment on the generally high social acceptability of renewable and energy efficiency technologies compared to BAU was well aligned with previously published studies [62–65].

The 3BL results confirmed that BAU is not a sustainable pathway for communities due to its poor performance in all 3BL metrics. The FB goals would not be satisfied and Melbourne’s sustainability targets would not be achieved if BAU were to be continuously employed. It can be observed that the results were in good agreement with Australia’s ongoing shift towards renewable energy sources and it slowly moving away from the use of BAU technologies due to their unsustainability in the long run. BAU’s bottom ranking in the 3BL analysis could be explained by the increasing uptake of renewable technologies and decreasing development of coal-fired power plants [66,67]. The current trend provides more competitiveness and accessibility for renewable and energy-efficient technologies.

While the results of the 3BL analysis in this case study might not have necessarily reflected the most competitive technology in reality, the approach that was introduced
here enabled us to quantitatively compare technologies in the early stages of their design. While the number of both indicators and technologies were limited here, the approach can easily be scaled up to accommodate more in order to improve the accuracy. Similarly, the pairwise comparisons can be scaled up and/or passed on to decision makers to quantify those that would otherwise remain subjective opinions.

5.2. Technology Portfolio

With Option 4 being the optimal technology mix based on the results of this analysis, the differences between the technologies that were considered could be due to a number of different factors, such as the development timeframe, capacities and production efficiencies and maturity of each technology. The difference in percentage share was not that big between these two technologies, since energy-efficient technology usually complements other RE technologies to maximise the reduction in energy demand from the grid [68].

Energy efficiency technology allows buildings to save electricity. The results of the case study showed that efforts that are applied to saving electricity through energy-efficient technology lessen the demand for grid-sourced energy. On the other hand, solar energy serves as a resource that provides clean and sustainable energy to augment the demand for energy from the grid. The installation of more rooftop PVs in the FB project would not be a challenge to implement due to the increasing awareness and uptake within the community. For instance, the growth in the installation of rooftop solar panels in Australia in 2020 was massive and added up to 3GW of new capacity [69].

Ground source heat pumps ranked third in the optimal technology options that were identified from the case study. The results of the analysis suggested that 25% of the electricity demand from heating and/or cooling could be satisfied by heat pumps. The resulting share of heat pumps coincides with the findings of Law and Osman [70], wherein they found that a typical household in Melbourne consumes 25% of the total electricity demand for heating and cooling purposes. However, compared to energy efficiency and rooftop PVs, there could be a challenge in widely utilising ground source heat pumps. Data on performance and the system’s associated costs are not publicly available; thus, the suitability of application can be difficult to assess [71].

On the other hand, unlike the other technologies, the implementation of wind technology (which finished last in the results) needs to consider land requirement, which may limit the number of wind technology devices that can be installed, as well as the wind speed in the area to determine the size or capacity of the technology. The Wirraway precinct (one of the residential precincts) near Port Phillip Bay has a low average wind speed [72]. Thus, for the FB project, a typical 5 MW precinct-scale wind turbine would not be viable [73]. Given the limitations for onsite wind farms, it was reasonable to allocate only a small energy share from this RE source.

5.3. Local Targets and Global SDG Achievement

Through the EMP framework, the potential technologies were prioritised to better suit the goals of the community. In addition, the influence of the resulting higher priority technologies could also be mapped to identify which global SDGs would be met by utilising the appropriate driving forces that were informed by the process. Therefore, the results of the EMP framework could not only answer community needs, but also contribute to the achievement of global SDGs. For example, the use of energy-efficient technology would influence SDGs 9 and 11, with it being regarded as an emerging and enabling technology in Australia [74]. In another example, the implementation of wind energy would help to decrease the energy use and the carbon intensity of FB, which is related to the technology (carbon intensity and energy intensity) driving forces and matches SDGs 4, 7–9 and 11–13. According to the results, SDGs 3, 4, 6–9 and 11–15 were addressed by the FB energy master plan in our case study. A more detailed elaboration of the way in which the EMP technologies and SDGs were mapped via the SSPs is listed in Appendix B.
5.4. Policy Recommendations

Many of the goals of the FB project that would be achieved by the optimal technology profile result (Option 4) are in line with national and subnational targets. From the results, Option 4 of the EMP technology profile could potentially be supported by the existing policies that were mentioned in Section 2.1. Since Option 4 may need aggressive implementation and support from enabling policies as early as 2028 for the proposed RE and EE technologies, the FB project could take advantage of the currently available policies and incentive programs.

