Sustainability Assessment of Energy Production: A Critical Review of Methods, Measures and Issues

Abstract

Sustainable operations of energy production systems have become an increasingly important policy agenda globally because of the massive pressure placed on energy resources needed to support economic development and population growth. Due to the increasing research interest in examining the operational impacts of energy production systems on the society and the environment, this paper critically reviews the academic literature on the clean, affordable and secure supply of energy focussing on methods of assessments, measures of sustainability and emerging issues in the literature. While there have been some surveys on the sustainability of energy production systems they have either tended to focus on one assessment approach or one type of energy generation technology. This study builds on previous studies by providing a broader and comprehensive examination of the literature across generation technologies and assessment methods. A systematic review of 128 scholarly articles covering a 20-year period, ending 2018, and gathered from ProQuest, Scopus, and manual search is conducted. Synthesis and critical evaluation of the reviewed papers highlight a number of research gaps that exist within the sustainable energy production systems research domain. In addition, using mapping and cluster analyses, the paper visually highlights the network of dominant research issues, which emerged from the review.

Keywords: Sustainability; Energy Production; Systematic Review; Systems Thinking; Energy Policy; Sustainability Assessment

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1. Introduction

Over the past three decades, Sustainable Development has become a mainstream concept, which has underpinned key international and national policy initiatives on environmental and socio-economic development. It is based on this concept that grand sustainability agenda such as the Millennium Development Goals (MDGs) were implemented at the turn of the century followed by the subsequent adoption of the Sustainable Development Goals (SDGs) in 2015. These have been motivated by concerns over climate change and global population growth leading to focus on the development of holistic approaches to tackle sustainability challenges and ensure a more sustainable future (Reinhardt et al., 2019). The sustainability of energy production systems has become central to these grand sustainability challenges and so trickled down to the national levels.

Indeed, the seventh goal of the SDGs aims at ensuring access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015). Sustainability is a major energy policy requirement because the limits of conventional energy generation sources have become clearer for policy-makers. Additionally, the indirect impacts and new risks associated with even renewable generation resources have made planning decisions on the operations of energy production systems pertaining to sustainability even more challenging. This global requirement for clean, secure and affordable energy, the awareness of the limits of non-renewable primary resources, environmental and social impacts of both renewable and non-renewable energy generation technologies have been promoted by strong research in the area, which has subsequently engaged policy, industry and public interest.

Policy relevance of sustainability in energy systems is not only evident in the SDGs, but by energy policy objectives and legally binding treaties in various intergovernmental organizations (Stamford and Azapagic, 2014). The United Kingdom, for example, has set three priority areas in its energy review: reduction in greenhouse gas emissions, secure energy supply for the future, and reduction in fuel poverty (Allan et al., 2015). Similarly, to confront rising energy demands, the 2015 UN Climate Change Conference in Paris agreed to the reduction in greenhouse gas emissions with the aim of limiting global warming below 2°C by 2100 (Olmedo-Torre et al., 2018). The Economic Community of West African States (ECOWAS) has also passed an ECOWAS Energy Efficiency Policy (EEEP) and a Renewable Energy Policy (EREP) with aim of ensuring universal access to clean electricity by 2030 (Ohene-Asare and Turkson, 2018). These are a few of the several global and national efforts at ensuring sustainable practices in energy generation.

In this study, we conduct a synthesis and critical review of research on the sustainable operation of energy production systems by examining the main and emerging issues, the measures of sustainability and the methods employed in examining sustainability. The growing interest in this area of research has attracted a number of surveys on various issues related to sustainability and energy generation to be specific, even ignoring the plethora of survey papers on sustainability in general (Diaz-Balteiro et al., 2017, Brandenburg et al., 2014). While these studies have provided useful insights into the literature on sustainability assessment of energy generation systems they have either tended to focus on one assessment approach (Varun et al., 2009, Asdrubali et al., 2015) or one type of energy generation technology (Peng et al., 2013, Liu, 2014). As a result, there is a limited understanding of the extent of the literature focussing on the sustainability of the operations of energy systems in general. Additionally, studies that have been broader in focus have not yet provided insights on emerging issues like systems modelling and the concepts of weak and strong sustainability as they relate to energy systems. Such studies are shown in Table 1.

Table 1

Surveys on Sustainable Energy Systems

Authors	**Title**
Varun et al. (2009)	LCA of renewable energy for electricity generation systems—A review
Bazmi and Zahedi (2011)	Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review
Peng et al. (2013)	Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems
Liu (2014)	Development of a general sustainability indicator for renewable energy systems: A review
Asdrubali et al. (2015)	Life cycle assessment of electricity production from renewable energies: Review and results harmonization
Martín-Gamboa et al. (2017)	A review of life-cycle approaches coupled with data envelopment analysis within multi-criteria decision analysis for sustainability assessment of energy systems

Varun et al. (2009), for example, reviewed the literature on life cycle assessment (LCA) of renewable electricity generation systems. Their aim was to point out that such renewable energy generations systems also produce carbon emissions when examined throughout the product's life (that is, cradle to grave). Peng et al. (2013) also conducted a review of literature on LCA, however, they focused on LCA literature on solar photovoltaic (PV) systems. By examining the literature on energy payment and greenhouse gas (GhG) emissions of five common PV systems, they concluded that PV technologies have been proven to be very sustainable and environmentally friendly. They also postulated that the sustainability of PV systems will only improve with improvement in manufacturing technologies. The strength of the LCA approach is its ability to assume a systems approach and quantify all impacts of the entire supply chain thereby allowing for rational choice among energy supply systems (Varun et al., 2009).

Similar to Varun et al. (2009) and Peng et al. (2013), in relatively recent times, Asdrubali et al. (2015) and Martín-Gamboa et al. (2017) have based their reviews on LCA approaches to sustainability. Except that while Asdrubali et al. (2015) aimed at harmonizing the LCA results of papers in literature, Martín-Gamboa et al. (2017) were interested in reviewing studies that had combined LCA and Data Envelopment Analysis (DEA) for sustainability assessment of energy systems. After extensive harmonization and normalization of empirical results presented in the literature, Asdrubali et al. (2015) found that while wind-powered technologies are at the low end of environmental impact, geothermal and PV technologies are at the high end of environmental impact compared to other renewable energy generation technologies. On their part, Martín-Gamboa et al. (2017), after reviewing the literature on potentials for the combining of LCA and DEA modelling approaches, proposed a new methodological framework that allows for endogenous integration of life-cycle indicators, ranking and benchmarking and energy planning and facilitations of decision-making process using dynamic DEA approach. Note that the study by Martín-Gamboa et al. (2017) did not only focus on renewable energy generation sources as was done in the previous reviews discussed.

There have been other reviews and surveys, which are not focussed on LCA or its combination with other modelling techniques. Bazmi and Zahedi (2011), for example, conducted a review on the role of optimization modelling techniques in sustainable power generation and its supply. They find that optimization approaches have found wide applications especially at the decision making and planning stages such as production planning, scheduling, location, resource allocation, engineering design and even transportation problems. They see potential intellectual advances if superstructure-based modelling and optimization is widely adopted in such studies. The study was based on a systems approach where alternative technologies are captured (Bazmi and Zahedi, 2011). Finally, the review by Liu (2014) was focussed on developing a general sustainability indicator that includes many basic sustainability indicators. Their proposed framework, which incorporates multicriteria decision making (MCDM) approaches, provides a numerical basis, even for fuzzy criteria, which they believe is useful as a guide for sustainability assessment of various renewable energy systems.

In this study, we examine 128 peer-reviewed journal articles that examine the social, economic and environmental impacts of various energy production systems. We provide insights on the extent of research in the area in terms of methods used, measures and emerging research issues discussed. Based on which we identify gaps and provide recommendations for setting a research agenda. The next section provides a brief overview of the concept of sustainability, systems thinking and other research themes reviewed in this study. This is followed by Section 3 which presents the survey methodology used in gathering the papers for the review. Section 4 is a critical evaluation of the selected literature and the identification and presentation of gaps and recommendations. Finally, in Section 5, provides conclusion which lays the future research agenda.

2. Literature Review

2.1 Sustainability: towards a definition

While the origin of the term 'sustainability' can be traced to sixteenth-century German foresters (Kuhlman and Farrington, 2010, Schlör et al., 2012), modern resurgence of the term is attributed to the 1987 report of the Brundtland Commission of the United Nations World Commission on Environment and Development - WCED (Bonevac, 2010, Kajikawa et al., 2007). The report stresses that: "sustainability requires views of human needs and well-being that incorporate such non-economic variables as education and health enjoyed for their own sake, clean air and water, and the protection of natural beauty" (Brundtland, 1987, p. 53). This stimulus for sustainability is strengthened by the realization that human-activities are jeopardizing its own long term interests through atmospheric changes, biodiversity and freshwater depletion, among others (McMichael et al., 2003). As such, fundamental to the area of sustainability and sustainable development is the idea that human and natural systems interact and are interconnected (Schoolman et al., 2012).

Although the term 'sustainability' is ubiquitous in policy and literature, there is little consensus on its meaning. It is a difficult concept to define because it is an evolving one and its meaning is both abstract (Martens, 2006) and contextual (Kajikawa et al., 2007, Young and Dhanda, 2013) and described in varying ways by different parties (Campbell and Garmestani, 2012). Post the 1987 Brundtland report; definitions in literature have had some human or ecological underpinnings. Shaker (2015) sees sustainability as humanity's target goal for human and ecosystem equilibrium. Finkbeiner et al. (2010) observe that sustainability should not focus on environmental impact alone but there should be a balance or even an optimum in environmental, economic and social well-being dimensions of society. Similarly, McMichael et al. (2003) believe that sustainability means transforming human ways of living in order to maximize chances that environmental and social conditions can support human security, well-being and health indefinitely. Kahle and Gurel-Atay (2013) believe that "sustainability implies the use of resources in a manner that can continue indefinitely."

The problem becomes confounded when the meaning of sustainable development is explored. Critics believe 'sustainable development' is vague and can be an oxymoron (Bonevac, 2010, Kajikawa et al., 2007). Additionally, Bonevac (2010) and Büyüközkan and Karabulut (2018) do not make a distinction between sustainability and sustainable development. For Giovannoni and Fabietti (2013) they use the terms sustainability and sustainable development as analogues though observing that whereas sustainability refers to a 'state', sustainable development refers to the processes required to be at that state. However, Gallopín (2003) asserts that the two concepts are quite different in that the word "development" points to the idea of a progressive change, which may not necessarily be quantitative. Shaker (2015) sees sustainable development as the holistic approach and temporal processes that lead us to the end-point of sustainability. Perhaps, the most widely cited definition of sustainable development is the one outlined in the Brundtland report that sustainable development is, "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987, p. 43).

There remains no unanimity regarding theoretical and conceptual foundations on the issues of sustainability and sustainable development (Shaker, 2015). Despite its vagueness and ambiguity, the Brundtland report's definition has been highly instrumental and spurred up research interest with respect to the future of the planet (Mebratu, 1998). It is even believed that the absence of a rigorous definition of the terms provides an opportunity for more debate about the issues in search of common grounds (Lélé, 1991). However, modern discussions on both sustainability and sustainable development believe that life on earth has environmental limits for which humans, through interconnected consideration of the economy, environment and society, have a responsibility of preserving (Young and Dhanda, 2013). These environmental limits are highlighted in the concept of the planetary boundaries (Rockström et al., 2009).

2.2 Systems thinking and sustainability

There are complex relationships within and between the various systems that need to be integrated into any sustainability assessment. There is a need to understand the dynamic behaviour of the system under study in order to develop a more integrated and resilient solution to sustainability objectives (Fiksel, 2006). There is also little unanimity and theoretical grounding on sustainability (Shaker, 2015), which makes sound and robust assessment for policy difficult. Gallopín (2003) advocates that due to the ambiguity and lack of strong theoretical background to the field, sustainability could be discussed from a system's perspective where careful consideration of the aspect of the system to be sustained should be emphasised

Systems thinking can offer a useful perspective, compared to other analytical approaches, when thinking about sustainability since it is a way of thinking in terms of connectedness, relationships and contexts, which are key underlining principles of sustainability (Gallopín, 2003). This provides a more robust and conceptually sound framework for sustainability analysis. Indeed, the idea of the system view of sustainability is gradually becoming mainstream in sustainability literature. A survey of 96 papers, published from 1990 to 2015, on systems thinking in sustainability analysis by Williams et al. (2017) found that 67 out of the 96 papers published using systems thinking were published from 2010. This shows a growing acceptance of the ability of systems thinking in enhancing understanding of the dynamic interactions within and across interconnected systems (Whiteman et al., 2013, Williams et al., 2017). System's thinking of sustainability is very useful given the complexity, dynamic interactions and nonlinear interdependencies of related systems (Fiksel, 2006).

Since all physically existent systems are open, the behaviour of a system depends on the system's internal interactions, how the external elements or variables from the environment affects it and outputs of the system into the environment (Gallopín, 2003). There is, therefore, the need to always determine the boundaries of the system under study and the adjacent systems that interact with the system under study (Foley et al., 2003). Figure 1 shows possible interactions between energy generation system, ecology and society. The systems approach can be useful as the basis for understanding the meaning of sustainability by providing insight into the need for continuous management of system resources over time; understanding the significance of interactions among systems; understanding the importance of planning and designing the system; appreciating the need to re-evaluate the system sustainability at regular intervals and examining issues related to resilience of the system (Fiksel, 2006, Foley et al., 2003). It is therefore useful to examine in this survey the extent to which system thinking has been used in sustainability assessment literature of energy generation.

