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# The Role of Renewable Energy Communities in the Sustainable Urban Development

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**Abstract.** Economic, social, and environmental sustainability is becoming increasingly important in territorial development policies in Europe and internationally. Among the sustainable development goals, the theme of the energy transition is particularly important, which translates not only into a move away from energy from fossil fuels in favor of renewable ones but also into an improvement in energy efficiency linked to energy production and greater awareness of energy consumption by citizens. To achieve a paradigm of sustainable development, combating the problem of resource scarcity and biodiversity loss, as well as the unsustainability of today's consumption and production systems, the Renewable Energy Communities (CER) can be a suitable model to support urban space redevelopment projects. Actions that aim to recover the pre-existing building heritage to give new life to abandoned areas are increasingly necessary for the protection of the environment. This encourages the propensity to act responsibly, promoting virtuous circles for the territories and communities of reference. This work aims to analyse and understand the actual benefits of the Renewable Energy Communities model for sustainable urban development. An additional aim is to consider Renewable Energy Communities as criteria for identifying industrial areas to convert or redevelop into sustainable industrial areas (SIAs) through a logical-mathematical approach.

**Keywords:** Energy community · renewable energy · transition · sustainable development · logical-mathematical approach

## 1 Introduction

The sustainability paradigm, already central at the international level with the Agenda 2030 and at the community level with new policies of the European Union (i.e. European Green Deal) has acquired increasing importance in the business choices of enterprises, also considering the social and environmental dimension when defining their corporate objectives. In this regard, it is necessary to overcome or integrate the conventional business model based on maximizing economic well-being, with objectives aimed at other issues such as environmental protection, enhancement of natural resources, equity, inclusion, solidarity, and social cohesion, in order to create value for themselves and their


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stakeholders in the long term. Thus, the adoption of a holistic approach, also pursuable through the latest ESG criteria (Environmental, Social, and Governance) implies that companies will be required to an evolution in the management of production processes or the provision of services, starting with the supply of raw materials. For example, reducing the use of certain fossil fuels through an energy-efficiency operation is one of the ways to integrate the ESG approach into business strategies [1]. Fundamental is the use of renewable energy sources in the pursuit of ESG criteria and sustainability policies.

Therefore, in today's economic and geopolitics scenario, energy efficiency is an absolute priority that assumes a "triple value", economic, social, and environmental.

This new interpretation of the management of business activities finds full consistency in the phenomenon of the Renewable Energy Communities, which can contribute to the energy transition. The Energy Community can be considered as an integrated model in which the entire territory is involved producing local energy, through interventions calibrated on the local availability of resources and respectful of the patrimonial values of the territory, overcoming upstream the environmental criticalities that arise from an approach oriented to the intensive exploitation of resources. Its creation is an opportunity to experiment with a model of energy capitalization of the territory.

In particular, sustainable development of urban areas has become the prime challenge in the energy sector, promoting objectives such as energy consumption and carbon footprint reduction; low-cost and low-carbon electricity supply; a smart European electricity grid; alternative fuels and mobile energy sources; innovative knowledge and technologies; market uptake of energy and ICT innovation; robust decision making and public engagement.

In this regard, the European Commission (2016) presented the "Clean Energy for All Europeans" package, also known as the "Clean energy package", which includes several measures in the fields of energy efficiency, renewable energy, and internal energy market power [2], making a clear reference to Energy Communities. These can be understood as a way to "organise" collective energy actions around open, democratic participation and governance and the provision of benefits for the members of the local community [3]. There are two formal definitions of Energy Communities: "citizen Energy Communities" [4], and "renewable Energy Communities" [5]. These Directives represent the first time an enabling EU legal framework for collective citizen participation in the energy system. They describe Energy Communities as new types of non-commercial entities that, although they engage in economic activity, their primary purpose is to provide environmental, economic, or social community benefits rather than prioritise profit-making [6].

