Economic, Environmental, and Social Impacts of Renewable Energies: What have We Learned by Now?

Edimar Ramalho[1], *Max* López-Maciel[2], *Mara* Madaleno[3], *José* Villar[4], *Marta* Ferreira Dias[3], *Anabela* Botelho[3], and *Margarita* Robaina[3]

[1]DEGEIT, University of Aveiro, Campus Universitário de Santiago, 3810-193, Aveiro, Portugal
[2]CESAM & Department of Environment & Planning, Aveiro University (DAO-UA), Portugal
[3]DEGEIT & GOVCOPP, University of Aveiro, Campus Universitário de Santiago, 3810-193, Aveiro, Portugal
[4]Centre for Power and Energy Systems, INESC TEC, Campus da FEUP, Rua Dr Roberto Frias, 4200-465 Porto, Portugal

Abstract. Renewable energy is an essential driver of the energy transition towards a more sustainable world. However, sustainability requires the coordination of the economic, environmental, and social dimensions, turning it into a complex objective. The aim of this study is to review the state of the art of the articles that analyze economic, environmental, and social metrics that can be used to evaluate the impact of renewable. In addition, this work also classifies metrics into two main approaches: macro-studies, corresponding to those that evaluate based on global and aggregated impacts, and micro-studies, corresponding to those that focus on regional and local impacts. A systematic literature review was used to identify and define these main metrics, based on common research databases. Seven metrics were found and described for the environmental impact, four for the economic impact and five for the social impact. The main finding revealed that micro-studies are more prevalent in comparison to macro-studies. Moreover, the systematic literature review allows achieving the objective and highlighting the proposed sustainability assessment framework as crucial for gauging and evaluating impact metrics across the economic, social, and environmental dimensions. The difficulty in isolating and measuring each metric may be attributed to the challenges involved in studying the corresponding impact, whether at the micro or macro level. More targeted studies can help in a more efficient energy transition.

1 Introduction

The energy transition is increasingly present in the national agendas of many countries around the world [1], and several countries are following the Sustainable Development Goals (SDGs) and the Paris Agreement to undertake the energy transition [2]. Some studies show these efforts in different countries or regions, such as Morocco [3], [4], Mexico [5], India [6], Bangladesh [7], Laos [8], The United States [2], Ecuador [9], Brazil [10], China [11], Malaysia [12] or multi-countries, e.g., countries of the Organization for Economic Co-operation and Development (OCDE) [13] and several European countries [1], [13], [14]. The energy transition, in short being the shift from fossil-fuel based systems for energy production and consumption to renewable energy sources, must be seen as a possibility for economic development [15] and as a prime factor for sustainability [16]. However, sustainability is a complex concept. In theory, sustainability refers to meeting "the needs of the present without compromising the ability of future generations to meet their own needs" [17, p.41]. In practical terms, sustainability involves the coordination of the economic, social, and environmental dimensions [16]. Thus, a framework for evaluating the impact of renewable energies from the sustainability perspective should include these three dimensions [11]. A correct assessment of these impacts is needed to guide the investment decisions on renewable generation, and to suggest ways to mitigate potential negative impacts [18]. Indeed, according to [19], impacts can be conflicting, making the decision process towards sustainability a huge challenge.

The literature on metrics to assess these impacts is extensive and scattered. The goal and main contribution of this work is a systematic literature review to identify and describe the main metrics used to assess the economic, environmental, and social impacts of renewable generation technologies. Although there are studies that have addressed these impacts, [6], [20], [21], no systematic review was found addressing the three dimensions together. In addition to identifying impacts, this work also classifies the metrics under two main approaches: macro-studies, corresponding to those that make the assessment based on global and aggregate impacts, and micro-studies, corresponding to those that focus on regional and local impacts. As a result, the present study encompasses greater coverage of the literature and provides a deeper understanding of these metrics.

2 Methodology

The Web of Science and Scopus databases were used, and all articles containing the words "renewable energy", "economic impact", "social impact" and "environmental impact" were initially considered. This led to an initial set of 2808 articles found (Table 1). The next filtering process was to select only those articles written in English, producing a set of 2087 articles. This approach was adopted to ensure access to all articles dealing at least with one of the impacts. The titles, keywords, and abstracts of all 2087 papers were then read, and any literature that did not refer to the metrics of economic, social, and environmental impacts was disregarded. Thus, papers that analyze consumer preferences, estimate energy demand, quantify fossil energies and more technical studies were not included in this present study. After applying these selection criteria, the set of selected works was reduced to 67 articles.

