Multicriteria Spatial Economic Decision Support Systems to Support Positive Energy Districts: A Literature Review

Adriano Bisello, Marta Bottero, Marco Volpatti, and Tiziana Binda

Abstract To meet the ambitious targets set by the European Union to reduce CO_2 emissions, action in cities is essential. In fact, cities are responsible for 67% of the world's primary energy consumption and about 70% of energy-related CO_2 emissions. To support the urban energy transition, widespread implementation of net-zero districts, or even better, positive energy districts (PEDs), is expected. PEDs could be defined as energy efficient and energy flexible urban areas that aim to provide a surplus of clean energy to the city through renewable energy. However, the development of the PED concept needs to take into account not only the technical issue of energy systems, but also the environmental, social, and economic aspects. To be effective, it is important to provide decision makers with tools based on a Multi-Criteria Decision Analysis (MCDA) approach that can effectively assess the complexity of impacts from a multi-stakeholder perspective. The MCDA approach can be supported by a Geographic Information System (GIS) that helps to analyze the data and make it communicable to everyone. The purpose of this research, through a scientific literature review, is to investigate different MCDA supported by GIS in the framework of economic evaluation methods, aiming to contribute to the definition of an effective multi-criteria spatial economic decision making method to support and sustain the design and development of PEDs.

Keywords Multi-Criteria Decision Analysis (MCDA) · Geographic Information System (GIS) · Energy transition · Positive Energy District (PED) · Economic evaluation

A. Bisello (✉) · M. Volpatti · T. Binda
Institute for Renewable Energy, Eurac Research, Viale Druso 1, 39100 Bolzano/Bozen, Italy
e-mail: adriano.bisello@eurac.edu

M. Volpatti
e-mail: marco.volpatti@polito.it

M. Bottero · M. Volpatti · T. Binda
DIST, Politecnico di Torino, Viale Mattioli 39, 10129 Turin (TO), Italy
e-mail: marta.bottero@polito.it

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1 Introduction

The European Union has placed great emphasis on reducing CO_2 emissions in cities and related systems. Cities account for more than 50% of the global population, 80% of the global GDP, two-thirds of global energy consumption and more than 70% of annual global carbon emissions (IEA 2020). These factors are expected to increase significantly in the coming decades: it is anticipated that by 2050 more than 70% of the world's population will live in cities, resulting in massive growth in demand for urban energy infrastructure (European Commission 2023). Climate action in cities is essential to achieve the ambitious net-zero emissions goals. From this perspective, it is known that urban development in the coming years will have to shift from simple building solutions to positive-energy neighbourhoods and districts (Becchio et al. 2020). All of this, along with other innovative concepts developed in the past for cities of the future, will be key to achieving Europe's energy and climate change goals (Suppa et al. 2022). With the new Horizon Europe research and innovation plan (which will cover the period 2021–2027), Europe is aiming to vigorously address a number of global challenges that affect our cities and society: health and safety, digitization, energy and climate change in the first place (Guarino et al. 2022). With this in mind, PEDs fall under this heading. The area of Smart Cities and Communities was already defined as a priority and strategic by both the previous European Horizon 2020 program and the 17 Sustainable Development Goals established by the UN and the 2030 Agenda (Kroll et al. 2019). Over time, however, it became apparent that financing large smart city projects at the urban level was a complex task, with a huge demand for resources and investment. For this reason, the authors decided to focus efforts on smaller urban areas, such as city blocks, pilot districts and neighbourhoods, towards a concept of a diffused smart land focusing initially on energy efficiency in buildings and on-site local renewable energy production. In recent years, to sustain the urban energy transition, the concept became even more ambitious, from highly efficient buildings to net-zero ones. Later on, by including energy sharing, waste heat recovery, e-mobility and energy storage, the scope was broadened to include the implementation of net-zero districts or even better PEDs (Guarino et al. 2022). PEDs represent a new approach towards a sustainable and efficient city and urbanization model. An urban Positive Energy District combines the built environment, mobility, sustainable production and consumption to increase energy efficiency and decrease greenhouse gas emissions and to create added value for citizens. Positive Energy Districts also require integration between buildings, users and various energy networks, mobility services and IT systems.

2 Context of the Research

2.1 Features of PEDs

Research all around the world is still struggling to find a unique definition for PEDs. From an energy-focused perspective, a PED is seen as an energy self-sufficient and carbon–neutral urban district. Indeed, positive energy means that energy districts also play an important role in producing excess energy using renewable energy sources and feeding it back into the grid (Bossi et al. 2020). However, widening the perspective, it is expected that PEDs will increase the quality of life in European cities, help achieve the COP21 goals and improve European capabilities and knowledge to become a global model (Derkenbaeva et al. 2022).

Moreover, considering the keen interest of the European Commission to deliver at least 100 PEDs by 2050 and the current situation of European cities (IEA 2020), it is necessary to address this concept not only for new areas of urban development and the construction of new buildings and neighbourhoods, but especially for redevelopment of the existing building stock (Derkenbaeva et al. 2022).

The discussion on how and where to define the boundaries of these entities is still open and conclusions may differ depending on whether one considers physical limits and management aspects or those related to the overall energy balance and energy carriers, ranging therefore from local to regional scale (Zhang et al. 2021; Bossi et al. 2020). The discussion also often starts from the local dimension of city blocks, up to the urban dimension. To this regard, some interesting research on existing tools to support decision-making toward climate neutrality in cities and districts has been already carried out by Suppa et al. (2022).

In an attempt for extreme simplification, it can be said that PEDs have to strike an optimal balance between energy efficiency, energy flexibility and local energy production (European Commission 2023) in turn also achieving integrated sustainability based on environmental, economic and social features (see Fig. 1) (Muñoz et al. 2020).