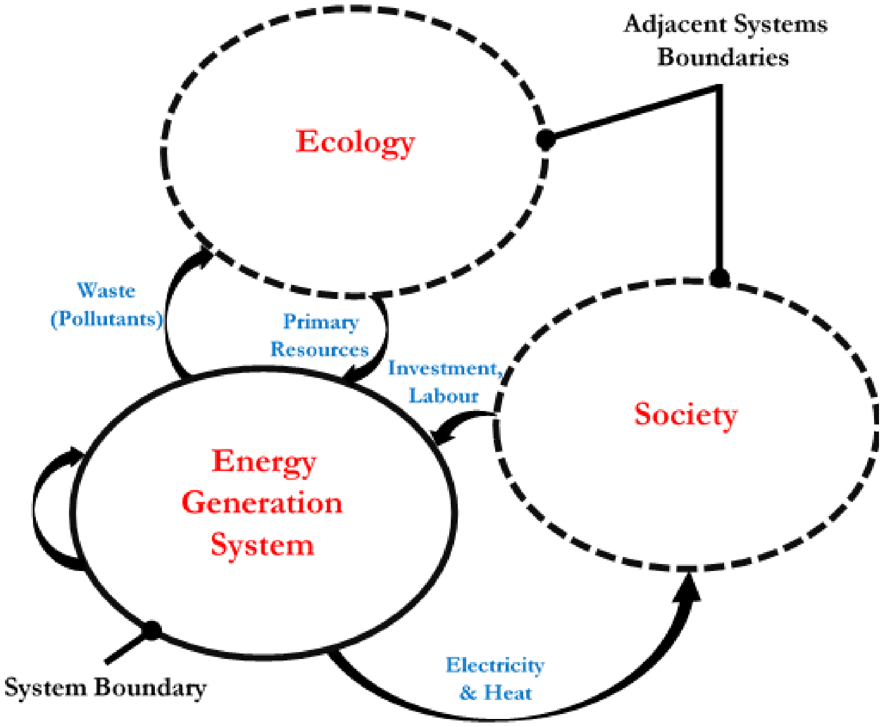


Figure 1: A system representation of the relationship between energy generation system, ecology and society; (Adapted from Foley et al. (2003))

2.3 Dimensions of Sustainability

The core ideas of modern thinking around sustainability and sustainable development are based on the interaction and inter-dependency between different dimensions of a system. This is because industrial, social and ecological systems are closely linked when making effective decisions regarding sustainability (Fiksel, 2006, Finkbeiner et al., 2010). Since the Brundtland report, there have been two major developments in sustainability literature (Kuhlman and Farrington, 2010): a) the three dimensions of sustainability and; b) the distinction between 'strong' and 'weak' sustainability. The three dimensions assessment of sustainability pioneered by Elkington (1997) is a framework which emphasises the need to consider economic, social and environmental objectives in sustainability assessment. Although there have been arguments to include other dimensions like technological and institutional dimensions to sustainability (International Atomic Energy Agency [IAEA], 2005, Maxim, 2014), the three dimensions remain the basis of most sustainability assessment. The three dimensions consist "environment", "economy" and "social well-being", for which society (or the system under consideration) needs to find a balance (Finkbeiner et al., 2010). The distinction between 'strong' and 'weak' sustainability coined by Pearce and Atkinson (1992) and further divided by Turner (1993), presents different perspectives on the relationship between nature and society. Based on economic growth theory, the concept of capital is defined to comprise manufactured capital, human capital and natural capital (Pearce and Atkinson, 1998). Weak sustainability ensures that aggregate capital is non-declining, even to the detriment of other types of capital over time, therefore, implicitly allows for substitution of capital for all forms of capital. Strong sustainability (very strong by Turner (1993)), on the other hand, advocates that the next generation should inherit a stock of environmental assets which is not less than the stock inherited by the current generation (Kuhlman and Farrington, 2010), therefore, imposes an additional constraint on weak sustainability, as proponents of this school believe that natural capital has no substitute.

Although these dimensions of sustainability have served as the building blocs for subsequent developments in sustainability assessments, it is uncertain the extent to which sustainability assessment literature in energy systems rely on such conceptual perspectives. It is important to review whether other sustainability dimensions, other than the three, are prominent in the literature as well as the extent to which models and methods employed for sustainability assessment incorporates the ideas of strong and weak sustainability. It is important to examine the preferences/weights given in the literature to the various dimensions when making a composite judgement of the sustainability of the system.

2.4 Energy and Sustainable Development

Activities related to the sustainable development of energy systems include a reduction in emissions and pollutant gases, increased safety of energy supply, use of renewable energy sources, improved energy efficiency and improved quality of life (Jovanović et al., 2009). Energy, therefore, has implications on the environment, economic development and social welfare. Ensuring that affordable and reliable energy is derived from environmentally appropriate supply sources is critical for sustainable development (Afgan et al., 2007b). This is because of the substantial environmental impacts from the production of various forms of energy. Apart from its contribution to social and economic development, energy consumption is recognised as also a major source of greenhouse gas emissions (Lu et al., 2016). A significant proportion of world carbon dioxide (CO_2) emissions and air pollution is as a result of fossil fuel combustion in order to satisfy energy demand (Rafaj et al., 2006). Coal, for example, has the highest CO_2 emissions per kW h but continues to dominate the market due to low cost and high availability (Varun et al., 2009, Evans et al., 2009). The role of energy sustainability is indispensable in social development. This is because the availability of energy is the driving force that facilitates the development of vital social systems such as education, health and employment among others.

Principles such as good quality of life, human well-being, equitable opportunities for all, diversity and even democratic civil society are central constituents that form the backbone of a socially sustainable society (Khan, 2015). As development in any society is directly linked with the level of energy consumption, energy is a critical input for national economic development (Mondal and Denich, 2010). It is one of the major pillars of economic development for countries globally (Shaaban and Scheffran, 2017). Electricity demand is a major component of both economic and social development as countries that lack an adequate supply of electric energy find it difficult to ensure positive development in production, national income, health and education (Onat and Bayar, 2010). Access to cheap energy is essential for economic development and poverty reduction, on the other hand, expansion of energy-related infrastructure is critical for energy security (Fouquet, 2016). The dependency on critical and recyclable materials in the production of low carbon energy technologies has become paramount as development of societies and technologies continue to require more and more resources (Jin et al., 2016).

3. Review Methodology

We conduct a systematic review in providing a synthesis and critical evaluation of the emerging issues, measures of sustainability and methods used in sustainability research of energy generation systems. This involved a three-stage procedure comprising literature generation, screening and evaluation.

The first stage of the review methodology is the literature generation stage. This is undertaken to gather the papers to be examined in the review process. A broad range of literature on the sustainability of energy generation systems was gathered from ProQuest-Business Premium Collection and Scopus using relevant keywords. For both databases, articles selected were restricted to peer-reviewed scholarly journals published before October 2018 and written in the English language. Additionally, a keyword search was limited to abstract search as highlighted in the Literature Review procedure in Figure 2. To be considered, an article is expected to have the words 'sustainability' and either 'measurement' or 'assessment' appearing in its abstract together with either 'energy' or 'electricity' generation. This generated a total of 375 articles in ProQuest and 330 in Scopus. It must be noted that since the search was limited to peer-reviewed scholarly articles, reports such as the IPCC (2018) Global warming of 1.5°C and the Global energy assessment by Johansson et al. (2012), and other non-academic sources which conduct sustainability assessment of energy systems are not included in this review. Such reports usually rely on a plethora of academic sources or later result in peer-reviewed academic papers which are the focus of this survey.

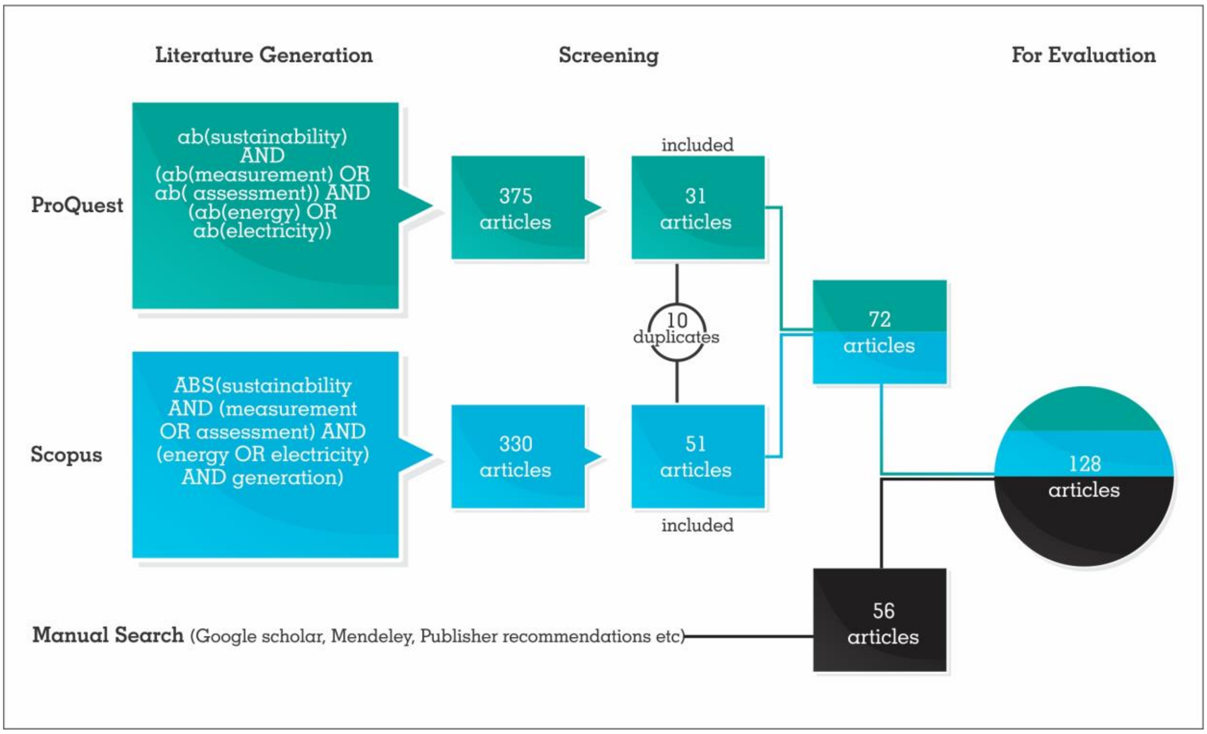


Figure 2: Literature review procedure

Stage two of the Literature Review process involved screening the papers gathered to identify the relevant literature to be included in the review. The first step in this stage was a title search, where articles were screened for relevance based on the title. Since the work was limited to sustainable operations in energy generation systems, papers that focused on energy use in buildings, public transportation systems and oil and gas extraction etc., were eliminated. If the title was not informative enough to determine acceptance of the paper, a further abstract evaluation was used as the criteria for elimination. Correcting for duplicates in the two databases, a total of 128 articles qualified for the evaluation stage. This final list of 128 articles also included those gathered in a manual search on google scholar, Mendeley recommendations and publisher recommendations, to gather other relevant papers not captured in the database search. These studies are summarised in the supplementary materials section. The final stage of the review process is the evaluation of the articles gathered, which is captured in section 4 of this paper.

4. Results and Discussions

4.1 Descriptive Analysis

Peer-reviewed articles published on sustainable energy generation are first analysed based on the yearly distribution of publication, publication sources and authors. This provides a broad overview of the articles considered relevant for the survey. Starting with the yearly distribution of papers, it is clear that there is a growing research interest in this area as over 90 per cent of the articles reviewed were published after 2006. Additionally, as of October 2018, 14 articles had already been published equalling the second highest yearly number of publications and only one behind the highest number of 15 articles recorded in 2015 (see appendix). This shows the increasing relevance of sustainability to the evaluation of energy generation.

The distribution of the articles based on the publication sources shows that among the sources with a high number of publications in this area are Energy Policy (22), Renewable and Sustainable Energy Reviews (16) and Energy (16). These high impact journals have been leaders in promoting research on the sustainability of energy generation systems. Other high impact journals among the top 15 are Applied Energy (7.9), Environmental Science and Technology (6.653) and Energy Conversion and Management (6.377). In addition to the 15 sources identified in Figure A2 in the appendix, the remaining articles came from 35 other journals within a wide array of academic disciplines.

Table 2 shows the major authors who have contributed to this area. Table 2 is populated based on the frequency of publications rather than the number of citations or H-index. Among the leading authors are Naim H. Afgan, who has contributed to about 12 papers mainly focused on model development, evaluation and scenario analysis on various types of energy sources. These researches have been in collaboration with Maria G. Carvalho, Petros A. Pilavachi, Marina Jovanović and a number of other researchers who also appear in Table 2. Another prominent author is Adisa Azapagic who, together with Laurence Stamford and other researchers, have contributed to the multi-dimensional evaluation of electricity technologies.

Table 2

Prominent Authors on Sustainability Assessment of Energy Systems

No	Author	Count	Cited by [a]	No	Author	Count	Cited by
1.	Naim H. Afgan	12	888	17.	Christian Bauer	2	70
2.	Maria G. Carvalho	7	635	18.	Geoffrey P. Hammond	2	62
3.	Adisa Azapagic	6	307	19.	Craig I. Jones	2	62
4.	Marina Jovanović	4	106	20.	Vukman Bakic	2	52
5.	Laurence Stamford	4	97	21.	Ángel Galán-Martín	2	46
6.	Gonzalo Guillén-Gosálbeza	3	52	22.	L. Jiménez	2	32
7.	Annette Evans	2	563	23.	A. Ewertowska	2	32
8.	Tim J. Evans	2	563	24.	Ibrahim Dincer	2	30
9.	Vladimir Strezov	2	563	25.	Kevork Hacatoglu	2	30
10.	Petros A.Pilavachi	2	212	26.	Marc A. Rosen	2	30
11.	Roland Clift	2	156	27.	Mustafa Music	2	20
12.	Dalia Štreimikienė	2	141	28.	Elma Redzic	2	20
13.	John J. Burkhardt, III	2	119	29.	Anes Kazagic	2	20
14.	Craig S. Turchi	2	119	30.	Jürgen Scheffran	2	8
15.	Garvin A. Heath	2	119	31.	Mostafa Shaaban	2	8
16.	Stefan Hirschberg	2	70	32.	Kathrin Volkart	2	5

[a] *Citations from Scopus as at February 2019*

4.2 *Network Analysis*

The 128 articles selected for review were subjected to mapping and cluster analyses using VOSviewer (version 1.6.9), a software for analysing and visualizing bibliometric networks, by van Eck and Waltman (2018). Specifically, titles and abstracts of the articles were subjected to co-occurrence analysis in order to identify the most occurring issues in these papers as well as how they link to each other. The strength of the links between the co-occurring terms is measured by the number of times the specific terms occur together in different articles. Additionally, clustering of the terms has been conducted to identify the broader domains in which these terms occur. As such, this mapping and cluster analysis are aimed at identifying the main research issues in the sustainable energy production research domain and how these topics relate to each other (Waltman et al., 2010). The network visualization of the papers is presented in Figure 3 showing the binary count of terms with at least five occurrences. Additionally, Figure 3 shows the top 350 strongest links among the terms.

