A Life Cycle Approach to Sustainability Assessment on Community Energy Projects in the UK

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ABSTRACT

Sustainability assessment of electricity production options has become a popular topic in the past few decades. However, the large volume of existing literature mainly focuses on sustainability issues at national scale or cooperate level, with little attention given to community-related sustainability issues. This study proposes a community-focus based wholistic and systematic method that combines life cycle approach and sustainability theory, which can be used to examine the sustainability of community energy projects in the UK. A community-based approach gives preference to electricity generation options that serve the local community values and sustainably utilize local natural resources. In addition, stakeholders and decision makers in the region can be informed on sustainability issues which are generally neglected. Application of the proposed method was demonstrated through sustainability assessment of a designed community energy project.

(Keywords: Sustainability assessment, life cycle assessment, community energy)

INTRODUCTION

Community energy covers aspects of collective action to reduce, purchase, manage and provide energy for local communities(DECC, 2016). It is a relatively new sector in the UK. Although the first community energy scheme in the UK was established in 1996 (CEE, 2015), community-led energy projects were seen to flourish only since the introduction of supporting policy measures in the past decade. As reported by the UK Department of Energy and Climate Change, installed operational capacity for community energy projects had reached 49MW by 2014 (DECC, 2014). In reality, this number is expected to be higher due to lack of records for a number of known installations. According to a recent survey carried out by Community Energy England (CEE), community energy schemes provided over 57GWh of clean electricity to date and had reduced CO2 emission by 26,500 tones.(CEE, 2015, p. 9)

There are mainly two types of community energy projects in the UK: small-scale and large single installations. For small-scale projects, local groups are established to raise funding for a small number of renewable energy systems installed within the local community such as schools. These local groups generally start with one “pilot project” and then go on to complete further schemes upon the success of the initial project. Solar photovoltaic (PV) is the most popular option for such small-scale projects. Large single installations generally involve one large-scale scheme alone, such as a solar farm or wind turbines etc. These projects rely on expertise due to its complexity. Development and completion of these projects require a large commitment of time in addition to external funding in the form of commercial or social loans.

In the UK, the national government creates a market for energy technologies and supports its growth, then the duty is passed along to local planning authorities to encourage local stakeholders to take part in energy projects and implement energy technologies (Smith, 2007). This provides an explanation for the reason why community energy projects are highly dependent on government subsidies. Community energy projects appear mostly concentrated in Scotland ostensibly because community groups have been able to access to an investment fund through the Climate Change Fund and Centre for Applied Research and Environmental Systems for the past years.(DECC, 2014) For England, the booming of the community energy sector was mainly created through the introduction of the Feed-in Tariff (FiT) in 2010, where the small-scale generation of electricity received a fixed payment from the government for electricity generated. FiT acts as clean energy cash back scheme and has not only reduced investment risk for community energy projects but also offered long-term incentives for some communities to establish revenue-generating energy projects.(Seyfang *et al.*, 2013)

Apart from cutting down carbon emissions, community energy has provided a wide range of economic and social benefits for local communities. Firstly, these projects would typically contribute to their local community fund which was then invested back into the community to support local sustainability activities, and assist with solving local sustainability-related issues. For example, Plymouth Energy Community was able to invest surplus income from its renewable energy projects into improving fuel poverty and purchasing computers for low-income schools (CEE, 2015). Secondly, the energy generated from these projects was able to reduce energy costs for host organizations. There are 20 schemes currently generating energy savings of £172,500 per year (CEE, 2015)for its hosts, such as local schools, sports centers, etc. This benefit is expected to increase as electricity price rises. Finally, these community projects typically employed local people for the duration of the installation works in such positions as maintenance, accountancy, etc. This generated cash flow and employment within the region. As stated by the CEE, the value of existing contracts with local suppliers is approximately over £1.1million per year. Given the majority of these services is required for 20 years, local businesses will benefit further from long-term income.

