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Italiadomani
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Guidelines for energy communities and composting communities, and sustainable business models

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Owner	UNIPD
Contributor/s	Vincenzo Depalo (energy4com) Fiorella Stella (energy4com) Daniela Baglieri (UNIME) Roberta Salomone (UNIME)
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Executive summary

This document provides guidelines for energy communities and composting communities, focusing on sustainable business models.

We explore business models for Renewable Energy Communities (RECs) creating a dynamic knowledge base to aid in their establishment and operation. We evaluate RECs through technical, economic-financial, and governance dimensions, aiming to systematize information and highlight best practices from literature and field experience. A structured methodology organizes the data into clusters of homogeneous models and a macro-matrix. Key REC models identified include *Public RECs*, led by local authorities to foster sustainability; *Industrial RECs*, driven by private companies focusing on efficiency and competitiveness; and *Social RECs*, which address community-specific socio-economic needs. These models leverage renewable energy technologies, such as photovoltaics and smart meters, to optimize energy sharing and self-consumption while improving sustainability. We highlight challenges like financing, governance, and regulatory adaptability: financing strategies range from participatory models to public-private partnerships, while governance emphasizes inclusivity and transparency. Our policy recommendations include diversifying REC models, supporting local authorities, incentivizing self-generation, and integrating sustainable mobility. Collaborative efforts among stakeholders are crucial to achieving scalable energy transition and socio-economic benefits.

Biowaste management, particularly composting, offers environmental benefits such as reducing greenhouse gas emissions and improving soil quality. However, transitioning to sustainable biowaste systems requires innovative business models. The research undertaken by the University of Messina as part of the REWARD-ME project focuses on designing business models for composting communities to advance sustainable biowaste management. We analyze biowaste management data, review legal frameworks, and develop a conceptual framework to identify strategies for value creation and foster citizen participation through engagement. We emphasize the need to integrate decentralized and centralized composting technologies. Preliminary findings from a case study illustrate how municipalities can reduce municipal solid waste by enhancing collection methods and citizen participation. Our policy recommendations highlight the need for economic incentives, governance frameworks,

and public-private partnerships to advance composting communities and achieve net-zero emissions goals.

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1. Presentation and description of the research activity undertaken

1.1 Design of a business model of energy communities and related actions to improve energy policies and management infrastructures

The main purpose of the research activity is the creation of a knowledge base on business models for Renewable Energy Communities (RECs). This will be achieved through the analysis of technical, economic-financial, and social indicators, with the intent of providing a comprehensive and operational overview of business strategies for setting up and operating RECs. The definition of the business models will be based on a search of existing literature, including the most recent publications, and direct experience accumulated by the working group. In fact, over the past two years, the team has conducted techno-economic feasibility studies for the configuration and implementation of energy communities, thus contributing to the wealth of knowledge in this area.

The creation of this knowledge base represents a goal that will be achieved through an articulated and structured research methodology. First, the characterizing variables of business models, which have emerged from both the literature analysis and the experience and data collected by the working group, will be defined. These variables will be organized according to three main dimensions: the *energy dimension*, which will cover technical and operational aspects related to energy production and management; the *economic-financial dimension*, which will include indicators of economic sustainability and profitability; and the *governance dimension*, which will focus on the organizational and management structures necessary for the proper functioning of energy communities.

On this basis, it will be possible to isolate homogeneous clusters of business models, that is, groups of models that share similar characteristics in terms of structure and operational potential. The creation of a macro-matrix will make it possible not only to systematize the information collected, but also to assess the best practices that have emerged from literature or the team's direct experience, thus providing a useful tool for planning and implementing efficient and sustainable energy communities. In addition, the definition of key variables may be further refined through the administration of targeted surveys. These questionnaires will be addressed to specific target individuals, identified by the working group based on their relevance to the CER sector and their practical experience. The responses collected will help to improve and update the structure of the macro-matrix, ensuring that it stays abreast of industry developments and continues to reflect best practices and most effective approaches in defining business models for energy communities.

In this way, the knowledge base on business models will be a dynamic and evolving tool, capable of providing concrete guidance for configuring and managing CERs over time.

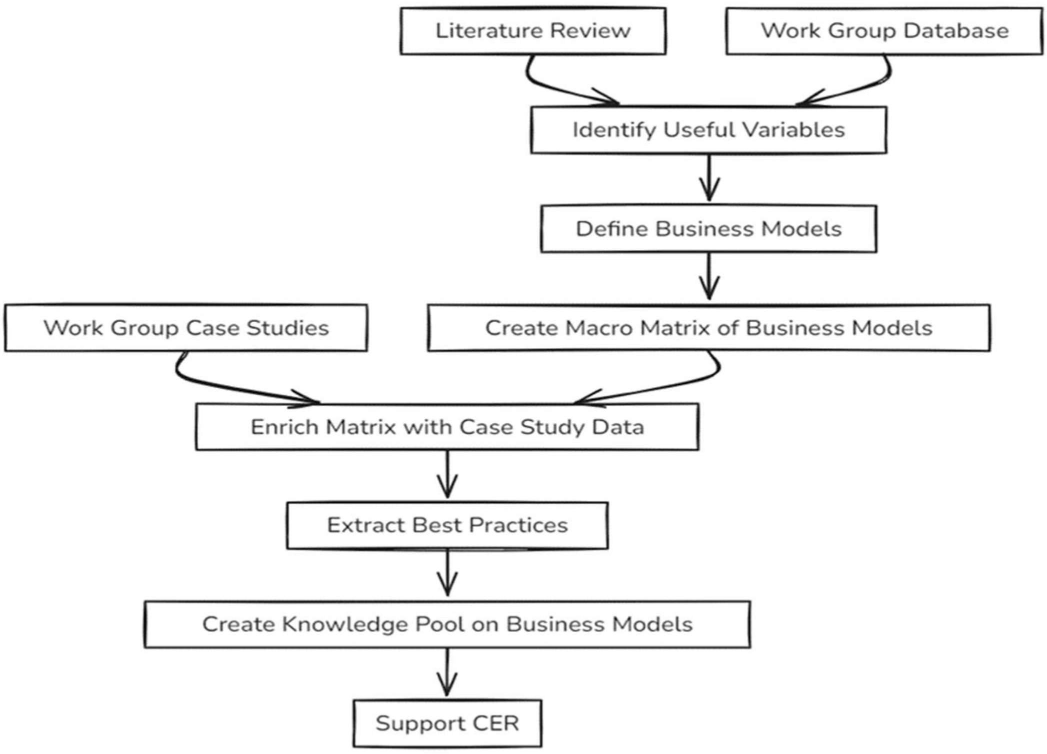

Figure 1

1.2 Design of a business model of composting communities and related actions to improve waste policies and management infrastructures

