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# Adoption and Diffusion of Micro-Grids in Italy. An Analysis of Regional Factors Using Agent-Based Modelling

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**Title:** Adoption and diffusion of Micro-Grids in Italy. An analysis of regional factors using agent-based modelling.[1]

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**Abstract:**

The Italian electricity system, based on a centralized grid, presents important inefficiencies in the transmission infrastructure and is highly import-dependent. At the same time, it has a high renewable potential. These three aspects might encourage Italy to shift from the traditional centralized grid to a new decentralized electricity system by adopting Micro-Grids (MGs). This transition, however, has not yet started.

This work aims to study the possible scenarios of adoption and diffusion of MGs in Italy, by analysing the influence of regional factors, the potential role of subsidies and people's attitude. An agent-based model is formulated in order to simulate the diffusion of MGs as a function of those characteristics and to analyse which policies could facilitate the adoption of MGs in the country.

The results show the high dependence of the diffusion process on regional factors (electricity demand, renewable potential and population). Moreover, the model confirms that subsidies can encourage the diffusion (mainly when they are regional-based rather than national-based) and that a higher "green" attitude by users can accelerate the diffusion of MGs in Italy.

**Keywords:** Micro-grids, Agent-based model, Innovation diffusion

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[2] Also working at JRC, European Commission.

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# 1 Introduction

Generation of electricity and heat represents the main cause of CO2 emissions; in 2010 they accounted for 41% of world greenhouses gas (GHG) emissions[3]. Countries may substantially benefit in the challenge of global warming and climate change by addressing household energy use. There are number of options: improving efficiency, adopting zero-emission technologies and installing decentralised systems. Since the beginning of the century, decentralised generation (DG) systems for the production and distribution of electricity have attracted a strong interest in the technical and scientific community (Ackermann *et al.*, 2001; Asmus, 2001; IEA, 2002; Hatziargyriou and Meliopoulos, 2002; Lasseter, 2002). A DG system is usually defined as "any source of electric power of limited capacity, directly connected to the power system distribution network where it is consumed by the end users" (Akorede *et al.*, 2010, p. 726). When the DG system is composed by a "cluster of loads and micro-sources operating as a single controllable system", it is also defined Micro-Grid (MG) (Lasseter, 2002, p.305).

The interest for DG and MG is driven by three main factors related to the transition to a more sustainable production and use of energy: (i) minimising transmission losses by reducing the distance between electricity generation and final users (Ackermann *et al.*, 2001; Pepermans *et al.*, 2005); (ii) a higher share of renewable technologies and the consequent reduction of emissions (Hadley and Van Dyke, 2005; Chiradeja and Ramakumar, 2004); and (iii) improving energy security (Asmus, 2001). More recently, along with a number of studies stressing the importance of DG systems and MGs in the transition towards a more efficient, sustainable, and inclusive electricity production system, there are others indicating the need to stimulate public and private investments (Block *et al.*, 2007; Lopes *et al.*, 2007; Driesen and Katiraei, 2008; Marnay *et al.*, 2008; Battaglini *et al.*, 2009; Agrell *et al.*, 2013). However, until now, neither policy interventions have been very effective in stimulating the diffusion of DG systems and MGs, nor energy utilities have yet designed the right business model allowing for large revenue.

In the next decades the demand for electricity is estimated to increase along with population growth. Therefore, in order to reduce the overall impact, citizens might play a crucial role in the challenge of global warming and climate change and, consequently, they should be involved in this process. Within the Micro-Grids structure, consumers are not only the final rings of the chain but they also become generators of electricity, increasing their strategic role (Watson, 2004). Adoption and diffusion of MGs necessitate users' acceptance in terms of individuals' capital investments, common utilization and willingness to install MGs in their neighbourhood. (Sauter and Watson, 2007). In conclusion, building a decentralized electricity system can be seen as an emerging bottom-up process requiring a careful understanding of consumers' behaviour and perspective (Groh *et al.*, 2014).

To sum up, MG is a small-scale electricity power system capable to satisfy energy needs at a local level. It requires an investment made by a group of people. Such investment is made only when it guarantees savings compared to the current case, that is purchasing electricity directly from the traditional centralized electricity system. The higher the adoption of MGs, the more the probability to move towards a decentralized electricity system, which seems to have potentiality to be more efficient, more sustainable and more secure compered to the present electricity system. The obvious and legitimate question, therefore, regards the diffusion of MGs and what are the drivers that could stimulate this process. This paper, through and Agent-Based simulation[4], tries to answer to this question. The answer will be given by studying the case of the Italian electricity system, which presents inefficiencies in the transmission system, it is highly import dependent, but it has a high renewable potential. These three reasons could encourage Italy to shift from the traditional centralized grid to a new decentralized electricity system. The characteristics of the Italian system are similar to many other developed countries presenting a well-established centralised electricity infrastructure. In these contexts, the transition towards a decentralised system is more difficult, despite the environmental potential. In fact, new technologies face the incumbent technologies, which prevent the (desired) smooth process of substitution or co-existence and integration. Therefore, outcomes of the Italian case can be generalised to provide insights for policy-making.

The paper is structured as follows. Section 2 reviews innovations diffusion theories applied to the case of Micro-Grids. Section 3 presents the model, whose results are discussed in section 4. Section 5 concludes.

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[3] IEA/OECD 2012.

[4] The model is implemented in C++ by using the LSD software (Laboratory for Simulation Development) specifically geared for evolutionary modelling (Valente, 2008).