From a micro-economic perspective, "keep values in the community" (CEE, 2015) lead to the "local multiplier effect". When a local economy creates new job opportunities by bringing in new businesses, there will be a higher demand for local goods or services, additional jobs are then created to satisfy growing demand. Moretti (2010) discovered that in a given city, for each extra job created in the manufacturing industry, 1.6 additional employment opportunities are generated in the non-trading sector, and the demand for local goods and services also upsurges. The more skilled jobs created within the region, the larger the multiplier effect is due to higher earnings for skilled jobs. In addition, for each additional skilled employment opportunity created in the tradable sector in a given city, 2.5 employment opportunities are then generated in local goods and services. Businesses that are associated with high technology have the largest multiplier effect among all. In the case of community energy, members of the community groups have already established local connections. As stated by CEE, for a typical small PV scheme, community organization offers 4%-6% share interest on average, which generates wider economic benefits to the local business involved in community schemes. (CEE, 2015)

However, despite an apparent booming of community energy in the UK, the sector faces major difficulties following the reduction of the FiT in August 2015. Solar PV as a major community energy project faces severe pressure in particular. Prior to the revision of FiT, any system with a capacity of less than 4 kW receives 12.47 pence for per kWh electricity generated, and for the system of 4 kW- 10 kW capacity government offers 11.39 pence for per kWh electricity generated. The new revised tariff offers only 4.39 pence for per kWh electricity generated, for any system with installation capacity less than 10 kW. This change doesn't apply to existing systems that are already benefiting from the scheme. However,the duration of FiT payments has been cut from 25 years to 20 years for solar PVs installed after 1 August 2012.(Ofgem, 2016a) Lower FiT means longer payback time for solar panels. From a consumer's perspective, this change makes solar PV a longer-term investment since the system will not generate profit until it had paid for itself.(DECC, 2015)

The deployment of community energy projects has aid transparent communication with the public and provides stakeholders with better understandings of trade-offs risks and uncertainties associated with alternatives. (Morrison-Saunders et al., 2015) Community energy as a tool in the transition to a low-carbon economy faces a difficult time ahead in the UK. It is crucial for the community energy sector to evaluate its sustainability issues in order to respond to the changes it is facing. Existing research on community energy projects is mainly qualitative with a focus on consumer driven behavior-change to reduce carbon emissions, rather than community energy per se (Seyfang et al., 2013). The aim of this study is to develop a methodology providing a comprehensive method for examining the sustainability of community energy projects in the UK, which can be utilized to provide constructive feedback for stakeholders to improve the viability of community energy as a part of a future low-carbon economy. Moreover, quantifying sustainability benefits of community projects makes this sector more competitive in the energy market.

Establishing the framework

A literature survey was carried out in two stages in order to establish the assessment framework. In the first stage, sustainability theory was analyzed to establish a theoretical framework; in the second stage, a range of existing sustainability assessment methodology was explored to shape the structure of a proposed assessment model; a life cycle approach was found to be the best fit for purpose at this stage. Given the vast quantity of literature on sustainability assessment, selection for further study was based on following criteria:

1) Relevance. Only literature related to energy (electricity generation) projects are to be reviewed;

2) Literature on assessment frameworks and indicators are given priority to the post-2000 literature, on the assumption that most recent literature captures the progress of sustainable development over the time and hence focuses on more up-to-date sustainability issues;
3) Community specific literature is included to give a focus on community-based sustainability issues.

Conceptual Review of Sustainability

The term sustainability was first brought into the public realm in 1980 in the World Conservation Strategy (IUCN, 1980). In 1987, the sustainability concept was first introduced in the Brundtland Report, as "development that meet[s]the needs of the present without compromising the ability of future generations to meet their own needs"(WCED, 1987). This concept is the result of the global acknowledgment of connections between environmental and socio-economic issues as well as concerns for the future of humanity. (Hopwood *et al.*, 2005) The most important characteristic of sustainability that it must act as an "integrating concept" (Robinson, 2004, p. 379) and equally representing the "three pillars" of sustainability: environmental, economic, and social values (Martens, 2006; Ciegis *et al.*, 2009; Baumgartner and Ebner, 2010). In order to achieve a balance between these sometimes competing, sometimes complementary interests (Shepherd and Ortolano, 1996), co-ordination and negotiation between these values are required but also trade-offs must also be made from time to time. (Berke and Conroy, 2000)

Reviews on sustainability assessment methodologies

A comprehensive appraisal of all energy options is essential for evaluating the sustainability performance of energy technologies (Youds, 2013) since it can efficiently assist decision making by providing solutions to prevent sustainability burdens (Berke and Manta, 1999; Lundin, 2003; Afgan and Carvalho, 2004).