The research activities carried out within the project REWARD-ME by the University of Messina team focus on analyzing how to design composting communities' business models to promote sustainable biowaste management practices while reducing greenhouse gas emissions. Preliminary, various activities have been carried out:

1) Analysis of data sources and databases dealing with biowaste management practices at Italian and European level identifying the limits and potentialities of available databases

2) Preliminary analysis of the state of the art of legal framework related to waste management and waste classification at both European and National level

3) Literature review on biowaste management practices and Life Cycle Assessments (LCA)

4) Development of a conceptual framework for composting communities' business models by considering different strategies on value creation and value capture

5) Developmental drafting case study of municipality best practices

6) Developmental drafting of a questionnaire to investigate the behavior of citizens and families in organic waste, on the adoption of recycling waste and the propensity to take part in composting communities

7) Literature review on engagement and nudging strategies to foster pro-environmental behaviors and developmental design of experiment

1. Relationship with the existing literature on the topic

2.1 Design of a business model of energy communities and related actions to improve energy policies and management infrastructures

Renewable energy communities (RECs) represent an innovative model for the transition to a more sustainable and decentralized energy system by enabling citizens and businesses to collaborate in energy production and consumption. However, one of the main obstacles to their deployment lies in the development of robust business models. A recent analysis identified at least 25 emerging design options, which vary by geographic, socioeconomic, and regulatory context (Reis et al., 2021). Some of these models focus on collective self-consumption strategies, where locally produced energy (e.g., from solar panels) is distributed among community members, while others involve the integration of storage technologies such as shared batteries to optimize the management of the energy produced (Kubli et al., 2023). One of the most critical aspects for the success of business models seems to be flexibility. Models must adapt to different regulatory environments, which vary widely across countries and regions. In Europe, for example, legislation promoted by the "Clean Energy for all Europeans" package has encouraged the creation of energy communities, but differences in local regulations require diverse approaches (Breukers et al., 2021). This section examines the business models of RECs and focuses on the organizational structures and financing used to promote the energy transition. RECs business models vary significantly depending on the context. For these authors, three main typologies can be identified:

- Centralized generation model from REC-owned plant(s): renewable energy is generated from community-owned plant(s). Each member uses the "shared" energy through individual meters, while unused energy is sold on the wholesale market. A significant example is Enercoop Midi-Pyrenees, which operates collective self-consumption projects with photovoltaic systems. The cooperative has self-financed its projects through its own funds and bank loans, while also collecting donations from members to support vulnerable families (Energy Community Platform, 2024)

- Distributed generation model: energy is generated by plants placed on the buildings of community members. In this case, energy is shared directly among members without going through a supplier. An example is the project in the "Otterbeek" neighborhood of Mechelen, where an energy cooperative has installed solar panels on 70 houses. The tenants benefit from lower rates than the social ones thanks to the sharing of the energy produced (EU Commission, 2024)
- Individually owned distributed generation model: energy is generated from facilities owned by individual members and shared with other community members. This model can use digital platforms to facilitate the exchange of energy between producers and consumers. One example is OurPower, which connects renewable energy producers with small consumers, offering competitive rates and promoting transparency in the energy market (Energy Community Platform, 2024)

Financing is one of the main challenges for the development of energy communities. Most communities rely on a mix of private investment, public grants, and contributions from the members themselves (Lüdeke-Freund et al., 2018). However, these funds are often insufficient to cover for the large expenses of installing and maintaining energy infrastructure, such as photovoltaic systems or storage systems. Many Horizon2020 projects have highlighted the need to create innovative financial instruments, such as revolving funds or public-private partnerships, to ensure the economic sustainability of energy communities in the long run (Kubli et al., 2023). Another strategy that has emerged is that of participatory financing models, where community members are involved directly as investors, obtaining economic benefits from the energy produced in return. This approach not only facilitates the raising of initial capital but also increases citizens' sense of ownership and active participation.

Governance is another key pillar for successful energy communities. Governance structures must be inclusive and participatory, ensuring that all community members have a voice in strategic decisions. This is particularly important to avoid conflicts of interest and promote an equitable environmental distribution of economic benefits (Maio, 2022). Governance models vary from cooperative structures, where each member has a vote independent of the investment share, to more hierarchical models, where governance is concentrated in more experienced or professional hands. Effective governance enables RECs to address political and economic challenges, promoting an environment conducive to growth. Recent studies point out that transparent and participatory governance is essential for maintaining social acceptance of energy communities and ensuring that they operate in line with sustainability goals (Breukers et al., 2021).

In conclusion, the business models of energy communities are evolving rapidly, but their success depends on an appropriate combination of innovative financial instruments and inclusive governance structures. Developing tailored strategies that take into account local specificities is essential to ensure that these communities can thrive and actively contribute to the transition.

2.2 Design of a business model of composting communities and related actions to improve waste policies and management infrastructures

2.2.1 Biowaste management and Life Cycle Assessment: the role of composting

It is widely recognized that conventional biowaste management have created various environmental issues such as greenhouse gas emissions and leachate. The awareness of these environmental issues has encouraged policy makers and practitioners to find viable alternatives to manage the organic waste disposal process instead of landfills. From 1999, the EU Landfill directive implementation held a continuous decrease in landfilled waste volumes, as well as an acceleration in other processing approaches. Accordingly, in the last twenty years, an increase of over 200% in composted waste quantities has been identified, contributing to a considerable reduction in landfilled waste reduction. This result has been reinforced by the European Commission's Circular economy package that accelerated the adoption of other treatment methods, such as composting instead of landfilling.