To give substance to international and community policies regarding the diffusion of the sustainability paradigm, the use of renewable sources must, first of all, take shape in the local dimension, acting on territorial contexts with appropriate and locally defined solutions based on the specificities of the places.

Therefore, the objectives of this research are 1) to analyse and understand the actual benefits of the Renewable Energy Communities model for sustainable urban development; 2) to consider Renewable Energy Communities as criteria for identifying industrial areas to convert or redevelop into Sustainable Industrial Areas through a logical-mathematical approach.

## 2 Methods and Materials

Energy Communities can support the redevelopment of industrial areas into Sustainable Industrial Areas through the transition to decentralised energy. Producing, storing, and consuming electricity in the same area produced by a local generation plant allows the prosumer to actively contribute to the energy transition, encourages energy efficiency, and promotes the development of renewable energy sources and the sustainable development of the territory. Today, self-consumption can be implemented not only in an individual form but also in a collective form within apartment blocks, local Energy Communities, or precisely in the context of Sustainable Industrial Areas where there is already a unitary manager who could also take care of the management of the operational schemes underlying the Renewable Energy Communities.

### 2.1 The Energy Communities Model

The change in today's production and consumption systems towards more sustainable and eco-efficient forms is more stringent than ever. The energy transition towards more suitable forms that allow a reduction in consumption and a lower impact on the environment, is one of the processes implemented by society in response to the reduction of environmental impacts.

In this regard, there is growing attention to the Energy Community model, in order to consider new forms of energy sharing in the energy transition. Being a concept of recent development, this cannot be identified as unitary, being accessible to multiple interpretations, connoting it with a widely acceptable flexible meaning. This would facilitate the spread of the concept of an Energy Community, functioning as a bridge concept that facilitates the treatment and dialogue concerning the theme between subjects and their different interests [7].

Already in the early 2000s, the concept of the Energy Community referred to the idea of energy sharing to address issues related to climate change, the use of renewable resources, and sustainability [8].

Over the years, the field of investigation of Energy Communities changes considerably and brings with it the succession of different terminologies adopted to identify the phenomenon. Alongside Energy Community, expressions such as Renewable Energy Community [9] collective and politically motivated renewable energy projects [10], Energy Democracy [11], Sustainable Energy Communities [12]. Despite the different terminology used, the intrinsic meaning is shared: Energy Community identifies initiatives in which the community itself benefits from the collaboration that is established between the participants in terms of energy, obtaining advantages regarding the generation, management, acquisition, and consumption of the same. These initiatives have a positive impact on the community through the development of renewables promoted and the significant reduction of energy consumption, in a context of social cohesion and innovation. The activity carried out by Energy Communities can be different and multiple [13]: a local activity; an interest-based activity; a collaborative, citizens-managed process with locally distributed benefits in an equitable manner; an activity at the intermediate level between the individual and that of enterprises; an energy management agency; an experiment by a few.

Whatever definition is given of the Energy Community concept, there is no doubt that the benefits of this new model of energy sharing are multiple and disparate. The sense of identity, the sharing of places, values, visions, and interests, solidarity, the ability to participate and mobilize collectively, and resilience, give Energy Community the appointment of an ideal model to identify sustainable ways to produce, use and share energy from a technological, organizational and economic point of view. Hence, Energy Communities represent a new model that promotes the link between energy choices and economic, environmental, and social perspectives [14]. The Community becomes a place where the willpower of different actors (citizens, enterprises, public administrations), located in a specific area, to share the will to self-produce and self-consume energy from renewable energy sources is expressed.

In this paper, the concept of Renewable Energy Communities will be considered.

### 2.2 Sustainable Industrial Areas: A Conceptual Overview

The growing attention to the environmental sustainability of products and production processes led to the transformation of the current global production system. Therefore, in recent years, interest in industrial areas and their redevelopment in Sustainable Industrial Areas.