Sustainability assessment methods have been widely discussed and developed. Contrary to sustainability theory, some of the existing assessment frameworks consider only one dimension of sustainability; the environmental aspect in general, while others have attempted to integrate two or three-dimensional sustainability into a common assessment framework. (e.g. (Diakoulaki and Karangelis, 2007; Madlener *et al.*, 2007)). A sustainability reporting guideline developed by Global Reporting Initiative (GRI, 2006) which overlooks all economic, environmental and social impacts, is widely applied for measuring cooperate sustainability. There are also a number of frameworks that are integrated as part of the assessment for national development by governmental authorities, such as Australia (ABS, 2008), UK (DEFRA, 2008), Austria (AMC, 2008) and Canada (EC, 2005). It is considered by the author that these frameworks are too generic and lack focus on technology.

In terms of UK sustainability assessment, most existing sustainability assessment methods focus at a national level (Riley, 2001; Del Río and Burguillo, 2008), and there are fewer available methods that can be used to assess sustainability at community level (Gahin *et al.*, 2003; Coelho *et al.*, 2006). Models proposed by Youds (2013) and (Stamford and Azapagic, 2012) which are built based on Azapagic's previous research (Azapagic, 2004; Azapagic and Perdan, 2005b; Azapagic and Perdan, 2005a) are by far the most comprehensive for assessing the sustainability of energy technologies in the UK. Both studies follow sustainability theory and equally represent the "three pillars" of sustainability. Both studies consider a mix of top-down and bottom-up approaches. Youds employed a multiple-criteria decision analysis, and the assessment method mainly relies on qualitative data; while Stamford and Azapagic took on life cycle approach (LCA) and examined sustainability impact throughout the entire electricity production cycle. However, despite the quality of both studies, the narrow focus on sustainability issues at a national scale gives little attention to local sustainability issues, such as the financial feasibility for deployment of community energy projects.

There are a vast amount of existing sustainability assessment tools. These tools are developed at different levels with a different focus of sustainability issues. LCA is the most well-developed of these tools and it had been widely and commonly applied to examine environmental impacts on energy systems (Pehnt, 2006; Bhat and Prakash, 2009; Gasol et al., 2009; Ling-Chin et al., 2016). Both Opetuk and Dukic (2014) and Liu et al (2011) reviewed more than 100 sustainability-related research projects and concluded that sustainability assessment has moved to a life cycle approach from the evaluation of a single phase. LCA is sometimes described as a "cradle-to-grave" approach (Ness et al., 2007) and, as the name suggests, assesses the associated impact of a product's entire life cycle. This concept efficiently assists the optimization of the environmental performance of a single product and it allows a fair comparison between a few products so the most burdensome can be avoided. (Varun et al., 2009; Stamford and Azapagic, 2012).

Reviews on sustainability assessment indicators

A large number of reviewed indicators are based on a qualitative method. Despite the potential for a more flexible descriptive tool, this qualitative method introduces uncertainty to the result of an assessment due to the interpretation of its content, therefore, opening up the possibility for inaccuracy and unreliability. For example, Kowalski et al (2009) employs only qualitative indicators to examine social impacts brought by energy systems, criteria such as social cohesion which aims to examine possibilities to create social capital by joined initiatives Not only is the outcome of this assessment criterion highly dependent on the author's interpretation, there is also a degree of uncertainty of the stakeholder's opinion on this parameter. The same can be said for indicators such as visual impact proposed by (Polatidis and Haralambopoulos, 2007).

Across reviewed literature, there are impact categories that are widely discussed and are assigned with similar names; however, they were calculated differently. Climate change, cost, and employment are the most commonly examined categories. Climate change, or "global warming potential," is generally calculated as the amount of greenhouse gas emissions expressed as the equivalent emission in kilograms of CO_2 per KWh or TJ of electricity produced. The methodology employed to examine the cost of production varies greatly across reviewed studies. Some studies only take into account the investment cost (e.g. (Begić and Afgan, 2007)) or non-discounted production cost (e.g. (Hirschberg *et al.*, 2004); while other studies determine net present value after applying a discounted rate (e.g.(Polatidis and Haralambopoulos, 2007). In addition, employment is another category that is widely examined however with no agreed methodology. Some studies simply quantify employment as hours of work required per kWh electricity produced (e.g. (Begić and Afgan, 2007)), while other studies looked into both direct and indirect employments, as number of employees required (e.g. (NEA, 2007))

Clarity and consistency are both essential for providing valid and helpful information for decision-making. Local community characteristics also need to be taken into account to make sure stakeholders interests are well considered and protected.