Composting can be used for biological decomposition, and this technology has the potential to manage organic waste, transform it into valuable agricultural products and minimize pollution. Composting offers substantial environmental benefits, including extending the life of landfills, reducing GHGs emissions by diverting organic waste from landfills, and improving soil quality and structure by using the compost produced as fertilizer. This practice could contribute to the transition to a circular economy by closing the nutrient loop, decreasing dependence on finite resources, and encouraging resource conservation and resilience. Several important aspects need to be considered before implementing composting technology (Manea et al., 2024). These include:

- sources of waste feedstock in terms of quantity (small scale like home composting, medium scale, or large-scale composting)
- quality (moisture content and nutrient content)
- technology set-up in terms of site location and area required
- managerial skills and capabilities
- capital and operating costs (Malakahmad et al., 2017)

In other words, the adoption of composting practices requires new technological equipment and skills and underlines the relevance to taking a strategic approach. Municipalities and companies should design effective business models to understand where the value is created in the supply chain and the role in the value creation of the entire network of suppliers, manufacturers, retailers and households. By taking a systemic view, business models are tools that play a pivotal role in promoting composting communities that contribute to reduce GHG emissions, according to net-zero scenario, while accelerating the Circular Economy perspective.

2.2.2 Promoting composting communities through business models

The transitioning towards more sustainable biowaste practices involves investing in low-carbon technologies - for example, anaerobic digestion – by leveraging effective circular business model. The concept of business model refers to how a company creates, captures, and delivers value (Zott et al. 2011).

In the circular economy perspective, this means that the value creation is primarily designed to improve resource efficiency while contributing to extending the useful life of products and parts (e.g., through long-life design, repair and remanufacturing) and closing material loops. Consequently, designing effective business models is critical for organizations to meet their social and environmental ambitions by leveraging environmentally, socially, and economically effective technologies and solutions.

To achieve these goals, business models have to pursue a business logic while seeking to align different incentives of stakeholder groups involved. These groups include:

- stakeholders internal to the company
- stakeholders in the value chain
- stakeholders in the network

This wide lens is appropriate to analyze composting communities since the focus is on the complementary actors and interdependencies among those actors in delivering and scaling value propositions and business models (Ritala et al. 2023).

Therefore, adopting more sustainable biowaste management to reduce GHG emissions implies facing specific socio-economic challenges because it is more complex, novel, and radical knowledge structures than conventional disposal technologies and thus requires firms and local governments to acquire new capabilities to engage in such innovation. This change is also systemic since includes technical, economic, political, and social systems (Köhler et al. 2019) and has a high urgency to prevent the negative impacts of climate change (Pinkse et al., 2024). In addition, to produce positive environmental impacts, the adoption of new biowaste practices is subject to the directionality of government policy more than other types of innovation. This creates major challenges for firms and municipalities.

Accordingly, stakeholders take on the role of collaborative partners, which may differ from those in the traditional value chain.

3 Research output

3.1 Design of a business model of energy communities and related actions to improve energy policies and management infrastructures

Three distinct meta-models have emerged in the work so far in the analysis of RECs, which vary according to the type of promoting entity that intends to accelerate the energy transition and socioeconomic development of territories. These three meta-models are:

1. Public REC: promoted by local or public entities

2. Industrial REC: led by private companies, especially energy-intensive ones

3. Social/ETS REC: initiated by third sector entities (ETS) or social enterprises

These three ERC models offer distinct and complementary approaches to the common goal of energy transition, presenting specific characteristics depending on the initiator and inherent purpose.

The most relevant dimensions for the analysis and characterization of these meta-models include general, energy, technological, economic-financial, socio-environmental, and governance aspects.

3.1.1 General dimension

This dimension includes a description of the initiating entity, the territorial context, and the objective of the RECs. Each type of REC arises from a specific need of the area or sector involved and responds to different objectives: from municipal sustainability policies for public RECs, to energy efficiency goals for industrial RECs, to social impact goals for RECs initiated by ETSs. In this sense, the experience of the working group makes it possible to confirm that the RECs promoted by municipalities, public entities and ETSs aim to take advantage of savings in electricity bills -derived from physical self-consumption- and energy sharing to have more funds available for social actions, especially in the form of economic support toward families most in need. An additional general information of fundamental importance concerns the extent of the REC. According to national regulations, a REC can share the energy produced by plants within the primary power transformation substation; therefore, it is within this boundary that its incentives accrue. However, the concept of "Wider Area" RECs is emerging: a single legal entity that includes RECs belonging to different primary substations. In this sense, the Wide Area ERC does not have limited geographical boundaries like that of the primary cabin but can extend to the whole country. The advantages are mainly administrative and managerial. A municipality -for example- can decide (with its facilities and its technical-economic feasibility study of RECs) to join the vast area CER entity it prefers without having to establish itself as a legal entity. This implies that, subsequently, it will not have to deal directly with the sharing of benefits from energy sharing. The example just given is not accidental. According to the experience gained by the working team, the main difficulty for public administration is related to the lack of personnel who will have to manage the ERC after it becomes operational.

3.1.2 Energetic dimension

The energy dimension of a REC refers to the potential for production from Renewable Energy Sources (RES), physical self-consumption, and sharing of the energy produced among community members. Public administrations and industrial facilities, due to the increased availability of space, such as solar pavements, are particularly suitable for the installation of PV systems. This makes them key players in promoting RECs, as they can contribute significantly to increasing renewable energy production and achieving sustainability goals. In this context, the involvement of municipalities is crucial: taking advantage of public surfaces not only allows them to increase energy self-production, but also to reduce dependence on external energy sources, promoting a sustainable and inclusive development model. The working group defined Key Performance Indicators (KPIs) to assess the effectiveness of ERC configurations. The KPI "Self-Consumption Index" measures the percentage of energy produced that is consumed and shared within the community. A high value of this indicator indicates good efficiency in using the energy produced, reducing waste and costs. The "Self-Sufficiency Index" KPI measures how much of the total energy needs of REC members are met by the energy produced and shared. Improving this value means increasing the community's ability to meet its own energy needs by reducing the purchase of energy from external sources. The experience of the working group showed that, in the case studies analyzed, RECs tend to have a self-consumption index of 30 percent and a self-sufficiency index of 20 percent. This data indicate a good start, but also wide room for improvement. Increasing the energy self-sufficiency of RECs is key to ensuring greater energy resilience at the local level and reducing costs for community members. Collaboration between government, businesses, and citizens is therefore key to promoting energy self-sufficiency, efficiency, and social benefit, creating a virtuous model that can be replicated and scaled up on a large scale.