## 2 Innovation diffusion theories applied to the MG study case

The Micro-Grid case study can be studied as a specific case of diffusion of innovation (Rogers, 2003). The diffusion process of MGs needs four main elements to be accomplished. First, MG can be considered as an innovation because of its modern practice of producing electricity, which is not only based on the utilization of new technologies but it also involves the idea of social production of electricity. Second, diffusion of MGs requires communication among the social network (McMichael and Shipworth 2013). People, leaving geographically close to each other, form communities and exchange information thorough personal interactions. Time, the third element of Rogers' list, defines how long the diffusion process is. This study precisely aims at evaluating the duration of Micro-Grids diffusion in Italy and what factors influence it. Last, the social system has an impact on the diffusion process of MG. It embeds firms, users and governments, which are required to act in harmony. Therefore, the transition from the dominant centralized electricity grid towards a more decentralized system involves sociological, technical and economic dynamics, driven by the environmental goal (Geels, 2002).

Governments and institutions are required to made possible the shift towards the "green" techno-economic paradigm (Perez, 1983; Freeman, 1992) and to promote environmental innovations and technical change (OECD, 2012). Public and private research resources need to be allocated properly in order to focus on technologies that might have positive impact on the environment (Rosenberg, 1976). National policies should be designed in order to stimulate the development of energy options that could help the achievement of environmental goals (Freeman and Soete, 1997). Firms might follow particular trajectories of technical change and establish technological paradigms concerning the development of MGs (Rosenberg, 1969; Nelson and Winter, 1977; Dosi, 1982). Moreover, within the Micro-Grids structure, consumers are not only the final rings of the chain but they also become generators of electricity. This creates a market dynamic which reduces the distance between consumers and suppliers (IEA, 2002). Under this perspective, consumers are more responsible for their energy choices becoming an essential factor in the transition towards an environmental friendly social structure.

Diffusion of MGs is strictly related to the users' decision to implement or not a certain innovation. The decisional step, in fact, is one of the five stages that Rogers indicates in his innovation-decision process and is the main focus of this paper. Decision to adopt a MG system is dependent on economic and social aspects, both of them under the same umbrella of the environmental goal. In the studies of the process of diffusion, economists seem to prefer the "profitability criterion" as the main one, while sociologists seem more likely to focus on diffusion and adoption by referring to the "cognitive" process, which is also influenced by the "availability of information" (Mansell and Steinmuller 2000, p. 104-105). The approach followed in this study takes into account both aspects: the sociological aspect behind the way in which consumers join a community and the pure economic adoption decision according to the profitability of shifting electricity supply system. Indeed, the decision to adopt MGs is a "collective innovation decision" where a common consensus is required beforehand, which then has to remain valid for the future (Rogers, 2003). Collective decision, obviously, is influenced by the size of the community. The more numerous the community, the cheaper the investment. However, the size of the community has a double, and opposite, effect on the rate of adoption. On the one hand, by reducing the cost of innovation, it encourages diffusion resulting in a rapid growth. On the other hand, because of coordination difficulties, the higher the number of people the slower the rate of adoption (Olson, 1971; Rogers, 2003).

To sum up, the combination between market dynamics, environment-related innovations and technological transition are the key ideas necessary to understand why studying diffusion and adoption of MGs is an interesting topic. Nowadays, even though all the key elements indispensable for starting this transition are partially present in the social system, it has not yet launched. This work aims to give a better understanding about the reasons for that stationary point. More specifically, through the specific case of Italy, this paper tries to understand which are the favourable (and the unfavourable) regional factors needed to complete this innovation-diffusion process, how subsidies can influence that process, and, eventually, to evaluate the impact of the user's attitude about Micro-Grids. In conclusion, by modelling the adoption and diffusion process of MGs in Italy, it is possible to achieve a double result. First, the research question can be answered achieving a better understanding of the factors influencing, positively or negatively, the wide use of this new electricity infrastructure. Second, it is possible to check whether or not the case studied corroborates the related theory on the diffusion of innovations.

## 3 Model description

The model simulates the electricity market, which consists of a demand side and a supply side (Figure 1). At the beginning of the simulation, it is assumed that all consumers in the demand side are connected to the national grid, but they have the option to shift to a more decentralized system, by purchasing a Mirco-Grid (MG).

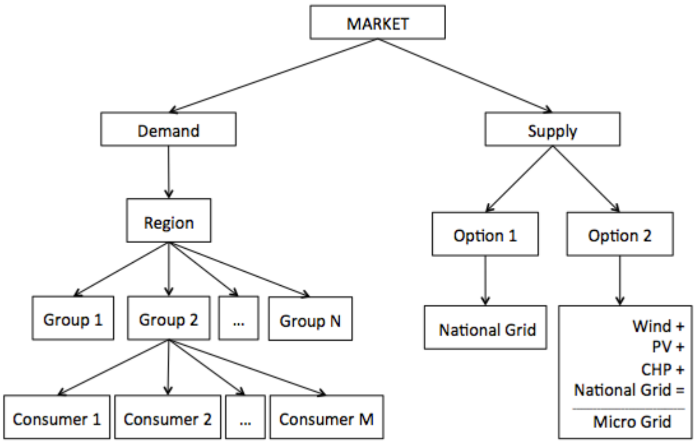

Figure 1: Model diagram

Each consumer belong to a specific group, each group is located in a specific region. Groups simulates neighbourhoods were people live close to each other, since MGs need to be installed and used by consumers living geographically in the same area. Regions define specific characteristics, such as electricity demand, market share and MG functioning hours[5]. The two options available to consumers in the supply side are: (i) to maintain the current energy supply system, which is the national grid, that is the direct supply of electricity by paying only the cost of energy consumed; or (ii) to shift to an almost independent micro-grid energy system, which includes both fixed and variable costs, minus subsidies. The two options are compared based on an investment horizon of 20 years. After this period components in the MG become obsolete and they have to be removed and substituted. Consequently, the user will evaluate again the opportunity to invest in MG based on the new conditions, which have changed during this period of time. Each time step, the model checks if for each consumer knows the opportunity to buy a MG and whether he/she is willing to invest in MG. If both are positive, the consumers evaluate the investment opportunity. The model computes the total cost of the two options. The option with the lowest cost is chosen.