Homeowners in FB could benefit from the rebates that are offered by the Victorian government for the installation of rooftop solar panels and batteries, as well as the FiT from the PV system’s operation, which is subject to the amount of energy export that the local distribution network can absorb. Moreover, the FB project could also benefit from the incentives that are offered by the national SRES, since the assumptions in the EMP framework also take the limit on the capacity of solar PV technology into consideration. These incentives are available for PV systems that are installed before 2030, which is within the completion target for installing rooftop PVs that was suggested by the results of the EMP technology portfolio option from Section 4.2 (Option 4).

Energy-efficient technology would also be prioritised based on the results of the 3BL analysis, which agreed with the results of the technology portfolio assessment. Thus, as with the policy support that would be needed for the rooftop PV implementation, energy-efficient technology could also benefit from existing state and country policies. The retrofitting of existing buildings in FB to improve energy efficiency could be supported by the state VEU as this program is remaining in force indefinitely. Similarly, the installation of heat pumps could also be supported by the state VEU to enhance feasibility and adoption due to the current implementation limitation of the technology. However, the state VEU benefit would not apply to the new buildings that are expected to be constructed in FB. For wind energy technology, the City of Melbourne’s commitment to facilitating PPA could provide significant support for the successful implementation of this development.

Given the current limitations of the existing policies, the policy-related actions that would provide further support to the FB project if they were to be implemented are listed below. However, planning and policy validation is generally challenging; thus, there is a need to verify these recommendations as outputs of the proposed EMP framework.

- Advancing VRET beyond 2030 and setting the goal of 100% by 2050. As discussed in Section 2.1, the VRET is currently only defined up until 2030 (50%). However, the share of renewable power must increase beyond 50% if Victoria is to achieve its net-zero emissions target by 2050. To that end, a VRET that progressively increases to 100% by 2050 would be compatible with the state’s carbon neutrality ambitions;
- An extension of the national RET program beyond 2030. As discussed in Section 2.1, there has not yet been any indication that the RET program may remain in force after 2030. The termination of this program would impact the potential beneficiaries of the SRES in FB’s residential precincts under the options with timeframes B (2040) and C (2050), which was discussed in Section 4.2. Moreover, the discontinuation could hinder the uptake of renewable energy projects nationwide, which would impact the fulfilment of Australia’s commitments to the Paris Agreement. Moreover, national policies, such as RET, would be crucial for Australia to progressively increase the ambitions of its national emissions reduction target, which is stipulated by the Paris Agreement;
- Increase in the minimum FiT in Victoria. The minimum FiT that is set by the Victorian government has been declining in recent years, which is allegedly a reflection of the decreasing wholesale price of electricity [75]. However, a lower FiT may discourage many residents from installing PV systems as the revenue from FiT would help to pay back their upfront investment. For this reason, an increase in the minimum FiT would potentially boost rooftop PV uptake. Naturally, this would need to be accompanied by an upgrade of the distribution network to ensure that it could absorb the amount of PV energy being exported into the grid;
• The creation of new policies related to the “Trajectory for Low Energy Buildings”. These could offer, for instance, financial incentives for projects that deliver high energy efficiency standards that are beyond the NCC minimum requirements (surpassing the current benchmark standards from NatHERs and NABERS).

5.5. Limitations and Future Work

The scope of the EMP framework in this paper only included the energy use and GHG emissions of residential buildings that were related to electricity consumption. In terms of the types of buildings, further study should extend to commercial and industrial buildings to ensure that all energy demands are taken into account. Transportation-related energy use and carbon emissions actually make up a great proportion of the total energy use and carbon emissions of FB [20]. In future, the proposed framework should be extended to include all energy demands from various sectors, including transportation emissions. This would be particularly important due to the recent and potential growing use of electric vehicles across the world.

The data that were used in this paper were referenced from various resources, were not necessarily specific to Australia/Victoria and were scaled to match the area of study. Moreover, the AHP that forms part of the EMP framework employed subjective scoring that was based on expert opinions. For example, the percentage score of the social acceptability indicator was only an assumption to simplify social perception. While the percentage group was wide, the indicator was merely an approximation of what the literature has generally reported about the technology, coupled with the expert judgements of the authors. The validation of the results of the energy master planning and policy recommendations could be quite challenging and may need another structured process. The main point of this paper was to demonstrate the capabilities of the proposed approach in a way that is replicable and scalable, instead of proving that the resulting values of the assessment were accurate. Bottom-up modelling and sensitivity analyses can be performed in the more advanced stages of the design, considering the EMP execution requirements for more accurate results. Further, a rough or fuzzy set analysis should be undertaken to allow for the consideration of the EMP framework process and data vagueness.

It is also noted that a set of more popular RETs were selected and analysed in this paper. However, there are still lots of other technologies that are worthy of consideration in the EMP process, such as hydropower, biomass, smart control systems, etc., which could help to optimise the energy design and monitoring of buildings further. The proposed EMP framework could be used to analyse other innovative technologies.