3.1.3 Technological dimension

The technology dimension of RECs focuses mainly on the use of PV as the predominant technology. This is due not only to the ease of installation and design compared to other RES technologies but also to its economic scalability that makes it a more financially accessible investment. In fact, PV can be adapted to different sizes and contexts, starting from small residential installations for prosumers to large installations on public or industrial solar slabs. This versatility allows RECs to involve a wide range of stakeholders, from citizens to businesses, thus promoting inclusive and widespread participation. Another key element in the technological development of RECs is the adoption of smart meters, devices that allow real-time monitoring of energy consumption and energy sharing among community members. These tools are essential to ensure efficient management of energy produced and consumed, facilitating the adoption of transparent and accountable governance models. The team's experience has shown that integrating smart meters is a crucial step in optimizing the operation of RECs, enabling accurate accounting of shared energy and improving overall grid management. In addition, to enhance the flexibility of the electricity grid and promote the development of urban smart grids, RECs can also include charging stations for electric vehicles. Although still uncommon in feasibility studies to date, this infrastructure represents a significant opportunity to integrate renewable energy generation with sustainable mobility. Indeed, the installation of charging points within RECs can help optimize the use of locally produced energy, reducing the need to release it to the grid while promoting greener mobility.

3.1.4 Economic and financial dimension

RECs are projects that require sound and sustainable business models. The economic-financial dimension concerns the ability to attract financing, generate economic value, and repay investments. In this respect, Industrial RECs show a high potential for scalability and profitability. In contrast, while Industrial RECs are -according to the different case studies from the project group's experience- self-financed by the budgets of the companies that promote them, public RECs -less profit-oriented- can have access to a variety of European, national, and regional public funds. An outline aimed at clarifying the structure of funding -in the experience of the project team- useful for supporting the start-up phase of a public ERC is given below in Figure 2.

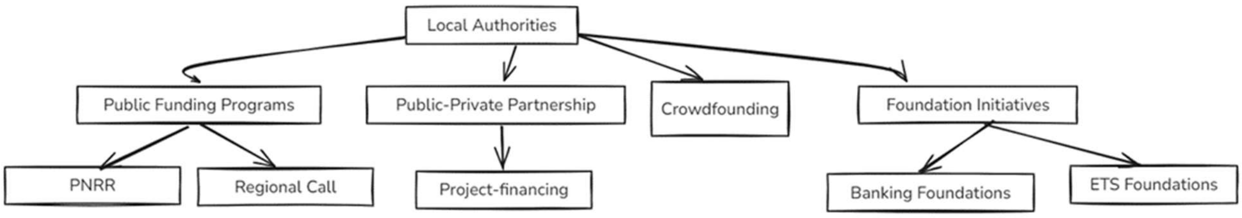

Figure 2

3.1.5 Social and economic dimension

RECs have a direct impact both on the environment, reducing greenhouse gas emissions, and on the community, improving the quality of life for citizens by reducing energy costs and creating new job opportunities. Social RECs, in particular, are often geared to address the needs of vulnerable groups, such as low-income households or rural communities, helping to reduce energy poverty.

3.1.6 Governance dimension

The governance of RECs concerns how the participation of community members is managed and organized. Public and social RECs typically have participatory governance, which actively involves citizens, local authorities and local organizations. Industrial RECs, on the other hand, tend to have a more centralized governance, with greater involvement of private companies that promote and finance the initiative.

There are three legal forms that can be activated to establish a REC: recognized association, participation foundation and cooperative society, each with different characteristics and organizational structures according to the Civil and Business Code. The experience gained by the working group confirms that, for Municipalities, it is generally preferable to establish a cooperative society. This legal form allows for the broad participation of citizens and local organizations while maintaining a flexible and democratic structure in management. Cooperatives favor a governance model based on mutuality and equity, which is well suited to the management of public initiatives aimed at the well-being of the community. For businesses, however, it is recommended to set up a participatory foundation, which allows for the involvement of various private entities while maintaining a more stable and centralized governance structure. This model ensures efficient management of resources and facilitates the financing of initiatives, thanks to the possibility of attracting private capital and managing the project with greater continuity. Finally, recognized associations are particularly suitable for social foundations or ETS (Third Sector Entities), as they offer a light structure suitable for projects oriented towards social impact and widespread citizen participation. This legal form allows for great organizational flexibility and is well suited to the management of social and community projects, facilitating collaboration with other entities and organizations in the area.

In conclusion, the macro matrix of business models according to the dimensions chosen by the working group can be summarized in Figure 3.

