Sustainability Assessment Framework for Renewable Energy Technology

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ABSTRACT

The UK government has identified energy use in non-domestic buildings as one of the major contributors of carbon emissions in the UK. In order to help businesses to reduce the carbon emissions from their buildings the government has developed a number of incentive schemes designed to encourage renewable energy production. Consequently renewable energy technologies, such as solar photovoltaic and wind turbines, are becoming a more popular and affordable alternative energy solution. While providing a practical option for supplying clean energy, considered holistically these solutions may not always provide the most sustainable option. The scope of this research specifically considers commercial offices and in particular aims to provide those with building management responsibilities with a mechanism to assess the sustainability of renewable energy technologies. Based upon a review of literature, a set of performance indicators has been developed taking into consideration economic, social, environmental and technical factors. The resulting framework of factors enables building managers to assess the suitability and sustainability of particular renewable energy technologies for their buildings.

Keywords:
Sustainability assessment framework, renewable energy, renewable technology, indicators

Glossary:

Renewable energy: an alternative energy resource, such as, solar, wind, heat pumps, hydro, biomass, and combined heat and power.

Renewable energy technology: small installations that generate electricity or heat from renewable energy resource and can generate close to the consumer, e.g. on the roof of a building.

Sustainability of renewable energy technologies: renewable energy technology is financially sustainable (pays for itself and reduce consumption of expensive fuel), reduces environmental impact (produce little or no greenhouse gases) and is socially acceptable (meets basic human needs and well-being).
Sustainable energy: provision of energy with minimum resource use, waste and harmful emissions.

Sustainable technology: practical solutions to achieve economic and social development in harmony with the environment.

Sustainability indicators: communicate information about a renewable energy technology’s key performance data considered relevant for sustainable development.

1. INTRODUCTION

In the last decade, the UK government has shown a keen interest in helping non-domestic building owners adopt the use of renewable energy technology to help reduce their carbon footprint and reliance on fossil fuels. The technology to convert renewable energy into useful energy is commercially available. There is a variety of renewable energy technology that can be fitted to non-domestic buildings. However, not all renewable energy technology options are sustainable.

Many factors need to be taken into consideration when investing in a renewable energy technology and lessons can be learnt from sustainable development when selecting the optimal solution for a building. The important goal is trying to find the right balance between economic, social and environmental aspects of sustainable development. The three aspects act as the guiding principles to ensure the factors being considered for a renewable energy technology is relevant for sustainable development. This should, in theory, ensure that the renewable energy technology is a sustainable option.

The purpose of this paper is to propose a mechanism to assess the sustainability of renewable energy technologies. There are a variety of renewable energy technologies that are small in size, affordable and can be installed onto buildings, such as, solar photovoltaic (PV), solar thermal, heat pumps, wind turbines, etc. The scope of this research specifically targets building managers and commercial offices, which is a type of non-domestic buildings. The challenge that building managers have is how to select the most suitable and sustainable renewable energy technology for their buildings.

In this paper, sustainable energy and sustainable technologies are discussed in section 2. Our proposed sustainability assessment framework and the methodology for selecting sustainability indicators are described in section 3. Section 4 explores the development of an indicator set using the sustainability assessment framework as the foundation. Section 5 presents the results and discussion of a case study to test the proposed indicators and section 6 presents the conclusions of this paper.

2. SUSTAINABLE ENERGY AND SUSTAINABLE TECHNOLOGIES

Sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations General Assembly, 1987). The 2005 World Summit Outcome document (United Nations, 2005) quotes the three components of sustainable development comprises of economic development, social development and environmental protection. But how does this apply to energy and technology?
Sustainable energy is a combination of savings in energy demand, efficiency improvement in energy production, and renewable and non-renewable energy sources. Renewable energy should not be confused with sustainable energy. If nuclear energy, which is not considered a renewable energy source, is coupled with energy efficiency and savings in energy demand it could be used for many generations. Renewable energy comes from natural sources, such as, solar, wind, waves, tidal, hydro, biomass, ocean current and geothermal heat. Renewable energy is becoming a very important resource as there is a need to seek alternative energy sources and as such many studies and research have been undertaken to understand the impact of renewable energy (Malik & Sukhera, 2012; Lund, 2010; Tock et al., 2010).