In the demand side consumers are the unit of analysis and the model simulates individual decision, which impacts the final collective decision. The supply side, on the contrary, provides consumers with two alternative options, whose costs change over the simulation. This structure allows simulating consumers' adoption decision based on mutable cost conditions of the available options in the market, which is the objective of this paper. Furthermore, both the ownership structure of the MG and the market dynamic are important in the diffusion process of MG. However, these are not analysed since they are beyond the scope of this work. Nevertheless, it is worth to say that the growing market liberalisations in the energy sector have already facilitated adoption of decentralised systems (Madlener and Schmid, 2003; Markard and Trffer, 2006). In particular, energy utilities have been the major beneficiary of this deregulation (Siddiqui and Maribu, 2009). Investments related to decentralised energy systems are related to the installed capacity (Straka, 2002). While large decentralised infrastructures require efforts from utilities, small-scaled energy systems can be affordable also by local communities, which ultimately is the focus of this paper.

### 3.1 The Supply Side

The national grid guarantees distribution of electricity in both alternative but at different percentage. Price is not constant during the simulation time, and it needs to be calculated each time step. Price follows the same raising pathway observed in Italy in the last nine years. Therefore, the computation of the electricity cost (in €/kWh) at each time step ($E_t$) is:

$$E_t = E_{t-1} * (1 + v) \qquad (1)$$

---

[5] MG involves renewable technologies that by definition are intermittent, and in each region they do not work the same number of hours in one year.

where $v \in [-0.015, 0.023]$ is a random number generated in order to keep the raising trend in the price of electricity. The minimum and maximum values are respectively computed as the average of negative and positive changes in percentage between two consecutive observations of electricity price in Italy, from January 2005 to June 2013. At the starting point (t=0), $E_0 = 0.28753$ €/kWh. $E_t$ is the only cost component for option 1.

$Tot\_NG_{t,r}$, the cost that, for 20 years in total, each user in the regional community has to pay when connected to the national grid is:

$$Tot\_NG_{t,r} = E_t * D_r * 20 \tag{2}$$

where $D_r$ is the consumer's demand, which varies from region to region.

$E_t$ also has an impact on the cost of option 2, but at a lower percentage, since the overall cost of MG depends on the other technologies involved in the energy infrastructure. Each technology $k$ included in the MG has (i) a variable cost ($VC_{k,t}$) measured in €/kWh and dependent on fuel cost ($F_{k,t}$), operation cost ($O_{k,t}$) and subsidy ($S_{k,t}$), and (ii) a fixed cost ($I_k$), measured in €. In ( 2 ) the variable costs computation is defined.

$$VC_{k,t} = F_{k,t} + O_{k,t} - S_{k,t} \tag{3}$$

The total MG fixed cost is the sum of the technology fixed cost ($I_k$) and the cost of batteries ($B$), needed to store the electricity produced by the intermittent renewable sources, minus subsidies. Because of the incremental improvement, the model additionally simulates the learning curve and its resulting cost depreciation (Faber, Valente and Janssen, 2010). Therefore, the fixed cost ($FC_{t,r}$, in €) is computed as formula ( 3 ) shows.

$$FC_{t,r} = \left[\left(\sum_{k=1}^{3} I_k + B\right) * \left(NC_{t-1,r}\right)^{-\alpha}\right] - SP_t * \left(NC_{t-1,r}\right)^{-\alpha} \tag{4}$$

where:

$I_k$ : is the installation cost for each of the three technologies involved in MG [€];

$B$ : is the cost of battery [€];

$NC_{t-1,r}$ : is the number of communities at the previous time step that have already adopted and therefore it is equal to the number of MGs installed in one region at that moment;

$\alpha$ : is a constant measure reflecting the rate of cost decrease, and determines the progress rate PR through: $PR = 2^{-\alpha}$. $\alpha = 0.217$;

$SP_t$ : is the subsidy received by purchasing and installing MG [€][6]. The way in which the adoption phenomenon will change in relation to this value will be analysed in detail during the discussion of the results.

The final investment cost of MG is regional-dependent since it implies the use of renewables technologies, which have, consequently, different functioning hours. Therefore, the model utilises the regional utilization factor in order to capture these regional characteristics. Consequently, at regional level, Wind and PV have cover a different percentage of the yearly production while the cogeneration system is stable in its coverage. National grid (NG) guarantees the remaining supply.

The total cost per-capita of MG at time $t$ and in region $r$ is computed by the following formula ( 5 ):

$$Tot\_MG_{t,r} = \frac{FC_{t,r}}{N_{t,r}} + \left\{D_r * \left[\left(\sum_{k=1}^{3} VC_{k,t} * x_{k,r}\right) + \left(E_t * x_{k=4,r}\right)\right]\right\} * 20 \tag{5}$$

with:

$$\sum_{k=1}^{4} x_{k,r} = 1 \;\; \forall r \tag{6}$$

where:

$x_{k,r}$ : is the functioning percentage of each technology $k$ in the micro-grid, based on regional area $r$;

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[6] In the formula, the subsidy provided for purchasing a MG decreases in the same way the installation cost does. It is assumed indeed that the amount of subsidy given has to decrease together with the technological progress and the learning curve.