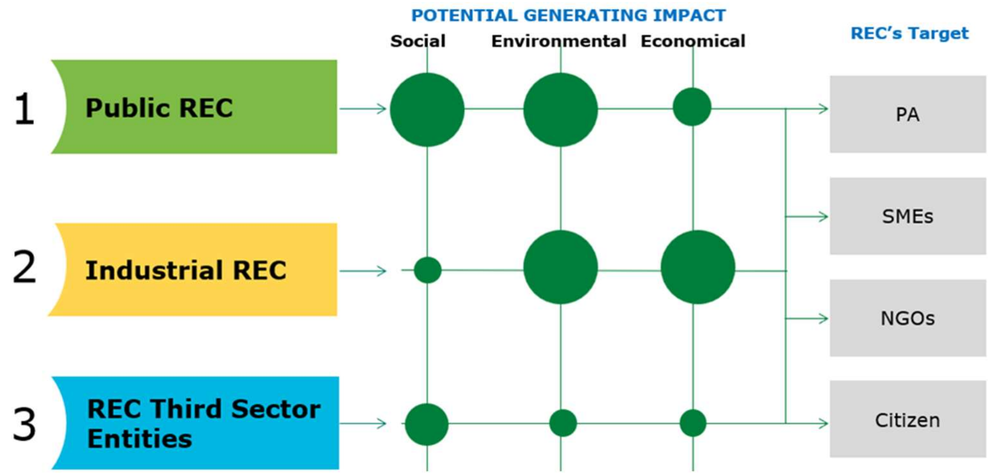

Figure 3

Public and Industrial RECs intrinsically present a greater potential for scalability and impact. Public RECs, thanks to the involvement of local administrations, can expand more easily on supra-municipal territories, while industrial RECs, thanks to the financial and technical resources of the companies involved, can rapidly grow in size and production capacity. Both models have the potential to significantly contribute to the balancing of the national energy grid and to the decarbonization of the territories in which they are implemented. On the contrary, the Social CER model can be an effective first graft of "bottom-up" activation, especially in less developed territorial contexts or with fewer resources. These initiatives, although starting on a small scale, have the potential to grow over time through future aggregations, as more communities and local entities come together to share energy resources and economic benefits. The successful implementation of CERs strongly depends on the active role of several key actors:

- Local Public Authorities that play a key role as facilitators and proactive actors of the energy and social transition. Their participation is crucial to fostering the creation of public CERs and ensuring effective integration of energy solutions within communities. Local authorities can act as catalysts for change, promoting the adoption of renewable energies and mobilizing resources for the financing of CERs, both at municipal and supra-municipal levels.
- Private Enterprises: Cooperation between enterprises, especially energy-intensive ones, has a double objective. On the one hand, enterprises seek to increase their competitiveness by reducing energy costs through self-production and energy exchange within the CER. On the other hand, these same enterprises play a proactive role in balancing the network, given their high energy needs. This contributes to improving the stability of the national energy system and reducing the risk of blackouts or overloads of the network.
- ETS and Social Enterprises: Third-sector organisations and social enterprises can provide a fundamental impetus for the development of initiatives aimed at generating local socio-economic impacts. Their contribution is particularly relevant in Social CERs, where the primary objective is not only to produce energy, but also to respond to the specific needs of the territory. These initiatives can include projects aimed at reducing energy poverty, creating green jobs and improving social cohesion.

In summary, the creation and development of CERs requires coordinated action between a variety of actors, each with different objectives and roles. Public and Industrial CERs offer opportunities for large-scale growth and immediate impact on the energy network and the environment, while Social CERs represent a crucial initial step towards energy and social inclusion. In all cases, the proactive role of Local Authorities, cooperation between businesses and the impetus provided by social organizations will be crucial for the success of the energy transition and the socio-economic development of the territories.

3.2 Design of a business model of composting communities and related actions to improve waste policies and management infrastructures

3.2.1 Biowaste management and Life Cycle Assessment: the role of composting

Sustainable biowaste management mitigate environmental impacts, especially in terms of emissions reduction, and provide also opportunities to exploit economically this waste, according to the business model approach. Consequently, there is a growing interest among scholars and practitioners in conducting LCA for biowaste management practices to identify the best scenario. To identify best practices in terms of GHGs emissions, many different methods and approaches have been used. The literature shows that these methods range from open dumping and unsanitary landfilling to more environmentally friendly methods like waste-to-energy technologies, anaerobic digestion and bioconversion (Salomone et al., 2017). Each technique has pros and cons regarding environmental sustainability, and a better understanding of these aspects is crucial for practitioners and decision-makers to select a suitable model for managing biowaste in practice. To identify such pros and cons, we take a Life Cycle Assessment (LCA) perspective to identify and holistically assess the potential environmental impacts related to all phases of a product's life cycle and to select a suitable model to manage biowaste within a specific context. To achieve this goal, we applied a combination of bibliometric and systematic literature review to (1) review the state-of-the-art of research on LCA in biowaste management, (2) synthesize key case studies of biowaste management, and (3) identify and evaluate the best biowaste management practices. An overview of the research methodology we deployed is described in Figure 4.

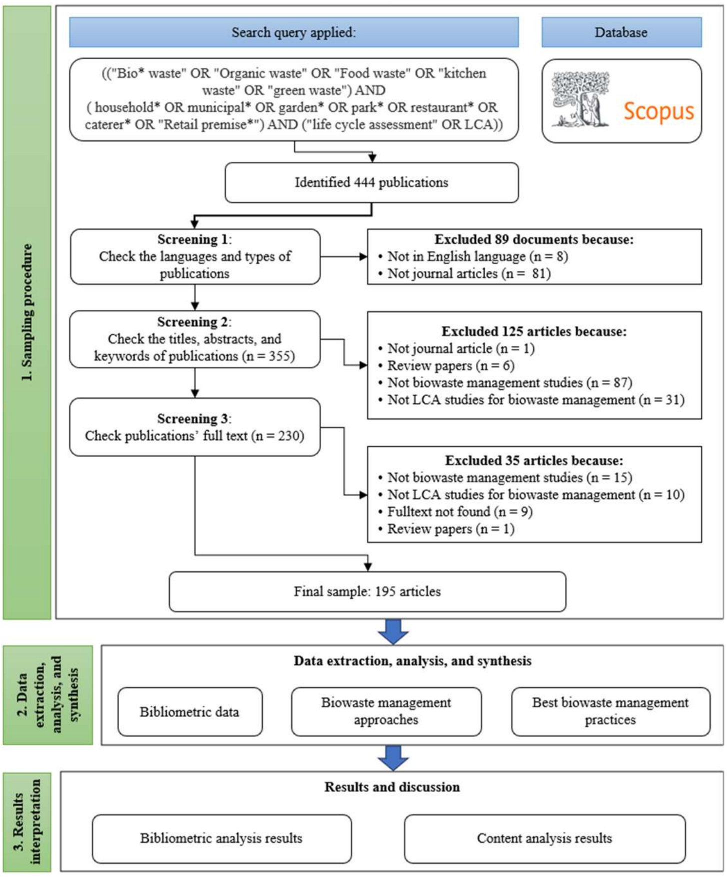

Figure 4

This study reveals that conducting LCA for biowaste management practices has drawn scholarly attention since 1999, with an increasing number of papers from 2015. (see Figure 5).