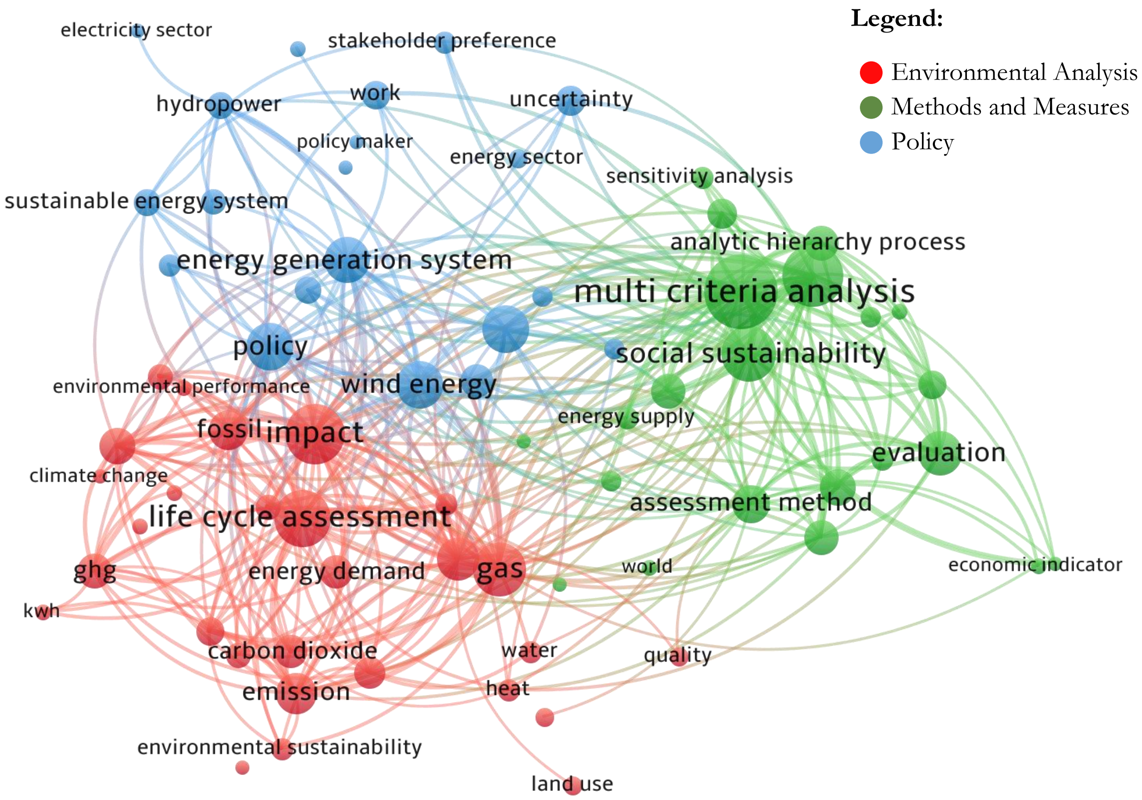


Figure 3: Network visualization of the most occurring terms in the studies. Size of the bubble reflects the number of occurrences of the term. Links between the terms is measured by the number of times the specific terms occur together in different articles.

Among the frequently occurring terms in these studies are multi-criteria analysis, impact, life cycle assessment, policy and social sustainability. Multi-criteria analysis, or similar terms such as MCA and MCDM, appeared in 44 different articles and co-occurred with 64 out of the 70 terms that qualified. This is not particularly surprising since the idea of sustainability often requires considering multiple dimensions using multiple indicators. Impact, policy and social sustainability were also among the most frequently appearing terms showing the relevance of impact assessment, that consider social impacts of energy generation, for policy. Note that the size of the nodes in Figure 3 is based on the number of occurrences of each term in the 128 papers surveyed.

Another important feature of Figure 3 is the clustering of the terms based on the strength of the association between terms determined by co-occurrences (Waltman et al., 2010). Evidently, the co-occurring terms can be clustered into three main groups. The characteristics of these clusters have been summarised in Table 3.

Table 3

Clustering of Literature

Cluster	Number of Terms	Main topics	Average Occurrences	Average Links
1: Environmental Analysis	28	impact; life cycle assessment; gas; coal; emission; fossil; environmental impact; ghg; carbon dioxide; energy demand; solar energy; oil; electricity generation	13	46
2: Methods	22	multi-criteria analysis; criterium; social sustainability; evaluation; assessment method; environment; analytic hierarchy process; comparison; sensitivity analysis	14	42
3: Policy	20	energy source; policy; wind energy; energy generation system; energy technology; uncertainty; energy security; hydropower; sustainable energy system; energy policy	12	41

Cluster one comprises 28 terms appearing, on average, in 13 papers. This cluster is dominated by various non-renewable sources of energy and aspects concerning environmental impacts such as greenhouse gas emissions, carbon and other emissions. Life cycle assessment; one of the main topics, is primarily used for environmental impact assessments of individual products/technologies. It must be noted, however, that the use of LCA, although predominantly used for environmental assessment, has also been used for social impact assessment. Hondo and Moriizumi (2017), for example, conducted a life cycle environmental and socio-economic impact analysis of the employment creation potential of renewable power sources using input-output models. Cluster two comprising 22 items occurring in 14 articles, on average, bother on methods for evaluation. MCDMs, AHP, sensitivity analysis are all approaches for evaluating the sustainability of energy systems. The final cluster mainly captures policy-related issues like renewable energy sources, energy security and uncertainty. This cluster also bothers on the social aspects of sustainability such as stakeholder preference, energy source and technology selection and ensuring secure supply of energy. Research issues captured in these studies, therefore, focus on environmental impact, assessment approaches and energy policy.

4.3 Review of Methods of Assessment

This section reviews the nature of assessment approaches used in examining the sustainability of the energy generation systems. The study of sustainability issues often requires the integration of multiple dimensions of operation involving multiple indicators (Diaz-Balteiro et al., 2017). The result is the reliance on composite indices to study and quantify the level of sustainability of units under investigation. Methods used for sustainability assessment in these studies include MCDM approaches (Afgan and Darwish, 2011, Doukas et al., 2010), exergy analysis (Koroneos and Nanaki, 2007, Lo Prete et al., 2012), LCA (Evans et al., 2009, Burkhardt et al., 2011, Rehl et al., 2012), and other optimization-based approaches such as multi-objective optimization and tax/subsidy optimization (Zhang et al., 2012, Mondal and Denich, 2010, Resnier et al., 2007). There have been other studies which have been descriptive without the need to form composite indices (Gallego Carrera and Mack, 2010, Tsoutsos et al., 2005).

The most widely used approach for sustainability assessment is MCDM approaches. This is mainly due to the multi-dimensionality of the problem of sustainability which requires that different objectives or indicators are considered or integrated simultaneously (Brandenburg et al., 2014). Indeed Janeiro and Patel (2015) believe sustainability is inherently an MCDM problem. The review of the literature shows the use of a vast variety of MCDM approaches such as a) distance functions like TOPSIS (Štreimikienė et al., 2012, Brand and Missaoui, 2014), b) outranking approaches like PROMETHEE (Troldborg et al., 2014, Buchholz et al., 2009) and NAIADE (Browne et al., 2010, Giampietro et al., 2006), c) hierarchical techniques like AHP (Chatzimouratidis and Pilavachi, 2009, Karger and Hennings, 2009), and ANP (Zhao and Li, 2015), d) ranking and classification methods like DEA (Ewertowska et al., 2016, Galán-Martín et al., 2016) and e) optimizing averages approaches such as MAUT/MAVT (Santoyo-Castelazo and Azapagic, 2014, Phdungsilp, 2010), ASPID (Vučićević et al., 2014) and weighted average (Klein and Whalley, 2015, Frangopoulos and Keramioti, 2010). Approaches have been classified according to Diaz-Balteiro et al. (2017).

These approaches are sometimes used in combination with other approaches with crisp and fuzzy indicators. In their assessment of the sustainability of urban energy systems in Serbia, Jovanović et al. (2010), for example, used fuzzy set theory together with ASPID approach. The problem with MCDM approaches is usually with the dimension weighting, which may rely on different expert opinions or equal weighting across dimensions. Additionally, the additive nature of most approaches means that poor performance on one dimension can be compensated by higher performance on the other dimensions, which seem to be at variance with the idea of sustainability. These approaches tend to be compensatory and must be interpreted in terms of the trade-off between the dimensions (Hacatoglu et al., 2015a).

The other well-used approach is the LCA method. This is an analytical approach, which allows for the examination of organizational impact across the supply chain. Rehl et al. (2012) used attributional (aLCA) and consequential (cLCA) approaches to analyse biogas system environmental impacts in the German electricity mix. They observed that the calculated environmental performance is affected by the methodology selected. A number of other studies have also used the LCA to estimate 'cradle-to-grave' impact of energy systems. LCA approach is often used together with other MCDM or other aggregating approaches. Roldán et al. (2014), von Doderer and Kleynhans (2014) and Hacatoglu et al. (2015b) all used LCA results together with other MCDM techniques in order to arrive at a composite sustainability index. The review of the papers showed that studies that used LCA tended to mainly focus on the environmental dimension of the operation with little, or no, emphasis on the economic and social aspects of the sustainability triad. It must be noted, however that, the use of LCA goes beyond the environmental dimension. For example, while Hondo and Moriizumi (2017) conducted a life-cycle employment creation potential impact using input-output models, Malik et al. (2016) conducted a triple bottom line LCA of Australian cellulose-refining industry. Also, there are significant variations in the nature of system boundaries examined in the various papers. For example, a number of papers have focussed on a 'cradle-to-gate' thinking (Hammond et al., 2013, Quek et al., 2018) while others conducted a 'cradle-to-grave' assessment (Azapagic et al., 2016, Volkart et al., 2018).

Exergy analysis is another method observed in the review. Exergy analysis includes the quality of the output in the modelling process thereby following the first and second laws of thermodynamics (Koroneos and Nanaki, 2007). The differences in the quality of output are important when comparing different energy conversion processes (Lo Prete et al., 2012). Outside these major approaches, there have been other optimization and descriptive-based approaches used to understand the sustainable operation of energy generation systems. Studies that use descriptive statistics, such as Gallego Carrera and Mack (2010) and Tsoutsos et al. (2005), do not make attempts at generating composite indices but primarily focus on discussing the sustainability of these generating technologies across a number of indicators.

While 'hard' quantitative examination of sustainability is relevant, the importance of stakeholder perceptions and inputs cannot be ignored. This is particularly important since there is a lack of ‘soft’ approaches like soft systems methodology (SSM), strategic options development and analysis (SODA) among others in the literature reviewed.

4.4 Review of Measures of Sustainability

4.4.1 Dimensions of Sustainability

Next basis for discussion is the dimensions of sustainability considered by these papers. Generally, in the sustainability literature, the Triple Bottom Line concept first put forward by Elkington (1997) , which requires consideration for social, economic and environmental objectives, is well accepted as the holistic dimensions of sustainability. This has therefore been translated into the sustainability literature of energy generation systems. It is important to note that almost every paper made an attempt to examine the impact of the system under investigation based on some clear dimensions. Even the few studies, like Browne et al. (2010), who did not identify specific dimensions being studied, had consideration for environmental, economic or social implications based on the indicators used.

Another observation from the literature is the prevalence of studies, which consider a fourth dimension. Pilavachi et al. (2006), Chatzimouratidis and Pilavachi (2009), Frangopoulos and Keramioti (2010), Rovere et al. (2010), Afgan and Darwish (2011) and Duan et al. (2011) all included a “technical” or “technological” dimension as part of the economic, social and environmental dimensions studied. This fourth dimension is often defined to consider the factors that relate directly to the operation of the generation technology that cannot be considered environmental, social or economic. Maxim (2014) defines it to include the ability to respond to demand, efficiency and capacity factor. The separation of the technical aspect is central to the idea of the systems approach to technology sustainability assessment of Musango and Brent (2011), which integrates the ideas of technology development, sustainable development and systems dynamics. From a systems perspective, the separation or decoupling of the technical dimension from the other dimensions allows for the modelling of the impact of other systems on the technology dimension and vice versa.

4.4.2 Weighting of Dimensions

Multi-criteria analysis is by definition an assessment of multiple dimensions of a problem which might have different levels of importance. Weighting is therefore important in any multi-criteria analysis. Dimension and indicator weighting has been one of the critical issues in the sustainability literature. This is mirrored in the energy generation sustainability literature as well.

Different papers have different approaches to dimension weighting. These include equal weighting (Evans et al., 2009, Varun et al., 2009), unequal weighting (Doukas et al., 2010, Jovanović et al., 2009) or even both (Klein and Whalley, 2015, Malkawi et al., 2017). There are studies which do not even attempt to weight the dimensions in their assessment. These studies which do not weight dimensions either tend to focus on one specific dimension or provide a descriptive assessment of the sustainable operation of the energy generation systems. As there is no consensus on the importance of the various dimensions of sustainability, studies tend to be subjective in their weighting of dimensions. Most studies, however, conduct some form of scenario or sensitivity analysis to determine the robustness of their ranking to changes in dimension weighting (Lipošćak et al., 2006, Rafaj et al., 2006, Atilgan and Azapagic, 2016).