$N_{t,r}$ : is the number of potential consumers in the community willing to do a common investment at time *t* in region *r*.

Once the consumer, who is taking part in the common investment decision, knows the total costs of both options, he can compare them and decide whether or not to adopt a MG. In the next paragraph, the way in which a community is formed will be described.

### 3.2 The Demand Side

The demand side of the market involves consumers and their characteristics. Therefore, the model, before studying the monetary investment decision, evaluates the social aspect of the common investment. This consists of consumers' attitudes and characteristics necessary to join a community that will share the cost of an investment.

First, since MG supplies electricity to a confined local area, communities are formed within people living in the same neighbourhood. Consequently, consumers have to be geographically close to ach other. The model is structured in a way to have already a prefixed number of agglomerations (groups of consumers in each regions). This feature reflects the segregation model in Schelling (1971), where people with similar characteristics decide to live in the same area.

Second, every consumer, before starting the decisional process, is required to know the opportunity to invest in MG. The model simulate knowledge creation and exchange has in (Faber, Valente and Janssen, 2010). A regional variable called "visibility" is computed in the following way:

$$V_{t,r} = \max\left[V_{t-1,r}\ ;\ \left(MG\_us_{t-1,r}\right)^{\delta}\right] \qquad (7)$$

where:

$MG\_us_{t-1,r}$ : is the users share of Micro-Grid in the previous time step for the region *r*. It represents the share of the total users in a region that have already adopted MG before the current time step starts. $MG\_us_{t-1,r} \in [0,1]$;

$\delta$ : is a parameter (set equal to 0.9) reflecting the bandwagon effect.

The variable "visibility" is proportional to the market share of MG already reached in one region and represents the extent to which the MG alternative is known in the region. Moreover, by means of the parameter $\delta$, the model simulates consumer behaviour in taking the decision to buy a new product, which is strictly dependent on others' previous behaviour. Indeed, his or her decision is influenced not only by the expected added value of the product, but also by the previous mass decision (Arthur, 1989; Smallwood and Conlisk, 1979). The user sees the MG with probability $V_{t,r}$.

Once the consumer knows the opportunity to invest in MG, the model considers also his attitude. This characteristic represent the consumer's positive attitude (Balram and Dragićević, 2005) and it also reflects the willingness to pay for green electricity (Hansla *et al.*, 2008). The model uses a parameter to indicate how much a consumer is inclined to invest in a decentralized electricity system, and consequently, to become a in a certain percentage independent from the national grid. This parameter is exogenously set at 0.054[7]; therefore every user has a "green" attitude with 5.4% probability. Assessing or quantifying the attitude needed to adopt "green" innovations is not straightforward. Difficulties are more acute when the focus is on the specific case of MG, which implies self-generation and self-consumption of electricity. In fact, while many studies propose surveys to assess consumers' attitude regarding "green" products, no contribution related to autonomous electricity generation has been found. For these reasons, the share of electricity produced in Italy for self-consumption over the total production has been used as indicator of "green" attitude. However, acknowledging the highly variability of this indicator over time and across national contexts, the paper also discusses results of the analysis on this parameter.

To sum up, every time step of the model, a consumer, who has not yet adopted the Micro-Grid system, starts his decision-making process. Firstly he looks at the market for the opportunity to invest in MG. When he is able to see this alternative, he decides to join an investment community on the basis of its "green" attitude. When he has this characteristic, he enters in a community of people, geographically close to him, in order to evaluate the investment opportunity. This is also the way in which the community is formed. The MG infrastructure can supply electricity for a certain amount, which, consequently, determines the maximum number of users that the same infrastructure can provide with the energy service ($N_{t,r}$, in formula 5). In other words, the electricity production potential is regional-dependent as

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[7] The amount of electricity produced for self-consumption in 2012 was 16056.5 kWh. The total electricity produced in the same year was 299275.9 kWh. (Terna, 2013).

well as the maximum number of users' demand met by the MG. This implies that consumers need to form communities of investment, which have different size depending on the region in which they are located.

## 3.3 Model configuration

In this paragraph, the model configuration is presented. Table 1 introduces both variable and fixed cost of MG. There are two sources for those data. The subsidies values are taken from the national regulation D.M. 6 Luglio 2012 and D.M 5 Luglio 2012. All the others costs come from Politecnico di Milano (2010). In this study, costs have been computed by the "levelised cost of electricity" (LCOE) and are already discounted for 20 years.

| **Id_Tech (k)** | | **1** | **2** | **3** |
|---|---|---|---|---|
| **Label** | | **Wind** | **PV** | **CHP** |
| **Power** | [kW] | 30 | 20 | 50 |
| **Investment (I)** | [€/kW] | 4500 | 5500 | 1400 |
| | [€] | 135000 | 110000 | 70000 |
| **Fuel Cost (F)** | [€/kWh] | | | 0,098 |
| **Operation Cost (O)** | [€/kWh] | 0,083 | 0,108 | 0,111 |
| **Subsidy (S)** | [€/kWh] | 0,268 | 0,196 | 0,257 |

Table 1: Starting values for technologies in MG

The cost of battery (B) is set to €100,000. The value is an approximation of values reported in literature and online specialized websites. Nowadays the innovation process and technological improvement is at its starting point, therefore the cost of batteries is inclined to have very disparate estimations.