Sustainable technology has the characteristics of minimising consumption, minimising negative environmental impact and satisfying human needs. Technology is a broad term that include that includes, symbols, methods, processes and the physical tools that humans use toward the solution of problems. Sustainable technologies are practical solutions to achieve sustainable development. The use of non-renewable energy should be minimised as we are further limiting the potential use of it for our future generations. Minimising negative environmental impacts such as greenhouse gas emissions should help towards the protection and preservation of the Earth’s ecosystem. A sustainable technology must fulfil the needs of people it is intending to serve. There is the possibility that environmental and economic requirements may conflict with human needs. But human satisfaction should not be ignored and “must be met with the most resource-efficient methods possible” (Robert et al., 1997).

A renewable energy technology installed on a building is sustainable when, in the long term, reduces the negative impacts on the environment, and raises opportunities for economic and social development. A renewable energy technology must therefore fulfil the three dimensions of sustainable development:

- Economic: by reducing the consumption of expensive fuels and by covering the life-cycle costs;
- Social: by meeting basic needs without affecting human health and well-being;
- Environmental: by reducing the negative environmental impact: greenhouse gas emissions and depletion of fossil fuels.

3. SUSTAINABILITY ASSESSMENT FRAMEWORK

The proposed sustainability assessment framework takes into consideration the three dimensions of sustainable development as well as the additional technical dimension. The technical dimension is added for the purpose of assessing the functions of the technology. It is widely recognised and accepted (Azapagic & Perdan, 2000; Labuschagne et al., 2005; Musango & Brent, 2011) that sustainability assessment should take into account the three dimensions of sustainable development. Therefore our proposed framework will adopt the same approach as shown in figure 1. The factors associated with each dimension in the framework which influence the development of a new indicator set are as follows:

Economic Factors: *Life cycle costs* cover the capital expenditure, maintenance and operation (duration of the technology or building – leasehold, freehold). *Government schemes* cover the government back initiatives, carbon tax, tax relief, etc. *Expenditure on energy* covers the expenses of resources, such as, gas, electricity, water, etc. *Income from energy* covers the analysis of the revenue generated from government schemes, payback time, etc.
Social Factors: *Direct impact of technology* relates to how the technology affects building stakeholders.

### Sustainability Assessment Framework

<table>
<thead>
<tr>
<th>Factors</th>
<th>Economic</th>
<th>Social</th>
<th>Environment</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Life cycle costs</td>
<td>- Direct impacts of</td>
<td>- Resource usage by</td>
<td>- Performance of the</td>
</tr>
<tr>
<td></td>
<td>- Government schemes</td>
<td>technology</td>
<td>building</td>
<td>system</td>
</tr>
<tr>
<td></td>
<td>- Expenditure on energy</td>
<td></td>
<td>- Technology capacity</td>
<td>- Durability</td>
</tr>
<tr>
<td></td>
<td>- Income from energy</td>
<td></td>
<td>- Environmental impact</td>
<td>- Flexibility &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>adaptability</td>
</tr>
</tbody>
</table>

**Figure 1** Sustainability Assessment Framework for Renewable Energy Technology

Environment Dimension: *Resource usage by building* covers the use of electrical, gas, water resources by the building. *Technology capacity* covers the surface area required the renewable energy technology. *Environmental impact* relates to the greenhouse gas emission produced by the building as well as the carbon emissions saved by the technology.

Technical Dimension: *Performance of the system* includes power rating of the technology and its potential generation capacity. *Durability* related to the expected lifetime of the system. *Flexibility and adaptability* covers the ability to make future changes to the system.

The process of filtering and selecting indicators adopts a similar approach to Neves and Leal (2010) in which there are seven steps. The methodology is adapted so that the indicators were selected based on our requirements. The fourth step is modified so that the three selection criteria helped the filtering process remain in scope of selecting indicators for renewable energy technology. The first step is to research the latest developments in sustainability indicator sets from literature. Next, indicators that are related to renewable energy and renewable technologies are selected. Repetitions or similarities will be removed in step 3. The fourth step involves the selection of indicators that are related to sustainability assessment of renewable energy technology as the next step investigates whether each indicator passes the three selection criteria:

1. Relevance of the indicator for considering investment in renewable energy technology
2. Potential measurability of each indicator
3. Power of the stakeholders to change outcomes measured by the indicator

The methodology may not identify all the expected indicators from the literature review and so new indicators need to be added in step 5. This should result in a core set of indicators, categorised into the four factors of the sustainability assessment framework in step 6.