Community Energy Sustainability Assessment Model

Following the literature survey and critical analysis of these previous research findings, a sustainability assessment model is proposed. The framework of this model is constructed based on sustainability theory and inspired by the previous study carried out by Stamford (2012). The proposed model employs LCA as an assessment tool.

Electricity generated from projects is regarded as a product, and the model proposed in this study evaluates the sustainability of this product throughout its entire life cycle, which includes following stages: construction, operation and maintenance, waste disposal and decommissioning. Evaluation parameters are divided into three categories to represent the "three pillars" of sustainability: techno-economic, environment and social impacts. Sustainability issues within each impact categories are identified through both literature survey and stakeholder consultation. A group of stakeholders comprising local authorities, academics and researchers, community energy associations and energy consultancies kindly provided opinions on sustainability issues associated with community energy projects. Establishing relevant sustainability issues provided a framework for this assessment model; then indicators with associated algorithms were developed to finalize the model.

For ease of application, a set of only eleven indicators are selected with four addressing economic issues, three addressing environmental issues and four addressing social issues are included in the final constructed framework (see Table 1).

The Selection of indicators follows these principles:

1) Geographical and technological relevancy to community energy projects
2) Avoidance of double counting
3) Indicators have to be quantifiable

4) Value preference of each indicator shall be made clear and consistent.
5) Feasibility for model to be applied in real life according to resource availability
6) Easiness to understand, so that the indicator is useful to decision makers and understandable to the public
7) The indicators and analysis details must be transparent and accessible to all stakeholders.

Principles above are concluded based on data quality criteria stated by ISO 14040 standard[1].

During the assessment, the performance of each project is compared against the indicators listed below. How each sustainability issue is evaluated through indicators is explained in following sections. It should be noted that for non-comparative studies, weighting method[2] is optional for LCA (Guinée, 2002) for which no established clear method is available; however for comparative methods which are disclosed to the public, LCA standard ISO14040 explicitly states that weighting method is allowed. Therefore, weighting method is not included in this study.

Category	Sustainability Issues	Indicator	Unit	Life Cycle Stages			
				Construction	Operation	Waste Disposal	Decommissioning
Economic	Levelised Cost of Generation	Capital Costs	£/MWh	x	-	-	x
		Operation and maintenance costs	£/MWh	-	x	x	-
		Total levelised cost	£/MWh	x	x	x	x
	Financial Feasibility	Payback Period	Years	x	x	x	x
Environmental	Material Recyclability	Recyclability of input materials	%	x	-	x	x
	Global Warming	GreenHouseGas(GHG) Emission	$kgCO_2$ eq./kWh	x	x	x	x
	Land Use	Land Use	m^2-years/kWh	x	x	x	x
Social	Employment Provision	local Employment	person/GWh	x	x	x	x
	Community Impacts	Spending on Local Suppliers	%	x	x	-	-
		Investment in local community	%	x	x	-	-
	Fuel Poverty	Bill Reduction	%	-	x	-	-

Table 1 Community Energy Project Sustainability Assessment Framework

Economic indicators

Economic performance is a crucial factor for the possibility of deployment of energy technologies and energy projects. For example, if the payback period is long then project appears less attractive for investors. There are two categories to address sustainability issues from economic aspect: levelised cost of generation, and financial feasibility.

Levelised cost of generation stands for the cost for each unit of electricity generated throughout the entire lifetime of the project, with discount rate applied where appropriate. Total levelised cost includes capital costs and operational and maintenance cost. Capital costs cover the costs at both construction stage and decommissioning stage of an energy project. Operational cost covers cost generated at the operational stage of the project including maintenance costs, fuel costs, and waste disposal costs

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[1] ISO 14040 is international standard for LCA studies

[2] Weighting method is a process of applying value of importance onto results of indicators. (ISO, 2006)

$$LEC = \frac{\sum_{n=1}^{N} \frac{CC_t+M_t+F_t}{(1+r)}}{E_t} \times 10^{-2} \qquad (1)$$

CC_t- Capital costs in year *t (£)*
MC_t-Maintenance cost in year *t (£)*
FC_t- Fuel costs in year *t (£)*
WC_t- Waste disposal costs in year t *(£)*
E_t- Energy harvested in year *t (kWh)*
r - Discount rate
N- Life time of the plant *(years)*