In the Declaration of Toledo (2010), the European Ministers for regional development, in light of the principles of sustainability, defined the territory as a complex system, comprising not only urbanized, rural, and other spaces, e.g., industrial land, but nature as a whole and the environment surrounding mankind; therefore, a holistic multidisciplinary approach should be adopted, capable of harmonizing the various of variables, economic, environmental, and social sustainability locally. In contrast, production systems can be understood as a set of many interdependent and different elements. These have the objective to transform input resources into output finished products. This definition of the production system fits into a larger context, which is the industrial area defined as the territory in which they are located to achieve economies of scale due to common services and infrastructure [15].

Internationally, the sustainability of a territory is defined using the concept of Eco-Industrial Parks (EIPs), within which mutually beneficial relationships are established between organizations and their environment, through the management of raw materials, by-products, and waste shared as indicated by the principles of industrial ecology [16]. Actually, different terminologies and definitions are used by various organizations around the world to refer to Sustainable Industrial Areas or relatively similar concepts, the most accredited one is Eco-Industrial Park.

One of the most accredited definitions of EIP is given by Lowe and Moran (1995), for which the eco-industrial parks can be understood as a community of manufacturing and service businesses located together on common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues [17]. By working together, the community of businesses seeks a collective benefit that is greater than the sum of benefits each company would realize by only optimising its performance [17].

One of the most significant drivers of EIPs is the opportunity to increase business, industrial competitiveness, and sustainable growth. Support for the development of EIPs can be offered through the provision of economically, environmentally, and socially aligned services and a plan to meet the sustainability agenda for an industrial area. In particular, it is possible to identify key environmental, economic, and social drivers of EIPs (Table 1).

**Table 1.** Main key drivers of Eco-Industrial Parks.

| Economic | Environmental | Social |
|---|---|---|
| Direct and indirect employment creation | Climate change commitments at global and national levels | Better working and labour conditions |
| Skills upgrading of the labour force | Increased demand to improve efficiency and growth | Transition to more sustainable land use |
| Technology and knowledge transfer through foreign direct investment | Responding to environmental and social concerns from consumers | Improved occupational health and safety |
| | Ensuring infrastructure is resilient to higher resource costs and adapts to climate change risks | Provision of vocational training |
| Linkages between the industrial park firms and small and medium-sized enterprises (SMEs) and communities outside the industrial park | Greening the supply chain and alleviating resource constraints, which can lead to improved resource management and resource conservation | Support to local community well-being and community outreach |
| | | Provision of social infrastructure to workers and community |
| Demonstration effects arising from the application of good international industry practices and regional development approaches | The presence of relevant policy mechanisms (for example, taxes and market mechanisms, such as carbon pricing) | Improvement of gender equality |
| | | Creation of local jobs |
| | | Better security and crime prevention |

Reaching these targets will require deep and long-lasting changes by organizations in different industrial sectors. Therefore, in this context, EIPs have the potential to play an important role.

However, it is interesting to note that nationally, an industrially developed area could be configured differently on the territory. In Italy, it can also refer to two specific patterns when analysing an industrialized area: industrial districts and sustainable productive areas. Most of the time, both are defined similarly or as aggregates of production realities, not specifying that the aggregation concerning sustainability requires the development of policies and practices different than the traditional way of managing an industrial district. It is possible to have a district every time several undertakings belonging to the same industry or producers of the same product are located on a relatively small territory, to determine a series of processes of exchange of raw materials, ideas, and knowledge between them [18]. The district so defined is more of a territorial productive model. That territory, due to its historical, geographical, cultural, and administrative role, becomes the connective tissue of relationships between businesses and enterprises and the local community. In contrast, the concept of a Sustainable Productive Area refers to a set of enterprises that do not necessarily need to be in the same production sector. The objective of the area is to obtain high environmental and social performance through a unified management system. Sustainable productive areas can be considered as an evolution of industrial districts and could support the process of revitalization of the numerous Italian industrial districts, today characterized by a great crisis that could lead to increased risk of disappearance of the same.