Consequently, in the evaluation of a PED using the model proposed by Binda et al. (2022), these four dimensions include intrinsic and extrinsic features of a PED that are intertwined without precise separation but rather highlight areas of overlap and coexistence in fuzzy logic. Economic evaluation approach tools used in the evaluation process enable decision-makers to have the effects of their decisions on the basis of selected KPIs under control. Even more, evaluation of urban projects is inspired by a circularity approach, which corresponds to the relationship between the Life Cycle Assessment (LCA) of the same projects and the overall Whole-Life Cost (WLC) (Grazieschi et al. 2020). LCA is a process to evaluate the effects a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities (Grazieschi et al. 2020).

WLC is basically rooted in a monetary perspective and thus related to the economic sustainability of investments by accounting for the total expense of owning an asset over its entire life from purchase to disposal, as determined by financial analysis

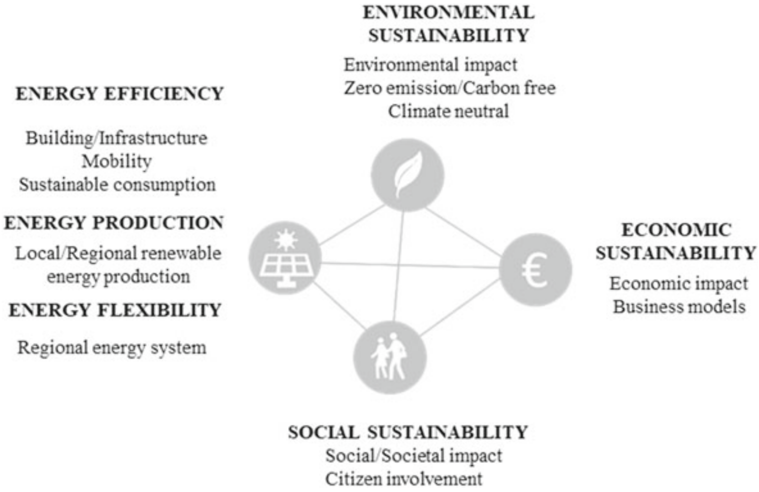

Fig. 1 The four main areas for evaluating PEDs. *Source* Own elaboration

(Fregonara 2020). The Life Cycle Cost (LCC) related to urban projects includes land acquisition and site preparation, design and building costs, operating costs, maintenance, associated financing costs, depreciation and disposal/demolition costs (Becchio et al. 2020).

As shown in Fig. 2, WLC also considers certain costs that are usually overlooked, such as factors related to environmental and social impact. In addition, we have an "extended" version of costs, which includes costs/benefits related to externalities (Becchio et al. 2020), cost savings and other effects (Fregonara 2020). This extended version includes the co-benefits commonly adopted to define the additional positive impact of smart energy renovation projects alongside the desired primary goal (Bisello 2020).

2.2 Towards an Integrated Sustainability Evaluation

To move from a mere economic evaluation of PEDs towards an integrated sustainability assessment (Binda et al. 2022), including the spatial dimension, in this research, two additional elements were considered: Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS).

As shown in Fig. 3, there are different characteristics in each circle that by complementing one another contribute to defining methods and tools. MCDA is a powerful tool that enables the concurrent evaluation of qualitative, quantitative and monetary elements (Binda et al. 2022). It is a simplified way to consider environmental social and governance (ESG) criteria (European Commission 2023). This method also

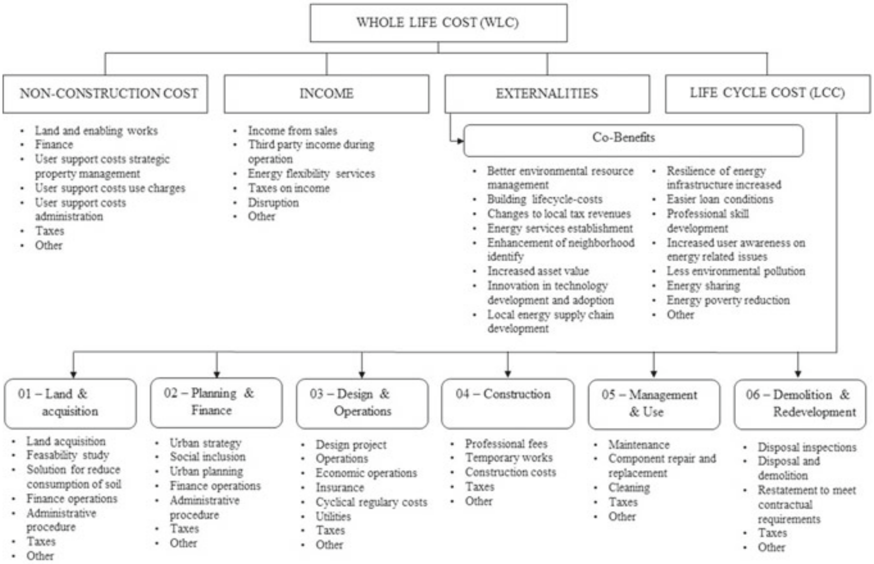

Fig. 2 Whole-life cost with externalities. *Source* Own elaboration based on Becchio et al. (2020), Bisello (2020), Fregonara (2020)

increases the transparency of the decision-making processes making the disadvantages and vantages in the alternatives clear (Bottero et al. 2021). Under this category, several different applications can be identified such as Fuzzy Multi-Criteria Decision Analysis (FMCDA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Multi-Criteria Decision Making (MCDM), Spatial-Multi-Criteria Analysis (SMCA) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

GIS is important to represent and analyse geo-referred data that are used to analyse the spatial development and temporal dynamics of transformation processes and is therefore the graphical representation of the results for a suitability map (Coutinho-Rodrigues et al. 2011). These two additional elements complement the economic analysis, which focuses on setting an evaluation as the balance between overall advantages/disadvantages (Binda et al. 2022), identifying economic efficiency measures and meaning a cost-effective situation as a socially appropriate condition. Finally, a Cost Benefit Analysis (CBA) makes it possible to synthesize the performance of different evaluation aspects, transfer all impact into monetary terms (Bottero et al. 2021) and elaborate specific KPIs such as Net Present Value (NPV) or Return of investment (ROI) (Bottero et al. 2016). In this framework of economic and financial analysis, the Social Return on investment (SROI) is also becoming popular to evaluate urban projects (Hunter et al. 2022).

