Territorial Energy Decentralisation and Ecosystem Services in Italy: Limits and Potential

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Abstract: This article focuses on the complex relationships between energy processes and ecosystem services. It highlights the conflicts between them due to the anthropocentric value that characterizes their interrelationship. The article reports the initial results of ongoing research on energy decentralization processes in Italy, examining the Italian districts heating performance, concerning ecosystem provisioning and regulating services. The analysis is based on a sample of more than 150 Italian district-heating systems. Contrary to studies that positively evaluate processes of energy decentralization, the results of the research show some critical factors and impacts. An efficiency gap between districts heating and traditional energy systems emerged. The data processed show a critical situation in the development of local networks, highlighting that the decentralized energy model is not deeply rooted in the local area and is poorly characterized by shared governance, which instead would benefit from the integration of ecosystem services. The significant presence of large energy groups and the considerable use of fossil sources in Italy reduces the effectiveness of the decentralization of energy systems. The article presents some conclusive considerations, which outline some general guidelines for proceeding towards a more correct relationship with ecosystem services and greater integration with the territories.

Keywords: ecosystem services; energy decentralization; district heating; urban planning; energy transition

1. Introduction

The interest in ecosystem services arose following an increasing awareness of the interdependence between human beings and natural elements [1]. On one hand, communities receive essential elements both for their personal (e.g., food, reproductive spaces, raw materials, air purification, drinking water, etc.) and social (e.g., places, communities and economic and environmental conditions, which directly impact human well-being) survival, through (direct and indirect) ecosystem services; on the other hand, anthropic interventions are able to alter and irreparably compromise the balance and quality of ecosystem features and components [2].

The production and consumption processes of energy sources, including their complicated internal systems, are strictly related to human activities. Useful energy, which comes from primary sources and goes through the processes of transformation, transport, storage and distribution, up to the so-called “end-use energy”, is strictly created by man for man. It starts by using existing natural resources, both exhaustible and renewable. The idea of “useful energy” itself, therefore, has an anthropic, or rather anthropocentric, connotation. It highlights the strategy of energy processes that are focused directly or indirectly on the human being and his social, cultural and economic organisations.
The useful energy processes now influence, as they did in the past, all human activities, behaviours, socio-economic organisations and settlements, with increasing overall intensity over time. It is foreseen that the growth of this trend will increase in the near future.

Useful energy is one of the main interface elements with ecosystems and it uses ecosystem services [3,4], by affecting them in ways that have become critical for their vitality itself [5].

Monitoring energy production in relation to the features of ecosystems is important because it allows us (i) to keep the entire “ecological infrastructure” intact; (ii) to evaluate environmental issues deriving from anthropogenic pressure on ecosystems, due to the exploitations of energy sources; (iii) to measure the dependence on exhaustible energy sources, taking into account the strong ecosystem stress; (iv) to examine the balance between the different types of energy resources and Ecosystem Services; (v) to control the energy demand and the definition of energy plans, on the basis of a thorough knowledge of the resulting ecosystem problems; (vi) to reduce environmental impacts, which occur in presence of local energy systems, of directional flows (e.g., hydroelectric energy, etc.), of extended technological systems (e.g., wind farms, biomass systems, etc.) [6].

The two trends (growth of useful energy and preservation of ecosystem services) move in the same anthropocentric direction but increasingly conflict with each other. The social model—especially of advanced industrial societies, as well as the emerging economies—demands increasing quantities of useful/commercial energy, that affects the energy sources themselves of ecosystem services and, in the near future, they threaten the existence of these invaluable resources.

2. State of the Art

The production of useful/commercial energy involves and, both directly and indirectly, influences all the ecosystem services categories [7–9]. Thus, complex interactions between energy processes and ecosystem services emerged. The dynamics can hardly be defined within a logical framework; the complex conceptual mapping of these interactions is still incomplete due to the vastness of the subject, as reported in Holland [10]. The most relevant direct impacts of useful energy, which affect us more than the four classic classification categories [11–14], involve the ecosystem services classified as “provisioning services”, which refer to the production function of ecosystems and—as for our case study—they refer to the primary energy sources (fossil sources, biomass, geothermal, solar, hydraulic, wind energy, etc.) [15] as well as the secondary energy sources (electricity, fuels and biofuels, fuel oil, etc., that derive from the transformation of the primary sources). The most relevant impacts of useful energy that mainly involve us, are also the classification of the category defined as “regulation services”, which provide for the balance conditions of ecosystems and, as for our case study, they concern the control of climate-changing emissions and polluting factors deriving from anthropic energy processes.