Then, implementing the principles of sustainability in a production area means not only improving the environmental performance of each production sector but, rather, implementing harmonious sustainable development in the municipality of productive activities and the territory, whereby the strategic objectives of single-unit production must be coincident with those of other units belonging to the same area. In fact, for sustainable economic development, a production area needs to focus not only on technological and managerial innovations aimed at maximizing profits and optimization of production efficiency but also, on improving environmental performance and enhancement of human resources. This implies a greater willingness of the business community to cooperate with the other actors, both public and private, in the area to improve the governance of the territory.

This means that creating synergy between enterprises through joint management processes and/or exchange of raw materials and sharing energy can lead to economies of scale, an increase in the innovation potential, a reduction in environmental impacts, an increase in their competitive advantage, to promote the conservation of ecosystem functions in the long term, environmental protection, and the development of the urban spaces, through a land system.

Sustainable Industrial Areas represent the management structures and governance of the urban space which are the closest to the concept of a land system.

## 3 Data Analysis: Benefits of CER in Italy

In Italy the Renewable Energy Communities result is divided as follows: 35 operational, 41 planned and 24 being established [19]. The Energy Communities that are being born are extremely heterogeneous in the social, environmental, and geographical contexts in which they develop, for the actors involved and their motivations. What unites their constitution is undoubtedly the desire to seek sustainable and responsible ways of producing, consuming, and using energy, in addition to the incentives that come from it in economic terms. Concerning the impacts of the implementation of Renewable Energy Communities, four macro-categories of benefits can be identified [20]:

- Technical-energetic: The electricity system benefits from considerable positive effects deriving from the collective action of producers and consumers who, by aggregating collectively in local energy projects, contribute to the reduction of network losses, to the improvement of voltage profiles as well as the lower stress of the distribution network, with a consequent increase in self-consumption and self-sufficiency indicators.

- Environmental: With the CER model, there is a proportional increase in the production and share of renewable energy consumption at a local level. For Italy, it is quantified in 17.2 GW the new renewable capacity expected by 2030 through the establishment of Renewable Energy Communities and self-consumption models that would allow a reduction in $CO_2$eq emissions by 2030 estimated at 47.1 million tons, considering the average consumption of 2700 kWh of Italian families [19]. To these direct benefits can be added the indirect effect of increasing awareness of the use of energy resources by members.
- Social: social impacts can be seen both in the process of construction and operation of the CER (increase in participation in the decision-making process), and in the allocation of the value generated.
- Direct and indirect economic impact on sustainable urban development: The direct benefits were given by the cost reduction, deriving from a conscious use of energy. The indirect benefits are associated with the possibility that the coordination between the organisations of the territory (i.e. industrial areas) experienced within the CERs and the collaboration with other relevant local actors, can trigger virtuous processes of shared construction of strategies and actions for sustainable local and urban development.

Other researchers of the sector have investigated the benefits deriving from Energy Communities in a report on Smart grids, providing four classes of recipients [21]: energy users, the electricity system, the territory, and the consumer. In order to obtain these benefits will be necessary to consider the key factors for the success of Renewable Energy Communities, that are [22]:

- Group: a group of members that synergistically and in an organized and cohesive way, acts for a common purpose, and overcomes adversity.
- Project: an idea supported by relevant knowledge and skills, financial and material resources.
- Community: benefits from the implementation of projects.
- Support network: adequate information on Renewable Energy Communities for the realisation of sustainable projects.
- Policy: Without a policy framework to support CERs, their development is not desirable. The diffusion of Energy Communities shows that renewable technologies are now ripe to give life to communities, but also that the obstacles concern the political-regulatory support for these projects.

This highlights that it is necessary to create new tools, models, and approaches, which allow for identifying, realisation, and evaluating urban industrial areas redevelopment projects in SIAs through also Renewable Energy Communities. Therefore, the implementation of the SIA model through the Renewable Energy Community's contribution can promote the highest environmental, economic, and social repercussions in the territorial context of reference.