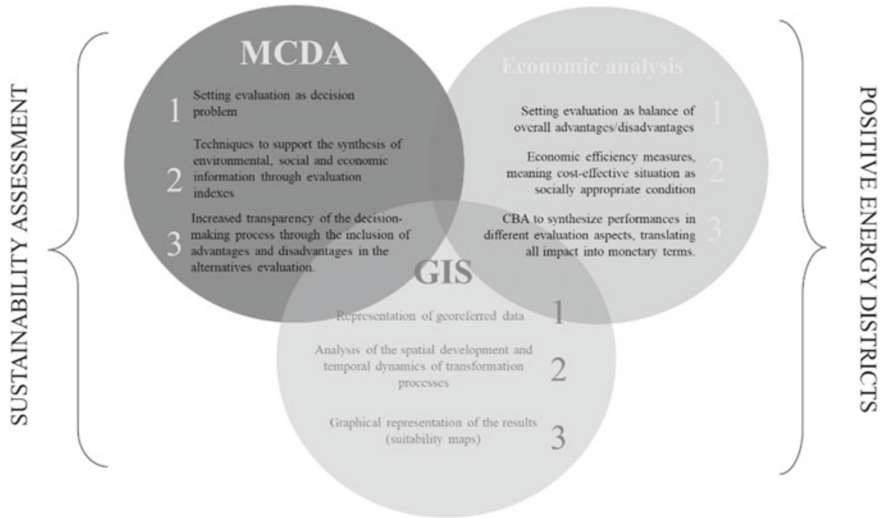

Fig. 3 Conceptual framework for Multicriteria-Spatial-Economic analysis of PED diagram (*Source* Own elaboration)

3 Research Methodology

Structure of the analysis (Fig. 4) is composed of three steps. In the first, we searched the literature from a scientific bibliographic database, in the second, we have the review based on the combination of three concepts shown in Fig. 3, and finally, the analysis phase. Literature bibliography analysis was conducted using the SCOPUS database with the following keywords in different combinations: Multicriteria, GIS, Economic. For a more informative literature review, we believe it is best to push the district boundary so as not to exclude valid methodologies for narrowings to which we have no explanation. Analysis was conducted to see how many documents are present for different combinations, specifically four combinations were found. Group A-B-C is research that shows historical production, country productivity affiliation and research topic, while Group D was conducted using more specific analysis as it is the heart of the analysis. Below are the strings used for the different groups:

1. **GROUP A**: "Multicriteria | GIS", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System") = **4,440 documents**

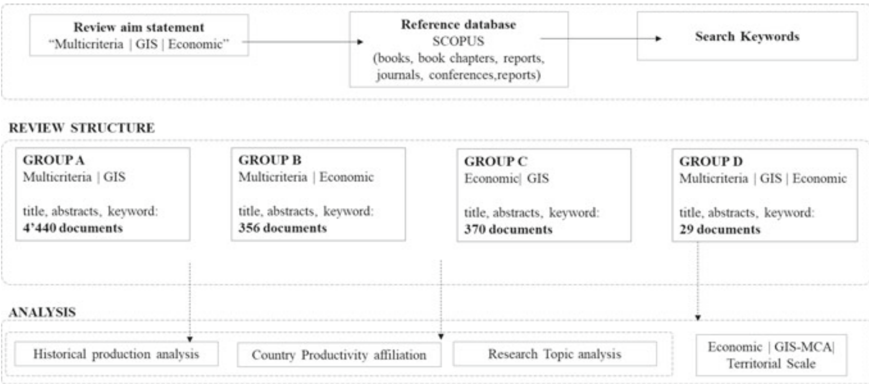

Fig. 4 Research method (*Source* Own elaboration)

2. **GROUP B**: "Multicriteria | Economic", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND (*"economic evaluation" OR "economic valuation" OR "economic assessment"*) = **356 documents**
3. **GROUP C**: "Economic | GIS", limited research "*title, abstract, the keyword*", using the words: (*"economic evaluation" OR "economic valuation" OR "economic assessment") AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System"*) = **370 documents**
4. **GROUP D** "Multicriteria | Economic | GIS", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System") AND (*"economic evaluation" OR "economic valuation" OR "economic assessment"*) = **29 documents**

As shown in Fig. 4, to identify the research articles in group A, B, C, analysis was conducted both by year of publication of the papers, chronological order to assess the increase or decrease in techniques as the years passed, an analysis regarding publication status, and finally according to the research fields belonging to the macro fields. For group D specific analysis was conducted related to the Economic, GIS-Multicriteria and Territorial Scale.