They pursue the maintenance of the levels of the two components of the ecological source and sink model [16], which seems to be very difficult to achieve. Indeed, the gap from the balance system increases.

Therefore, the two categories of ecosystem services are severely compromised in their function, due to the intensity of production and consumption, which considerably exceed the ability of ecosystem services to cover energy demand without affecting existing natural resources (see fossil sources), as well as natural heritage. The two categories are also compromised in their function due to the inability of the ecosystem services to properly provide for the absorption and/or the metabolization of the negative effects resulting from the energy processes.

Looking ahead, the convergence of guidelines between the transformation of the energy model and the enhancement of ecosystem services is required. Thus, an explanation of the latter is essential for the pursuit and stabilisation of the former, as well as the virtuous change of the former, which must align and integrate with the features of the latter, also following strategies and time programs.

In this context, an important strategic role is played by the local dimension—that is the territories as providers of ecosystem services in relation to energy processes. The local dimension could lay the basis for the wide (shared and inclusive) governance of these strategies and integration programs,
as well as for a socio-cultural growth, and the strengthening and development of virtuous models regarding ecosystems.

The literature \cite{17,18} positively evaluates energy decentralization (both in terms of governance and technological systems) in terms of increasing environmental protection, combatting climate change and boosting sustainable development. Local energy grids/networks (smart grids; heat/cold grids; electricity grids; micro-grids, etc.) represent an important development path for energy decentralization, supported by the energy liberalization process promoted in Europe since 1990 \cite{18}. District heating is based on the local production and distribution of thermal fluid, which can have a significant impact on the physical and functional organization of settlements—particularly on the economy, on the enhancement of endogenous energies (biomass and biofuel, waste-to-energy, the energy use of urban waste, geothermal, solar thermal uses) and on environmental protection. Local energy grids can also have positive impacts on the ecosystem services \cite{10}. Compared to traditional centralised energy systems, local district-heating systems have greater energy efficiency—and therefore less environmental impact—as well as better effects on the socio-political-cultural dimension. The research conducted shows that all good implications related to local energy networks are not always achieved, and that it is necessary to recalibrate the energy policies for a better relationship with the ecosystem services.

In Italy, the local district-heating systems do not seem to maintain a good relationship and integration with the ecosystem services.

The article aims to verify this consideration, through a study on district-heating systems in Italy. This study aims to outline two aspects of the relationship between local energy networks and ecosystem services: 1) how the ecosystem services are taken in consideration for the development of local energy networks, with regards to provisioning services and regulating services, in terms of greater or lesser efficiency compared to traditional energy systems; 2) how the energy decentralization characterized by a shared management and governance in relations with the ecosystem services.

The study outlines an overall critical situation in Italy, whose critical factors may characterize the relationship with the ecosystem services. In conclusion, the paper provides a list of opportunities and guidelines for a better local energy policy.

3. Materials and Methods

The methodology applied is shaped by the four following points:

1. The management of “energy” within the framework of ecosystem services refers to the production and consumption of both fossil and renewable sources, and the impact they have upon the environment. The “anthropogenic energy” topic, in relation to the ecosystem services, is still underestimated in literature. It considers only some man-made energy supply chains in relationship with ecosystem services (e.g., the biomass supply chain). Other, even more important sources, such as fossil sources, which display straight involvement within ecosystem services, are not fully described, probably due to the complexity of the relationship. This research analyzes the topic literature, in order to highlight and identify the ecosystem services involved. Energy management following forms of decentralization and energy localism are positively considered in relation to ecosystem services. It allows us to get close the demand and the supply, and therefore it demonstrates the efficiency achievement. This occurs when energy management is deep-rooted in territories and settlements and promotes participation and inclusive governance possibilities concerning the ecosystem dimension. The research analyzes the topic literature. This point aims to answer the following question: 1) in literature, is the relationship between decentralized energy systems and ecosystem services considered particularly important?

2. The third step of the research is an operative assessment of the Italian context. Does energy decentralization (especially in Italy) create virtuous conditions in relation to the ecosystem services? A detailed analysis of local energy networks in Italy has been conducted and the first results are reported. The criteria used are the consumption efficiency (energy consumption and monitoring systems) and the impact on the social cohesion and inclusion. The results of this
elaboration provide negative results. The district-heating systems analyzed in Italy do not seem to develop an effective relationship with the ecosystem services. The analysis also reveals elements of crisis in the development of the field itself, which must be analyzed in depth. The elaboration process, data used and the interpretations from which the results were obtained are reported below. This step aims to answer the question: In Italy does the energy decentralization process establish a positive relationship between the ecosystems?