## 4 The Diffusion of SIA Through a Logical-Mathematical Approach

The use of Operations Research techniques and tools allows for the structuring of optimisation models aimed at solving specific evaluation questions by defining an objective function and identifying one or more constraint conditions of various kinds [23].

The expressions of the mathematical model referred to the decisional problem posed is constructed based on the linearity principle of Linear Programming, useful, for example, to support the selection process between design alternatives aimed at the redevelopment of the urban industrial area in Sustainable Industrial Areas [24–26], by assessing the suitability of exploiting the Renewable Energy Communities schemes as the dominant criteria. Since in the first instance each design alternative must be evaluated in its entirety to establish whether to carry it out or whether to exclude it, the algorithms of Discrete Linear Programming (DLP) are used. In analogy to how specifically it proceeds in the resolution of choice cases between investment projects within urbanized fabrics to be redeveloped through integrated intervention programs, also for the optimal selection of areas to be allocated to projects that respect the eco-functional logic at the base of SIAs, the mathematical models to be used are to be considered characterized by the integer constraint placed on the decision variables and resolved through the algorithms of the Discrete Linear Programming (DLP). The use of multi-criteria assessment techniques – capable of taking into account, both in the programming and management phases of the individual initiatives to be implemented, multi-dimensional aspects relating to the same type of work – appears useful when it comes to redeveloping an urban industrial area in Sustainable Industrial Area [27, 28]. Depending on the productive sector of interest and available data, it is possible to use different assessment tools that can express the multi-dimensional nature of initiatives related to the redevelopment of territory according to the SIA model. In particular, by resorting to the Operations Research optimization algorithms [29], it is possible to resolve decision-making problems regarding the selection of the site on which to carry out interventions that include actions to transform industrial areas into SIAs through the use of multiple evaluation criteria, able to consider both the morphological characteristics that socio-economic of the area and in this study energy choices also, through the construction of functional relationships between variables.

Intending to pursue the objectives deriving from interventions carried out according to principles of eco-efficiency, the problem arises of selecting, among some areas to be redeveloped, those most suitable to be transformed through actions of this type. Each area is assessed by identifying certain criteria defined according to the objective attributable to the target to be reached (e.g. possibility of integrating the functional schemes of Renewable Energy Communities to achieve the target of a Sustainable Industrial Area).

DLP makes it possible to solve both cases of selection between urban areas that are better suited to be redeveloped with forestation [26], as well as cases related, for example, the composition of the best portfolio of investment projects evaluated through urban sustainability criteria (for example, the atmospheric CO2 emissions and acoustic pollution, the use of renewable energy sources, the land and water use, the circular economy models) [25].

In general, models of linear programming can be implemented through specific mathematical programming tools, such as, for example, MatLab, A Mathematical Programming Language (AMPL), Excel, Lingo, and Lindo. The selection of the type of software to be used is a function of the number of parameters and the number of win-win conditions that characterise the evaluation problem to be solved.

Among the most used are those of dynamic programming, implicit enumeration (such as the Branch & Bound), the algorithms of the cutting planes, and the Brunch & Cut algorithm [30]. The model proposed for the selection and evaluation to implement transformation actions of industrial areas in SIAs can be implemented through the software A Mathematical Programming Language (AMPL).

AMPL software corresponds to a mathematical language used to describe and solve optimisation problems [31], in particular those of scheduling problems [32]. This language is well suited to modeling decision-making cases related to urban industrial redevelopment projects according to eco-system logic [33].