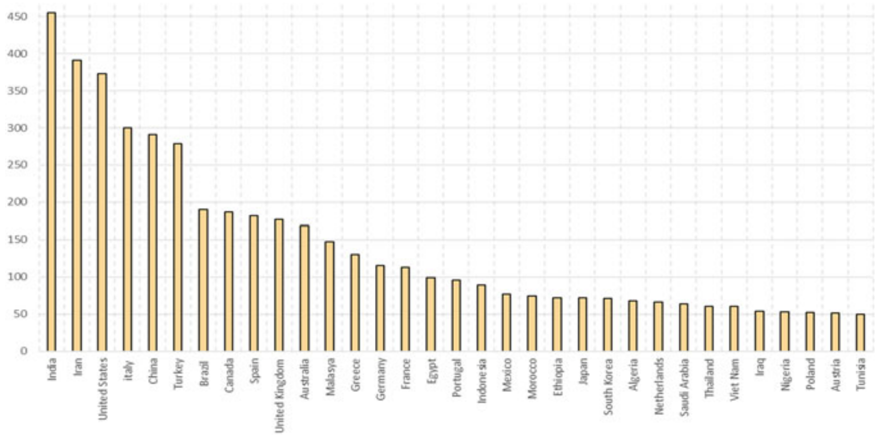

Fig. 5 Analysis by nations of publications that use multicriteria/GIS methods

4 Results

4.1 GROUP A (Multicriteria I GIS)

From the perspective of historical production analysis, this theme first appeared in 1976. Between 1976 and 1999, this theme only appeared in 18 articles. While, since 1999 production has increased with an exponential growth every year reaching 605 papers in 2021. As shown in Fig. 5, in Country Productivity Affiliation, the country that has produced the most regarding this topic is India with 455 papers, followed by Iran with 391 papers and then the United States with 373 papers.

As shown in Fig. 6 in research topic analysis, the main areas of development of this topic are Environmental Sciences, Earth, Planetary Sciences and Social Sciences with respectively, 2,121, 1,226, 1,219 and 879 papers. The energy field has only 514 papers.

4.2 GROUP B (Multicriteria I Economic)

As far as historical analysis of production is considered group B began publishing in 1981, with exponential growth, so much so that a substantial increase in publication was noted from 2005, gradually increasing to 46 items in 2021. As shown in Fig. 7, in Country of Productivity, the largest producing country in this area is Italy, producing 60 papers, followed by the United Kingdom with 41 papers and the United States with 40 papers.

As shown in Fig. 8, in the Research topic, the main research Topic of analysis regarding Group B (MCA I Economic) is Environmental Sciences with 144

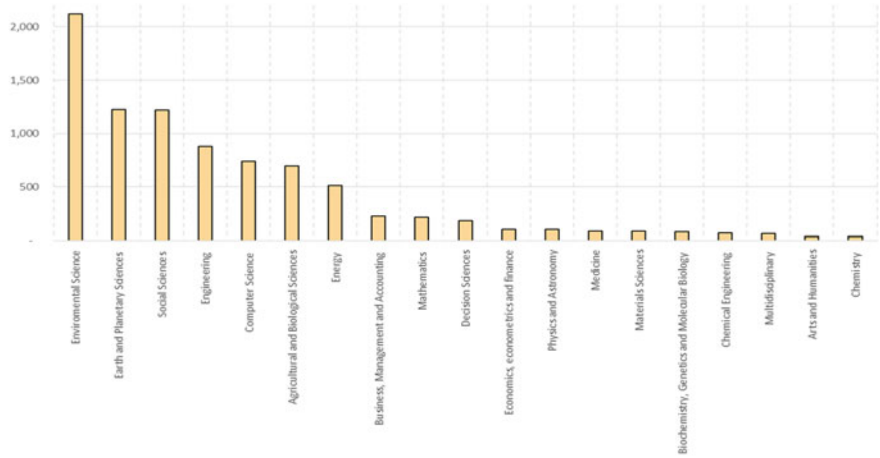

Fig. 6 Analysis by field of research of publications that uses multicriteria/GIS method

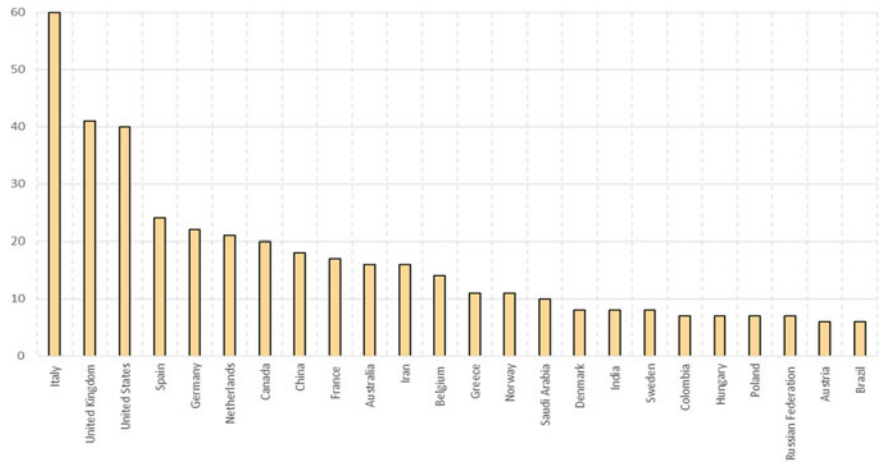

Fig. 7 Analysis by nation of publications that use multicriteria/economic

documents, followed by Engineering with 88 documents and Energy with 85 documents.