Table 1. Search methodology.

Criteria	Steps	Number of papers
Search String	"renewable energy" AND "economic impact" AND "social impact" AND "environmental impact".	2808
Document type/Language	Article/English	2087
Restrictions	Title, Keywords, and Abstracts	67

3 Results

The 67 scientific articles on the economic, social, and environmental impacts of renewable energies covering the proposed literature review methodology were published over time with an upward trend from 2010 to 2022 (see Fig. 1).

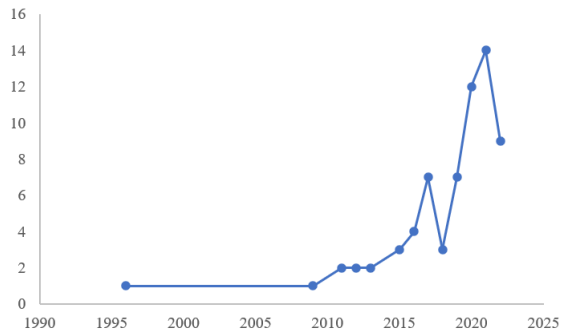

Fig. 1. Publication trends (number of articles) on the economic, social, and environmental impacts of renewable energies.

The distribution over time of the selected articles shows the growing interest of re-searchers in this topic, as can be seen in Figure 1. Considering the focus of the national agendas following the Paris agreement and the research initiatives on the transition from fossil-based to renewable energies, this growing interest was already expected. The chosen metrics were based on the number of citations in the 67 select-ed papers.

3.1 Environmental Impact

The environmental impact was discussed in 43 articles of the 67 analyzed (Table 2). The more frequent metrics mentioned were Greenhouse Gas (GHG) Emissions, Air pollution, Land use, Bird mortality, Biodiversity, Climate Change, and Water pollution.

The most cited metric was GHG Emissions and is usually defined as the CO2 emissions savings [22], that is the GHG emissions avoided in the substitution of conventional energy sources for renewable energy [23], [24]. However, some works also include other pollutants, such as nitric oxides (NOx), or sulfur dioxide (SO2) [25].

The second metrics mostly referred were Biodiversity and Land use. The first consists in assessing the animals' quality of life [6] and how much the power plant harms the surrounding nature [26]. A more specific metric is Bird mortality, that resembles Biodiversity but refers only to the number of birds that were killed with the implementation and operation of the power plant. Land use can be described as the reduction in the quality and quantity of the resources that the land can give [6] or as the income generated by leasing or selling the land for the construction of the plant [27].

Air pollution is another metric that assess the air quality after the implementation of renewable energy [7], [11], [13], [27].

Climate change is a metric that can be defined as changes in air temperature during the day (decreases) and at night (increases) in wind farms [6], [28], [29].

Finally, the water pollution metric refers to the amount of water saved or used in the exchange of conventional energy for renewable energy.

The main metrics of environmental impact found in the literature review revealed that micro-studies studies are predominant, that is, are studied with an emphasis on local or regional impact. There is a paucity of macro-studies that adopt environmental impact metrics as their framework, with only the GHG metric being comparatively more prevalent in such studies.

Table 2. Papers with Renewable Energy Environmental Impact Metrics.

Metric	Reference	Number of papers	
		Micro	Macro
GHGEmissions	[10], [11], [13], [16], [20], [21], [28]–[36]	9	6
Air pollution	[13], [20], [30], [32], [37]–[40]	5	3
Land use	[6], [20], [27]–[29], [34], [41]–[44]	10	0
Bird mortality	[5], [11], [20], [28]–[30]	4	2
Biodiversity	[6], [20], [21], [26]–[28], [35], [41], [45], [46]	8	2
Climate Change	[6], [20], [28], [29], [43], [44], [47]	6	1
Water pollution	[22], [35], [45], [48], [49]	4	1

3.2 Economic Impact

The economic impact was discussed in 35 articles of the 67 analyzed .The main metrics were Employment and job creation, Gross Domestic Product (GDP), Investment costs, and Operation and maintenance costs (Table 3).