Moreover, the number of indicators that were analysed was limited to two indicators for each criterion and the selection was based on expert judgement that was informed by the existing literature. There could be other indicators that are of importance to planners or decision-makers that could also be included in the EMP framework. For instance, the cost of recycling (as part of a circular economy) should also be included under the economic criteria. The framework is flexible enough to accommodate this in future applications of the EMP.

The EMP framework used various manual modelling tools to analyse the 3BL and technology mix. The process for the manual changing of data and assumptions within the tool could be tedious for planners or decision-makers. Thus, the improvement of the modelling tools should be further explored, with a focus on the input data requirements and links to available software.

6. Conclusions

This paper proposed a technology assessment approach for the triple bottom line (environmental, social and economic) sustainability assessment of renewable energy technology alternatives in the early stages of energy master planning. The capabilities of the proposed approach included a modelling tool, which was demonstrated in the case study of a residential urban renewal project in Melbourne.
The key findings showed that the technology assessment approach could facilitate the design and comparison of various technology options and scenarios at the community level. In the case study, it was seen that the BAU 3BL scoring performed the worst in all scenarios, while rooftop PV systems performed the best in all scenarios except pro-social. Otherwise, the technologies varied in scores across the different scenarios, which reflected the impact of the pairwise comparisons. The energy demands of FB and the net-zero emission targets could be satisfied using an energy share from both RE and EE technologies. These RE and EE technologies could not only satisfy community goals, but also international targets, such as the UN SDGs. While there are existing policies that are ideally in place to support the implementation of these technologies, it is also important to review their applicability and limitations. Thus, the results from this approach could be used in the facilitation of policy enhancement or recommendations. However, the 3BL accuracy of the case study was limited by the indicators, data and weights. However, these aspects can easily be scaled within the framework to improve accuracy and the pairwise comparisons can be performed by decision-makers to accurately identify the most competitive technologies according to their priorities.

In future work, the application of fuzzy or rough sets should be considered to further enhance the inputs to the EMP framework. Policy links and recommendations should also be further validated by considering the potential changes in the policy sector and other relevant factors. Moreover, the implications and feasibility of other technologies should be investigated through a more detailed assessment of the sustainability indicators using a combination of available simulation software, especially recent innovative solutions, such as the fifth generation of district heating and cooling systems, digital twins, energy storage and combinations of all of these technologies.

Author Contributions: Conceptualisation, B.R., S.C.S., M.R.S., J.W.S. and M.P.d.L.; methodology, S.C.S., M.R.S., J.W.S. and Y.H.; validation, B.R., S.C.S., M.R.S., J.W.S. and M.P.d.L.; formal analysis, M.R.S., J.W.S. and Y.H.; investigation, M.R.S., J.W.S., M.P.d.L., Y.H. and S.C.S.; data curation, M.R.S. and J.W.S.; writing—original draft, M.R.S., S.C.S., J.W.S., M.P.d.L. and Y.H.; writing—review and editing, B.R., S.C.S., M.R.S., J.W.S., M.P.d.L. and Y.H.; visualisation, M.R.S. and J.W.S.; supervision, B.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This work was conducted within the Department of Infrastructure Engineering as a part of an ongoing research project.

Conflicts of Interest: The authors declare no conflict of interest.
Appendix A

Table A1. Abbreviations.

| Abbreviation | Description |
|---------------|-------------|
| 3BL           | Triple Bottom Line |
| AHP           | Analytic Hierarchy Process |
| BAU           | Business As Usual |
| C&I           | Construction and Installation |
| CBD           | Central Business District |
| CH₄           | Methane |
| CO₂           | Carbon Dioxide |
| CO₂ₑ          | Carbon Dioxide Equivalent |
| EE Technology | Energy-Efficient Technology |
| EMP           | Energy Master Planning |
| ESC           | Essential Services Commission |
| FB            | Fishermans Bend |
| FiT           | Feed-in Tariff |
| GHG           | Greenhouse Gas |
| GWP           | Global Warming Potential |
| HFCs          | Hydrofluorocarbons |
| IPCC          | Intergovernmental Pollution Prevention and Control |
| LRET          | Large-scale Renewable Energy Target |
| MREP          | Melbourne Renewable Energy Project |
| N₂O           | Nitrous Oxide |
| NABERS        | National Australian Built Environment Rating System |
| NatHERS       | Nationwide House Energy Rating Scheme |
| NCC           | National Construction Code |
| NEIC          | National Employment and Innovation Cluster |
| NEM           | National Electric Market |
| NEPP          | National Energy Productivity Plan |
| O&M           | Operations and Maintenance |
| PFCs          | Perfluorocarbons |
| PPA           | Power Purchase Agreements |
| RE Technology | Renewable Energy Technology |
| RET           | Renewable Energy Target |
| SRES          | Small-Scale Renewable Energy Scheme |
| SSPs          | Shared Socioeconomic Pathways |
| UN SDGs       | United Nations Sustainable Development Goals |
| VEECs         | Victorian Energy Efficiency Certificates |
| VEET          | Victorian Energy Efficiency Target |
| VEU           | Victorian Energy Upgrades |
| VRET          | Victoria’s Renewable Energy Target |
Table A2. The descriptions of the indicators.

