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3.2.1

Guidelines for energy and composting communities, and sustainable business models

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Executive summary

The research activities carried out by Spoke 6 - WP3 focus on four distinct lines of research: Positive Energy Districts (PEDs), the role of energy communities in accelerating the energy transition, cost and benefit trade-offs of investments in energy communities, and interventions on urban congestion.

The first research line focuses on developing tools and guidelines for an ecological transition at the neighborhood level in the Mediterranean area. The research involves assessing the carbon footprint of an existing non-residential district case study (UNIPA Campus) to determine the environmental and economic costs of achieving PED status. The team aims to provide feasibility studies and policy implications at the EU level. The research also extends to developing a methodological model for urban applications and a repository for data visualization.

The second research line investigates the role of energy communities in energy transition acceleration. The research covers data analysis, legislative reviews, the development of a dataset on Italian renewable energy communities, business model proposals, questionnaire drafting, and a literature review on the impact of energy communities in fostering various transitions.

A third research line, dedicated to Renewable Energy Communities (RECs), focuses on modeling RECs as coalitions implementing renewable energy projects. The study considers sources of revenue, market prices, subsidies, and consumption, presenting RECs as a modified stag-hunt game. The research explores the dynamics of cooperation, individual and community-level decision-making, and the impact of different parameters on REC equilibrium.

The fourth research team concentrates on interventions to enhance sustainability in traffic-congested environments. The team designs laboratory experiments using a threshold public goods game to investigate the impact of a road navigation system on traffic congestion and CO2 emissions. The study aims to understand individual and group behavior concerning negative externalities associated with congestion and the implication of the adoption of a navigation system that manages congestion.

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1. Presentation and description of the research activity undertaken

1.1 Positive Energy Districts

The research team at the University of Palermo will provide a set of tools and guidelines for the development of an ecological transition to a neighborhood perspective in the Mediterranean area. This goal will be pursued following different approaches: on a lower geographical scale, we will assess the carbon footprint of an existing non-residential district case study (UNIPA Campus) to detect the environmental and economic costs involved to achieve the status of Positive Energy District (PED) and its current carbon equivalent emissions during its operation and life cycle. Anticipated results include preliminary feasibility studies for similar PEDs in the Mediterranean area, benchmarking values for the same applications, as well as policy implications and potential suggestions for the final implementation of the current PED definition at the EU level. As a further step, a methodological model and a consequent practical application at the urban level will be developed. Moreover, a repository and a data visualisation instrument to be used within the energy community will be defined. Finally, on a larger scale, the focus will be extended to the urban planning level.

1.2 Analysis of the role of energy communities in accelerating the energy transition

One of the research lines active in the Spoke-6 team at the University of Padova is to study the role of energy communities and their members in fostering the (energy) transition. Various activities have been carried out:

1) Analysis of data sources and databases dealing with energy communities at the Italian and European level identifying the limits and potentialities of available databases

2) Preliminary analysis of the state of the art of Italian and European legislation concerning energy communities

3) Creation of a dataset comprising quantitative and qualitative information about Italian renewable energy communities (active or designed), renewable and solidarity energy communities, places with self-consumption experience and social, demographic, economic, entrepreneurial, geographical, and cultural information at the municipality level

4) Study of the state of the art of the literature on business models for energy communities and development of a theoretical proposal for a business model canvas for energy communities

5) Developmental drafting of a questionnaire to investigate the behavior of citizens and families in the energy sector, on the use of energy from renewable sources and the propensity to take part in energy communities

6) Literature review on the role played by energy communities in fostering transitions

1.3 Cost and benefit trade-offs of investments in energy communities

One of the research lines of this WP focuses on Renewable Energy Communities (RECs): groups of individuals, organizations, or local governments that gather to promote, develop, and implement renewable energy projects in a given geographic area or community. RECs have three sources of revenue: the saved costs of energy produced and not purchased externally, the sale of an energy production surplus, and the subsidy arising from energy produced and self-consumed. The variables producing RECs are the market price of energy, the selling price of self-produced energy, the government subsidy for self-consumption, the consumption of the whole community, and energy accumulation technologies. Community member expectations regarding all these factors matter, too. RECs can be modelled as a modified stag-hunt game where investing in ecological energy is a Nash equilibrium in dominant strategy. Policies should set subsidies to incentivize RECs and to deter overconsumption, proposing thresholds to energy trading.