3. The study outlines some policy guidelines to consider in order of improving the non-positive trend for the development of Italian local energy networks. The question to be answered in the research is: Which are the prospects for increasing the state of Italian districts hating, in terms of institutional frameworks review for promoting the sector in relation to the ecosystem services?

The research is based on the study on the Italian district-heating systems, which also includes many cogeneration plants (production of electricity and heat), and less cold grids, based on a trigeneration plant (production of electricity, heat and cold), which is still few presents.

It is estimated that in Italy, district-heating systems amount to over 350 units, concentrated mainly in Northern Italy. The district-heating systems, built from the 1970s, had a great development between the 2010 and 2015, after that, they show a slowdown. This was due to the expansion of existing networks (especially the larger ones, located in Turin, Milan, and Brescia, rather than the small ones). The main document reporting the general status of the Italian district-heating systems [AIRU] shows a little increase of new local networks, which concerns small systems. This evolution path is explained by operators as an effect of the absence of a stable institutional framework for supporting the sector. Other critical factors exist, some of which are reported below. For the study, two main data sources were used:

- AIRU report [19] which reports the data of about 340 local networks, of which 150 (including the biggest ones) are in a detailed and complete form, and for the remainder few data are unavailable. The analysis is based on a sample base variable within this range, which is the most complete and significative sample;
- ISTAT (National Institute of Statistics) data [20] which provides information on the district-heating systems located in the provincial cities—42 district-heating systems of a total of 109 Italian capitals of the province. The ISTAT source has also been used for population and housing data that have been cross-referenced with the local energy networks data.

For the statistical analysis, three groups of energy sources were considered which feed the local networks. The three groups concern fossil sources (now almost exclusively refer to natural gas), geothermal energy, and biomass. In many cases, the district-heating systems are supplied by a mix of energy sources, such as residual parts of urban waste, recovery heat, solar source, industrial waste, etc.). The criterion adopted is that of the prevailing source used according to the official statistics.

4. Results

Considering only the district-heating systems fed by fossil sources (in general natural gas), it is found that 28% of the networks considered have higher consumption than that of the traditional energy systems and 33% of them have lower consumption of just 10% (Figure A1). Overall, more than 60% of the district-heating systems have a consumption of fossil sources approximately equal or even higher than traditional systems. This percentage generally regards local grids with small energy production plants. The local networks with medium-large energy production plants have higher fossil consumption avoided (between 10% to 30%). The largest district heating, in Turin, reaches 23.4% of fossil consumption avoided. The local networks that exceed 30% of fossil consumption avoided represent about 10% of the total sample. The total set of district-heating systems considered and based on fossil fuels do not seem to reach high percentages of fossil fuel consumption avoided. Figure A1 is provided in Appendix A.
Figure A2 shows the percentages of fossil consumption avoided by the district-heating systems (compared to the traditional energy systems), broken down by the energy source in the power plant (fossil, geothermal, biomass source), by the plant's first year of operation. For fossil-fuel plants, there is an approximation of overtime of the consumption of fossil fuels towards parity with traditional energy systems; especially in the last few years, in which the energy-saving range has decreased considerably, concentrating approximately within $-10\%$ and $+10\%$. The trend line represents this slightly upward trend which tends to cross the abscissa axis. It shows very low values, considering that individual energy production systems, such as natural gas condensing boilers—now widely used—easily save $15\%$–$20\%$ of energy compared to traditional boilers, and that heat pumps and micro-cogeneration can reach even higher values. The few plants with geothermal sources indicate a virtuous trend towards a lower consumption of supplementary fossil sources, approaching the maximum percentage value (100%). District-heating systems supplied by biomass show a trend with a discrete upward inclination which indicates an increase over time of the use of fossil sources. The district-heating performance tends to worsen over time with respect to the consumption of fossil fuels and therefore in the relationship with the ecosystem services, probably due to the greater presence of mixed plants (fossil + renewable). Figure A2 is provided in Appendix A.