Employment/job creation metric is the most referred and consist of all the jobs generated by the deployment of renewable energies, which can be direct or indirect [30], that is, the increased employment opportunities [45] during all phases of production, installation, maintenance, and support of renewable energies [29].

GDP is the second most commented metric in the literature and measures the economic growth in monetary values associated to the use of renewable sources [1].

Investment costs are another metric that is estimated by the construction costs [8], drilling cost, heat exchanger costs [41], cost of generators [50] and installation costs [51].

The operation and maintenance costs are all actual cash project operation, maintenance, and administrative expenditures [52]. This includes the integration of material, transportation, replacement parts, personnel, and other costs connected with keeping the unit operational [53].

While GDP and employment/job creation are commonly employed as macro-studies indicators, investment costs and operational maintenance costs are typically utilized as micro-studies analytical tools.

Table 3. Papers with Renewable Energy Economic Impact Metrics.

Metric	Reference	Number of papers	
		Micro	Macro
GDP	[11], [16], [18], [27], [30], [36], [45], [54]–[57]	2	9
Employment/job creation	[29], [31], [32], [35], [45], [48], [54], [56], [58]–[66]	8	9
Investment costs	[8], [41], [50], [52], [57]	4	1
Operation and maintenance costs	[50], [51], [53], [57], [67]	3	2

3.3 Social Impact

From the selected works, 37 of the 67 analyzed focus on the social impact. The main metric found was again job creation and employment (Table 4), already referred in the economic impact section, since these metrics are commonly found to assess both the social impact and the economic impacts simultaneously. According to our analysis, there is no difference in the way it is used to assess both impacts [19], [55].

The adequate application of clear social metrics may help in choosing the location and scale of the renewable energy plants to install, because, from a social point of view, job creation and employment may support rural and small communities, even if it goes against the logic of efficiency in economic terms because it implies a conflict of choice between a decentralized system of small plants and centralized system of big plants [68]. Another metric used is related to the fact that, during the lifecycle of renewable energy, there is a health risk due to emissions, during the use and end-of-life phases. [68]. Despite being an environmental impact, it has also a social impact since residents of communities close to wind farms may be disturbed by the noise of the turbines, harming their health due to anxiety and stress levels and sleep quality [21].

The Labor rights and decent work metric is a social metric that assess to what extent the human rights of workers in the phases of construction, transport, and maintenance of the power plant are being guaranteed [69], [70].

The Cultural issues metric, is a feeling of injustice to their cultural heritage, possibly provoking negative effects on the cultural traditions, values, and styles of the region [4], [69], [71]. The correlation between this metric and renewable energy pertains to the influence of technology on the identity and cultural heritage of the local community [4] as a result of heightened immigration of foreign laborers and students [68].

Finally, the Education metric shows the level of education of the resident population or acceptance of new renewable technologies [72]. Otherwise, the education metric can be seen as one of the determinants of human development [73], raising the human capital of residents [4] and positive when related to renewable energies [45].

The main social impact metrics are predominantly assessed through micro-studies, with the exception of the employment/job creation metric, which has a greater number of macro-studies.

Table 4. Papers with Renewable Energy Social Impact Metrics.

Metric	Reference	Number of papers	
		Micro	Macro
Employment/job creation	[9], [11], [16], [18], [19], [27], [33], [34], [36], [57], [68], [71], [74]–[76]	7	8
Labor rights and decent work	[42], [47], [69]	2	1
Health and Safety	[21], [38], [47], [52], [54], [57], [64], [68], [69], [71]–[73], [75], [77]	10	4
Cultural issues	[4], [26], [52], [68], [69], [71], [75]	7	0
Education	[4], [27], [45], [72], [73], [75]	4	2

4 Conclusion

The conclusion drawn is that the proposed framework for sustainability assessment is essential in facilitating the estimation and quantification of impact metrics across the economic, social, and environmental dimensions. The challenge in measuring each metric in isolation may be attributed to the complexity of studying the corresponding impact, be it at the micro or macro-study. Thus, future research may be carried out to: 1) Apply the framework and verify if there are significant differences in relation to the micro and macro approach, 2) Analyze the metrics individually by phases of the implementation of renewable energy or by period of time (short, medium and long term), 3) Estimate or calculate the cost of environmental and social impacts through key metrics and 4) Define the advantages and disadvantages of implementing renewable energy for each impact. The analysis of all these points would make the energy transition more efficient.

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