1.4 The impact of different interventions on urban congestion

The research team at Tor Vergata University in Rome is investigating interventions to increase sustainability in environments affected by traffic congestion. Congestion has been shown to have a large effect on individuals' well-being and CO2 emissions. We

are working on a framed laboratory experiment designed to investigate the impact on traffic congestion and CO2 emissions of using a road navigator system designed to reduce congestion, by directing drivers to different roads to minimize the economic and environmental costs of congestion.

We intend to analyze this topic experimentally using a variant of a threshold public good game, in which typically people contribute with their actions to the achievement of a threshold guaranteeing a given outcome (for a review, see Croson et al. 2000).

2. Relationship with the existing literature on the topic

2.1 Positive Energy Districts

According to the Urban Europe Joint Programming Initiative SET-Plan Action no. 3.2, a PED can be seen as a "district with annual net zero energy import and net zero CO2 emissions, working towards an annual local surplus production of renewable energy". Specifically, European SET-Plan ACTION no.3.2 Implementation Plan, through the "Positive Energy Districts and Neighbourhoods for Sustainable Urban Development" program in JPI Urban Europe, promotes and supports the planning, deployment and replication of 100 Positive Energy Neighborhoods by 2025.

In line with these goals, the PED Programme Management of JPI Urban Europe collected and issued an exemplary set of projects for sustainable urbanisation and energy transition all over Europe. Moreover, the White Paper on the PED Reference Framework for Positive Energy Districts and Neighborhoods invites experts and representatives of "problem-owners" to discuss and analyze the various issues related to PEDs.

In light of the above remarks, the research work aims to consider the multiple implications of the concept of PEDs at various levels and will assess the technical feasibility of achieving a positive balance for a specific application context (i.e., UNIPA Campus).

2.2 Analysis of the role of energy communities in accelerating the energy transition

Accelerating energy sustainable and just transitions is an important challenge in the EU; energy communities can be a critical instrument in this context as they represent

the development of energy efficiency, financing the transition, increasing social acceptance, and stimulating people in adopting virtuous behaviors (Lode et al., 2020; Vernay and Sebi, 2020).

A key role is played by citizens as members of energy communities and their shift from passive consumers to active participants in the energy transition in the form of prosumers – producers (of at least a portion of their own energy needs with local production) and consumers (Gržanić et al., 2022; Volpato et al., 2022). In addition, small and medium-sized firms, institutions, and community organisations are important because they stimulate the energy transition at different levels, investing, producing, selling, and distributing renewable energy (Interreg Europe, 2018). Furthermore, they promote and disseminate knowledge and awareness of energy-related sustainable practices in both the production and consumption phases (Vernay and Sebi, 2020). Relationships between the local community, the public and the private sectors are sources of knowledge sharing, private finance, local consumption, land seeking, community employment and leasing (Eitan et al., 2019).

Various cases were investigated to broaden our knowledge of the role of community-based energy systems in leading sustainable transitions. Among others, for Spain see Capellán-Pérez et al. (2018), for the UK see Seyfang et al. (2013; 2014), for the Netherlands see Doci et al. (2015) and van der Schor and Scholtens (2015), for France see Vernay et al., (2023), for Italy see Di Silvestre et al. (2021), for a comparison between France and the Netherlands see Vernay and Sebi (2020).