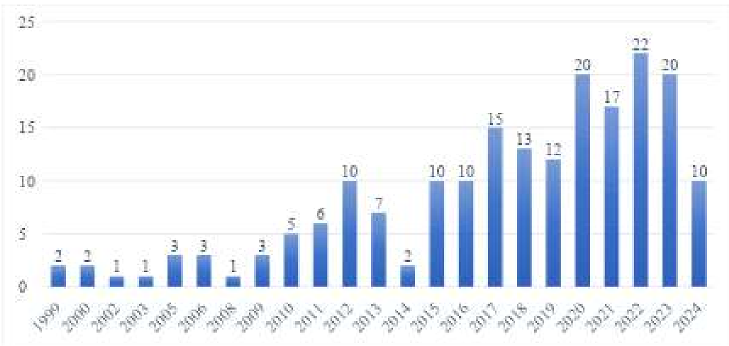

Figure 5 - *The evolution of LCA research and Biowaste management practices*

It is worth noting that research on LCA for biowaste management practice has drawn attention from scholars worldwide. However, developed countries are more productive than countries in the Global South, except in the case of China (see Figure 6).

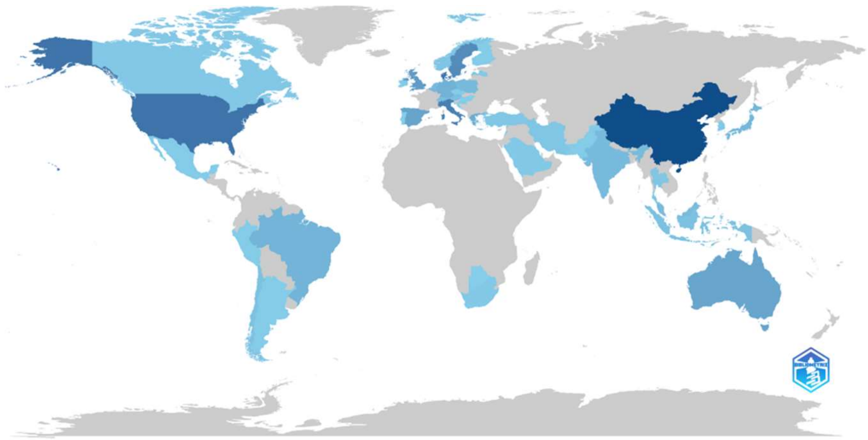

Figure 6 - *LCA research and Biowaste management practices: a geographical overview*

In addition, the keywords co-occurrence map of our sample (n. 195 papers) highlights that the most frequently occurring keyword is "life cycle assessment" (n = 143), which is more than triple the second most frequently occurring one, "anaerobic digestion" (n = 47). These are followed by "food waste" (n = 43), "composting" (n = 42), "biowaste" (n = 36), and "municipal waste solid waste management" (n = 35). Thus, these findings suggest that "anaerobic digestion" and "composting" are the most popular techniques applied in biowaste management practice (see Figure 7).

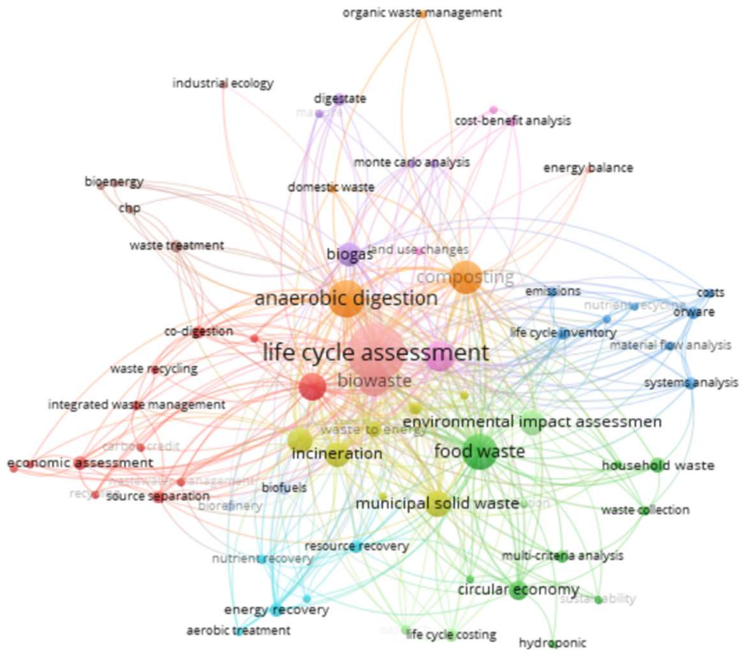

Figure 7 - *The co-occurrence map of the authors' keywords*

At the international level, composting is one of the two most applied technologies to handle biowaste due their environmental impacts, especially in terms of centralized treatment. Apparently, to decide the scale of facilities – centralized or decentralized -, it is recommended that practitioners and decision-makers take into consideration the business model and infrastructure conditions of the case areas. Currently, centralized compost has a capacity of at least 15, usually greater than 100 tons per day (Xiao et al. 2023), Therefore, this study categorizes those with a capacity of less than 15 tons per day as decentralized composting**.** In addition, considering the technical perspective, the integration of anaerobic digestion and composting should be considered in biowaste management because of their benefits (Salomone et al, 2017). Technically, this combination first starts with the AD of biowaste, followed by the composting of AD digestate matter. Particularly when this combination is conducted in decentralized facilities, it can yield benefits from the reduction of long-distance transportation, the low energy needed for the treatment process, the potential to offset energy consumption by energy produced from the AD process, as well as energy and nutrient savings or recovery from the compost.