### 4. Development of Indicators for Sustainability Assessment
4.1 Other Approaches to Sustainability Indicators for Renewable Energy Technology

In trying to assess renewable energy technology by using indicators it is essential to consider two factors: how would the indicators be practically useful and will the indicators be measurable in terms of sustainability? These have been considered in approaches developed by other researchers.

A project by Rezaie et al. (2011) used a technology, environmental impact and cost-based approach to assess renewable energy technology but does not take human satisfaction into consideration. A number of renewable energy technology configurations are tested against four domestic and non-domestic buildings. A set of indicators aided in the comparison of each renewable energy technology configuration. The results of the case studies concluded that there is a best option for either CO₂ reduction or a low cost based target. Even though the assessment approach has not been designed to find the most sustainable option it has still identified a number of indicators that takes the economic and environmental aspects of sustainable development into consideration.

Varun et al. (2009) had identified three key indicators for the sustainability assessment of renewable energy technology which also only takes economic and environmental factors into consideration. The performance of four different renewable energy technology installed around the world was assessed by using the three indicators. The authors had concluded that overall wind and small hydro systems are the most sustainable renewable energy technology. However, the method used by Varun et al. may not be suitable for assessing renewable energy technology for buildings. Other factors, such as, location could have a huge impact on a renewable energy technology’s performance, i.e. a wind turbine installed in an urban area with many obstructions. This, in effect, could change the outcome of which technology is the most sustainable option.

In trying to encapsulate the three dimensions of sustainable development Evans et al. (2009) carried out a comprehensive literature review to identify seven key sustainability indicators for the assessment of renewable energy technology. Having critically reviewed a number of life cycle analysis (LCA) tools the authors had identified two limitations with them. The tools take a more economic and environmental approach to assess renewable energy technology with less consideration for social impacts. Also, not enough indicators are used in LCA tools to assess the sustainability of renewable energy technology. Although, there are only seven indicators it does take the economic, environmental and social factors into consideration.

The approach used by these authors emphasises the challenge of developing indicators that would fully encompass the issues of sustainability. However, Rezaie et al. (2011), Varun et al. (2009) and Evans et al. (2009) have provided a comprehensive review of the sustainability indicators, which has been validated and tested using their methodologies. This provided the grounds for us to use a similar approach in which the indicators are selected taking into consideration the three dimensions of sustainable development.

4.2 Sustainability Indicators for Renewable Energy Technology

The review of recent literature and following the methodology of creating a new indicator set resulted in 32 indicators. The extraction from existing indicator sets (Rezaie et al., 2011; Rovere et al., 2010; Carrera & Mack, 2010; Varun et al., 2010; Evans et al., 2009; BRE, 2008) and subsequently in step 2 resulted in 66 sustainable energy and technology based
indicators. In step 3, a number of similar or repeated indicators were removed from the set which resulted in 58 indicators. Step 4 further reduced the number of indicators as the three selection criteria was applied to the indicators as shown in figure 2. However, when identifying gaps and adding new indicators to the set in steps 5 and 6 it was decided that some of the indicators had to be removed or changed because they could be interpreted in the same way. For example, the indicators greenhouse gas emissions and CO$_2$, sulphur dioxide, nitrous oxide emissions could be interpreted as representing both CO$_2$ and non-CO$_2$ gases.

In total, 14 indicators were extracted from literature and an additional 18 indicators was included in the set. The initial 14 indicators do not take account of all the factors as mentioned in the proposed sustainability assessment framework. As our research is specific to assessing renewable energy technology for commercial offices more research is required to understand what impact would the UK government schemes have on the development of our indicator set. As a result, a number of government schemes were identified (HMRC, 2012; DECC, 2012a; DECC, 2012b; Ofgem, 2011) and a further 18 indicators were included to our existing indicator set. There were a number of proposed changes to the indicators to ensure that they are clear, simple and easily understood. A total of 32 indicators have been identified for the purpose of assessing renewable energy technology.

5. RESULTS & DISCUSSION

A building from the University of Reading was considered as a case study in order to test the proposed framework and indicators. This was a suitable choice for testing as the building already has an existing solar PV system installed on the roof. The purpose of this test is to examine the effectiveness of using the indicators to assess whether the solar PV installation is a suitable and sustainable option for the building.