2.3 Cost and benefit trade-offs of investments in energy communities

Transitioning from fossil fuels to renewable sources for energy production represents a pivotal milestone in reaching net zero emissions. Most countries are actively striving for this transition by employing large renewable energy plants such as offshore wind plants, and decentralized, stakeholder-driven energy production in renewable energy communities (RECs). RECs constitute coalitions of stakeholders (individuals, organizations, or local authorities) formed to implement renewable energy projects in their local community.
As part of the European Green Deal, the EU strategy to achieve long-term neutrality provides for at least 75 percent of overall energy demand to be sourced from renewables by 2050, and approximately 16 percent of electricity to be generated by collective projects (Reis et al., 2021; EU Commission, 2018; Kampman et al., 2016). RECs have recently been regulated by EU 2018/2001/EU Directive (Revised Renewable Energy Directive—RED II), but REC experiences extend to several other countries, too. In the US,

RECs contribute roughly 11 percent of the country's total energy output, notably playing a significant role in electrifying low-density areas (Reis et al., 2021).

2.4 The impact of different interventions on urban congestion

Our analysis is connected to different strands of literature. A first natural connection is with the urban and transport economics literature illustrating the economic relevance of congestion (Akbar and Duranton, 2017; Couture et al., 2018; Kreindler, 2019). In particular, we connect to the literature showing the relevance of the heterogeneity in travelers' value of time and reliability (Small, 2012; Small et al. 2005, 2006).

We connect to the literature using experimental methods to investigate choices in transportation (for a review, see Dixit et al., 2017). This literature has identified three main areas of focus: how information is processed and learnt, the effect of commuting habits on decision-making, and the effects of travelers' attitudes to risk (Innocenti, 2013; Lida, 1992; Lu, 2011; Helbing, 2004; Chmura and Pitz, 2004a and 2004b, Selten et al. 2007, and Razzolini and Datta Mago, 2011). Further experimental studies have explored the decision-making process about the choice of routes (Schneider and Weimann, 2004; Rapoport et al., 2004; and Ziegelmeyer et al., 2008) without investigating how the use of navigation systems may reduce congestion.

In the field of behavioral and experimental economics, many studies have investigated how other-regarding preferences and the principles of fairness contribute to the formulation of the agent's choices in social dilemmas (Fehr and Gächter, 2000, 2002; Gächter, 2007; Ostrom et al., 1992). Several analyses have confirmed the ability of humans to voluntarily sustain cooperation in the case of resource dilemmas as in the public good game (Andreoni, 1988. 1990; Casari and Plott, 2003; Charness and Villeval, 2009; Chaudhuri, 2011; Fehr and Leibbrandt, 2011; Ledyard, 1994; Ostrom et al., 1992). The dynamic of free-riding, the role of social preferences, how social norms and institutions or communication affect the outcomes in public goods games, as well as the subject beliefs and framing, have been extensively explored in the experimental and behavioral literature (Cookson, 2000; Fischbacher, and Gächter, 2010, Gächter and Renner, 2010; Kosfeld et al. 2009; Oprea et al, 2014; Zelmer, 2003). Different variations of the game have been studied, especially considering threshold public goods (Cadsby and Maynes, 1999; Corazzini et al, 2015; Croson and Marks, 2000; Kosfeld et al. 2009; Marks and Croson, 1999; Palfrey et al., 2017).

3. Research output

3.1 Positive Energy Districts

Our research included a systematic collection and inventory of energy data and building features, evaluating and assessing possible retrofit interventions. The plan of action devised can be described as follows:

i) UNIPA buildings of interest are being modelled (architecturally, via building materials and by adopting energy-saving installations); the models are calibrated according to boundary conditions, energy profiles, the occupancy rate and overall performance. Research outputs at this stage are individual building models in the refinement phase. The following months will require further modeling and a harmonization procedure for all the models under investigation.
ii) Non-steady state simulations for the existing case studies will be generated, to assess existing energy features and to outline possible retrofit solutions (both at the building construction level and regarding technical system improvements/replacements).
iii) Hence, after defining various retrofit scenarios and running the related simulations, some initial strategies and guidelines can be formulated.
iv) Step by step, the analysis will be fine-tuned and gradually extended to broader contexts, up to the district scale: actually, which can be useful to understand and test a customized concept of PEDs in selected pilot areas in the city of Palermo, among other things helping to define sustainable business models.