Theoretically, in the present study, to pursue the m objectives deriving from interventions carried out based on the eco-functional principles of the SIA, the problem arises of selecting, among the n industrial areas to be redeveloped, those most suitable to be transformed through sustainability actions, in particular, through the role that Renewable Energy Communities can play in supporting the redevelopment project. Each area – assumed as variable Xi of the problem – is evaluated based on k evaluation criteria defined according to the objective attributable to the m-th target to be reached. In consideration of the investment cost, Ci of the project carried out on the i-th area and of the budget available, which define the financial constraint characterizing the system. A logical-mathematical approach proposed by Discrete Linear Programming can be written as:

$$\mathrm{Xij} = \mathrm{f}(\mathrm{Ci}, \mathrm{K}, \mathrm{kj}).$$

where:

Xi = Area (i = 1,…, n)

Ci = Costs

K = Budget

kj = Evaluation criteria (j = 1,…, m)

Therefore, the mathematical logic approach considered, using the AMPL software, will be able to support the implementation of the SIA model through some fundamental steps, such as: identifying the elements of the problem (specific objectives with the targets, number of areas, evaluation criteria) as a set; specifying the parameters of the problem (Budget, Costs, Multi-criteria Evaluation Matrix) to be inserted in the system; defining the value of the variables (var X binary); structuring the objective function as a linear algebraic expression that maximises the capacity to pursue the multiple aims of the sustainable development initiatives of the urban industrial areas; specifying the constraints of the problem to be solved.

In addition, the use of a logical-mathematical approach developed in terms of Linear Programming allows rationalising the decision-making problem considered with the sustainability objectives underlying the interventions aimed at realising Sustainable Industrial Areas. This is made possible through the writing of simple algebraic expressions in which the variables, the parameters relating to the characteristics (economic, social, and environmental type) of the reference territorial context of the industrial areas are transformed into SIAs, as well as the effects produced by redevelopment initiatives, developed according to the eco-functional principles of the SIAs in the area expressed through appropriate performance indicators, they are placed in correspondence with each other. The choice of which indicators to use during the construction of the model depends on the evaluation questions to be solved, which in turn depends on the type of target considered [34].

The use of multi-criteria analysis models of such structural and formal characteristics, such as the one proposed in the present work, can support the implementation of territorial and local development sustainable policies. This approach can be useful for decision-makers (public and private) in implementing a program of investment in Renewable Energy Communities able to contribute to the pursuit of targets at the base of the SIA respecting the available financial resources. Thus, it is possible to encourage a form of territorial governance shared in which the design, implementation, or conversion of industrial areas in SIAs can involve enterprises, consumers, and citizens and benefit the entire community; contributing to the achievement of objectives for improving environmental and social performance and territorial development according to principles of sustainable development paradigm.

## 5 Conclusions

The diffusion of CERs represents a great opportunity to experiment with new energy models based on the self-organization of members and on the enhancement of the resources available to the territories. The CERs have above all great social value as well as economic and environmental, as they can represent models of synergy and cooperation spread throughout the national territory, helping to experiment with innovative solutions in the management of the common good, and in the implementation of new urban and local development policies.

The theoretical model must adapt to the nascent concrete cases, starting from the ability to penetrate urban systems, facilitated by self-consumption schemes, which remains a great challenge for any ecological transition policy. All this must be combined with the rational exploitation of resources, compatible with environmental constraints, which respects the territories, encouraging the development of 'ethical' initiatives.

Therefore, in this study, it was suggested that a mathematical logic approach be adopted to select criteria of a different nature to favour redevelopment projects. Among the different selection options, it is suggested to also include Renewable Energy Communities that could support SIA participants from the point of view of energy efficiency. Renewable Energy Communities can be acting beyond the energy sector and play a more transformative role at the local level. They are characterised by the participation of a wide range of actors, and local administrations often play a key role in facilitating implementation and future development. These are actions that, besides energy savings, promote other initiatives including sustainable mobility, local employment, educational and dissemination programs, building renovation, and/or urban redevelopment projects.

Future findings of this research will be through the application of learning in a specific local context, quantifying the economic, environmental, and social benefits of a Renewable Energy Community implementation that promotes green services and infrastructures for sustainable urban redevelopment.

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