<table>
<thead>
<tr>
<th>Economic</th>
<th>Environmental</th>
<th>Social</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installation cost</td>
<td>£60,000.00</td>
<td>Energy consumed by building</td>
<td>N/A</td>
</tr>
<tr>
<td>Corporate tax</td>
<td>0%</td>
<td>Total Greenhouse gas emission by building</td>
<td>N/A</td>
</tr>
<tr>
<td>Operational costs</td>
<td>N/A</td>
<td>Total water consumption by building</td>
<td>N/A</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>N/A</td>
<td>Occupied area for electricity generation</td>
<td>N/A</td>
</tr>
<tr>
<td>Total from corporate tax deduction</td>
<td>£0.00</td>
<td>Carbon saved per year</td>
<td>12574.14</td>
</tr>
<tr>
<td>Government incentive scheme</td>
<td>£0.329</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumed on premises</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy exported to grid</td>
<td>0%</td>
<td></td>
<td></td>
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<tr>
<td>Assumed standard import tariff</td>
<td>£0.082</td>
<td></td>
<td></td>
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<tr>
<td>Government scheme - Export tariff</td>
<td>£0.031</td>
<td></td>
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<tr>
<td>Government incentive income</td>
<td>£6,968.22</td>
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<tr>
<td>Annual fuel bill savings</td>
<td>£1,736.76</td>
<td></td>
<td></td>
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<tr>
<td>Annual value of energy exported</td>
<td>£0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government scheme - Carbon tax</td>
<td>£12.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon tax savings</td>
<td>£144.00</td>
<td></td>
<td></td>
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<tr>
<td>Total value of energy generated</td>
<td>£8,560.98</td>
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<tr>
<td>Basic payback time</td>
<td>7</td>
<td></td>
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<tr>
<td>Annual return on investment</td>
<td>14.27%</td>
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<tr>
<td>Remaining benefit from income</td>
<td>£154,024.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remaining lease of building</td>
<td>0</td>
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</table>

Table 1 Sustainability indicator analysis of solar PV installation
Table 1 presents the indicators and results in the four dimensions of the proposed framework. It shows that the solar PV system in the case study has a power rating of 25kW costing £60,000 to install. Because the total installation cost exceeds £25,000 it is not eligible for tax relief therefore the university will have to pay for the full system (HMRC, 2012; DECC, 2012a). However, taking into consideration the revenue this solar PV system generates from the government’s incentive scheme (Ofgem, 2011) and the savings made from not using electricity from the Grid it earns a total value of just over £8,500 per annum. The renewable energy technology does not suffer from major functional or aesthetic impact and therefore does not affect nearby lecture theatres in the university. Basic payback time for this installation is 7 years on a system that has a design life of 25 years. The government incentive scheme for solar PV also lasts for 25 years, which means the solar PV installation will continue generating revenue for the next 18 years as indicated by the ‘remaining benefit from income’ of just under £160,000. It also generates just over 21,000kW of electricity which is consumed by the building and helps the university reduce their carbon footprint by 12.5 tonnes per year. Based on the indicators, the solar PV installation is a suitable and sustainable option for this building.

6. CONCLUSION

This paper has presented a framework for the development of sustainability indicators to assess renewable energy technology taking into consideration the economic, social, environmental and technical factors. Research into sustainable development, renewable technology and indicators were used as the guiding principles that contributed to the development of the proposed framework and indicators. The indicators could be used as an analytical tool for assessing the sustainability of a renewable energy technology and for identifying more sustainable options for a commercial office building. Currently, the framework and indicators can only be applied to specific types of renewable energy technology.

In developing the theoretical framework and sustainability indicators, the aim was to perform a literature review on sustainable development and other works in sustainability assessment frameworks. Many other frameworks included all three dimensions of sustainable development. Our proposed framework adopted the same approach with the additional technical dimension for the purpose of assessing renewable energy technology. The methodology used for selecting indicators also ensured the indicators were relevant to the three dimensions.

The indicators were used to assess a solar PV installation for a building in the University of Reading and as a result it helped identified a number of factors that emphasised why it was a suitable and sustainable option. The case study shows that the solar PV installation receives financial support from the UK government which pays for the installation and generates revenue. The system also helps the university to reduce their carbon footprint. Staff members and students are not affected by this installation due to the minor functional and aesthetic impact it has. Therefore, the solar photovoltaic installation is highly unlikely to be taken offline.

The proposed framework and indicators provides a natural guide for future research. Initially, the scope of this research includes specific types of renewable energy technology and one type of non-domestic buildings. More case studies are needed to test and validate the proposed framework and indicators.
REFERENCES