4.3 GROUP C (Economic I GIS)

This topic started to appear in 1988, and the period with the most production was 2019 with 29 documents, followed by 2017 and 2013 with 23 documents. As shown in

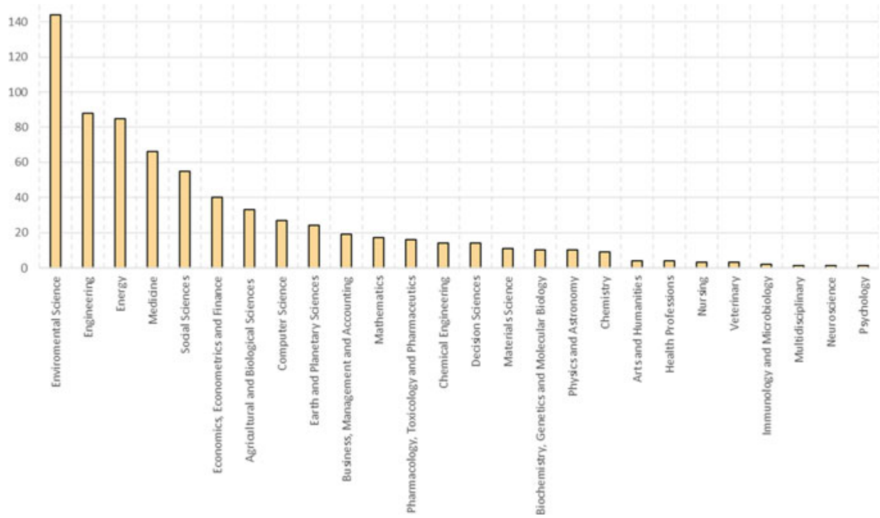

Fig. 8 Analysis by field of research of publications that uses multicriteria/economic methods

Fig. 9, in Country Analysis, the analysis showed that the United States is the country, which has produced the most documents, specifically 69 documents, followed by the United Kingdom with 40 documents and Italy with 39 documents.

As shown in Fig. 10, in Research Topic Analysis, the areas regarding this topic are Environmental Sciences with 163 documents followed by Agricultural and Biological Sciences with 71 documents and Social Sciences with 69 documents.

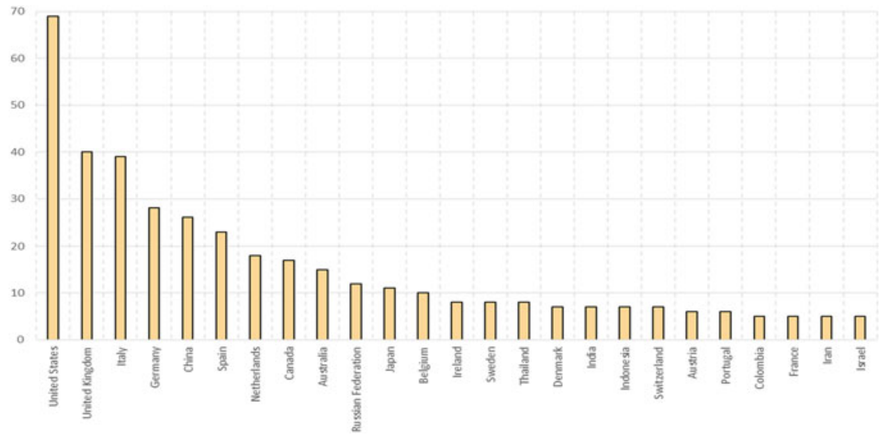

Fig. 9 Analysis by nations of publications that use economic/GIS

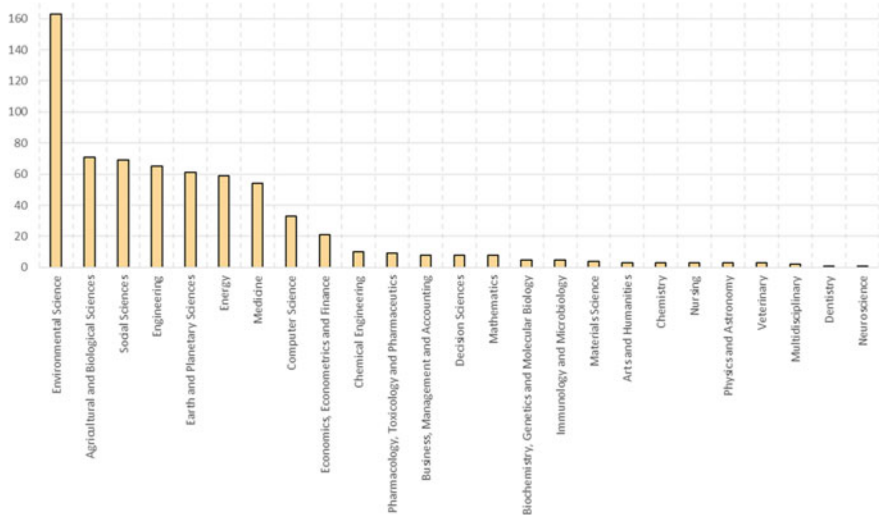

Fig. 10 Analysis by field of research of publications that use economic/GIS method

4.4 GROUP D (Multicriteria I GIS I Economic)

Group D as the main topic of research-specific analysis was conducted regarding the 28 documents related to the Economic, GIS-Multicriteria and Territorial Scale (see Table 1).

Starting with "Economic Analysis", the main economic method used is the "Techno-Economic Assessment", with 11 documents, followed by Cost Benefit Analysis (CBA) with 6 articles and Cost and Revenue Analysis with 5 documents.

There are different uses of Multicriteria Analysis and GIS. In particular, the methods found in the analysis are those which are most used in the general Weighted Combination (WC) followed by Analytic Hierarchy Process (AHP).

MCDA-WC aims to include normalized criteria that are weighted to determine the relative importance of each criterion, prioritizing some criteria over others. This is necessary to achieve a flexible decision-making method that can balance choices based on set objectives (Martín-Hernándaez et al. 2021).

MCDA AHP makes it possible to compare multiple alternatives with a plurality of criteria, either quantitative or qualitative, and derive an overall evaluation for each. This makes it possible to sort the alternatives in order of preference, select the best alternative, and ultimately be able to assign the alternatives to predefined subsets (Muñoz et al. 2020).

It became clear that all articles were divided into these three categories, namely, regional scale, city and parts of buildings. Interestingly, most of these analyses focus extensively on regional spatial contexts, which produced the majority of the documents with 21 papers, followed by "Parts of the building" with 4 documents and in the end with the "city" (Fig. 11).