| Indicators                        | Units         | Description                                      |
|----------------------------------|---------------|--------------------------------------------------|
| Embodied GHG emissions           | kgCO₂e/kWh    | CO₂e of GHG emissions per kilowatt hour          |
| Cumulative Avoided GHG Emissions |               | Annual number of jobs per megawatt of technology |
| Job Creation                     | No. of jobs/year/MW | Annual number of jobs per megawatt of technology |
| Capital Costs                    | AUD/kW        | Upfront costs per kilowatt of technology in Australian Dollars |
| O&M Costs                        | AUD/kW/year   | Annual costs per kilowatt of technology in Australian Dollars |

Appendix B

Table A3. The elaboration of how the technologies and the SDGs were mapped via SSPs.

| Technologies              | Related SSPs Driving Forces | Related SDGs                      | Relationship with SDGs |
|---------------------------|----------------------------|-----------------------------------|------------------------|
| Energy Efficiency         | Development & Transfer     | 4,7,8,9,11,12,13                 | The implementation of this tech can help improve this tech’s development and help this tech to transit from R&D to commercial use in Fishermans Band. |
|                           | Carbon intensity & Energy  | 7,8,9,11,12,13,15               | The implementation of this tech helps decrease the energy use as well as the carbon intensity in FB. |
|                           | intensity                  |                                   |                        |
|                           | Fossil constraints         | 7,8,9,11,12,13,15               | The implementation of this tech can help to decrease the energy use of this area thereby decrease the fossil-based energy. |
|                           | Environment & Resilience   | 3,6,7,8,9,11,12,13,14,15         | The tech helps decrease the use of energy thereby can help decrease the carbon emission, protect the environment of FB and reduce climate change impact. |
|                           | against climate change    |                                   |                        |
|                           | impact                    |                                   |                        |
| Heat Pump                 | Development & Transfer     | 4,7,8,9,11,12,13                 | The implementation of this tech can help improve this tech’s development and help this tech to transit from R&D to commercial use in Fishermans Band. |
|                           | Carbon intensity & Energy  | 7,8,9,11,12,13,15               | The implementation of this tech helps decrease the energy use as well as the carbon intensity in FB. |
|                           | intensity                  |                                   |                        |
|                           | Fossil constraints         | 7,8,9,11,12,13,15               | The implementation of this tech can help to decrease the energy use of this area thereby decrease the fossil-based energy. |
|                           | Environment & Resilience   | 3,6,7,8,9,11,12,13,14,15         | The tech helps decrease the use of energy thereby can help decrease the carbon emission, protect the environment of FB and reduce climate change impact. |
|                           | against climate change    |                                   |                        |
|                           | impact                    |                                   |                        |
### Table A3. Cont.

| Technologies | Related SSPs Driving Forces | Related SDGs | Relationship with SDGs |
|--------------|-----------------------------|--------------|------------------------|
| Wind Energy  | Technology Development & Transfer | 4,7,8,9,11,12,13 | The implementation of this tech can help improve this tech’s development and help this tech to transit from R&D to commercial use in Fishermans Band. |
| Carbon intensity & Energy intensity | 7,8,9,11,12,13,15 | The implementation of this tech helps decrease the energy use as well as the carbon intensity in FB. |
| **Environment & natural resources** | 3,6,7,8,9,11,12,13,14,15 | This tech provides clean energy and decreases the reliance of fossil fuel energy, which can decrease the carbon emission, protect the environment of FB and reduce climate change impact. |
| Solar PV      | Technology Development & Transfer | 4,7,8,9,11,12,13 | The implementation of this tech can help improve this tech’s development and help this tech to transit from R&D to commercial use in Fishermans Band. |
| Carbon intensity & Energy intensity | 7,8,9,11,12,13,15 | The implementation of this tech helps decrease the energy use as well as the carbon intensity in FB. |
| **Environment & Natural resources** | 3,6,7,8,9,11,12,13,14,15 | This tech provides clean energy and decreases the reliance of fossil fuel energy, which can decrease the carbon emission, protect the environment of FB and reduce climate change impact. |

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