Where, LEC- Levelized Energy Cost *(£/kWh)*

Financial feasibility looks into the amount of time take for investors to break-even their expenditure with income generated through the project. As previously stated, in the UK community energy projects profitable from export surplus electricity generated to the national grid, receiving state financial support for per unit of electricity generated, as well as savings on electricity bills.

$$PP = \frac{LEC}{\sum_{n=1}^{N} \frac{S_t+FS_t+SP_t}{(1+r)}} \qquad (2)$$

Where, SP_t-Profit generated through selling surplus energy in year *t (£)*
PP- Payback period *(years)*
S_t -Savings on utility costs in year *t (£)*
FS_t -Governmental financial support received *t (£)*

Environmental indicators

Environmental impact is evaluated through three categories: material recyclability, global warming potential, and land use. Material recyclability investigates the proportion of recyclable material within the total mass of materials required for selected project. Construction and decommissioning stage of the project are assessed under this category because material consumption of energy projects is most intensive at these two stages. Material recyclability is calculated as:

$$MR = \frac{\sum_j^J R_j}{M_p} \times 100(\%) \qquad (3)$$

Where, MR- Material recyclability
j- Material required/used
R_i- The recyclable mass of material *j (t)*
M_p- Total mass of material acquired for energy system *(t)*

Global warming potential (GWP) examines the potential of greenhouse gas (GHG) emissions that are generated throughout a project's entire life cycle to cause climate change. Emission of GHGs at each life cycle stage of the project is interpreted as per kg of CO_2 equivalents. CML 2001 [3]impact assessment method is recommended for calculating GWP (Guinée, 2001), for the reason that CML is the most commonly applied and the most completed methodology. GWP is calculated as :

$$GWP = \sum_j^J GWP_j \times B_j \ (kgCO_2\ eq./kWh) \qquad (4)$$

Where, GWP- Global Warming Potential ($kgCO_2\ eq.$/kWh)
J- Total number of greenhouse gasses
B_j- Emission of greenhouse gas j (kg/kWh)
GWP_j- GWP factor of greenhouse gas *j* ($kgCO_2\ eq.$/kg)

Land use measures the total area of land that is occupied by energy projects for which is not available for other use, or not available to carry on activities that already took place. This measure is quantified as below:

$$LU = \frac{A * t_A}{E} \qquad (5)$$

Where, LU- Land Use ($m^2 -$ years/kWh)
t_A- Duration of land occupation
E_t- Total electricity harvested in throughout the project (kWh)
A-Land area occupied (m^2)

Social Indicators

Social indicators are less well developed compared to environmental and economic indicators, mainly due to the complexity of social issues. Social impacts are analyzed through three categories in this framework: employment provision, community impacts and reduction of fuel poverty.

A major social contribution of community energy project is employment provision. Employment is expected to be generated throughout the entire life span of the project, hence all life cycle stages of the project is accounted for within this indicator.

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[3] CML 2001 method developed by Centre of Environmental Science of Leiden University, is a mid-point LCA impact assessment method. Further information can be accessed here: http://www.openlca.org/documents/14826/2c5b8391-68d9-49a1-b460-a94f18e7d2df

$$LE = \frac{\sum_{i=1}^{I} LE_i}{E_t} \qquad (6)$$

Where, LE- Local employment generated throughout life span (person-days/kWh)
I-Total number of life cycle stages
LE_i- Number of employment generated at life cycle stage *i*
E_t- Total electricity harvested in throughout the project (kWh)

When an energy project spends on local suppliers, it is considered as a direct return on investment, which promotes equal distribution of wealth within the community (Azapagic, 2004; Stamford and Azapagic, 2011). Therefore, community impact is assessed based on revenue generated through energy projects that are invested back to the community. This impact is evaluated using two indicators: the proportion of total annual expenditure that is spent on local suppliers; and proportion of annual revenues that are a direct investment in local schools, community centers, hospitals etc.