The regional consumption per capita in terms of kWh/y ($D_r$) is available through statistical data published yearly from the Italian electricity transmission operator TERNA (Table 2)

| **Region** | **Demand [kWh/y]** |
|---|---|
| **Abruzzi** | 4913 |
| **Basilicata** | 4497 |
| **Calabria** | 2819 |
| **Campania** | 3014 |
| **Emilia Romagna** | 6242 |
| **Friuli Venezia Giulia** | 8118 |
| **Lazio** | 4077 |
| **Liguria** | 4029 |
| **Lombardia** | 6674 |
| **Marche** | 4768 |
| **Molise** | 4403 |
| **Piemonte** | 5701 |
| **Puglia** | 4597 |
| **Sardegna** | 6728 |
| **Sicilia** | 3836 |
| **Toscana** | 5400 |
| **Trentino Alto Adige** | 6406 |
| **Umbria** | 6022 |
| **Valle d'Aosta** | 7490 |
| **Veneto** | 6060 |

Table 2: kWh consumed per citizen in each regional area in one year (Source: Terna, 2011)

The regional utilization factor ($x_{k,r}$) in each region (Table 4) is calculated in relation to the functioning hours (Table 3). Therefore, $x_{k,r}$ represents the proportion of hours during which each technology in the MG produces power, plus the share of hours during which consumers satisfy their energy need through the national grid. In other words, it is the proportion of total demand [kWh] met by each technology in MG and national grid.

| Region | Wind |  | PV |  |
|---|---|---|---|---|
|  | % | hours | % | hours |
| **Abruzzi** | 8,09 | 709 | 14,11 | 1236 |
| **Basilicata** | 15,14 | 1327 | 15,15 | 1327 |
| **Calabria** | 16,67 | 1460 | 15,18 | 1329 |
| **Campania** | 13,91 | 1219 | 14,41 | 1262 |
| **Emilia Romagna** | 11,54 | 1011 | 12,50 | 1095 |
| **Friuli Venezia Giulia** | 28,49 | 2495 | 12,57 | 1101 |
| **Lazio** | 17,02 | 1491 | 14,36 | 1258 |
| **Liguria** | 10,83 | 949 | 13,38 | 1172 |
| **Lombardia** | 7,67 | 672 | 12,75 | 1117 |
| **Marche** | 11,62 | 1018 | 14,21 | 1245 |
| **Molise** | 18,80 | 1647 | 14,57 | 1276 |
| **Piemonte** | 11,60 | 1016 | 13,68 | 1198 |
| **Puglia** | 22,30 | 1954 | 15,42 | 1350 |
| **Sardegna** | 18,38 | 1610 | 15,63 | 1369 |
| **Sicilia** | 25,20 | 2207 | 15,95 | 1398 |
| **Toscana** | 11,90 | 1042 | 13,10 | 1148 |
| **Trentino Alto Adige** | 15,14 | 1327 | 11,95 | 1047 |
| **Umbria** | 15,91 | 1394 | 14,11 | 1236 |
| **Valle d'Aosta** | 15,14 | 1327 | 13,92 | 1220 |
| **Veneto** | 7,50 | 657 | 12,50 | 1095 |

Table 3: Regional functioning hours for Wind and PV

| Region | Wind | PV | CHP | NG |
|---|---|---|---|---|
|  | k=1 | k=2 | k=3 | k=4 |
| **Abruzzi** | 8,09% | 14,11% | 34,25% | 43,55% |
| **Basilicata** | 15,14% | 15,15% | 34,25% | 35,46% |
| **Calabria** | 16,67% | 15,18% | 34,25% | 33,91% |
| **Campania** | 13,91% | 14,41% | 34,25% | 37,43% |
| **Emilia Romagna** | 11,54% | 12,50% | 34,25% | 41,71% |
| **Friuli Venezia Giulia** | 28,49% | 12,57% | 34,25% | 24,70% |
| **Lazio** | 17,02% | 14,36% | 34,25% | 34,38% |
| **Liguria** | 10,83% | 13,38% | 34,25% | 41,54% |
| **Lombardia** | 7,67% | 12,75% | 34,25% | 45,33% |
| **Marche** | 11,62% | 14,21% | 34,25% | 39,92% |
| **Molise** | 18,80% | 14,57% | 34,25% | 32,39% |
| **Piemonte** | 11,60% | 13,68% | 34,25% | 40,48% |
| **Puglia** | 22,30% | 15,42% | 34,25% | 28,03% |
| **Sardegna** | 18,38% | 15,63% | 34,25% | 31,74% |
| **Sicilia** | 25,20% | 15,95% | 34,25% | 24,60% |
| **Toscana** | 11,90% | 13,10% | 34,25% | 40,75% |
| **Trentino Alto Adige** | 15,14% | 11,95% | 34,25% | 38,66% |
| **Umbria** | 15,91% | 14,11% | 34,25% | 35,73% |
| **Valle d'Aosta** | 15,14% | 13,92% | 34,25% | 36,69% |
| **Veneto** | 7,50% | 12,50% | 34,25% | 45,75% |

Table 4: Share of functioning hours per technology in one year (8760 hours)

Regarding the two renewables technologies, wind and photovoltaic, the functioning hours depend on climatic characteristics, which are themselves regional-dependent. Therefore, the first step in determining this parameter has been to estimate the wind and solar potential for each Italian region. In order to do that, online databases were consulted with the support of free online software. In the case of wind turbines, the average wind speed for each region has been found[8] and then the potential has been computed[9] in order to have the potential for wind plants. Almost the same procedure has been used to obtain the values for PV plant for which the main parameter is the solar irradiation[10]. The cogeneration system we are analysing in the micro grid is a 50kW capacity, which can be used for 3000 hours per year. Therefore, the percentage of regional usage is 34.25%. The last parameters, that is the number of hours in which the micro grid takes electricity from the national grid (NG), is the remaining time. As an example, a consumer, who decides to shift towards a decentralized electricity system in the region of Abruzzi, computes the variable cost of this opportunity in the following way: 8.09% is due to the Wind cost, 14.11% to PV, 34.25% to Biomass and the remaining part, 43.55%, is due to the electricity cost bought from the national grid.