On how the weights are determined, a number of papers have relied on some form of expert or stakeholder opinions (Dombi et al., 2014, Gallego Carrera and Mack, 2010, Grafakos and Flamos, 2017), using approaches like AHP to determine the overall weight of the dimensions, or have relied on estimation techniques that determine the dimension weights without the need for some direct weight input (Ewertowska et al., 2016, Ewertowska et al., 2017, Galán-Martín et al., 2016). Bojesen et al. (2015) determined the criteria weights from surveys carried out among a group of expert planners and decision-makers from the Danish central government. Cucchiella and D'Adamo (2015) conducted a survey of twelve experts with extensive experience in energy decision making. These experts included senior managers, policymakers and researchers. Similarly, Luthra et al. (2015) considered the opinions of ten experts including project managers, academicians, environment and forest ministry representatives and statistics and programme implementation persons who handle climate change programmes. Others rely on a broader array of stakeholders in order to ensure more representative and broadly acceptable weights. For example, Gallego Carrera and Mack (2010) in their sustainability assessment using social indicators sent surveys to 52 different European stakeholders in the energy sector, such as industry associations, political and administrative institutions, environmental groups, energy consumers and trade unions. Similarly, Parnphumeesup and Kerr (2011) examined stakeholder preferences in their study. They found that preference weights by experts and local residents are statistically different in the Thailand case raising the possibility of a disconnect between policymakers' views and that of other stakeholders. Evaluation approaches like DEA allow the units under investigation to choose their most favourable weights that maximise their performance, hence requiring no need to specify dimension weights (Yang et al., 2014). Others have tended to use weights based on researcher view on the perspective being studied. Moreira et al. (2015), for example, assigned 60% of the weight to the environmental dimension with an 'ecocentric' view.

4.5 Review of Emerging Issues

4.5.1 Modelling Weak and Strong Sustainability

The idea of capital substitution, which is captured in the debate between weak and strong sustainability (Gallopín, 2003, Turner, 1993) is another modelling dimension that is considered important in this review. Whereas the arguments for a weak form of sustainability support the idea of non-declining aggregate capital even at the expense of individual components of aggregate capital (Pearce and Atkinson, 1998), arguments for the strong form of sustainability do not support the idea of capital substitution or compensation between the various forms of capital (Kuhlman and Farrington, 2010). Capital (K) is defined to comprise manufactured capital (K_m), skills and knowledge of humans, otherwise called human capital (K_h) and natural resources and stock of environmental assets together known as natural capital (K_n) (Pearce and Atkinson, 1998). Mathematically, the difference between weak and strong sustainability can be expressed as (Pearce and Atkinson, 1998):

$$\frac{dK}{dt} \geq 0, \quad \text{where } K = K_m + K_h + K_n \qquad (1)$$

$$\frac{dK}{dt} \geq 0, \quad \frac{dK_m}{dt} \geq 0, \quad \frac{dK_h}{dt} \geq 0 \text{ and } \frac{dK_n}{dt} \geq 0 \qquad (2)$$

In other words, the change in aggregate capital K as a result of a change in time t should not fall. However, whereas weak sustainability, as depicted in equation (1) implicitly allows for substitution of capital for all forms of capital, strong sustainability in the equation (2) does not allow such substitution.

Papers surveyed were examined on whether they explicitly assumed or conducted their analysis from the perspective of strong or weak sustainability in relation to the relationship between the various forms of capital. Indeed, only, Rogner (2010), Duan et al. (2011), Myllyviita et al. (2013) and Moreira et al. (2015) explicitly indicated the capital substitution assumption made in their modelling. Myllyviita et al. (2013), for example, states that, because compensation between the dimensions of sustainability is allowed in their study, their framework should be considered to support the concept of weak sustainability. Most studies are silent on the issue of factor substitutability although the nature of their modelling seems to suggest weak sustainability.

Evidently, there is little consideration for the arguments of strong sustainability in the literature. The study by Giampietro et al. (2006) was one of the few exceptions since their modelling of the post-normal science paradigm in sustainability did not allow for compensation between social and technical dimensions. Closely related to this is the issue of compensability of the dimensions. If the method allows poor performance on one dimension to be compensated by excellent performance on other dimensions, then it can be argued that the dimensions are compensable which is akin to the idea of weak sustainability. This is because the approach allows for trade-off in the various dimensions (Hacatoglu et al., 2015a) and hence the aggregate performance is being maximized even at the expense of individual dimensions. If the approach does not allow for trade-off, however, then it is akin to strong sustainability.

4.5.2 Systems Thinking

Another issue considered as a basis for this review is the evaluation of the extent to which the literature includes systems thinking in the sustainability assessment of energy generation systems. Most studies do not consider sustainability as a systems problem. They, therefore, treat the environmental and social systems, for example, as 'black boxes'. There are a few studies that considered some form of the systems approach in the modelling. However, a look at these papers, like Rehl et al. (2012), Roldán et al. (2014) and von Doderer and Kleynhans (2014), that incorporate some systems thinking in the assessment reveal that these are mainly LCA-based papers. LCA is a systemic analytical model (Acquaye et al., 2011, Brandenburg et al., 2014) which requires an assessment of the impact across the life-cycle of the unit under investigation. Azapagic et al. (2016), for example, conducted an LCA assessment of UK's energy sector from extraction of primary resources, through construction, operation, decommissioning, waste treatment and disposal phases of the life cycle. There is little evidence of systems thinking outside the LCA literature especially in the energy generation sustainability assessment literature gathered.

4.5.3 Other Research Issues

These papers reviewed have studied a broad range of energy generation technologies, from renewables alone (Tsoutsos et al., 2005, Varun et al., 2009), non-renewable sources alone (Frangopoulos and Keramioti, 2010) to a combination of renewable and non-renewable sources (Ewertowska et al., 2016, Shmelev and van den Bergh, 2016). It is important, especially at the national-level energy planning to conduct an assessment that combines both renewable and non-renewable sources in order to understand the social, environmental and economic impacts of various technologies. Some papers even treat the energy sector as a 'black box' and consider sustainability issues from the total energy generated rather than at the technology level (Koroneos and Nanaki, 2007, Giampietro et al., 2006).

At the contextual level, though these studies span a broad range of countries, including both developed and developing nations, it is evident that such sustainability assessment is primarily done at the single state level. Most papers surveyed considered energy generation sustainability in a single country (Lipošćak et al., 2006, Assefa and Frostell, 2007). For example, while Assefa and Frostell (2007) developed an approach for assessing indicators for the social sustainability of technical systems in Sweden, Resnier et al. (2007), Buchholz et al. (2009) and Karger and Hennings (2009) examined various issues in China, Uganda and Germany respectively. Very few studies consider such sustainability issues at the multi-state level or the regional level (Begić and Afgan, 2007, Gallego Carrera and Mack, 2010). However, regional or global assessment is particularly important since energy and sustainability policies are now being formulated at the intergovernmental level rather than the state level. The European Union (EU), for example, has region-level energy policies and directives that are supposed to ensure sustainability in energy generation of member states. The EU, for example, has clear country-specific targets for climate and energy in its renewable energy directives (EEA, 2017). Additionally, the Paris Agreement and the incorporation of sustainable energy as Goal Seven of the SDGs show why energy and environment is a global rather than a national problem.

4.6 Gaps in the Literature

From the literature reviewed, a number of research gaps can be identified. Firstly, researches tend to mainly focus on quantitative methods that provide some form of composite indices to study the level and nature of sustainability of units under investigation. There is a lack of studies relying on problem structuring approaches such as ‘soft’ operations research approaches like soft systems methodology, strategic options development and analysis (SODA) and other qualitative approaches. This is important because such soft approaches are effective in highlighting stakeholder views which are equally important for energy policy formulation and evaluation.

Second, despite the availability of mathematical models and computational techniques for handling multi-objective and multiple indicator problems (Marler and Arora 2004, Greenberg et al., 2012), current models used for sustainability problems of energy systems do not seem to effectively model the practical implications of the integration of the various dimensions. This is because additive relations between dimensions seen in most MCDM approaches imply compensability, which means poor performance on the environment can be compensated on high economic and social performance or vice versa. This is not consistent with the central idea of sustainability that all three dimensions are important and there is the need to ensure good performance on all dimensions as required in the Triple Bottom Line principles (Elkington, 1997).

Third, although systems thinking to sustainability assessment offers a useful perspective for modelling the interconnectedness, relationships and interactions, which are key underlining principles of sustainability (Gallopín, 2003), systems thinking to sustainability assessment seem to be relegated to mainly life cycle assessment of environmental impact. This is particularly surprising since the systems idea of sustainability is gradually becoming mainstream in sustainability literature (Williams et al., 2017). For instance, there is little evidence of systems thinking outside the LCA literature in the energy sector. This is a clear research limitation given that the energy systems are central to national and regional development and so encompasses economic, social and ecological development (Musango and Brent, 2011). The implication is that the holistic impact of the energy system on environment, economy and society may not be well understood. Systems thinking also allow for the examination of the dynamic interactions and long term effects. There is the need for dynamic sustainability assessment as most methods used support static analysis.

Fourth, while different schools of thought with respect to capital substitution exist in sustainability literature, most studies are silent on this. As such, there is a need for the development of models that can better assess systems based on these sustainability perspectives. Most research papers surveyed are silent on this and implicitly assume weak sustainability. This means that relying on such models assumes an anthropocentric perspective that has the tendency of relegating nature as the source for raw materials and sink for wastes from human consumption (Gallopín, 2003). It is important to study sustainability from the various perspectives in order to better understand and make technical and policy decisions from a more encompassing view of sustainability.

Fifth, as there is no consensus on the importance of the various dimensions of sustainability, studies tend to be subjective in their weighting of dimensions. Irrespective of the approach selected in developing weights, there is the need for some form of scenario or sensitivity analysis to determine the robustness of modelling consideration to changes in dimension weighting. Finally, as contemporary energy policies are formulated at the intergovernmental level, it is important that sustainability assessment is conducted at the intergovernmental level as well. The impact of a nation's energy generation decisions has global implication as ecological systems are shared by all nations. The Paris Agreement, a universal legally binding global climate deal comprising 195 countries in 2015 (European Commission, 2018), is an example of the recognition given to need for regional and international cooperation to build resilience and decrease vulnerability to the harmful effects on the environment. There is the need for a regional focus, with country-level assessment and benchmarking, if the impact of sustainable energy policies will be effective.

5. Conclusion

Evidence from the review shows a growing area of research with an inter-disciplinary and trans-disciplinary orientation attracting researchers from various backgrounds. Mapping and cluster analysis of co-occurrence of terms showed three dominant research themes – environmental analysis, evaluation methods and energy policy-related research interest. For the methods used, the dominant method is MCDM though other approaches exist. A variety of MCDM approaches have been employed. Also dominant are LCA-based researches that have seen extensive use in environmental impact assessment of energy generation systems. With the multi-criteria approaches are the problems of indicator selection and weighting of dimensions which can lead to a variety of outcomes based on the choice of the decision-maker. On the side of the issue, though different schools of thought on the substitutability of natural, economic and social resources have emerged over the years, the consideration of this has been limited in the literature. Other issues include the limited systems approach consideration outside LCA research when it comes to the sustainable operation of energy production systems and the restriction of most studies on national rather than multi-national basis.

The relevance of sustainability to researchers from a diverse array of academic disciplines has meant different considerations on the modelling and evaluation approaches. While this is a growing area of research, however, what constitutes sustainability and how it can be measured has become an important topic dominating such energy research. Though several definitions of sustainability exist, there is a recognition that sustainability assessment should provide global to a local integrated evaluation of economy-nature-society systems in short and long-term perspectives to assist in arriving at actions to make society sustainable. This calls for a systems perspective towards sustainability assessment of energy; such evaluation should not only include the energy system in a local context but also its global effects on economic, social and environmental systems. There is a need for traditional measurement approaches to be revised to be a better fit for sustainability assessment and provide more appropriate decision support for policy.

In essence, this work seeks new insights into modelling of systems with sustainability considerations. Though due to stakeholder pressure, sustainability has become an integral part of national and business discourse, modelling approaches employed in such decision support frameworks do not seem to have fully considered the various views espoused in sustainability literature. There is, therefore, the avenue for a newer and broader assessment of sustainability in energy generation. There is also the avenue for methodological contributions to be made in most of the current models used in multi-criteria problems when it comes to sustainability.

References

Abouelnaga, A. E., Metwally, A., Aly, N., Nagy, M. & Agamy, S. (2010) Assessment of nuclear energy sustainability index using fuzzy logic. *Nuclear Engineering and Design* **240(7)**:1928-1933.

Acquaye, A. A., Wiedmann, T., Feng, K., Crawford, R. H., Barrett, J., Kuylenstierna, J., Duffy, A. P., Koh, S. C. L. & McQueen-Mason, S. (2011) Identification of 'Carbon Hot-Spots' and Quantification of GHG Intensities in the Biodiesel Supply Chain Using Hybrid LCA and Structural Path Analysis. *Environmental Science & Technology* **45 (6)**:2471-2478.

Afgan, N. H. & Carvalho, M. G. (2002) Multi-criteria assessment of new and renewable energy power plants. *Energy* **27(8)**:739-755.

Afgan, N. H. & Carvalho, M. G. (2004) Sustainability assessment of hydrogen energy systems. *International Journal of Hydrogen Energy* **29(13)**:1327-1342.

Afgan, N. H. & Carvalho, M. G. (2008) Sustainability assessment of a hybrid energy system. *Energy Policy* **36(8)**:2903-2910.

Afgan, N. H., Carvalho, M. G. & Hovanov, N. V. (2000) Energy system assessment with sustainability indicators. *Energy Policy* **28(9)**:603-612.

Afgan, N. H., Carvalho, M. G. & Jovanovic, M. (2007a) Biomass-fired power plant: the sustainability option. *International Journal of Sustainable Energy* **26(4)**:179-193.

Afgan, N. H. & Darwish, M. (2011) Multi-criteria sustainability assessment of water desalination and energy systems — Kuwait case. *Desalination and Water Treatment* **25(1-3)**:241-250.

Afgan, N. H., Veziroglu, A. & Carvalho, M. G. (2007b) Multi-criteria evaluation of hydrogen system options. *International Journal of Hydrogen Energy* **32(15)**:3183-3193.

Ahmad, S. & Tahar, R. M. (2014) Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. *Renewable Energy* **63**:458-466.

Akber, M. Z., Thaheem, M. J. & Arshad, H. (2017) Life cycle sustainability assessment of electricity generation in Pakistan: Policy regime for a sustainable energy mix. *Energy Policy* **111**:111-126.