The amount of total investment that paid for local suppliers is calculated as the proportion of expenditure on local suppliers compare to the total annual average expenditure at operational stage. Implication of this indicator is based on pervious work carried out by Stamford and Azapagic (2011)

$$LDI\% = \frac{LDI}{R_{total}} \times 100(\%)$$

$LDI\%$- Proportion of annual investment in local community (%)
LDI- Annual investment in local community (£)
R_{total}- Total annual revenue generated (£)

Investment in the local community is quantified as the proportion of investment that is returned back to the community per year compare the total annual revenue generated through energy projects. It is calculated as:

$$LDI\% = \frac{LDI}{R_{total}} \times 100(\%) \qquad (8)$$

Where, $LDI\%$- Proportion of annual investment in local community (%)
LDI- Annual investment in local community (£)
R_{total}- Total annual revenue generated (£)

One of the main purposes of a community project is to provide a solution for fuel poverty issues. Mitigation of fuel poverty is assessed through reduction on energy bills per household after deployment of energy projects.

$$BR = \frac{BS}{HB_{before}} \times 100(\%) \qquad (9)$$

Where, BR- Annual bill reduction (%)
BS – Household bill savings through installation of energy projects (£)
HB_{before} – Household annual energy bill before installation of energy projects (£)

Application of proposed model

This section demonstrates the application of model proposed in this study with an example fictitious project named project A. It should be noted that all the assumptions made in project A are only for demonstration purposes, real-life values may vary greatly from cases to case.

Data Assumptions

Project A is a rooftop solar PV project installed on a social housing estate in Northeast England. The neighborhood area consists of 50 households. The aim of project A is to provide clean energy for housing residents in order to meet carbon emission targets in the UK, mitigate fuel poverty in the neighborhood area, as well as create local employment opportunities.

This project was financed through a mixture of equity investment and Community Energy Fund provided by UK government. Any revenue generated through project A was placed into a community energy fund. This fund was used to improve the energy efficiency of social housing in the estate and thereby alleviate fuel poverty for the less fortunate residents.

Each house involved in the project is going to be equipped with 4 kWp mono-silicon solar PV system. Each system consists of solar PV panels, the balance of the system and an inverter. These systems have 30 years factory guaranteed lifetime. According to European legislation, PV installation companies registered in PV CYCLE scheme are required to remove the PV system and recycle them at the end of system life. However, since a PV system is still able to supply electricity to its host after guaranteed life with reduced efficiency and it is not required to be removed after 30 years, therefore for indicators examining decommissioning stage is not considered for project A apart from material recyclability.

Electricity harvested from solar PV mainly depend on the available solar radiation. According to operational figure directly quoted by UK's electricity regulator Ofgem, annual electricity yield for a rooftop solar PV that is installed at an optimal angle in the urban area of Northeast England region is approximately 800 kWh/kWp. Therefore, electricity harvested in a year for a 4kWp system is 3200kWh and 160MWh for the entire state.

Economic Sustainability

The local company provided a quota of £7000 of installation cost per system, and maintenance service charge of £7000 throughout the entire project. Waste disposal upon installation costs £3000 for the entire estate. In addition, inverter needs to be replaced every 15 years at a cost of £1500 each time. Discount rate in this study is considered to be 3.5% as recommended by the Green Book (2003)

Payment rate of income generated by PV systems is displayed in Table 3 below. There are three sources of income of project A, export of surplus electricity, FiT and bill reduction that is directly benefited by residents. For the export rate, since currently there is no export meter installed in the UK, utility company simply presume 50% of electricity generated from PV system is exported to the national grid. The current FiT rate is 4.39p/kWh (Ofgem, 2016b), and average electricity cost per unit in the UK is 9.6p/kWh. Both export rate and FiT are discounted at Retail Price Index (RPI) of 1.3% as reviewed by Office for National Statistics (ONS) at March 2016. (ONS, 2016). Base on above assumptions, levelised costs and a payback period of project A are estimated in Table 3. Profitability of project A is satisfying since the project will be running on debt free basis from year 3. However, financing difficulties are foreseeable since more than 69% of project financial load occurs at capital investment stage.

Income Category	**Payment Rate (£/kWh)**
FiT	0.0439
Bill Reduction	0.096
Export	0.0491

Table 3 Payment Rate Generated by Solar PV System for Project A

Lifetime Electricity Yield (MWh)	4800		
Levelised Costs	Capital Cost[£/MWh]	O&M Cost [£/MWh]	Total Levelised Cost[£/MWh]
	73.5	32.7	£106
Payback Period (years)	2		

Table 2 Economic Assumption for Project A

Environmental Sustainability

Material recyclability is measured by the amount of material required for energy project and its recycling rate. In theory, apart from the plastic used in solar panel wafers need to be down-cycled, other materials used in solar PV have over 80% of designed recycling rate; however, practical recycling rate varies significantly depending on actual recycling practice. The assumption of material used for each solar PV system used in project A and its recycling rate are listed in Table3 below (any material use with less than 5% of total system mass is ignored). In general, each PV system has 72.52% of material recycling rate, and material used in the solar panel has higher recycling rate compare to the material used in the inverter. Overall, copper and plastic have the lowest recycling rate in practice.