The maximum number of users' demand met by the MG is $N_{t,r}$, and it also is regional-dependent. Therefore, by multiplying the power installed for each technology (Table 1) with the respective number of functioning hours (Table 4), it is possible to estimate how much electricity can be produced and supplied by a MG at a regional level. Then, since

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[8] http://www.windguru.cz/int/index.php

[9] http://www.nrcan.gc.ca/energy/software-tools/7465

[10] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe

the regional demand per capita is known (Table 2), it is also possible to measure the maximum number of users that can join a specific community in a region. Table 5 sums up this computation process.

| Technology | Wind | | PV | | CHP | | Total regional production, MG | Demand (Dr) | $N_{t,r}$ |
|---|---|---|---|---|---|---|---|---|---|
| **Power [kW]** | 30 | | 20 | | 50 | | | | |
| **Region** | | kWh/y | | kWh/y | | kWh/y | kWh/y | [kWh/y/capita] | max value |
| **Abruzzi** | 8,09% | 21261 | 14,11% | 24727 | 34,25% | 150000 | 195988 | 4913 | 39 |
| **Basilicata** | 15,14% | 39796 | 15,15% | 26546 | 34,25% | 150000 | 216343 | 4497 | 48 |
| **Calabria** | 16,67% | 43813 | 15,18% | 26587 | 34,25% | 150000 | 220399 | 2819 | 78 |
| **Campania** | 13,91% | 36565 | 14,41% | 25239 | 34,25% | 150000 | 211804 | 3014 | 70 |
| **Emilia Romagna** | 11,54% | 30340 | 12,50% | 21902 | 34,25% | 150000 | 202242 | 6242 | 32 |
| **Friuli Venezia Giulia** | 28,49% | 74860 | 12,57% | 22019 | 34,25% | 150000 | 246879 | 8118 | 30 |
| **Lazio** | 17,02% | 44720 | 14,36% | 25155 | 34,25% | 150000 | 219875 | 4077 | 53 |
| **Liguria** | 10,83% | 28471 | 13,38% | 23445 | 34,25% | 150000 | 201916 | 4029 | 50 |
| **Lombardia** | 7,67% | 20154 | 12,75% | 22345 | 34,25% | 150000 | 192499 | 6674 | 28 |
| **Marche** | 11,62% | 30548 | 14,21% | 24903 | 34,25% | 150000 | 205450 | 4768 | 43 |
| **Molise** | 18,80% | 49405 | 14,57% | 25521 | 34,25% | 150000 | 224926 | 4403 | 51 |
| **Piemonte** | 11,60% | 30475 | 13,68% | 23965 | 34,25% | 150000 | 204440 | 5701 | 35 |
| **Puglia** | 22,30% | 58610 | 15,42% | 27010 | 34,25% | 150000 | 235620 | 4597 | 51 |
| **Sardegna** | 18,38% | 48298 | 15,63% | 27385 | 34,25% | 150000 | 225682 | 6728 | 33 |
| **Sicilia** | 25,20% | 66219 | 15,95% | 27953 | 34,25% | 150000 | 244172 | 3836 | 63 |
| **Toscana** | 11,90% | 31266 | 13,10% | 22956 | 34,25% | 150000 | 204222 | 5400 | 37 |
| **Trentino Alto Adige** | 15,14% | 39796 | 11,95% | 20941 | 34,25% | 150000 | 210738 | 6406 | 32 |
| **Umbria** | 15,91% | 41818 | 14,11% | 24719 | 34,25% | 150000 | 216537 | 6022 | 35 |
| **Valle d'Aosta** | 15,14% | 39796 | 13,92% | 24396 | 34,25% | 150000 | 214192 | 7490 | 28 |
| **Veneto** | 7,50% | 19719 | 12,50% | 21902 | 34,25% | 150000 | 191620 | 6060 | 31 |

Table 5: Maximum number of users in an investment community ($N_{t,r}$)

The overall structure of the model consists on two sides, the demand and the supply. The lowest level of the demand side is the individual consumer. Each consumer belongs to a group of 1,000 people; this number represents the proximity constraint among people. Groups are included in one region. The structure of the model has 20 regions, which is the number of Italian regions. The total number of groups per region is set in proportion to the number of residents in each region. Moreover, in order to maintain some speed in the simulation, the number of people considered in the analysis is only 2% of the total Italian citizens; this proportion has been maintained in the regions as well. Table 6 shows the number of groups of thousand people per region.