Allan, G., Eromenko, I., Gilmartin, M., Kockar, I. & McGregor, P. (2015) The economics of distributed energy generation: A literature review. *Renewable and Sustainable Energy Reviews* **42**:543-556.

Asdrubali, F., Baldinelli, G., D'Alessandro, F. & Scrucca, F. (2015) Life cycle assessment of electricity production from renewable energies: Review and results harmonization. *Renewable and Sustainable Energy Reviews* **42**:1113-1122.

Assefa, G. & Frostell, B. (2007) Social sustainability and social acceptance in technology assessment: A case study of energy technologies. *Technology in Society* **29(1)**:63-78.

Atilgan, B. & Azapagic, A. (2016) An integrated life cycle sustainability assessment of electricity generation in Turkey. *Energy Policy* **93**:168-186.

Azapagic, A., Stamford, L., Youds, L. & Barteczko-Hibbert, C. (2016) Towards sustainable production and consumption: A novel DEcision-Support Framework IntegRating Economic, Environmental and Social Sustainability (DESIRES). *Computers & Chemical Engineering* **91**:93-103.

Barros, J. J. C., Coira, M. L., López, M. P. d. l. C. & Gochi, A. d. C. (2015) Assessing the global sustainability of different electricity generation systems. *Energy* **89**:473-489.

Bazmi, A. A. & Zahedi, G. (2011) Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review. *Renewable and Sustainable Energy Reviews* **15(8)**:3480-3500.

Begić, F. & Afgan, N. H. (2007) Sustainability assessment tool for the decision making in selection of energy system—Bosnian case. *Energy* **32(10)**:1979-1985.

Bojesen, M., Boerboom, L. & Skov-Petersen, H. (2015) Towards a sustainable capacity expansion of the Danish biogas sector. *Land Use Policy* **42**:264-277.

Bonevac, D. (2010) Is Sustainability Sustainable? *Academic Questions* **23(1)**:84-101.

Brand, B. & Missaoui, R. (2014) Multi-criteria analysis of electricity generation mix scenarios in Tunisia. *Renewable and Sustainable Energy Reviews* **39**:251-261.

Brandenburg, M., Govindan, K., Sarkis, J. & Seuring, S. (2014) Quantitative models for sustainable supply chain management: Developments and directions. *European Journal of Operational Research* **233(2)**:299-312.

Browne, D., O'Regan, B. & Moles, R. (2010) Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. *Energy* **35(2)**:518-528.

Brundtland, G. H. (1987) *Report of the World Commission on environment and development: "Our common future."*. Oxford, Oxford University Press.

Buchholz, T., Rametsteiner, E., Volk, T. A. & Luzadis, V. A. (2009) Multi Criteria Analysis for bioenergy systems assessments. *Energy Policy* **37(2)**:484-495.

Burkhardt, J. J., Heath, G. A. & Turchi, C. S. (2011) Life Cycle Assessment of a Parabolic Trough Concentrating Solar Power Plant and the Impacts of Key Design Alternatives. *Environmental Science & Technology* **45(6)**:2457-2464.

Büyüközkan, G. & Karabulut, Y. (2018) Sustainability performance evaluation: Literature review and future directions. *Journal of Environmental Management* **217**:253-267.

Campbell, D. E. & Garmestani, A. S. (2012) An energy systems view of sustainability: Emergy evaluation of the San Luis Basin, Colorado. *Journal of Environmental Management* **95(1)**:72-97.

Chatzimouratidis, A. I. & Pilavachi, P. A. (2009) Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. *Energy Policy* **37(3)**:778-787.

Clift, R. (2007) Climate change and energy policy: The importance of sustainability arguments. *Energy* **32(4)**:262-268.

Cséfalvay, E. & Horváth, I. T. (2018) Sustainability Assessment of Renewable Energy in the United States, Canada, the European Union, China, and the Russian Federation. *ACS Sustainable Chemistry & Engineering* **6(7)**:8868-8874.

Cucchiella, F. & D'Adamo, I. (2015) A Multicriteria Analysis of Photovoltaic Systems: Energetic, Environmental, and Economic Assessments. *International Journal of Photoenergy* **2015**:1-8.

Deutsch, N. (2018) Electricity generation technologies and sustainability: The case of decentralized generation. *WSEAS Transactions on Business and Economics* **15**:143-161.

Diaz-Balteiro, L., González-Pachón, J. & Romero, C. (2017) Measuring systems sustainability with multi-criteria methods: A critical review. *European Journal of Operational Research* **258(2)**:607-616.

Dombi, M., Kuti, I. & Balogh, P. (2014) Sustainability assessment of renewable power and heat generation technologies. *Energy Policy* **67**:264-271.

Dominguez-Ramos, A., Held, M., Aldaco, R., Fischer, M. & Irabien, A. (2010) Prospective CO2 emissions from energy supplying systems: photovoltaic systems and conventional grid within Spanish frame conditions. *The International Journal of Life Cycle Assessment* **15(6)**:557-566.

Doukas, H., Karakosta, C. & Psarras, J. (2010) Computing with words to assess the sustainability of renewable energy options. *Expert Systems with Applications* **37(7)**:5491-5497.

Duan, Z., Pang, Z. & Wang, X. (2011) Sustainability evaluation of limestone geothermal reservoirs with extended production histories in Beijing and Tianjin, China. *Geothermics* **40(2)**:125-135.

EEA (2017) *Overall progress towards the European Union's '20-20-20' climate and energy targets*. European Environment Agency, See https://www.eea.europa.eu/themes/climate/trends-and-projections-in-europe/trends-and-projections-in-europe-2017/overall-progress-towards-the-european (accessed 24 December 2017).

Einsiedel, E. F., Boyd, A. D., Medlock, J. & Ashworth, P. (2013) Assessing socio-technical mindsets: Public deliberations on carbon capture and storage in the context of energy sources and climate change. *Energy Policy* **53**:149-158.

El-Fadel, R. H., Hammond, G. P., Harajli, H. A., Jones, C. I., Kabakian, V. K. & Winnett, A. B. (2010) The Lebanese electricity system in the context of sustainable development. *Energy Policy* **38(2)**:751-761.

Elghali, L., Clift, R., Sinclair, P., Panoutsou, C. & Bauen, A. (2007) Developing a sustainability framework for the assessment of bioenergy systems. *Energy Policy* **35(12)**:6075-6083.

Elkington, J. (1997) *Cannibals with forks: the triple bottom line of 21st century business.* Oxford, Capstone Publishing Limited.

European Commission (2018) *Paris Agreement*. European Environment Agency, See https://ec.europa.eu/clima/policies/international/negotiations/paris_en (accessed 12 June 2018).

Evans, A., Strezov, V. & Evans, T. J. (2009) Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews* **13(5)**:1082-1088.

Evans, A., Strezov, V. & Evans, T. J. (2010) Sustainability considerations for electricity generation from biomass. *Renewable and Sustainable Energy Reviews* **14(5)**:1419-1427.

Ewertowska, A., Galán-Martín, A., Guillén-Gosálbez, G., Gavaldá, J. & Jiménez, L. (2016) Assessment of the environmental efficiency of the electricity mix of the top European economies via data envelopment analysis. *Journal of Cleaner Production* **116**:13-22.

Ewertowska, A., Pozo, C., Gavaldà, J., Jiménez, L. & Guillén-Gosálbez, G. (2017) Combined use of life cycle assessment, data envelopment analysis and Monte Carlo simulation for quantifying environmental efficiencies under uncertainty. *Journal of Cleaner Production* **166**:771-783.

Feng, Q., Qiu, Q., Quan, Y. & Tang, L. (2017) Sustainability efficiency of Chinese cities involving coal-fired power plants with data envelopment analysis. *International Journal of Sustainable Development & World Ecology* **24(5)**:395-400.

Fiksel, J. (2006) Sustainability and Resilience: Toward a Systems Approach. *Sustainability: Science, Practice and Policy* **2(2)**:14-21.

Finkbeiner, M., Schau, E. M., Lehmann, A. & Traverso, M. (2010) Towards Life Cycle Sustainability Assessment. *Sustainability* **2(10)**:3309-3322.

Foley, B. A., Danieli, T. M. & Warner, R. F. (2003) What is sustainability and can it be measured? *Australian Journal of Multi-Disciplinary Engineering* **1(1)**:1-7.

Fouquet, R. (2016) Path dependence in energy systems and economic development. *Nature Energy* **1**:16098.

Frangopoulos, C. A. & Keramioti, D. E. (2010) Multi-criteria evaluation of energy systems with sustainability considerations. *Entropy* **12(5)**:1006-1020.

Gaete-Morales, C., Gallego-Schmid, A., Stamford, L. & Azapagic, A. (2018) Assessing the environmental sustainability of electricity generation in Chile. *Science of The Total Environment* **636**:1155-1170.

Galán-Martín, Á., Guillén-Gosálbez, G., Stamford, L. & Azapagic, A. (2016) Enhanced data envelopment analysis for sustainability assessment: A novel methodology and application to electricity technologies. *Computers & Chemical Engineering* **90**:188-200.

Gallego Carrera, D. & Mack, A. (2010) Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts. *Energy Policy* **38(2)**:1030-1039.

Gallopín, G. (2003) *A Systems Approach to Sustainability and Sustainable Development.* Santiago, Chile, ECLAC, Sustainable Development and Human Settlements Division.

Giampietro, M., Mayumi, K. & Munda, G. (2006) Integrated assessment and energy analysis: Quality assurance in multi-criteria analysis of sustainability. *Energy* **31(1)**:59-86.

Giovannoni, E. & Fabietti, G. (2013) What Is Sustainability? A Review of the Concept and Its Applications. In *Integrated Reporting: Concepts and Cases that Redefine Corporate Accountability*. (Busco, C., Frigo, M. L., Riccaboni, A., andQuattrone, P. (eds)) Springer International Publishing, Cham, pp. 21-40.

Grafakos, S. & Flamos, A. (2017) Assessing low-carbon energy technologies against sustainability and resilience criteria: results of a European experts survey. *International Journal of Sustainable Energy* **36(5)**:502-516.

Greenberg, H. J., Lootsma, F. A., Rijckaert, M. J. & Zimmermann, H. J. (2012) *Mathematical models for decision support.* Berlin, Springer Science & Business Media.

Grunwald, A. & Rösch, C. (2011) Sustainability assessment of energy technologies: towards an integrative framework. *Energy, Sustainability and Society* **1(1)**:3.

Guen, M. L., Mosca, L., Perera, A. T. D., Coccolo, S., Mohajeri, N. & Scartezzini, J.-L. (2018) Improving the energy sustainability of a Swiss village through building renovation and renewable energy integration. *Energy and Buildings* **158**:906-923.

Hacatoglu, K., Dincer, I. & Rosen, M. A. (2015a) A new model to assess the environmental impact and sustainability of energy systems. *Journal of Cleaner Production* **103**:211-218.

Hacatoglu, K., Dincer, I. & Rosen, M. A. (2015b) Sustainability assessment of a hybrid energy system with hydrogen-based storage. *International Journal of Hydrogen Energy* **40(3)**:1559-1568.

Hadian, S. & Madani, K. (2015) A system of systems approach to energy sustainability assessment: Are all renewables really green? *Ecological Indicators* **52**:194-206.

Hammond, G. P., Howard, H. R. & Jones, C. I. (2013) The energy and environmental implications of UK more electric transition pathways: A whole systems perspective. *Energy Policy* **52**:103-116.

Herbert, A.-S., Azzaro-Pantel, C. & Le Boulch, D. (2016) A typology for world electricity mix: Application for inventories in Consequential LCA (CLCA). *Sustainable Production and Consumption* **8**:93-107.

Holzer, V. L. (2005) The Promotion of Renewable Energies and Sustainability. *Intereconomics* **40(1)**:36-45.

Hondo, H. & Moriizumi, Y. (2017) Employment creation potential of renewable power generation technologies: A life cycle approach. *Renewable and Sustainable Energy Reviews* **79**:128-136.

International Atomic Energy Agency (2005) *Energy indicators for sustainable development: guidelines and methodologies.* Vienna, International Atomic Energy Agency.

IPCC (2018) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, andWaterfield, T.

Janeiro, L. & Patel, M. K. (2015) Choosing sustainable technologies. Implications of the underlying sustainability paradigm in the decision-making process. *Journal of Cleaner Production* **105**:438-446.

Jin, Y., Kim, J. & Guillaume, B. (2016) Review of critical material studies. *Resources, Conservation and Recycling* **113**:77-87.

Johansson, T. B., Patwardhan, A. P., Nakićenović, N., Gomez-Echeverri, L. & eds. (2012) *Global energy assessment: toward a sustainable future.* Cambridge, Cambridge University Press.

Jones, C., Gilbert, P., Raugei, M., Mander, S. & Leccisi, E. (2017) An approach to prospective consequential life cycle assessment and net energy analysis of distributed electricity generation. *Energy Policy* **100**:350-358.

Jovanović, M., Afgan, N. & Bakic, V. (2010) An analytical method for the measurement of energy system sustainability in urban areas. *Energy* **35(9)**:3909-3920.

Jovanović, M., Afgan, N., Radovanović, P. & Stevanović, V. (2009) Sustainable development of the Belgrade energy system. *Energy* **34(5)**:532-539.

Jovanović, M., Turanjanin, V., Bakic, V., Pezo, M. & Vucicevic, B. (2011) Sustainability estimation of energy system options that use gas and renewable resources for domestic hot water production. *Energy* **36(4)**:2169-2175.

Kahle, L. R. & Gurel-Atay, E. (2013) *Communicating Sustainability for the Green Economy.* Armonk, New York, M. E. Sharpe Incorporated.

Kajikawa, Y., Ohno, J., Takeda, Y., Matsushima, K. & Komiyama, H. (2007) Creating an academic landscape of sustainability science: an analysis of the citation network. *Sustainability Science* **2(2)**:221-231.

Kanbur, B. B., Xiang, L., Dubey, S., Choo, F. H. & Duan, F. (2018) Finite sum based thermoeconomic and sustainable analyses of the small scale LNG cold utilized power generation systems. *Applied Energy* **220**:944-961.