Insights from LCA find that centralized windrow composting has better environmental performance than home composting (Lu et al. 2020). The same results are seen in the case of centralized anaerobic co-digestion of source-separated organic waste (Yoshida et al., 2012). On the other hand, Martinez-Blanco et al. (2010) find that, compared to home composting, industrial, i.e., centralized composting, has lower impacts on acidification, eutrophication, and climate change, yet higher in other categories like abiotic depletion, ozone layer depletion, photochemical oxidation, and cumulative energy demand. This may suggest that both scales have pros and cons, and the decision should be made based on the current facility status of the study region. Furthermore, it is worth noting that the challenges of centralized treatment methods are long-distance transportation and being highly dependent on biowaste feedstock. Due to these reasons, in Singapore, a centralized AD plant was closed after just six years of being set up. In this context, a decentralized treatment mode is more suitable for biowaste management. The same results are observed in Italy, where the integration of anaerobic co-digestion of organic waste with sewage sludge in decentralized plants with composting yields many environmental benefits in small communities (Righi et al., 2013). Therefore, this approach should be highlighted to apply to managing biowaste, especially on a community scale.

3.2.2 Promoting composting communities through business models

The current research output joins a detailed literature review on the role played by composting communities for low-carbon policies while conducting qualitative analysis (i.e. focus groups and interviews) of the Messina municipality as one of the metropolitan Italian cities that have increased consistently recycling.

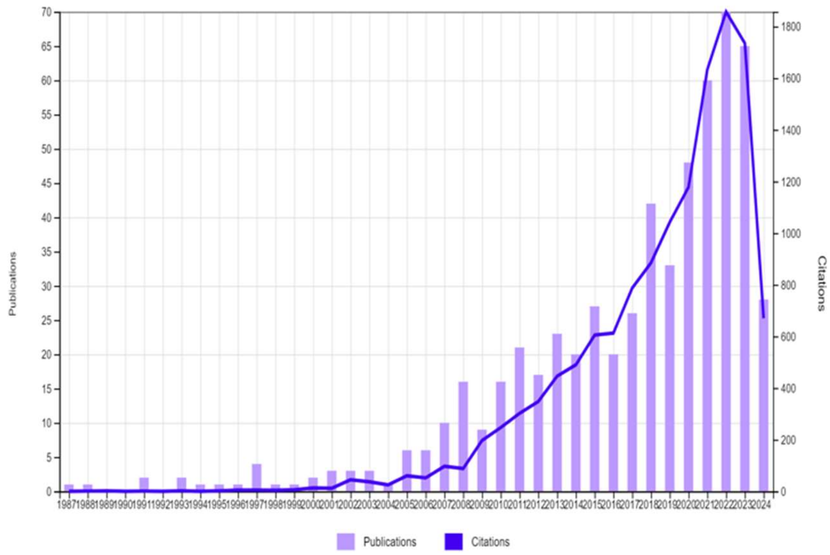

Figure 8 - Biowaste and Composting communities Research

We run a bibliometric analysis on biowaste management and composting communities (sample=590 articles) which revealed the increasing scholar attention to biowaste practices (Figure 8) while carbon low community is relevant topic, but still in its developmental phase (Figure 9).

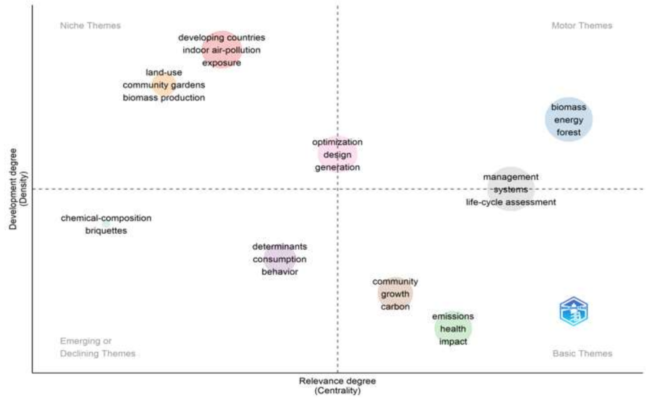

Figure 9 – Thematic Map Biowaste and Composting communities

CASE STUDY – MESSINA Municipality

Messinaservizi Bene Comune S.p.A. is the "in-house providing" company with a single shareholder, the Municipality of Messina, which manages the integrated waste cycle, door-to-door collection and other essential services for waste management, including also the removal of illegal landfills. The Company, operational since March 1, 2018, aims to achieve European standards on the levels of material recovery and to increase the separate waste collection of the Municipality of Messina.

In 2018, Messina exhibited 120.189 tons of municipality solid waste (MSW), and 18,09% recycled, almost far from the EU 65% recycling targets.

To achieve this goal, over the recent years, Messinaservizi Bene Comune has launched several actions including:

- revisioning the collection calendar by bringing the collection of paper and glass packaging to weekly frequency
- Introducing new collection and transport methods with the use of compacting semi-trailers.
- reinforcing street sweeping services by employing additional street sweeping teams.

Thanks to these incremental innovations on biowaste management practices, at the end of 2023, Messinaservizi Bene Comune achieved 55,39% of recycling while also preventing waste, measured in 95.075 tons (120.189 tons in 2018). At individual level, MSW turns from 514,9 tons/year to 424,42 tons/year in 2023. In addition, Messina is ranking among the best Southern metropolitan Italian cities in terms of biowaste.

Overall, preliminary findings reveal that municipalities keen to accelerate the transition to sustainable biowaste systems will benefit from considering five questions:

- How much value can our municipality create by ramping up our commitment to transitioning to
- sustainable biowaste systems?
- What operating model changes will we have to make?
- What investments, products, services, and procurement strategies will help us reach our targets?
- How can we help households obtain the financing and other support they need?
- Do we have the right partners, in the right models, to provide the support needed?