| Region | Residents | 2% of Residents | Number of Groups |
|---|---|---|---|
| **Abruzzi** | 1.342.366 | 26.847 | 26 |
| **Basilicata** | 587.517 | 11.750 | 11 |
| **Calabria** | 2.011.395 | 40.228 | 40 |
| **Campania** | 5.834.056 | 116.681 | 116 |
| **Emilia-Romagna** | 4.432.418 | 88.648 | 88 |
| **Friuli-Venezia Giulia** | 1.235.808 | 24.716 | 24 |
| **Lazio** | 5.728.688 | 114.574 | 114 |
| **Liguria** | 1.616.788 | 32.336 | 32 |
| **Lombardia** | 9.917.714 | 198.354 | 198 |
| **Marche** | 1.565.335 | 31.307 | 31 |
| **Molise** | 319.780 | 6.396 | 6 |
| **Piemonte** | 4.457.335 | 89.147 | 89 |
| **Puglia** | 4.091.259 | 81.825 | 81 |
| **Sardegna** | 1.675.411 | 33.508 | 33 |
| **Sicilia** | 5.051.075 | 101.022 | 101 |
| **Toscana** | 3.749.813 | 74.996 | 74 |
| **Trentino-Alto Adige** | 1.037.114 | 20.742 | 20 |
| **Umbria** | 906.486 | 18.130 | 18 |
| **Valle d'Aosta** | 128.230 | 2.565 | 2 |
| **Veneto** | 4.937.854 | 98.757 | 98 |
| **Total** | 60.626.442 | 1.212.529 | 1.202 |

Table 6: number of people for each region, in the simulation (source: http://www.comuni-italiani.it/regioni.html)

## 4 Results and discussion

The phenomenon of adoption and diffusion of Micro-Grids in Italy has been analysed for a time horizon of 200 years. Each time step in the model represents one year. This time horizon intends to consider both the installation time, which is relative long in case of new electricity infrastructure, but also the preliminary steps of knowledge, persuasion and decision. These are three of Rogers' phases of the innovation-decision process. In particular, knowledge diffusion and information flow require time, which, in turn, depend on the structures of consumers' social networks (Cowan and Jonard 2004). Furthermore, also the decisional step requires time, since the collective adoption necessitates agreement among community's members. This agreement is not immediate, specifically in large groups where negotiation is more complex (Olson, 1971).

The model runs 10 simulations for each configuration, with different random seeds, in order to control the random effect of the stochastic variables of the model. Therefore, the result of a configuration is presented as an average between those ten simulations.

This section presents and discusses the results of the model simulation. Firstly, a general overview of the outcome is given, while taking into account the classic literature about diffusion of innovations. Then, three sub-sections analyse different topic areas: regional analysis, subsidy policies and environmental analysis. The first one regards the diffusion of MGs at a regional level, trying to understand which factors can influence that process. In the second section, an analysis has been performed on the basis of different subsidy scenarios, at national level. The third section quantifies the environmental benefits achievable by MGs in Italy, mainly due to the installation of several Wind micro turbines and PV panels or to a higher attitude to be "green".

### 4.1 Results overview

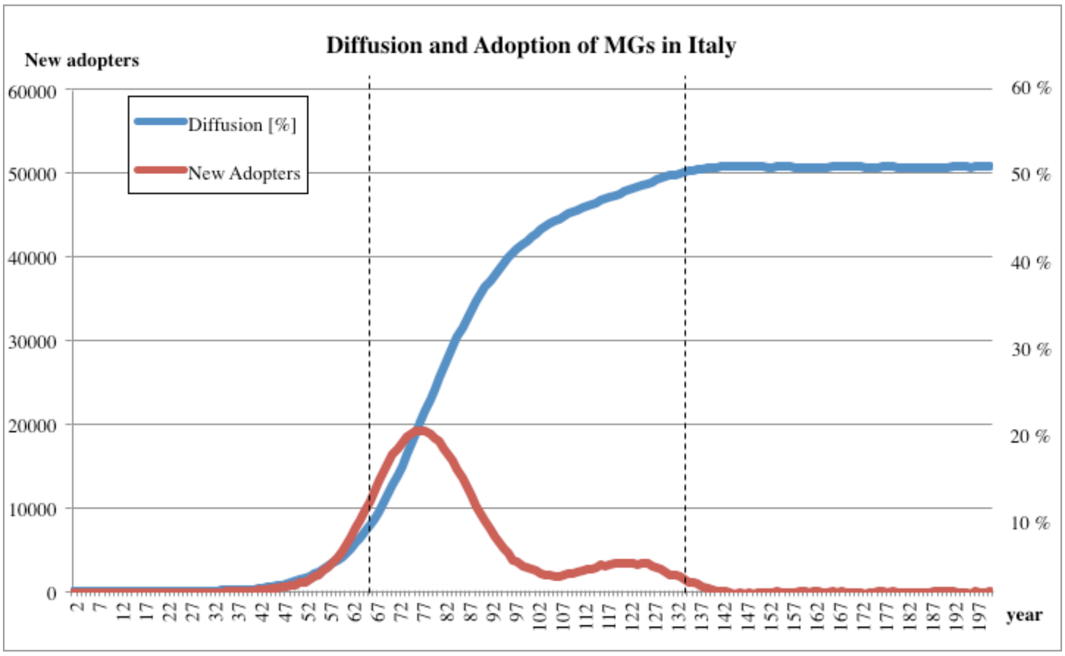


Figure 2: Diffusion and Adoption of Micro-Grids in Italy, Baseline case

The adoption and diffusion process in Italy in the Baseline scenario (without any incentive) is represented in Figure 2. First of all, it is possible to notice that the trend of the diffusion process follows an S-shaped curve. This outcome has a strong relationship with the assumptions made about the diffusion theory and the modelling exercise. The diffusion process starts very slowly in the first third of the time horizon analysed: in this early adoption phase, some "early adopters" show the interest in MGs and adopt the new infrastructure. In this way, the MG "visibility" increases among other users and the MG option becomes more attractive. These factors cause the take-off period where adoption becomes very fast: in a very short period of time, diffusion reaches almost the maximum value. In the case of MGs in Italy, the steady level achieved is about 50% of the potential adopters and this value will be maintained for all the maturity phase, which is roughly the final third period of the simulation. The likely possibility that some users do not adopt the MG system explains why the diffusion curve does not reach the 100% level. This is common in diffusion process of other eco-innovations (Faber, Valente and Janssen, 2010; Higgins et al., 2012; Shafiei *et a*l., 2012).