Many international studies [17,21,22] evaluate the efficiency of a district heating network considering two main indicators: the linear density (MWh/m) and the demand density (kWh/m$^3$). The study of the IEA [21] on a large number of plants proposes a limit value of 1.8 MWh/m for the linear density; the Woods work [22] reports the minimum demand density at 20 kWh/m$^2$, which can correspond about 7 kWh/m$^3$. The linear density (Figure A3) indicates the energy distributed per linear meter of the network. It should be noted that the trend line of the fossil-source based networks remains substantially constant over time, with a slight downward inclination, with average values between 2 and 3 MWh/m, close to the values coming from the international literature [17,18,21,22]. The local energy networks supplied by renewable sources (geothermal + biomass) have a very marked downward trend, which may indicate a decrease in the efficiency of renewable energy networks. This phenomenon can present a critical factor and should be examined in detail to highlight its causes. Figure A3 is provided in Appendix A.

Figure A4 shows the local networks by extension and by type of ownership (public, private, co-owners, private-public partnership, etc.) according to the initialization. The owners are grouped into three classes: energy groups, local companies, and local authorities. The analysis aims to understand the grade of shared governance and management linked to energy decentralization. Figure A4 shows the size of the networks with regard to new plants which tend to decrease over time. In recent years, the start-up of large plants in large cities has been decreased. The reduction in size does not only concern the networks but also the size of cities involved, analysed in terms of the size of settlements (millions of inhabitants) [20] (Figure A5). Figure A5 also shows that the realization of small local networks particularly affects energy groups, even those with national importance. Figures A4 and A5 are provided in Appendix A.

Figure A6 highlights how fossil-fuel supplied networks are mostly managed by large energy groups. To give some examples, the presence of the Hera group, with EUR 6.5 billion in total turnover, and the A2A group, with EUR 6.6 billion in turnover, and the Iren group, with a turnover of EUR 4 billion [23]. Local companies and local authorities mostly manage renewable energy plants, especially biomass plants. The small presence of local administrations is also highlighted in Figure A7, which reports the situation referred to in the provincial cities with district-heating systems. Figures A6 and A7 are provided in Appendix A.

Figure A8 examines the corresponding energy values in terms of MWh supplied per year. The figure shows the large gap between the quantity of energy supplied by the local energy networks managed by large energy groups and that supplied by local companies. Big energy private groups mostly own energy plants that use fossil sources (in general, natural gas), while renewable sources are less common. Figure A8 is provided in Appendix A.
5. Discussion

The energy decentralization process in Italy seems to negate the statements made in the literature, both in terms of sharing management—with the prevalence of centralized corporate economic entities—and in terms of sources used, with a large presence of fossil fuels resources being used, while other, endogenous sources (renewable energy sources) are less frequently used.

Furthermore, from the policymaking side, it is evident that the structural difficulty encountered in transforming energy processes to incorporate the ecosystem services with which they are related, such as those relating to the [11,12] relating to the provisioning and regulating services categories.

In our study, conducted on the Italian situation, a very fragmented picture of these relationships emerges—without a generalized institutional framework—able to drive and better inform the numerous stakeholders involved in these processes.

The energy decentralization path emerged from the ongoing energy liberalization process; however, it encounters resistance and obstacles to implementing virtuous models and even forms of transition to virtuous models which would incorporate measures for the protection of the ecosystem services.

Contrary to the widespread opinion that considers energy decentralization to always be positive, the data collected on the Italian situation do not seem to confirm this assumption. The study carried out on district-heating systems in Italy highlights several important critical factors in relation to ecosystem services and, at the same time, creates the opportunity to suggest guidelines for the sector. The data processed on the Italian district-heating systems present a problematic picture, from which the contradiction with the common, internationally favourable judgments is clear.

District-heating in Italy has only grown by a very limited extent in recent years, unlike in other European countries [24], and only due to the expansion of a few existing local networks and the construction of limited new networks in small towns.

The explanation coming from businesses is that there is lack of a regulatory and institutional framework, which would favour investment with a degree of security and stability for the future. The expansive prospects generated by some studies [25,26]—which reveal conditions for great development potential at the national level—have not found fulfilment.

In addition, other critical factors emerged from the study related to ecosystem services.

The first critical issue concerns the efficiency of district-heating systems, assessed in terms of the avoided consumption of fossil sources compared to the use of traditional energy systems, which corresponds directly to the emissions avoided. The study shows a substantially negative situation with regards the low values of fossil fuel consumption avoided. The critical situation mainly regards the networks fed by fossil sources, which are the majority and show very low overall values and—in many cases—even negative values, which means that they consume more than traditional plants.