	Material	**Mass of Material (kg)**	**Practical Recycling rate (Asokan *et al.*, 2009; DEFRA, 2015)**
Solar Panel	**Glass-fibre Reinforced Plastic**	0.19	10.0%
	Aluminium Alloy(AlMg3)	2.63	90.0%
	Board Box	1.11	80.0%
	Tempering Glass	10.08	67.8%
	Silicon Product	0.12	80.0%
Inverter	**Copper(Cable)**	0.11	50.0%
	Aluminium Alloy(AlMg3)	0.386	90.0%
Total Mass (kg)		14.626	
Recyclability		72.52%	

Table 4 Material Recycling Rate for Solar PV System Included in Project A

Since the rooftop area where proposed PV systems will be installed was not previously occupied, and installation of energy system will not interfere with any existing activity, therefore it can be presumed that project A has no land impact.

Global warming potential (GWP) of the proposed project is calculated using GaBi professional v6.115 and Ecoinvent 3.1integrated database. System boundary including the production of PV panel, the balance of the system, and inverter; transport from supplier to installation site, installation and operation. GWP assumption is displayed in Figure1 below, where processes with the impact of less than 5% are ignored in this analysis. Graph 1 had made it obvious that major source of CO$_2$ emission in project A is solar PV system itself rather than installation and O&M of the system. This means for each kWh of clean electricity local residents are benefiting from in the Northeast England, 14.6kg CO_2 is discharged into atmosphere at where the PV systems are produced. The majority of these emission originates from inverter production and aluminum material used in the solar panel.

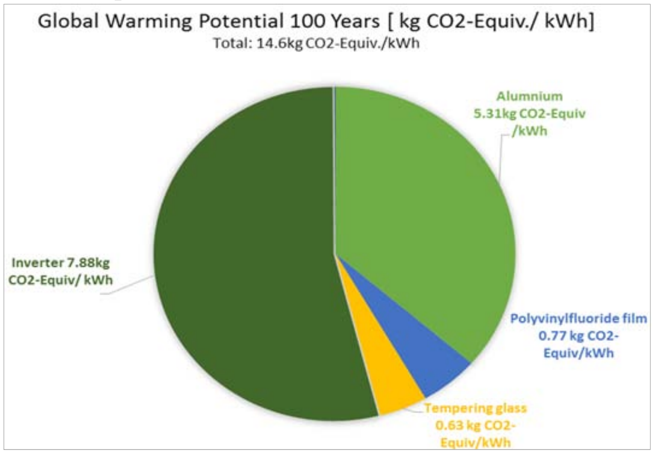

Figure 1 Global Warming Potential (100 years) of Project A

Social Sustainability

The assumption for employment provision is displayed in Table 5. Installation of PV systems for project A will take 15 days and 20 employees to complete. Maintenance service is required for the installed system every two years; each time takes five days and requires two professionals to carry out the task. In addition, three members are required for managing the project for 100 days per year. Therefore, it can be estimated that 1.97 person-days employment is required for generating one MWh electricity. Due to the easiness of installation and low-maintenance nature of solar PV technology, the majority of these employment opportunities is created for managing the project.

		Number of Employment (person)	Duration of Service (days)	Lifetime Occurance	Lifetime Employment (person-day/MWh)
Installation		20	10	1	0.04
O&M	System Maintenance	2	5	15	0.03
	Project Management	3	100	30	1.88
		Total:			1.95

Table 5 Employment Assumption for Project A

At an annual yield of 160MWh, project A is capable of generating income of £10952 per year. Presume annual expenditure of project A is £6000 with £3000 spending on local suppliers; therefore, 50% of annual of project expenditure is invested back to local suppliers, and 45% of annual revenue generated is invested back to the community.

Each solar PV system provides 3200kWh, which accounts for £307.2 free electricity for per household. Local average annual electricity consumption is 4600kWh(DECC, 2010); therefore, achievable the bill reduction rate of project A can be estimated as 69.6%.

