The use of indicators as a tool in environmental impact assessment studies of Renewable Energy Sources projects

Bratani D.*, Vagiona D.

[1]Department of Spatial Planning and Development, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece

*corresponding author:
e-mail: dimitra.itar@gmail.com

Abstract Indicators have been considered as an effective tool for data collection through quantitative and qualitative methods. They provide valuable insights and serve as a useful guide for decision-making, promoting social well-being and environmental protection. The present research focuses on the use of indicators as a tool for Environmental Impact Assessment (EIA) of Renewable Energy Source (RES) projects, highlighting their application as well as their contribution to sustainable development. The main categories of RES projects are examined, including hydroelectric, photovoltaic, wind, and biomass power stations, considering their environmental, social, and economic impacts. The methodology includes the following steps: (i) identification of the main environmental impacts of RES, (ii) definition of appropriate indicators (economic, social and environmental), (iii) deployment of indicators sheet and (iv) implementation of indicators in EIA studies of real RES projects to verify their applicability. 34 indicators consist the indicators' set (8 economic, 7 social and 19 environmental) and relevant indicators sheets are deployed. The study concludes that indicators, as a tool for multifactorial analysis, are suitable for the comprehensive depiction of the impacts of RES projects and the improvement of regulatory frameworks. Therefore, their application can support the energy transition, making them an integral tool for sustainable development.

Keywords: indicators, environmental impact assessment, indicator sheet, renewable energy sources projects

1. Introduction

Climate change, the energy transition, and the pursuit of sustainable development have placed Renewable Energy Sources (RES) at the heart of global energy strategies (Turney & Fthenakis 2011). While RES projects are central to the "green transition," they are not without environmental and social impacts. Environmental Impact Assessment (EIA) serves as a fundamental tool to anticipate, evaluate, and manage these impacts (Bayer et al., 2013).

EIA is a multidisciplinary and iterative process characterized by circular feedback and sequential stages that span from project selection to post-implementation monitoring (Hall et al., 2020). In the European Union, its significance is highlighted by the establishment of expert groups under the European Commission, providing advisory, coordination, and legislative support (Gürbüz et al., 2022). The EIA framework comprises 15 stages covering the full project lifecycle. Despite its institutionalization, the process often lacks completeness, especially in addressing decommissioning phases or assessing ancillary works (Chowdhury et al. 2022).

Indicators serve as qualitative and quantitative variables that enhance assessments, support comparability, and strengthen stakeholder engagement.

This paper proposes the use of indicators as a methodological enhancement to EIA, offering a more integrated and multifaceted approach to impact evaluation on the natural, social, and economic environments.

2. Methodology

The methodology includes the following steps: (i) identification of the main environmental impacts of the selected RES (hydroelectric, photovoltaic, wind, and biomass power stations), (ii) definition of appropriate indicators (economic, social and environmental), (iii) deployment of indicators sheet and (iv) implementation of indicators in environmental impact assessment studies of real RES projects to verify their applicability. Indicator selection is based on criteria such as scientific validity, clarity, measurability, timeliness, and data accessibility. Their effectiveness and relevance is based on the OECD framework and the SMART criteria (Specific, Measurable, Achievable, Relevant, Time-bound).

3. Results and Discussion

Regarding the first step of the methodology, indicative results of the environmental impacts of onshore and offshore wind farms are provided below. During the construction phase, significant impacts include seabed disturbances, NOx emissions, and habitat degradation. In the operational phase, changes to local climate conditions, seabed vibrations, and alterations in bird population densities are observed. During the decommissioning phase, reoccurring seabed disturbances and the potential release of toxic emissions from material recycling are notable concerns.

An example of an indicator selected in the second step is "Percentage of Materials Recovered/Recycled" and its indicator sheet is presented in Table 1.

Table 1. Example of Indicator Data Sheet

Indicator Data Sheet	
Indicator Name	Percentage of Materials Recovered/Recycled
Indicator Category	Environmental
Definition	The indicator concerns the assessment of the percentage of construction materials that: 1. Can be recycled at a rate of 90% or higher. 2. Have a significant participation rate in energy recovery after processing or incineration.
Assessment Methodology	Calculation of the materials used during the construction of the project, equipment materials, and unit consumables that can be recycled, reused, or contribute to energy recovery, thus reducing final waste.
Typical Form	- Percentage (%) - Evolution graph of the quantity of materials that are recycled or recovered.
Measurement Units	- **Volume**: Cubic meter (m^3) - **Mass**: Ton (tn)
Spatial Reference	RES project installation
Measurement Frequency	- **Short-term**: Annual frequency - **Medium-term**: Every 5 years - **Long-term**: -
Purpose	Reduction of non-recyclable materials
Specifications	**- Comparative sizes -** Comparison of data and results with similar scale projects in different spatial units
Data	Composition of construction and operational materials of the RES unit
Sources	Environmental Impact Assessments (EIA), machinery characteristics, and specifications
Problems	Based on examples from previous or similar Environmental Impact Assessments (EIA)
Comments	-

Adopting the same methodology for all the selected categories of RES projects, it is concluded that, based on the life cycle analysis of each specific RES project and the associated environmental impacts, the corresponding indicator sheets are deployed (third step). As shown in the Table 2, each proposed indicator is applicable to the entirety or a subset of the RES projects (forth step).