On a smaller geographical scale, the research project will evaluate the carbon footprint of an existing non-residential district in a case study, to verify the environmental and economic costs of achieving PED status and its current carbon equivalent emissions during operation over its life cycle. Anticipated results include preliminary feasibility studies for similar PEDs in the Mediterranean area, policy implications and potential suggestions for the final EU-wide implementation of the definition adopted for PEDs. The main *interim* output (completed) comprises a selection of PED case studies in Europe and a set of contributions by scholars in the field on methods related to the ecological transition.
Our study is also developing a methodological approach aimed at sustainable urban rebalancing and the ecological transaction. The main *interim* output (recently released) is a methodological scheme that contains the *criteria* for the application of an eco-sustainable district. On a larger scale, we released a new conceptual "working

paper" for the application of the ecological transition to urban and territorial planning with a specific reference.

3.2 Analysis of the role of energy communities in accelerating the energy transition

The current research output joins a detailed literature review on the role played by energy communities for (energy) transitions, which have been proven to be heterogeneous. The literature suggests that energy communities can help to achieve heterogeneous transitions via a democratic, sustainable, and decentralized system (Heldeweg and Saintier, 2020). First, they foster energy transition mainly by developing energy efficiency with local renewable energy production and consumption (Lowitzsch et al., 2020). Second, they enhance social change toward inclusion and better living conditions for vulnerable households (Berka and Creamer, 2018). Overcoming the (mainly financial) barriers to adopting renewable energy or energy efficiency measures due to the resulting energy savings and greater access is also often associated with social innovation, socio-economic regeneration of the locations of energy communities, and with the empowerment of citizens (Standal et al., 2023). Moreover, social impacts from a larger perspective can also be expected, such as the formation of local social capital and environmentally benign lifestyles (Bauwens and Defourny, 2017). Third, energy communities stimulate technological transition by the development of new clean energy technologies or platforms and devices to facilitate operational compatibility and communications between community members and the other agents involved, as well as in terms of transitioning to a decentralized electricity system (Koirala et al., 2016).

3.3 Cost and benefit trade-offs of investments in energy communities

We model RECs as communities made by active and passive prosumers, where the former own the energy plants and make the initial investment, and the latter share the production and consumption activities (i.e., benefits and costs). Citizens can choose to remain in the national markets as standard consumers, join a community as passive prosumers, or make an initial investment to set up a community as active prosumers. Active and passive prosumers agree on a membership fee and on how to share the energy produced. More specifically, the REC model can broadly be described as a social dilemma with parameters that can make the dilemma a multiplayer prisoner dilemma, a stag-hunt game or an original REC game.

During the day, there may be hours when the community overproduces energy (energy surplus), and others when it underproduces energy (energy shortage). The surplus is sold to the national electrical grid manager, and the shortage is covered by the purchase of energy from the national market. The energy purchase price is set at the national level, and is higher than the price for the sale of the surplus energy.
At the community level, the revenues are affected by the following parameters: energy price, installation costs, subsidies received for self-producing energy, and the costs saved due to self-production. Assuming economic rationality, people choose to set up or join an REC if the above-mentioned parameters make it more convenient than it would be to remain in the national market. At the individual level, each community member is also affected by the share of community-produced energy, and the membership fee. Active and passive prosumers can bargain over these factors to reach a fair sharing method.

The three sources of revenues of a REC may create conditions for an original REC game with mutual cooperation as the sole Nash equilibrium. Moreover, if the dynamic of the game is considered, the equilibrium can be reached sequentially after the first dominant strategy of the prosumer, i.e., setting up an REC. The REC model also differs from other standard multiplayer prisoner dilemmas and the version is adjusted for environmental choice, where mutual cooperation is always dominated by mutual defection (Becchetti and Slustri, 2019). Alternatively, the model can represent a stag-hunt game depending on the three parameters. In this scenario, the cooperative equilibrium, always leading to the social optimum, can be enforced only by preliminary binding contracts between parties. For this reason, our model also focuses on the profit bargaining problem between prosumers and passive consumers and shows how the equilibrium outcome partly depends on the power of accumulation technology.