Even traditional efficiency indicators (linear density and demand density) are located at the lower limits of the values considered to be effective at the international level, even with regard to the networks powered by renewable sources that have a trend line in a rapid descent.

This critical situation also has a negative impact in the future forecast for ecosystem services regarding the regulation and provision categories in terms of resource consumption and emission production.

The second critical issue concerns the social dimension of energy. The processes of energy decentralization should bring opportunities for the implementation of participatory social models. Energy Communities [27,28], starting from the shared management of energy, aim to foster a democratic process: where energy is a vehicle for the establishment of new social models with shared and inclusive governance, which also incorporate socio-economic development and cultural/behavioural change in the ecological-environmental field. From the conducted study, this form of political–cultural decentralization, connected to local networks, is not particularly noticeable. Indeed, it would appear that the overall picture is not quite favourable, due to the significant presence of large energy groups and the scarcity of local companies/cooperatives and municipal administrations. Finally, large groups are mainly active in plants supplied by fossil sources, primarily natural gases, which utilize
a centralized system of management/distribution. Few of them are involved in using renewable endogenous sources that benefit local ecosystem services and for which the integration between energy and territorial development is more relevant. The lack of a common institutional framework probably tends to undermine any certainties, especially in corporate governance models with strong “business-oriented” push.

6. Conclusions

Energy production and management, as well as energy end-use, have complex and high-impact relationships with ecosystem services. The anthropocentric dimension of the energy chain, triggered by man for man, has an intensive, often irreversible, impact on the ecosystem.

An increased awareness of the interaction between energy systems and ecosystem services is required. This would encourage better policymaking and management, with a view to address the new environmental and human challenges (land/sea use, overexploitation, climate change, etc.) [10].

The study provides some general guidelines for improving the sector towards a more effective relationship with ecosystem services and a greater integration with the territories:

- There is a need for a broad program to promote the redevelopment of the inefficient plants and local networks that consume more than traditional systems, and of those that only achieve a low avoided consumption. In many cases, it is necessary to rethink the entire network or parts of it, in relation to the territorial changes that have occurred, to improve the physical–functional organization of a settlement, and encourage a greater diversification of outputs (cogeneration, heat and cold production). A stable institutional framework must also be produced to facilitate the financing of interventions with innovative forms.

- The energy transition from fossil fuels to renewable sources is becoming central to European and even global policies. It is necessary to facilitate the progressive, but rapid, conversion to renewable sources, as well as the construction of new local networks supplied by renewable sources. For endogenous energies, it is necessary to operate through the creation of production chains, in which the district-heating system and the energy production are part of a sustainable territorial development (for instance, the use of agricultural and forest biomass, waste-to-energy, the use of heat recovery from industrial processes, etc.) which can have a virtuous impact on ecosystem services and integration with the territories.

- Energy production and management at the local level has important potential for the creation of social cohesion. The process of energy decentralization can foster innovative bottom-up initiatives and projects, including collaborative projects (inhabitants + energy companies)—often promoted by Local Administrations. The process of the liberalization of the energy market is not only open to large operators, but also to potential prosumers and local communities. The most interesting line is the creation of corporate-collective entities (e.g., small public companies or local cooperatives) in which citizenship directly participates, called Local Energy Communities (LECs) or Sustainable Energy Communities, or Green Communities [27–33]. The institutional framework should combine the promotion of business-oriented lines with community-based values rooted in the territories.

- Local energy networks can find an important role in socio-economic development plans in the inland areas and medium-sized cities, and they can be integrated into urban regeneration plans. Along this systemic line, the energy–environmental value can be a driver for settlement redevelopment and social inclusion. In this context, policies and programs can act as starters for projects with an eco-energy aim, with the stable and progressive recognition of ecosystem services.

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Appendix A

Figure A1. Avoided consumption of fossil fuels in district-heating systems using fossil sources, by the quantity of energy produced (MWh, MWhe) [19].
Figure A2. Reduction in the consumption of fossil fuel (%) of the local networks powered by fossil, geothermal and biomass sources, by initial year of production [19].

Figure A3. Linear Density (MWh/m) by start date (dark fossil, bright renewable) [19].
Figure A4. Network ownership by initialization and extension (km) [19].

Figure A5. Local networks per initialization year and size of settlements (millions of inhabitants) [19,20].
Figure A6. Number of local networks per ownership and energy source [19].

Figure A7. Number of local energy networks in capitals of province per ownership and energy source [20].
Figure A8. Thermal energy supplied (MWh/year) per ownership and energy source [19].

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