Karger, C. R. & Hennings, W. (2009) Sustainability evaluation of decentralized electricity generation. *Renewable and Sustainable Energy Reviews* **13(3)**:583-593.

Kazagic, A., Merzic, A., Redzic, E. & Music, M. (2014) Power utility generation portfolio optimization as function of specific RES and decarbonisation targets – EPBiH case study. *Applied Energy* **135**:694-703.

Kazagic, A., Music, M., Smajevic, I., Ademovic, A. & Redzic, E. (2016) Possibilities and sustainability of "biomass for power" solutions in the case of a coal-based power utility. *Clean Technologies and Environmental Policy* **18(6)**:1675-1683.

Khan, R. (2015) Small Hydro Power in India: Is it a sustainable business? *Applied Energy* **152**:207-216.

Klein, S. J. W. & Whalley, S. (2015) Comparing the sustainability of U.S. electricity options through multi-criteria decision analysis. *Energy Policy* **79**:127-149.

Kliucininkas, L., Zieniute, I. & Mockuviene, J. (2005) An assessment of the cogenerated electrical energy potential for Lithuania. *Management of Environmental Quality: An International Journal* **16(5)**:398-406.

Koroneos, C. J. & Nanaki, E. A. (2007) Electric energy sustainability in the Eastern Balkans. *Energy Policy* **35(7)**:3826-3842.

Krotscheck, C., König, F. & Obernberger, I. (2000) Ecological assessment of integrated bioenergy systems using the Sustainable Process Index. *Biomass and Bioenergy* **18(4)**:341-368.

Kuhlman, T. & Farrington, J. (2010) What is Sustainability? *Sustainability* **2(11)**:3436-3448.

Kumar, D. & Katoch, S. S. (2015) Sustainability assessment and ranking of run of the river (RoR) hydropower projects using analytical hierarchy process (AHP): A study from Western Himalayan region of India. *Journal of Mountain Science* **12(5)**:1315-1333.

Kurka, T. (2013) Application of the analytic hierarchy process to evaluate the regional sustainability of bioenergy developments. *Energy* **62**:393-402.

Lélé, S. M. (1991) Sustainable development: A critical review. *World Development* **19(6)**:607-621.

Li, J., Geng, X. & Li, J. (2016) A Comparison of Electricity Generation System Sustainability among G20 Countries. *Sustainability* **8(12)**:1276.

Lipošćak, M., Afgan, N. H., Duić, N. & da Graça Carvalho, M. (2006) Sustainability assessment of cogeneration sector development in Croatia. *Energy* **31(13)**:2276-2284.

Liu, G. (2014) Development of a general sustainability indicator for renewable energy systems: A review. *Renewable and Sustainable Energy Reviews* **31**:611-621.

Lo Prete, C., Hobbs, B. F., Norman, C. S., Cano-Andrade, S., Fuentes, A., von Spakovsky, M. R. & Mili, L. (2012) Sustainability and reliability assessment of microgrids in a regional electricity market. *Energy* **41(1)**:192-202.

Lu, H.-f., Lin, B.-l., Campbell, D. E., Sagisaka, M. & Ren, H. (2016) Interactions among energy consumption, economic development and greenhouse gas emissions in Japan after World War II. *Renewable and Sustainable Energy Reviews* **54**:1060-1072.

Luthra, S., Mangla, S. K. & Kharb, R. K. (2015) Sustainable assessment in energy planning and management in Indian perspective. *Renewable and Sustainable Energy Reviews* **47**:58-73.

Mah, D. N.-y. & Hills, P. (2012) Collaborative governance for sustainable development: wind resource assessment in Xinjiang and Guangdong Provinces, China. *Sustainable Development* **20(2)**:85-97.

Malik, A., Lenzen, M. & Geschke, A. (2016) Triple bottom line study of a lignocellulosic biofuel industry. *GCB Bioenergy* **8(1)**:96-110.

Malkawi, S., Al-Nimr, M. d. & Azizi, D. (2017) A multi-criteria optimization analysis for Jordan's energy mix. *Energy* **127**:680-696.

Manrique, S. M. & Franco, J. (2014) Assessing The Sustainability of Bioenergy Systems. *International Journal of Energy, Environment and Economics* **22(4)**:353.

Marler, R. T. & Arora , J. S. (2004) Survey of multi-objective optimization methods for engineering. *Structural and Multidisciplinary Optimization* **26(6)**:369-395.

Martens, P. (2006) Sustainability: science or fiction? *Sustainability: Science, Practice and Policy* **2(1)**:36-41.

Martín-Gamboa, M., Iribarren, D., García-Gusano, D. & Dufour, J. (2017) A review of life-cycle approaches coupled with data envelopment analysis within multi-criteria decision analysis for sustainability assessment of energy systems. *Journal of Cleaner Production* **150**:164-174.

Mattiussi, A., Rosano, M. & Simeoni, P. (2014) A decision support system for sustainable energy supply combining multi-objective and multi-attribute analysis: An Australian case study. *Decision Support Systems* **57**:150-159.

Maxim, A. (2014) Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. *Energy Policy* **65**:284-297.

May, J. R. & Brennan, D. J. (2006) Sustainability Assessment of Australian Electricity Generation. *Process Safety and Environmental Protection* **84(2)**:131-142.

McMichael, A. J., Butler, C. D. & Folke, C. (2003) New visions for addressing sustainability. *Science* **302(5652)**:1919-20.

Mebratu, D. (1998) Sustainability and sustainable development: Historical and conceptual review. *Environmental Impact Assessment Review* **18(6)**:493-520.

Mirjat, N. H., Uqaili, M., Harijan, K., Mustafa, M., Rahman, M. & Khan, M. (2018) Multi-Criteria Analysis of Electricity Generation Scenarios for Sustainable Energy Planning in Pakistan. *Energies* **11(4)**:757.

Mondal, M. A. H. & Denich, M. (2010) Assessment of renewable energy resources potential for electricity generation in Bangladesh. *Renewable and Sustainable Energy Reviews* **14(8)**:2401-2413.

Moreira, J. M. L., Cesaretti, M. A., Carajilescov, P. & Maiorino, J. R. (2015) Sustainability deterioration of electricity generation in Brazil. *Energy Policy* **87**:334-346.

Morimoto, R. (2013) Incorporating socio-environmental considerations into project assessment models using multi-criteria analysis: A case study of Sri Lankan hydropower projects. *Energy Policy* **59**:643-653.

Moslehi, S. & Reddy, T. A. (2018) Sustainability of integrated energy systems: A performance-based resilience assessment methodology. *Applied Energy* **228**:487-498.

Musango, J. K. & Brent, A. C. (2011) A conceptual framework for energy technology sustainability assessment. *Energy for Sustainable Development* **15(1)**:84-91.

Myllyviita, T., Leskinen, P., Lähtinen, K., Pasanen, K., Sironen, S., Kähkönen, T. & Sikanen, L. (2013) Sustainability assessment of wood-based bioenergy – A methodological framework and a case-study. *Biomass and Bioenergy* **59**:293-299.

Narula, K., Sudhakara Reddy, B., Pachauri, S. & Mahendra Dev, S. (2017) Sustainable energy security for India: An assessment of the energy supply sub-system. *Energy Policy* **103**:127-144.

Ohene-Asare, K. & Turkson, C. (2018) Total-Factor Energy Efficiency and Productivity of ECOWAS States: A Slacks-Based Measure with Undesirable Outputs. *Journal of African Business* **20(1)**:91-111.

Olmedo-Torre, N., Canals Casals, L. & Amante García, B. (2018) Sustainable design of a thermosolar electricity generation power plant in Burkina Faso. *Journal of Environmental Management* **226**:428-436.

Onat, N. & Bayar, H. (2010) The sustainability indicators of power production systems. *Renewable and Sustainable Energy Reviews* **14(9)**:3108-3115.

Orecchini, F. (2007) A "measurable" definition of sustainable development based on closed cycles of resources and its application to energy systems. *Sustainability Science* **2(2)**:245-252.

Parnphumeesup, P. & Kerr, S. A. (2011) Stakeholder preferences towards the sustainable development of CDM projects: Lessons from biomass (rice husk) CDM project in Thailand. *Energy Policy* **39(6)**:3591-3601.

Pearce, D. W. & Atkinson, G. D. (1992) *Are National Economies Sustainable?: Measuring Sustainable Development.* London, Centre of Social and Economic Research on the Global Environment.

Pearce, D. W. & Atkinson, G. D. (1998) Concept of sustainable development: An evaluation of its usefulness 10 years after Brundtland. *Environmental Economics and Policy Studies* **1(2)**:95-111.

Peng, J., Lu, L. & Yang, H. (2013) Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. *Renewable and Sustainable Energy Reviews* **19**:255-274.

Phdungsilp, A. (2010) Integrated energy and carbon modeling with a decision support system: Policy scenarios for low-carbon city development in Bangkok. *Energy Policy* **38(9)**:4808-4817.

Pilavachi, P. A., Roumpeas, C. P., Minett, S. & Afgan, N. H. (2006) Multi-criteria evaluation for CHP system options. *Energy Conversion and Management* **47(20)**:3519-3529.

Qudrat-Ullah, H. & Karakul, M. (2007) Modelling for policy assessment in the electricity supply sector of Pakistan. *International Journal of Energy Sector Management* **1(3)**:240-256.

Quek, A., Ee, A., Ng, A. & Wah, T. Y. (2018) Challenges in Environmental Sustainability of renewable energy options in Singapore. *Energy Policy* **122**:388-394.

Rafaj, P., Barreto, L. & Kypreos, S. (2006) Combining policy instruments for sustainable energy systems: An assessment with the GMM model. *Environmental Modeling & Assessment* **11(4)**:277-295.

Rehl, T., Lansche, J. & Müller, J. (2012) Life cycle assessment of energy generation from biogas—Attributional vs. consequential approach. *Renewable and Sustainable Energy Reviews* **16(6)**:3766-3775.

Reinhardt, R., Christodoulou, I., Gassó-Domingo, S. & Amante García, B. (2019) Towards sustainable business models for electric vehicle battery second use: A critical review. *Journal of Environmental Management* **245**:432-446.

Ren, J. (2018) Multi-criteria decision making for the prioritization of energy systems under uncertainties after life cycle sustainability assessment. *Sustainable Production and Consumption* **16**:45-57.

Resnier, M., Wang, C., Du, P. & Chen, J. (2007) The promotion of sustainable development in China through the optimization of a tax/subsidy plan among HFC and power generation CDM projects. *Energy Policy* **35(9)**:4529-4544.

Ribeiro, F., Ferreira, P. & Araújo, M. (2013) Evaluating future scenarios for the power generation sector using a Multi-Criteria Decision Analysis (MCDA) tool: The Portuguese case. *Energy* **52**:126-136.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. & Foley, J. A. (2009) A safe operating space for humanity. *Nature* **461(7263)**:472-475.

Rogner, H. H. (2010) Nuclear Power and Sustainable Development. *Journal of International Affairs* **64(1)**:137-163.

Roldán, C. M., Martínez, M. & Peña, R. (2014) Scenarios for a hierarchical assessment of the global sustainability of electric power plants in México. *Renewable and Sustainable Energy Reviews* **33**:154-160.

Roth, S., Hirschberg, S., Bauer, C., Burgherr, P., Dones, R., Heck, T. & Schenler, W. (2009) Sustainability of electricity supply technology portfolio. *Annals of Nuclear Energy* **36(3)**:409-416.

Rovere, E. L. L., Soares, J. B., Oliveira, L. B. & Lauria, T. (2010) Sustainable expansion of electricity sector: Sustainability indicators as an instrument to support decision making. *Renewable and Sustainable Energy Reviews* **14(1)**:422-429.

Sahabmanesh, A. & Saboohi, Y. (2017) Model of sustainable development of energy system, case of Hamedan. *Energy Policy* **104**:66-79.

Santoyo-Castelazo, E. & Azapagic, A. (2014) Sustainability assessment of energy systems: integrating environmental, economic and social aspects. *Journal of Cleaner Production* **80**:119-138.

Sartori, S., Witjes, S. & Campos, L. M. S. (2017) Sustainability performance for Brazilian electricity power industry: An assessment integrating social, economic and environmental issues. *Energy Policy* **111**:41-51.

Schlör, H., Fischer, W. & Hake, J.-F. (2012) The meaning of energy systems for the genesis of the concept of sustainable development. *Applied Energy* **97**:192-200.

Schmidt, T., Fernando, A. L., Monti, A. & Rettenmaier, N. (2015) Life Cycle Assessment of Bioenergy and Bio-Based Products from Perennial Grasses Cultivated on Marginal Land in the Mediterranean Region. *BioEnergy Research* **8(4)**:1548-1561.

Schoolman, E. D., Guest, J. S., Bush, K. F. & Bell, A. R. (2012) How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. *Sustainability Science* **7(1)**:67-80.

Shaaban, M. & Scheffran, J. (2017) Selection of sustainable development indicators for the assessment of electricity production in Egypt. *Sustainable Energy Technologies and Assessments* **22**:65-73.

Shaaban, M., Scheffran, J., Böhner, J. & Elsobki, M. (2018) Sustainability Assessment of Electricity Generation Technologies in Egypt Using Multi-Criteria Decision Analysis. *Energies* **11(5)**:1117.

Shaker, R. R. (2015) The spatial distribution of development in Europe and its underlying sustainability correlations. *Applied Geography* **63**:304-314.

Sharma, T. & Balachandra, P. (2018) Will the integration of renewable energy enable sustainable transition of Indian electricity system? *Energy Strategy Reviews* **21**:137-148.

Shmelev, S. E. & van den Bergh, J. C. J. M. (2016) Optimal diversity of renewable energy alternatives under multiple criteria: An application to the UK. *Renewable and Sustainable Energy Reviews* **60**:679-691.

Stamford, L. & Azapagic, A. (2011) Sustainability indicators for the assessment of nuclear power. *Energy* **36(10)**:6037-6057.

Stamford, L. & Azapagic, A. (2014) Life cycle environmental impacts of UK shale gas. *Applied Energy* **134**:506-518.