Table 1 Articles combining economic analysis, GIS and MCDA for PEDs evaluation

References	Economic analysis							GIS	MCDA
	LCOE	CBA	CRA	PBP	EI	DCF	LCC		
Settou et al. (2022)	x							GIS	MCDM + WC
Martín-Hernándaez et al. (2021)	x							GIS	MCDA + WC
Mokhtara et al. (2021a)	x							GIS	MCDM + WC
Almutairi et al. (2021)	x							GIS	MCDM
Mokhtara et al. (2021b)	x							GIS	AMC
Ali and Jang (2019)	x							GIS	MCDM
Stefanakou et al. (2019)	x							GIS	MCA + WC
Cozzi et al. (2019)		x						GIS	WLC
Mansouri Kouhestani et al. (2019)	x							GIS	MCA
Madi and Srour (2019)		x						GIS	WLC + Fuzzy
Mohammadzadeh Bina et al. (2018)	x							GIS	MCDM
Kolendo and Krawczyk (2018)	x			x				GIS	AHP
Escalante et al. (2016)	x							GIS	Fuzzy + AHP
Abdul-Mawjoud and Jamel (2016)			x					GIS	AHP
Kehbila et al. (2014)			x					GIS	AMC
Li et al. (2014)		x						GIS	MCDA + WC
Restrepo-Estrada (2013)			x					GIS	MCA
De Sousa et al. (n.d.)								GIS	MCA
Agostini et al. (2012)		x						GIS	MCA
van Haaren and Fthenakis (2011)						x		GIS	MCA
Wirtz and Liu (2006)		x						GIS	MCA
Jarrar et al. (n.d.)			x					GIS	MCA

(continued)

Table 1 (continued)

References	Economic analysis							GIS	MCDA
	LCOE	CBA	CRA	PBP	EI	DCF	LCC		
Agrell et al. (2004)			x					GIS	MCA (LC)
Spiekermann and Wegener (2003)		x						GIS	MCA (LC)
Vagiona et al. (2022)								GIS	AHP + TOPSIS
Gil-García et al. (2022)	x							GIS	Fuzzy + AHP
Supapo et al. (2021)					x			GIS	TOPSIS
Muñoz et al. (2020)							x	GIS	AHP

Legend (LCOE) Levelized Cost of Electricity, (CBA) Cost Benefit Analysis, (CRA) Cost Revenue Analysis, (PBP) Pay Back Period, (EI) Environmental Impact, (DCF) Discounted Cash Flow, (LCC) Life Cycle Cost, (GIS) Geographic Information Modelling, (MCDA) Multicriteria Decision Analysis, (FMCDA) Multi-Criteria Decision Analysis, (AHP) Analytic Hierarchy Process, (ANP) Analytic Network Process, (MCDM) Multi-Criteria Decision Making, (SMCA) Spatial-Multi-Criteria Analysis, (TOPSIS) Technique for Order of Preference by Similarity to Ideal Solution. (MCDM + WC) Multi-Criteria Decision-Making Weighted Combination. (WLC) Whole-life Cost

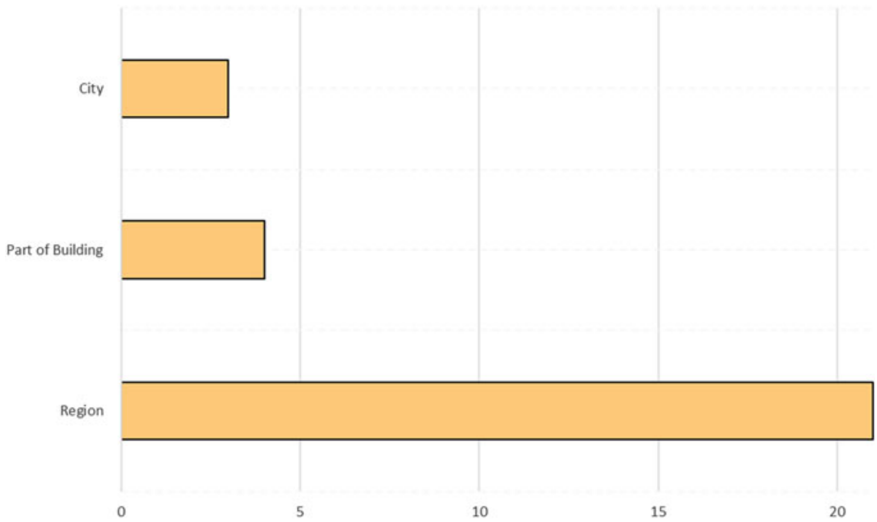

Fig. 11 Spatial reference scale of the publications considered, distinguishing between building (part of building), city-district and regional scales

5 Conclusion and Future Perspectives

The literature review of the above-mentioned elements was twofold.

Through further analysis of the scientific literature, this research can help to define an effective multi-criteria spatial economic decision-making methodology to support and sustain the design and development of PEDs. In this sense, the authors would like to investigate evaluation tools in the context of PEDs in order to understand the potential and critical elements of the available approaches to support decision-making processes in this field of application. To develop the PED concept, proper consideration must be given not only to the technical issue of energy systems but also to the environmental, social and economic spheres. To be effective, it is important to provide decision-makers with tools based on a multi-criteria decision analysis (MCDA) approach that can effectively evaluate the complexity of the impact from a multi-stakeholder perspective. The MCDA approach can be supported by a geographic information system (GIS), that helps to analyse data and make it accessible to all.

As a future outlook, however, it would be interesting to try to combine these three tools to support decision-making to identify the best area to apply PEDs to evaluate the full range of benefits of their implementation. In this regard on multiple benefit analysis to evaluate PEDs, it would be interesting to link the process of building PEDs with Building Information Modelling (BIM) implementations and District Information Modelling (DIM), to be able to support, a robust analysis as a support to the decision-making process even in the post-feasibility stages.