4 Policy implications

4.1 Design of a business model of energy communities and related actions to improve energy policies and management infrastructures

The analysis of CERs has highlighted three distinct meta-models, promoted by local authorities, private companies and third sector entities, each with specific characteristics and purposes. These models offer complementary approaches to the common goal of energy transition and socio-economic improvement. Their implementation presents significant opportunities, but also requires a series of supporting policies to maximize their impact. The main policy implications emerging from this analysis are outlined below. First, it is essential to support the diversification of CER models. Policies should incentivize different types of energy communities, adapting strategies according to the territorial context and local needs. For example, public CERs could receive specific funding to develop municipal sustainability policies, while industrial CERs could benefit from incentives linked to energy efficiency and competitiveness. This diversified approach would not only promote the growth of different CER models but would also contribute to creating a more resilient and inclusive energy ecosystem. Another crucial aspect is the facilitation of participatory governance. Policies should encourage inclusive management of CERs, actively involving community members and promoting transparency in decisions. Implementing tools that facilitate the participation of citizens and different local stakeholders is essential to building trust and acceptance of renewable energy initiatives. This could include the creation of local forums or working tables where citizens can express their opinions and suggest solutions. Furthermore, it is vital to provide training and resources for public administration. Local administrations often face difficulties in managing CERs due to a lack of qualified staff. Therefore, it would be appropriate to develop training programs that provide local authorities with the necessary skills to start and manage these energy communities. Providing adequate resources to support staff in the start-up phase of CERs will help ensure more effective and sustainable implementation in the long term. Another key point concerns incentives for self-generation and energy efficiency. Policies should encourage the installation of photovoltaic systems and other renewable technologies, especially in public areas and for energy-intensive businesses. Fiscal incentives, grants and technical support could help reduce initial costs and promote wider uptake of these installations, increasing self-generation and energy efficiency within CERs. This would not only reduce costs for community members but would also help reduce dependence on external energy sources. It is also important to consider integrating sustainable mobility into CER policies. In this context, policies could include the installation of electric vehicle charging stations within CERs. This integration would not only optimize the use of locally produced renewable energy but would also help promote a more sustainable mobility model. Policies could incentivize the use of electric vehicles within communities, creating synergies between energy production and sustainable consumption. Regarding funding, it is necessary to promote access to public funding for public and social CERs. Public CERs, in particular, can benefit from a variety of European, national and regional public funds. Creating clear and accessible mechanisms for requesting funding could facilitate the start-up and growth of these initiatives. Furthermore, financial support should be accompanied by clear guidelines on how to use these funds effectively to ensure the economic sustainability of CERs in the long term. Another crucial aspect is the monitoring and evaluation of CER performance. It is essential to establish KPI-based monitoring systems to assess the effectiveness of CERs in achieving energy and social objectives. Policies could include the creation of standards for measuring CER performance, allowing communities to adapt their strategies based on the results obtained. This approach would help identify areas for improvement and ensure continuous and adaptive implementation of energy policies. Collaboration between sectors is another key element for the success of CERs. Policies could include education and awareness-raising activities, such as public events, workshops and information campaigns, to illustrate the economic and environmental benefits of CERs and incentivize the active participation of community members. Finally, it is crucial to develop sustainable business models for CERs. Policies should support the creation of business models that ensure the economic sustainability of CERs, through feasibility studies and assistance in economic design. This could include the creation of partnerships with financial institutions to facilitate access to long-term loans and financing, making it easier for communities to start and manage their own CERs. In summary, the policy implications arising from the analysis of energy communities suggest a series of strategic and practical actions that could be undertaken to promote energy transition and socioeconomic improvement. These policies should favor the diversification of CER models, the active participation of communities, support for local governments, the incentivization of energy self-generation, the integration of sustainable mobility and the creation of accessible financing mechanisms. Only through coordinated and synergic action between different actors will it be possible to guarantee the success of the CERs and contribute significantly to the energy and social sustainability of communities.

4.2 Design of a business model of composting communities and related actions to improve waste policies and management infrastructures

4.2.1 Biowaste management and Life Cycle Assessment: the role of composting

Biowaste, especially food waste, is attracting and increasing policy attention due to the economic and social consequences of environmental impacts. The EU has put measures in place to reduce food loss and food waste, to halve the amount of food waste per capita by 2030.

The proposed Waste Framework Directive sets mandatory targets for food waste reduction by 2030: 10% in processing and manufacturing; and 30% per capita in retail, restaurants, food services and households. To achieve these goals, a proper management system for bio-waste is a pre-condition, since food waste represents more than one-third of total municipal solid waste.

In addition to setting targets for the prevention and reduction of food waste, the separate collection and recycling of bio-waste – including food waste – needs to be increased. In this regard, the European Compost Network (ECN) propose to introduce also dedicated recycling target addressing non-municipal and industrial food waste as this is not covered under the definition of a municipal waste of the Directive 2008/98/EC; still, it provides a significant resource as well for organic soil improvers and fertilizers, biogas and other bio-based applications.

Our analysis of biowaste management practices and Life Cycle Assessment (LCA) suggests how effective policy frameworks are needed to facilitate the expansion of intensive composting of municipal organic waste. This includes establishing quality standards and certifications to build consumer trust and demand. In addition, attempts should be made to develop *markets for compost produc*ts, by leveraging opinion campaigns to increase public support for composting and recycling of organic waste.

Policy measures are also required to promote cost-effective composting technologies innovation and business models that can be scaled to different infrastructures.

4.2.2 Promoting composting communities through business models

These preliminary results give an overview of composting communities' business models by mainly stressing the role of governance and economic incentives that are crucial to aligning stakeholders' interests and, in turn, improving bio-waste management. The adoption of these business models facilitates the prevention, collection, sustainable disposal and valorization of bio-waste by leveraging policy and economic balances. The deployment of economic measures to rebalance costs and incentivize effective waste management are imperative.

To deliver a viable business model in composting communities, a clear "hierarchy" of interests is needed to set up and, accordingly, a configurational approach might support policymakers. In line with this reasoning, mechanisms and incentives that encourage composting communities are needed since public engagement is mandatory.

Preliminary results from the case study of Messina municipality show how prominent it is to find ways to incentivize bio-waste collection instead of residual waste. To achieve this, several actions have been deployed, including:

- A clear definition of roles, responsibilities and quantity/quality objectives in waste-related private-public partnerships and public tendering
- Supporting investments in bio-waste management and innovation in the field, providing also grants and subsidies

- Improving public confidence and acceptability by supporting households with campaigns which affects public perceptions about the effectiveness of the new waste practices, its distributional effects, and its local appropriateness
- Promoting citizens' participation by providing digital support (apps) able to gather data and monitor related indicators, essential to evaluate and improve waste collection and enforcement
- Planning adequate bio-waste treatment infrastructure and related investments.

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