	INDICATORS	CATEGORIES OF R.E.S. PROJECTS			
		Hydroelectric stations	Photovoltaic stations	Wind stations	Biomass stations
Economic indicators	Cost of biomass collection and transportation				X
	Total maintenance cost of auxiliary works	X	X	X	X
	Total maintenance cost of surrounding area	X	X	X	X
	Total operating expenses cost	X			X
	Total equipment decommissioning cost		X	X	
	Percentage of regional unit beneficiaries from cogeneration of heat and electricity				X
	Percentage of GDP invested in the energy transition	X	X	X	X
Social indicators	Unemployment rate	X	X	X	X
	Total healthcare expenditures as a percentage of GDP	X			X
	Income inequality	X	X	X	X
	Life expectancy	X	X	X	X
	Population change rate	X	X	X	X
	Social Welfare Index	X	X	X	X
	Percentage of individuals specialized in energy production and electricity generation	X	X	X	X
Environmental indicators	Water quality	X			X
	Amount of water recycled	X	X		X
	Water footprint	X	X		X
	Air pollution (focused each time on the gases emitted by each respective project)	X	X	X	X
	Percentage reduction of toxic, CFCs and other hazardous materials	X	X	X	X
	Kilograms of NOx/ SOx/ CO emitted from burners	X	X	X	X
	Number of complaints about odors per 1000 hours of operation				X
	Kilograms of greenhouse gases leaked in carbon equivalent tons			X	X
	Carbon footprint	X	X	X	X
	Percentage of suppliers with environmental certification	X	X	X	X
	Compliance cost / cost from potential fines				X
	Percentage of materials recovered / recycled	X	X	X	X
	Total waste volume		X	X	X
	Total land area used for production activities	X	X	X	X
	Percentage reduction of agricultural - cultivated land area		X		X
	Living Planet Index (LPI)	X	X	X	X
	Percentage of species that migrated	X	X	X	X
	Percentage of habitats partially or completely destroyed	X	X	X	X
	Number of accidents involving wildlife species during the construction of power stations	X	X	X	X
	Percentage of energy-upgraded public buildings per category (education, health, public administration)	X	X	X	X

Table 2. Applicability of proposed indicators in RES projects

4. Conclusions

The study applies a total of 34 indicators to representative RES projects—hydropower, photovoltaic, wind, and biomass. Impact assessment spans the construction, operation, and decommissioning phases. Indicators such as equipment decommissioning cost, income inequality, and reduction of natural ecosystems provide insights beyond traditional environmental focus, enhancing the reliability of assessments and highlighting previously overlooked dimensions. The incorporation of indicators into the EIA of RES projects significantly enhances the completeness, credibility, and sustainability of impact evaluations. Despite inherent challenges, indicators enable informed decision-making, bridging technical analysis with real-world social and environmental concerns. Their institutionalization and systematic application will mark an essential next step toward a just and sustainable energy transition.

References

Bayer, P., Rybach, L., Blum, P., & Brauchler, R. (2013). Review on life cycle environmental effects of geothermal power generation. *Renewable and Sustainable Energy Reviews*, *26*, 446–463.

Chowdhury, N. E., Shakib, M. A., Xu, F., Salehin, S., Islam, M. R., & Bhuiyan, A. A. (2022). Adverse environmental impacts of wind farm installations and alternative research pathways to their mitigation. *Cleaner Engineering and Technology*, *7*, 100415.

Deborah, P., Francesca, V., & Giuseppe, G. (2015a). Analysis of the environmental impact of a biomass plant for the production of bioenergy. *Renewable and Sustainable Energy Reviews*, *51*, 634–647.

Gürbüz, E. Y., Güler, O. V., & Keçebaş, A. (2022). Environmental impact assessment of a real geothermal driven power plant with two-stage ORC using enhanced exergo-environmental analysis. *Renewable Energy*, *185*, 1110–1123.

Hall, R., João, E., & Knapp, C. W. (2020). Environmental impacts of decommissioning: Onshore versus offshore wind farms. *Environmental Impact Assessment Review*, *83*, 106404.

Mello, G., Ferreira Dias, M., & Robaina, M. (2022a/b). Evaluation of the environmental impacts related to the wind farms end-of-life. *Energy Reports*, *8*, 35–40.

Phillips, J. (2015). A quantitative-based evaluation of the environmental impact and sustainability of a proposed onshore wind farm in the United Kingdom. *Renewable and Sustainable Energy Reviews*, *49*, 1261–1270.

Turney, D., & Fthenakis, V. (2011). Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, *15*(6), 3261–3270.