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References

Abdul-Mawjoud AA, Jamel MG (2016) Using the analytic hierarchy process and GIS for decision making in rural highway route location. 7:359–375

Agostini P, Pizzol L, Critto A, D'Alessandro M, Zabeo A, Marcomini A (2012) Regional risk assessment for contaminated sites. Part 3: Spatial decision support system. Environ Int 48:121–132. https://doi.org/10.1016/j.envint.2012.07.005

Agrell PJ, Stam A, Fischer GW (2004) Interactive multiobjective agro-ecological land use planning: the Bungoma region in Kenya. Eur J Oper Res 158(1):194–217. https://doi.org/10.1016/S0377-2217(03)00355-2

Ali S, Jang CM (2019) Selection of best-suited wind turbines for new wind farm sites using techno-economic and GIS analysis in South Korea. Energies 12(16). https://doi.org/10.3390/en12163140

Almutairi K, Hosseini Dehshiri SS, Hosseini Dehshiri SJ, Mostafaeipour A, Jahangiri M, Techato K (2021) Technical, economic, carbon footprint assessment, and prioritizing stations for hydrogen production using wind energy: a case study. Energ Strat Rev 36. https://doi.org/10.1016/j.esr.2021.100684

Becchio C, Bottero M, Bravi M, Corgnati S, Dell'Anna F, Mondini G, Vergerio G (2020) Integrated assessments and energy retrofit: the contribution of the Energy Center Lab of the Politecnico di Torino. In: Mondini G, Oppio A, Stanghellini S, Bottero M, Abastante F (eds) Values and functions for future cities. Springer International Publishing, pp 365–384. https://doi.org/10.1007/978-3-030-23786-8_21

Binda T, Bottero M, Bisello A (2022) Evaluating positive energy districts: a literature review. In: Calabrò F, Della Spina L, Piñeira Mantiñán MJ (eds) New metropolitan perspectives. Springer International Publishing, pp 1762–1770

Bisello A (2020) Assessing multiple benefits of housing regeneration and smart city development: the European Project SINFONIA. Sustainability 12(19). https://doi.org/10.3390/su12198038

Bossi S, Gollner C, Theierling S (2020) Towards 100 positive energy districts in Europe: preliminary data analysis of 61 European cases. Energies 13(22). https://doi.org/10.3390/en13226083

Bottero M, Assumma V, Caprioli C, Dell'Ovo M (2021) Decision making in urban development: the application of a hybrid evaluation method for a critical area in the city of Turin (Italy). Sustain Cities Soc 72:103028. https://doi.org/10.1016/j.scs.2021.103028

Bottero M, Mondini G, Oppio A (2016) Decision support systems for evaluating urban regeneration. Procedia Soc Behav Sci 223:923–928. https://doi.org/10.1016/j.sbspro.2016.05.319

Coutinho-Rodrigues J, Simão A, Antunes CH (2011) A GIS-based multicriteria spatial decision support system for planning urban infrastructures. Decis Support Syst 51(3):720–726. https://doi.org/10.1016/j.dss.2011.02.010

Cozzi M, Prete C, Viccaro M, Romano S (2019) Impacts of wildlife on agriculture: a spatial-based analysis and economic assessment for reducing damage. Nat Resour Res 28:15–29. https://doi.org/10.1007/s11053-019-09469-6

De Sousa L, Eykamp C, Leopold U, Baume O, Braun C (nd) iGUESS—a web based system integrating urban energy planning and assessment modelling for multi-scale spatial decision making. http://www.iemss.org/society/index.php/iemss-2012-proceedings

Derkenbaeva E, Halleck Vega S, Hofstede GJ, van Leeuwen E (2022) Positive energy districts: mainstreaming energy transition in urban areas. Renew Sustain Energy Rev 153:111782. https://doi.org/10.1016/j.rser.2021.111782

Escalante H, Castro L, Gauthier-Maradei P, Rodríguez De La Vega R (2016) Spatial decision support system to evaluate crop residue energy potential by anaerobic digestion. Biores Technol 219:80–90. https://doi.org/10.1016/j.biortech.2016.06.136

European Commission (2023), Consumption footprint and domestic footprint. Accessed 21 April 2023. https://doi.org/10.2760/218540

Fregonara E (2020) A life cycle perspective for infrastructure management. Aestimum 5+. https://link.gale.com/apps/doc/A662609534/AONE?u=anon~7da61072&sid=googleScholar&xid=8c0be571

Gil-García IC, Ramos-Escudero A, García-Cascales MS, Dagher H, Molina-García A (2022) Fuzzy GIS-based MCDM solution for the optimal offshore wind site selection: the Gulf of Maine case. Renew Energy 183:130–147. https://doi.org/10.1016/j.renene.2021.10.058

Grazieschi G, Asdrubali F, Guattari C (2020) Neighbourhood sustainability: state of the art, critical review and space-temporal analysis. Sustain Cities Soc 63:102477. https://doi.org/10.1016/j.scs.2020.102477

Guarino F, Bisello A, Frieden D, Bastos J, Brunetti A, Cellura M, Ferraro M, Fichera A, Giancola E, Haase M, Kantorovitch J, Neumann C, Mankaa R, Segura IL, Traverso M, Tumminia G, Volpe R, Zhang X (2022) State of the art on sustainability assessment of positive energy districts: methodologies, indicators and future perspectives. In: Littlewood JR, Howlett RJ, Jain LC (eds) Sustainability in energy and buildings 2021. Springer Nature Singapore, pp 479–492

Hunter RF, Dallat MA, Tully MA, Heron L, O'Neill C, Kee F (2022) Social return on investment analysis of an urban greenway. Cities Health 6(4):693–710. https://doi.org/10.1080/23748834.2020.1766783