Results obtained from assumption above are further discussed in the following section.

Results and Discussion

Overall analysis outcome for project A is demonstrated in Figure 2 below. The strongest point of project A is the environmental aspect, due to the little interruption caused by the installation of energy systems, and little operational energy consumption. Although solar PV appear to offer clean energy for local residents, however, this is at a cost of 14.6kg CO_2 equip. /kWh which is more than that of the nuclear power (6.2 g CO_2 eq./kWh (Stamford and Azapagic, 2012)) for communities where these equipment are produced.

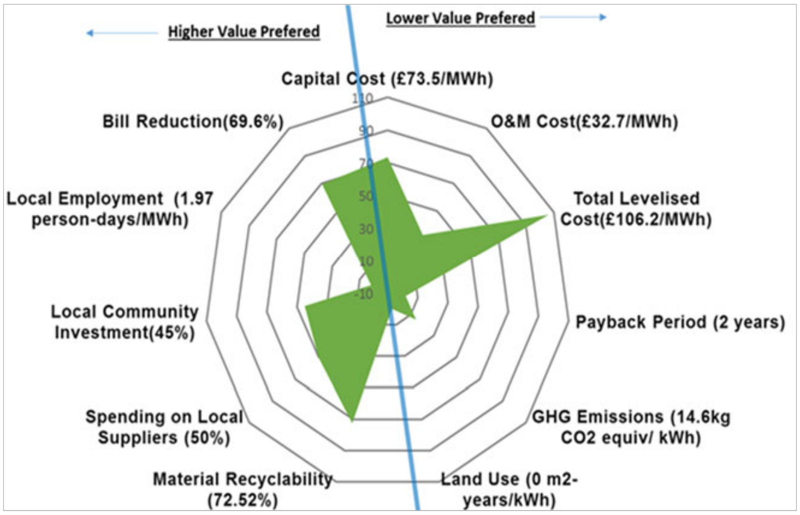

Figure 2 Sustainability Assessment Results for Project A. For indicators to the left of the dividing line higher values are preferred; for indicators to the right, lower values are preferred.

In terms of economic sustainability, levelised cost of solar PV (£106.2/MWh) is significantly higher compare to that of other renewable technologies, e.g. offshore wind (£90/MWh (IEA and NEA, 2015)). Cost-effectiveness of proposed systems could be let down by low solar radiation in the Northeast England. Despite its less than ideal cost-effectiveness, the satisfying payback period makes project A financially feasible. In addition, it should be noted that more than 20% of income generated through project A relies on FiT, which means any further reduction on FiT might have an adverse impact on project profitability.

Project A's ability to create employment opportunities is rather limited; however, the majority of these employment opportunities are associated with management of the project, which offers long-term benefit for the local community. Furthermore, the proposed project is able to deliver positive impacts for the local economy with 50% of its annual expenditure going to local suppliers, and 45% of its revenue invested in improving energy efficiency for local residents, reducing electricity bills for local residents by 69%.

In conclusion, project A is able to effectively mitigate fuel poverty and benefit the local community as it intended to. Although the proposed project can effectively reduce carbon emission and produce clean energy for the estate, the adverse environmental impact at the production end appears to be counterproductive.

Conclusion

The purpose of the sustainability assessment methodology proposed in this study is to provide a straightforward, effective, systematic and wholistic tool for evaluating sustainability performance of community energy projects, which can assist with decision-making process by keeping stakeholders well informed of the sustainability performance of the assessed project. The methodology's fitness for purpose is demonstrated through its application on fictitious project A. Project A is a simplified version of real-life scenario with only one technology considered for a project. The effectiveness of the proposed methodology can be further pronounced when the model is applied in more complicated cases, especially when a mixed portfolio of technologies is considered and/or compared to a project.

The combination of sustainability theory and life cycle approach enables the method to foster strengths and circumvent weakness of both: application of life cycle approach adds depth to sustainability theory; having sustainability theory as theoretical foundation ensures all aspects of sustainability are taken into account, which conventional LCA had failed to achieve.

Indicators listed in proposed framework are developed based on community energy projects in the UK, they could be less relevant for examining community energy projects in other countries due to the difference in the policymaking process and market mechanisms. In these cases, the model can be modified with case specific indicators, while the structure remains unchanged. Indicators selection shall follow criteria mentioned in previous sections.

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