3.4 The impact of different interventions on urban congestion

Our experiment, designed to be carried out in a laboratory by the Tor Vergata team, is based on a variant of a discrete threshold public goods game framed with the specificity of individual urban travel mobility, where people recruited to participate in the experiment are randomly matched in small groups. The experiment relies on a between-subject design, meaning participants are assigned to one protocol. Participants are recruited from a pool of university students in Rome. The experiment is incentivized, with each participant paid for each travel decision. Participants are informed about the effects of their route decisions in terms of externalities related to the travel cost from increasing travel time and in terms of group cost from increased pollution.

In each repetition of the game, individuals are randomly assigned a different travel cost and a different position in the ranking of the costs. In the baseline, individuals are asked to choose between a direct route, subject to congestion if a sufficiently large number of individuals choose it, or an alternative route, not subject to congestion. In the treatment, individuals can delegate the choice of route to a system of autonomous allocation of travelers to available routes. This baseline/treatment combination is studied both in the case of full information, in which the individuals are fully informed about their own and their peers' travel costs, and in the case of imperfect information, in which individuals know their own cost but have only partial information about the distribution of their peers' costs.

The research output of the experiment will enable the study of individual and group behavior concerning two sources of negative externalities usually generated by traffic congestion in urban areas. The first externality is related to the increased costs that each individual incurs on a congested route. The second externality is related to polluting emissions associated with traffic congestion.

Our experiment seeks to answer two questions:
(i) if and to what extent the opportunity to delegate an individual's travel choice to a central navigator system aimed at minimizing aggregate travel cost can increase social welfare;
(ii) what individual behavioral features are associated with a higher propensity to voluntarily participate in a mechanism to reduce congestion and environmental pollution?

4. Policy implications

4.1 Positive Energy Districts

After a careful analysis of current Italian energy policies and the economic framework, it seems that the ambitious and virtuous targets of the “Positive Energy Districts and Neighbourhoods for Sustainable Urban Development” program have not yet been incorporated by policymakers into official regulations.
Consequently, there is an urgent need to define and adopt an integrated, innovative, incremental, and adaptive planning protocol (including status and response indicators, as well as parameters for further design activities), able to relate policies and actions aimed at sustainability.
An open innovation model for PED planning, deployment and replication is required to meet EU standards. Italian policies should clearly define, parametrize and regulate the concept of PEDs, reconnecting National legislation with the ambitious and demanding EU targets.

In light of the above-mentioned approaches, the research within GRINS will investigate and define the development of a key performance indicator framework for consumer/prosumer engagement in ecological transition, including providing useful guidelines for energy communities and sustainable business models, able to support Italian Policy Makers in the path toward European objectives.

4.2 Analysis of the role of energy communities in accelerating the energy transition

Energy communities have already attracted political intervention and estimates in the Clean Energy Package (2016) suggested that large amounts of wind power (17% of installed capacity) and solar power (21%) may be acquired by energy communities by 2030. Several contributions also suggest that they play an important role in local economic development, mainly via new firms and job creation, surplus generation trading, and by driving collaborative social transformation (Berka and Creamer, 2018).

Based on the current literature, energy communities appear to have multiple objectives, involving various agents at heterogeneous levels and may need both joined-up planning between the diverse cases and single-driven instruments designed for a specific case to advance transitions. Policymakers should address the topic of economic viability and management and involve citizens as prosumers. Policy instruments should facilitate the creation of energy communities in specific places, their sustainability over time and resilience in changeable socio-economic contexts, eventually creating the conditions for the efficient attraction of private investments. This requires specific policy interventions according to the adoption by industry, the public sector, or private citizens. Moreover, policy should help to create intermediary agents to facilitate the implementation of efficient energy community business models. In this respect, local institutions and governments may be both key enablers and important stakeholders. Civil society plays a fundamental role in engaging local communities and distinguishes energy generation and management in energy communities from traditional large energy production; hence, policy tools should be designed to increase the awareness of energy community benefits and the involvement of stakeholders.