IEA (2020) CO_2 emissions in MT by sector, world 1990–2018. https://Www.Iea.Org/Data-and-Statistics

Jarrar A, Jayasuriya N, Othman M, Jayyousi A (nd) Integrated natural resources management framewrok in semi-arid regions

Kehbila AG, Alemagi D, Minang PA (2014) Comparative multi-criteria assessment of climate policies and sustainable development strategies in Cameroon: towards a GIS decision-support tool for the design of an optimal REDD+ strategy. Sustainability (Switzerland) 6(9):6125–6140. https://doi.org/10.3390/su6096125

Kolendo Ł, Krawczyk DA (2018) Spatial and economic conditions of the solar energy use in single-family houses—a case study. In: MATEC web of conferences, vol 174.https://doi.org/10.1051/matecconf/201817401038

Kroll C, Warchold A, Pradhan P (2019) Sustainable development goals (SDGs): are we successful in turning trade-offs into synergies? Palgrave Commun 5(1):140. https://doi.org/10.1057/s41599-019-0335-5

Li D, Zhang C, Pizzol L, Critto A, Zhang H, Lv S, Marcomini A (2014) Regional risk assessment approaches to land planning for industrial polluted areas in China: the Hulunbeier region case study. Environ Int 65:16–32. https://doi.org/10.1016/j.envint.2013.12.004

Madi N, Srour I (2019) Managing emergency construction and demolition waste in Syria using GIS. Resour Conserv Recycl 141:163–175. https://doi.org/10.1016/j.resconrec.2018.10.018

Mansouri Kouhestani F, Byrne J, Johnson D, Spencer L, Hazendonk P, Brown B (2019) Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada. Int J Energy Environ Eng 10(1):13–32. https://doi.org/10.1007/s40095-018-0289-1

Martín-Hernándaez E, Martín M, Ruiz-Mercado GJ (2021) A geospatial environmental and techno-economic framework for sustainable phosphorus management at livestock facilities. Resour Conserv Recycl 175. https://doi.org/10.1016/j.resconrec.2021.105843

Mohammadzadeh Bina S, Jalilinasrabady S, Fujii H, Farabi-Asl H (2018) A comprehensive approach for wind power plant potential assessment, application to northwestern Iran. Energy 164:344–358. https://doi.org/10.1016/j.energy.2018.08.211

Mokhtara C, Negrou B, Settou N, Bouferrouk A, Yao Y (2021a) Optimal design of grid-connected rooftop PV systems: an overview and a new approach with application to educational buildings in arid climates. Sustain Energy Technol Assess 47. https://doi.org/10.1016/j.seta.2021.101468

Mokhtara C, Negrou B, Settou N, Settou B, Samy MM (2021b) Design optimization of off-grid hybrid renewable energy systems considering the effects of building energy performance and climate change: case study of Algeria. Energy 219. https://doi.org/10.1016/j.energy.2020.119605

Muñoz I, Hernández P, Pérez-Iribarren E, Pedrero J, Arrizabalaga E, Hermoso N (2020) Methodology for integrated modelling and impact assessment of city energy system scenarios. Energ Strat Rev 32. https://doi.org/10.1016/j.esr.2020.100553

Restrepo-Estrada C (2013) Usos óptimos del suelo bajo enfoques ambientales y económicos/ Optimal land use under environmental and economic approaches. Revista Facultad de Ingeniería 229–243

Settou B, Settou N, Gahrar Y, Negrou B, Bouferrouk A, Gouareh A, Mokhtara C (2022) Geographic information-driven two-stage optimization model for location decision of solar power plant: a case study of an Algerian municipality. Sustain Cities Soc 77. https://doi.org/10.1016/j.scs.2021.103567

Spiekermann K, Wegener M (2003) Modelling urban sustainabilty. Int J Urban Sci 7:47–64. https://doi.org/10.1080/12265934.2003.9693522

Stefanakou AA, Nikitakos N, Lilas T, Pavlogeorgatos G (2019) A GIS-based decision support model for offshore floating wind turbine installation. Int J Sustain Energ 38(7):673–691. https://doi.org/10.1080/14786451.2019.1579814

Supapo KRM, Lozano L, Tabañag IDF, Querikiol EM (2021) A geospatial approach to energy planning in aid of just energy transition in small island communities in the Philippines. Appl Sci (Switzerland) 11(24). https://doi.org/10.3390/app112411955

Suppa AR, Cavana G, Binda T (2022) Supporting the EU Mission "100 climate-neutral cities by 2030": a review of tools to support decision-making for the built environment at district or city scale. In: Gervasi O, Murgante B, Misra S, Rocha AMAC, Garau C (eds) Computational science and its applications—ICCSA 2022 workshops. Springer International Publishing, pp 151–168

Vagiona DG, Tzekakis G, Loukogeorgaki E, Karanikolas N (2022) Site selection of offshore solar farm deployment in the Aegean Sea, Greece. J Mar Sci Eng 10(2). https://doi.org/10.3390/jmse10020224

van Haaren R, Fthenakis V (2011) GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): evaluating the case for New York State. In: Renewable and sustainable energy reviews, vol 15, no 7, pp 3332–3340. Elsevier Ltd. https://doi.org/10.1016/j.rser.2011.04.010

Wirtz KW, Liu X (2006) Integrating economy, ecology and uncertainty in an oil-spill DSS: the Prestige accident in Spain, 2002. Estuar Coast Shelf Sci 70(4):525–532. https://doi.org/10.1016/j.ecss.2006.06.016

Zhang X, Penaka SR, Giriraj S, Sánchez MN, Civiero P, Vandevyvere H (2021) Characterizing positive energy district (PED) through a preliminary review of 60 existing projects in Europe. Buildings 11:318. https://doi.org/10.3390/buildings11080318