Stougie, L., Tsalidis, G. A., van der Kooi, H. J. & Korevaar, G. (2018) Environmental and exergetic sustainability assessment of power generation from biomass. *Renewable Energy* **128**:520-528.

Strazza, C., Del Borghi, A., Costamagna, P., Gallo, M., Brignole, E. & Girdinio, P. (2015) Life Cycle Assessment and Life Cycle Costing of a SOFC system for distributed power generation. *Energy Conversion and Management* **100**:64-77.

Štreimikienė, D., Balezentis, T., Krisciukaitienė, I. & Balezentis, A. (2012) Prioritizing sustainable electricity production technologies: MCDM approach. *Renewable and Sustainable Energy Reviews* **16(5)**:3302-3311.

Štreimikienė, D., Šliogerienė, J. & Turskis, Z. (2016) Multi-criteria analysis of electricity generation technologies in Lithuania. *Renewable Energy* **85**:148-156.

Suomalainen, K. & Sharp, B. (2016) Electricity sector transformation in New Zealand: A sustainability assessment approach. *Journal of Renewable and Sustainable Energy* **8(3)**:035902.

Troldborg, M., Heslop, S. & Hough, R. L. (2014) Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. *Renewable and Sustainable Energy Reviews* **39**:1173-1184.

Tsoutsos, T., Frantzeskaki, N. & Gekas, V. (2005) Environmental impacts from the solar energy technologies. *Energy Policy* **33(3)**:289-296.

Turconi, R., Boldrin, A. & Astrup, T. (2013) Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. *Renewable and Sustainable Energy Reviews* **28**:555-565.

Turner, R. K. (1993) Sustainability: principles and practice. In *Sustainable Environmental Economics and Management.* (Turner, R. K. (ed)) Belhaven Press, London, pp. 3-36.

United Nations (2015) *Transforming Our World: The 2030 Agenda for Sustainable Development*. Report A/RES/70/1.

van Eck, N. J. & Waltman, L. (2018) VOSviewer version 1.6.9.) Centre for Science and Technology, Leiden University, The Netherlands.

Varun, Prakash, R. & Bhat, I. K. (2009) Energy, economics and environmental impacts of renewable energy systems. *Renewable and Sustainable Energy Reviews* **13(9)**:2716-2721.

Volkart, K., Mutel, C. L. & Panos, E. (2018) Integrating life cycle assessment and energy system modelling: Methodology and application to the world energy scenarios. *Sustainable Production and Consumption* **16**:121-133.

Volkart, K., Weidmann, N., Bauer, C. & Hirschberg, S. (2017) Multi-criteria decision analysis of energy system transformation pathways: A case study for Switzerland. *Energy Policy* **106**:155-168.

von Doderer, C. C. C. & Kleynhans, T. E. (2014) Determining the most sustainable lignocellulosic bioenergy system following a case study approach. *Biomass and Bioenergy* **70**:273-286.

Vučićević, B., Jovanović, M., Afgan, N. & Turanjanin, V. (2014) Assessing the sustainability of the energy use of residential buildings in Belgrade through multi-criteria analysis. *Energy and Buildings* **69**:51-61.

Waltman, L., van Eck, N. J. & Noyons, E. C. M. (2010) A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics* **4(4)**:629-635.

Wang, X., Chen, Y., Sui, P., Gao, W., Qin, F., Wu, X. & Xiong, J. (2014) Efficiency and sustainability analysis of biogas and electricity production from a large-scale biogas project in China: an emergy evaluation based on LCA. *Journal of Cleaner Production* **65**:234-245.

Watt, M. E., Johnson, A. J., Ellis, M. & Outhred, H. R. (1998) Life-cycle air emissions from PV power systems. *Progress in Photovoltaics: Research and Applications* **6(2)**:127-136.

Whitaker, M. B., Heath, G. A., Burkhardt, J. J. & Turchi, C. S. (2013) Life Cycle Assessment of a Power Tower Concentrating Solar Plant and the Impacts of Key Design Alternatives. *Environmental Science & Technology* **47(11)**:5896-5903.

White, L. & Noble, B. (2012) Strategic environmental assessment in the electricity sector: an application to electricity supply planning, Saskatchewan, Canada. *Impact Assessment and Project Appraisal* **30(4)**:284-295.

Whiteman, G., Walker, B. & Perego, P. (2013) Planetary Boundaries: Ecological Foundations for Corporate Sustainability. *Journal of Management Studies* **50(2)**:307-336.

Williams, A., Kennedy, S., Philipp, F. & Whiteman, G. (2017) Systems thinking: A review of sustainability management research. *Journal of Cleaner Production* **148**:866-881.

Wu, D., Yang, Z., Wang, N., Li, C. & Yang, Y. (2018) An Integrated Multi-Criteria Decision Making Model and AHP Weighting Uncertainty Analysis for Sustainability Assessment of Coal-Fired Power Units. *Sustainability* **10(6)**:1700.

Yang, G., Shen, W., Zhang, D. & Liu, W. (2014) Extended utility and DEA models without explicit input. *Journal of the Operational Research Society* **65(8)**:1212-1220.

Yang, Q., Chen, G. Q., Liao, S., Zhao, Y. H., Peng, H. W. & Chen, H. P. (2013) Environmental sustainability of wind power: An emergy analysis of a Chinese wind farm. *Renewable and Sustainable Energy Reviews* **25**:229-239.

Young, S. T. & Dhanda, K. K. (2013) *Sustainability: Essentials for Business.* Los Angeles, SAGE Publications.

Zhang, Q., McLellan, B. C., Tezuka, T. & Ishihara, K. N. (2012) Economic and environmental analysis of power generation expansion in Japan considering Fukushima nuclear accident using a multi-objective optimization model. *Energy* **44(1)**:986-995.

Zhao, H. & Li, N. (2015) Evaluating the performance of thermal power enterprises using sustainability balanced scorecard, fuzzy Delphic and hybrid multi-criteria decision making approaches for sustainability. *Journal of Cleaner Production* **108**:569-582.

Supplementary Materials

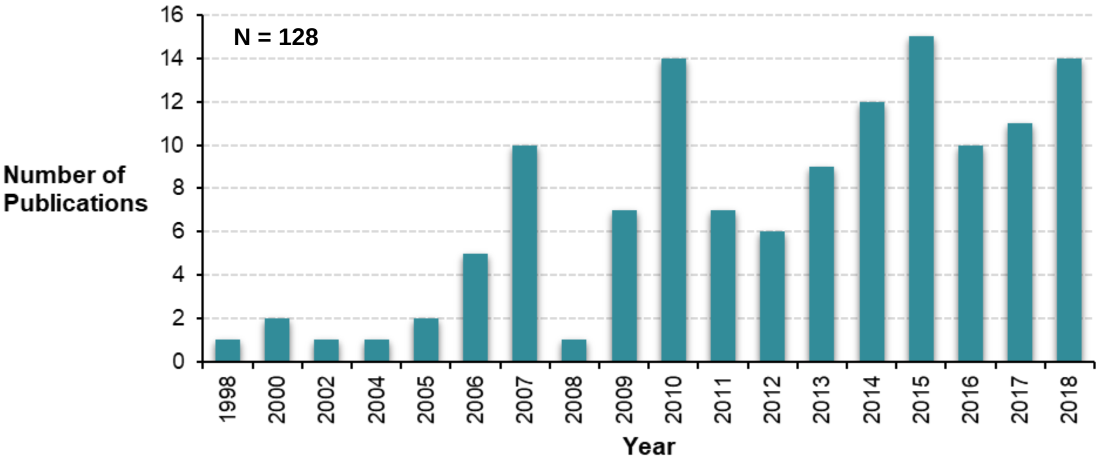
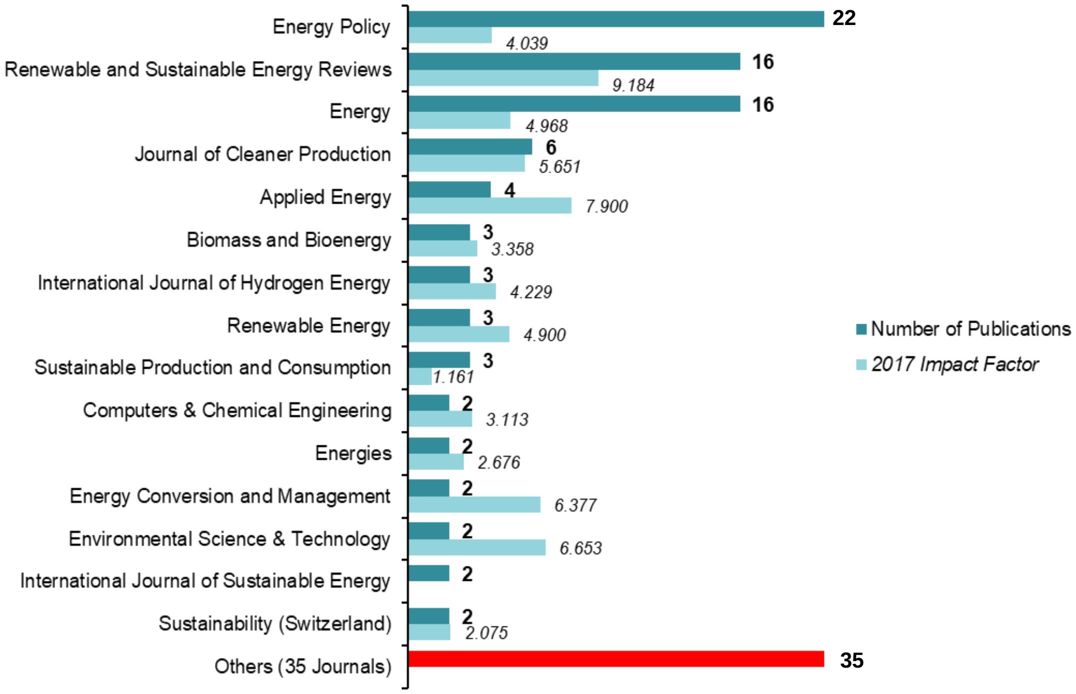


Figure A1: Yearly distribution of papers reviewed

Figure A2: Distribution of publications by journals



Note: *Impact factors are based on 2017 Journal Citation Report. For Sustainable Production and Consumption, impact factor reported is the source normalized impact per paper.*

Papers included in the review

No.	Authors	Methods	Dimensions	Context	Generation Technologies
1.	Watt et al. (1998)	LCA	Environmental	Australia	Renewables
2.	Krotscheck et al. (2000)	LCA, BioEnergy Assessment Model, Sustainable Process Index	-	New Zealand, EU	Renewables
3.	Afgan et al. (2000)	MCDM (ASPID)	Resource, Environmental, Economic, Social	-	Renewable and Non-renewables
4.	Afgan and Carvalho (2002)	MCDM (Linear aggregative functions)	Economic, Environmental	-	Renewable and Non-renewables
5.	Afgan and Carvalho (2004)	MCDM (Linear aggregative functions)	Performance, Market, Environment, Social	-	Renewable and Non-renewables
6.	Tsoutsos et al. (2005)	Descriptive	Environmental, Social	-	Renewables
7.	Holzer (2005)	Descriptive	Economic, Social, Ecological	Germany	Renewables
8.	Giampietro et al. (2006)	MCDM (NAIADE)	Economic, Ecological, Self-reliance, Safety	France, Italy, Spain	-
9.	Lipošćak et al. (2006)	MCDM (ASPID)	Environmental, Social, Economic	Croatia	Non-renewables
10.	Pilavachi et al. (2006)	MCDM (ASPID)	Economic, Social, Environmental	-	Non-renewables
11.	Rafaj et al. (2006)	Multi-regional, energy-system Global MARKAL Model (GMM)	-	Global	Renewable and Non-renewables

12.	May and Brennan (2006)	Normalization, LCA	Environmental, Economic, Social	Australia	Non-renewables
13.	Afgan et al. (2007b)	MCDM (Linear aggregative functions)	Performance, Market, Environment, Social	-	Renewable and Non-renewables
14.	Assefa and Frostell (2007)	ORWARE	Social, Environmental, Economic	Sweden	-
15.	Begić and Afgan (2007)	MCDM (ASPID)	Resource, Environmental, Economic, Social	Bosnia and Herzegovina	Renewable and Non-renewables
16.	Koroneos and Nanaki (2007)	Exergy Analysis	Environmental, Economic	Romania, Bulgaria, Turkey, Greece	-
17.	Resnier et al. (2007)	CDM Tax/Subsidy Optimization Model	Environmental, Economic	China	Renewable and Non-renewables
18.	Orecchini (2007)	Descriptive	-	-	Renewable and Non-renewables
19.	Afgan et al. (2007a)	MCDM (Linear aggregative functions)	Economic, Environmental, Technological, Social	-	Renewable and Non-renewables
20.	Qudrat-Ullah and Karakul (2007)	dynamic simulation model	-	Pakistan	-
21.	Clift (2007)	Descriptive	Environmental, Social, Techno-economic	United Kingdom	Renewables
22.	Elghali et al. (2007)	Descriptive	-	United Kingdom	Renewables
23.	Afgan and Carvalho (2008)	MCDM, Scenario Analysis	Environmental, Economic, Social	-	Renewable and Non-renewables