Finally, in the specific case of Italy, legislation in the form of Legal Decree 199/2021, following an EU directive, set up renewable energy communities as legal entities; however, there is as yet no implementation decree, limiting the actual development of several initiatives ready to be rolled out nationwide.

4.3 Cost and benefit trade-offs of investments in energy communities

A key role in fostering the implementation of RECs is played by incentives and energy prices, especially the price of the energy surplus. The factors are often determined or regulated by the government. Therefore, creating the conditions where these factors are constraints for the REC as equilibrium in dominant strategy turns out to be a political choice. These factors, as properly defined, can facilitate cooperation, fostering the REC.

The incentive system as assumed for RECs has several behavioural consequences. It encourages members to minimise (maximise) consumption in less (more) productive hours. This incentive may also accelerate the adoption and development of accumulation technology, as prosumers prefer to use solely self-consumed energy throughout the day.

However, accumulation technology may induce prosumers to over-consume energy in most productive hours. If accumulated, consumers may be willing to produce more than they would have done otherwise, because they are subsidised. This drawback needs to be considered when setting the incentive and can be mitigated by excluding the self-consumption incentive beyond a fixed threshold of energy consumption.

As for the general equilibrium implication, our model highlights some challenges. A rapid increase in the number of RECs in a short time could drive up investment costs and public expenditure due to higher demand pressure. To address this, the government might set a maximum target for energy produced by RECs in a specified period, possibly aligning with the EU target of 16 percent renewable energy from RECs.

Considering advancements in accumulation technologies, the anticipated progress could amplify the light blue area, increasing prosumer bargaining power in RECs. Although extending self-consumption subsidies to energy produced and accumulated by RECs may enhance prosumer bargaining power, it could exacerbate the general equilibrium problem, especially given the pace of technological advances.

4.4 The impact of different interventions on urban congestion

The experiment designed by the Tor Vergata team has two rationales: the first is to investigate the effects of a coordination device, such as a navigation system, on improving the social desirability of individuals' travel choices. The second is to investigate what makes a motorist decide to delegate to a navigation system, considering individual heterogeneity and different degrees of information concerning other people's behaviours, attitudes, and costs.

The experiment carried out by this research line will provide important insights for policymakers and urban planners seeking to address the pressing environmental and social challenges related to urban traffic issues. Understanding people's response to the presence of collective navigation systems and the dynamic of their adoption to reduce urban congestion has important implications for policymakers.

The improvement of smart and sustainable mobility in the near future is strictly linked to implementing cooperative intelligent transport systems (ITS) through cloud servers (Faisal, 2019; Kim, 2015). Microsimulations show that adopting cooperative systems into driving assistance technologies can significantly reduce congestion by integrating dynamic traffic assignments (Melson, 2018). Additionally, a collective navigation system like that one tested in the Tor Vergata team experiment, if integrated with the development of autonomous vehicles or integrated with vehicle-to-vehicle communication technologies, may be an essential and effective instrument to deal with the challenge society faces with urban mobility and related emissions. Indeed, integration with the adoption of autonomous vehicles can reduce greenhouse gas emissions by up to 34 percent of total emissions from transportation by 2050 (Ercan, 2022). In addition, adopting integrated vehicle-to-vehicle communication has significant potential to reduce congestion and the associated CO2 emissions (Neufville, 2022), while adopting autonomous and cooperative technology can play a vital role in increasing road capacity (Faisal, 2019). However, the public acceptability of these instruments may prove difficult. The evidence provided by our experiment can help policymakers identify which individual characteristics and motivations (biases) are associated with a higher willingness to be involved in a collective navigation system. This will also suggest potential economic and/or behavioural policy instruments to be adopted to promote public engagement in adopting these coordinating tools.

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