24.	Buchholz et al. (2009)	MCDM (Super Decisions (AHP), DecideIT (Delta Method), Decision Lab (Promethee II), NAIADE)	Ecological, Social, Economic	Uganda	Renewable and Non-renewables
25.	Chatzimouratidis and Pilavachi (2009)	MCDM (AHP)	Technological/Sustainability, Economic	-	Renewable and Non-renewables
26.	Evans et al. (2009)	Ranking	Economic, Environmental, Social, others	Australia	Renewables
27.	Jovanović et al. (2009)	Simulation, MAED, MCDM (WSM)	Economy, Social, Ecology	Serbia, Belgrade	Renewable and Non-renewables
28.	Karger and Hennings (2009)	MCDM (AHP)	Environmental, Health, Security of supply, Economic, Social	Germany	Renewable and Non-renewables
29.	Roth et al. (2009)	MCDM, LCA	Environmental, Social, Economic	Switzerland	Renewable and Non-renewables
30.	Varun et al. (2009)	Figure of merit, Energy Intensity	Energy, Economics, Environmental	-	Renewables
31.	Browne et al. (2010)	MCDM (NAIADE)		Ireland	Renewable and Non-renewables
32.	Doukas et al. (2010)	MCDM (Fuzzy TOPSIS)	-	Greece	Renewables
33.	Evans et al. (2010)	Descriptive	Efficiency, Environmental, Availability, Social	Australia	Renewable and Non-renewables
34.	Frangopoulos and Keramioti (2010)	MCDM (WSM), Exergy	Technical, Environmental, Economic, Social	-	Non-renewables
35.	Gallego Carrera and Mack (2010)	Descriptive statistics	Social	France, Germany, Italy	Renewable and Non-renewables

				and Switzerland	
36.	Jovanović et al. (2010)	MCDM (ASPID), Fuzzy logic	Economic, Social, Ecological	Serbia, Belgrade	-
37.	Mondal and Denich (2010)	GIS-based GeoSpatial Toolkit (GsT), Hybrid System Optimization Model for Electric Renewables (HOMER) model	-	Bangladesh	Renewables
38.	Onat and Bayar (2010)	Sum of Ranks	Economic, Environmental, Social	-	Renewable and Non-renewables
39.	Phdungsilp (2010)	MCDM (MAVT, AHP)	Resource use, Environmental, Financial Economic, Social, Practical (Political)	Thailand	Non-renewables
40.	Rogner (2010)	MCDM, LCA	Environmental, Economic, Social	Europe	Renewables
41.	Rovere et al. (2010)	MCDM, DEA	Technical, Socioeconomic, Environmental and Technological	Brazil	Renewable and Non-renewables
42.	El-Fadel et al. (2010)	Energy analysis, LCA	Technical, Environmental, Energy, Social	Lebanon	Renewable and Non-renewables
43.	Abouelnaga et al. (2010)	Fuzzy logic	Environmental, Economic, Sociopolitical	Egypt	Renewables
44.	Dominguez-Ramos et al. (2010)	LCA	-	Spain	Renewable and Non-renewables
45.	Afgan and Darwish (2011)	MCDM (WSM)	Technological, Environmental, Economic, Social	Kuwait	-

46.	Burkhardt et al. (2011)	LCA (Hybrid LCA), Capacity Expansion Decisions	Environmental, Economic	USA	Renewables
47.	Duan et al. (2011)	MCDM (AHP), Fuzzy synthetic evaluation	Resource, Technology, Environment	China	Renewables
48.	Jovanović et al. (2011)	MCDM (ASPID), Fuzzy logic	Social, Economy, Ecology	Serbia, Belgrade	Renewable and Non-renewables
49.	Parnphumeesup and Kerr (2011)	Case study, MCDM (AHP)	Environmental	Thailand	Renewables
50.	Grunwald and Rösch (2011)	Descriptive	Human health, Self-support, Natural resources, Renewable resources, Environment, Natural cultural factors	Germany	Renewable and Non-renewables
51.	Stamford and Azapagic (2011)	LCA	Techno-economic, Environmental, Social	United Kingdom	Renewable and Non-renewables
52.	Lo Prete et al. (2012)	Exergy, Simulation (COMPETES), Reliability Valuation	Environmental, Economic, Technical, Reliability	Belgium, France, Germany, Netherlands	Renewable and Non-renewables
53.	Rehl et al. (2012)	LCA (Attributional LCA, Consequential LCA)	Environmental	Germany	Renewables
54.	Štreimikienė et al. (2012)	MCDM (MULTIMOORA, TOPSIS)	Economic, Environmental, Social	European Union	Renewable and Non-renewables
55.	Zhang et al. (2012)	Multi-objective optimization, Nonlinear programming	Economic, Environmental	Japan	Renewable and Non-renewables
56.	Mah and Hills	Wind resource assessment		China	Renewables

	(2012)				
57.	White and Noble (2012)	Concordance analysis; AHP		Canada	Renewable and Non-renewables
58.	Morimoto (2013)	MCA, Least squares	Environmental, Economic, Social	Sri Lanka	Renewables
59.	Myllyviita et al. (2013)	MCDM, AHP	Ecological, Social, Economic, Cultural	Finland	Renewable and Non-renewables
60.	Turconi et al. (2013)	Critical Review, LCA		-	Renewable and Non-renewables
61.	Einsiedel et al. (2013)	Descriptive		Australia	-
62.	Whitaker et al. (2013)	LCA, Hybrid LCA		USA	Renewables
63.	Kurka (2013)	MCDM, AHP	Environmental, Economic, Technical, Social	Scotland	Renewables
64.	Yang et al. (2013)	Emergy analysis	Environmental	China	Renewables
65.	Hammond et al. (2013)	LCA	Environmental	United Kingdom	Renewable and Non-renewables
66.	Ribeiro et al. (2013)	MCDM (WSM), MILP	Economic, Job market, Quality of life, Technical, Environmental	Portugal	Renewable and Non-renewables
67.	Ahmad and Tahar (2014)	MCDM (AHP)	Technical, Economic, Social, Environmental	Malaysia	Renewables
68.	Brand and Missaoui	Optimization, MCDM (TOPSIS) Scenario Analysis	Economic, Energy security, Environmental, Social	Tunisia	Renewable and Non-renewables

	(2014)				
69.	Dombi et al. (2014)	MCDM, Non-compensatory, Choice of Experiment	Environmental, Economic, Social	Hungary	Renewables
70.	Maxim (2014)	MCDM(Multi-Attribute utility Method)	Economic, Technological, Environmental, Socio-political	Romania	Renewable and Non-renewables
71.	Roldán et al. (2014)	MCDM, AHP, LCA	Economic, Social, Institutional, Environmental	Mexico	Renewable and Non-renewables
72.	Santoyo-Castelazo and Azapagic (2014)	LCA, MCDM (multi-attribute value theory (MAVT)), Scenario Analysis	Environmental, Economic, Social	Mexico	Renewable and Non-renewables
73.	Troldborg et al. (2014)	MCDM (PROMETHEE)	Environmental, Socio-economic, Technical	Scotland	Renewables
74.	von Doderer and Kleynhans (2014)	LCA, GIS, Multi-period budgeting, MCDM (AHP)	Financial-economic, Socio-economic, Environmental	South Africa	Renewables
75.	Kazagic et al. (2014)	Portfolio optimization, MCA- General Index	Environmental, Economic, Social	Bosnia and Herzegovina	Renewable and Non-renewables
76.	Wang et al. (2014)	LCA, Emergy	Economic, Ecological	China	Renewables
77.	Manrique and Franco (2014)	MCDM (Weighted Linear Addition (WLA), Simple Multi-Attribute Rating Technique (SMART))		Argentina	Renewables
78.	Mattiussi et al. (2014)	MCDM (AHP), LCA	Technical, Economic, Environmental, Social	Australia	Renewable and Non-renewables
79.	Bojesen et al. (2015)	MCDM, AHP, Spatial multi-criteria evaluation	Economic, Environmental, Social	Denmark	Renewables
80.	Barros et al. (2015)	MCDM - Requirement trees, Value	Economic, Social, Environmental	Spain	Renewable and Non-

		functions and AHP			renewables
81.	Cucchiella and D'Adamo (2015)	MCDM, AHP, WSM	Energetic, Economic, Environmental	Italy	Renewables
82.	Hacatoglu et al. (2015a)	MCDM, WSM, LCA	Environmental	Canada	Renewable and Non-renewables
83.	Hacatoglu et al. (2015b)	MCDM, WSM, Exergy, LCA	Environmental	Canada	Renewables
84.	Hadian and Madani (2015)	Relative Aggregate Footprint, MCDM (Dominance, Maximin, Lexicographic, TOPSIS, SAW)	Environmental, Economic	-	Renewable and Non-renewables
85.	Klein and Whalley (2015)	MCDM (Weighted Sum)	Environmental, Economic, Social, Technical	-	Renewable and Non-renewables
86.	Luthra et al. (2015)	MCDM, Fuzzy AHP	Economic, Environmental, Social, Operational, Technological	India	Renewable and Non-renewables
87.	Moreira et al. (2015)	MCDM	Environmental, Social, Technical	Brazil	Renewable and Non-renewables
88.	Schmidt et al. (2015)	LCA	Environmental	Europe	Renewables
89.	Zhao and Li (2015)	MCDM, ANP, Fuzzy TOPSIS, Fuzzy Delphi, Sustainability balanced scorecard	Economic, Environmental, Internal Process, Learning and growth, Sustainable	China	Non-renewables
90.	Kliucininkas et al.	Descriptive	Environmental, Financial	Lithuania	Renewable and Non-renewables

	(2005)				
91.	Kumar and Katoch (2015)	MCDM, AHP	Economic, Environmental, Social	India	Renewables
92.	Khan (2015)	Descriptive	Social, Economic, Environmental	India	Renewables
93.	Strazza et al. (2015)	LCA, Life Cycle Costing	Environmental	European Union	-
94.	Azapagic et al. (2016)	LCA, MCDM (Multi-Attribute Decision Analysis), Scenario Analysis	Techno-Economic, Environmental, Social	United Kingdom	Renewable and Non-renewables
95.	Ewertowska et al. (2016)	DEA, LCA	Environmental	European Union	Renewable and Non-renewables
96.	Galán-Martín et al. (2016)	MCDM (DEA)	Environmental, Economic, Social	United Kingdom	Renewable and Non-renewables
97.	Shmelev and van den Bergh (2016)	MCDM, Aggregated Preference Indices System (APIS), MARKAL Model	Economic, Social, Resource inputs, Environmental, Risk, Technical	United Kingdom	Renewable and Non-renewables
98.	Štreimikienė et al. (2016)	MCDM (AHP, Additive Ratio)	Economic, Technological, Environmental, Institutional-political, Social	Lithuania	Renewable and Non-renewables
99.	Herbert et al. (2016)	LCA, Consequential LCA		Global (91 countries)	Renewable and Non-renewables
100.	Suomalainen and Sharp (2016)		Economic, Social, Environmental	New Zealand	Renewable and Non-renewables
101.	Li et al. (2016)	DEA	Environmental, Economic	G20 countries	Renewable and Non-renewables

102.	Kazagic et al. (2016)	MCDM, Single Criteria Analysis (SCA)	Environmental, Economic	South-East Europe	Renewable and Non-renewables
103.	Atilgan and Azapagic (2016)	LCA, MCDM (multi-attribute value theory (MAVT))	Environmental, Economic, Social	Turkey	Renewable and Non-renewables
104.	Akber et al. (2017)	LCA, Sustainability Score	Environmental, Economic, Socio-Political (Equal weighting)	Pakistan	Renewable and Non-renewables
105.	Ewertowska et al. (2017)	LCA, DEA, Stochastic Modelling, Monte Carlo Simulation	Environmental	-	Renewable and Non-renewables
106.	Jones et al. (2017)	LCA (Consequential LCA), net energy analysis	Environmental	-	Renewable and Non-renewables
107.	Malkawi et al. (2017)	MCDM (AHP)	Economic, Technical, Environmental, Ecological, Social, and risk assessment	Jordan	Renewable and Non-renewables
108.	Feng et al. (2017)	DEA	Nature, Society, Economy	China	Non-renewables
109.	Shaaban and Scheffran (2017)	Case study	Economic, Environmental., Social, Technical	Egypt	-
110.	Grafakos and Flamos (2017)	Survey	Economic, Environmental, Social, Energy, Technological	European	Renewable and Non-renewables
111.	Narula et al. (2017)	MCDM, WSM	Availability, Affordability, Efficiency, Acceptability (Environmental)	-	Renewable and Non-renewables
112.	Volkart et al. (2017)	MCDM (WSM), MARKAL, LCA	Environment, Economy, Society, Security of Supply	Switzerland	Renewable and Non-renewables
113.	Sartori et al. (2017)	DEA	Economic, Social, Environmental	Brazil	Renewable and Non-

					renewables
114.	Sahabmanesh and Saboohi (2017)	MCDM (AHP), Optimization (SESM)	Social, Economic, Environmental	Iran	Renewable and Non-renewables
115.	Stougie et al. (2018)	LCA, Exergy	Environmental, Exergy	-	Renewables
116.	Quek et al. (2018)	LCA	Environmental	Singapore	Renewable and Non-renewables
117.	Moslehi and Reddy (2018)	Optimization, Simulation		USA	Renewable and Non-renewables
118.	Ren (2018)	MCA, fuzzy two-stage logarithmic goal programming method, LCA, interval relational analysis, TOPSIS	Environmental, Economic, Social	United Kingdom	Renewable and Non-renewables
119.	Volkart et al. (2018)	LCA, Partial equilibrium energy system modelling, Global Multi-regional MARKAL		Global	Renewable and Non-renewables
120.	Gaete-Morales et al. (2018)	LCA,	Environmental	Chile	Renewable and Non-renewables
121.	Sharma and Balachandra (2018)	Optimization, MILP	Social, Economic, Environmental	India	Renewable and Non-renewables
122.	Cséfalvay and Horváth (2018)	Ethanol Equivalent		US, Canada, EU, China, Russia	Renewables
123.	Kanbur et al. (2018)	Finite sum modelling, Exergy analysis, Thermodynamic and environmental modelling	Environmental, Thermoeconomic	Singapore, India, Brazil	Non-renewables

124.	Wu et al. (2018)	Hybrid MCDM, Areal Grey Relational Analysis, Fuzzy, Entropy, AHP, Simulation	Flexibility, Economic, Environmental, Reliability, Technical	China	Non-renewables
125.	Mirjat et al. (2018)	MCDM, AHP	Technological, Environmental, Socio-Political, Economic	Pakistan	Renewable and Non-renewables
126.	Deutsch (2018)	MCDM, WSM	Economic, Engineering, Social, Environmental	-	Renewable and Non-renewables
127.	Shaaban et al. (2018)	MCDM, AHP, Simulation	Technical, Economic, Social, Environmental	Egypt	Renewable and Non-renewables
128.	Guen et al. (2018)	combining software CitySim, HOMER Pro, QGIS and Rhinoceros		Switzerland	Renewable and Non-renewables