The reason for rejecting MG is related to the *social system* in which citizens live and their attitude to shift towards a decentralized electricity system. A potential user, before taking the decision to adopt or reject the MG alternative, is strongly influenced by the social environment around him. Therefore, the fact that only 50% of neighbours have already adopted MGs might reduce attractiveness and the "fashion effect" of that option. Moreover, the Italian attitude to produce electricity for self-consumption is low (5.4%) and it strongly affects the degree of MG adoption in the model simulation. A further analysis will be presented in order to understand the variability of the diffusion process in relation to that parameter.

Even though the diffusion only reaches 50% of total users, the literature about the new adopters' prerogative is also confirmed. In fact, as shown in Figure 2, the adoption curve in Italy follows a bell-shape trend, as theorized by Rogers (2003). He demonstrated that the innovation adoption process is likely to follow a normal, bell-shaped curve, which can be divided into 5 sectors, each one categorizing a precise type of adopter: innovators, early adopters, early majority, late majority and laggards. This adopter's nomenclature recalls the three periods previously described in the time horizon of our diffusion curve.

The diffusion process is always related to the number of people adopting a specific innovation. In the MGs case study, the decision has been classified as a "collective innovation decision". This means that a certain number of people are taking a common investment decision. According to the diffusion theory involving network externalities, the number of people joining a community has a double opposite effect: on the one hand, as long as it increases it reduces the overall cost and; on the other hand, it makes diffusion slower. In order to verify whether or not that prerogative has been confirmed in the model presented, a correlation analysis has been performed. We are interested in evaluating the correlation between the maximum number of people in a regional community with both the regional per capita investment cost and the number of years necessary to reach 40% of diffusion at a regional level. The per capita investment cost is the total amount of money requested to invest in MG when a consumer joins a regional community, computed as the average cost during the full duration of the analysis (200 time steps). The rate of 40% diffusion has been chosen because it is a value reached by all the regions and it represents 80% of the steady diffusion level. Table 7 shows the normal distributed variables considered in the analysis, and in Figure 3 there are the two scatter plots regarding those three variables.

| Region | Nt,r max value | CostPerCapita [€] | diff_40% [years] |
|---|---|---|---|
| **Abruzzi** | 39 | 20711,99 | 100 |
| **Basilicata** | 48 | 14135,35 | 102 |
| **Calabria** | 78 | 8798,07 | 134 |
| **Campania** | 70 | 10529,97 | 126 |
| **Emilia Romagna** | 32 | 22673,29 | 78 |
| **Friuli Venezia Giulia** | 30 | 9885,14 | 57 |
| **Lazio** | 53 | 11456,76 | 95 |
| **Liguria** | 50 | 16070,19 | 112 |
| **Lombardia** | 28 | 27204,18 | 75 |
| **Marche** | 43 | 17386,90 | 97 |
| **Molise** | 51 | 12009,06 | 100 |
| **Piemonte** | 35 | 20030,50 | 79 |
| **Puglia** | 51 | 8501,18 | 80 |
| **Sardegna** | 33 | 15585,00 | 69 |
| **Sicilia** | 63 | 5621,35 | 90 |
| **Toscana** | 37 | 19593,25 | 88 |
| **Trentino Alto Adige** | 32 | 21243,80 | 80 |
| **Umbria** | 35 | 18034,59 | 84 |
| **Valle d'Aosta** | 28 | 24500,53 | 78 |
| **Veneto** | 31 | 25895,49 | 86 |

Table 7: Variables considered in the correlation analysis

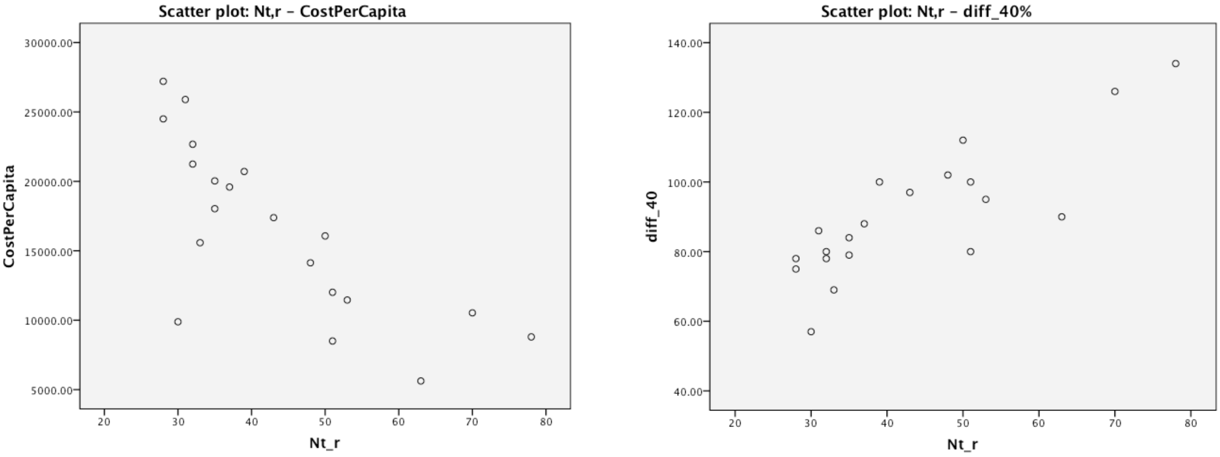
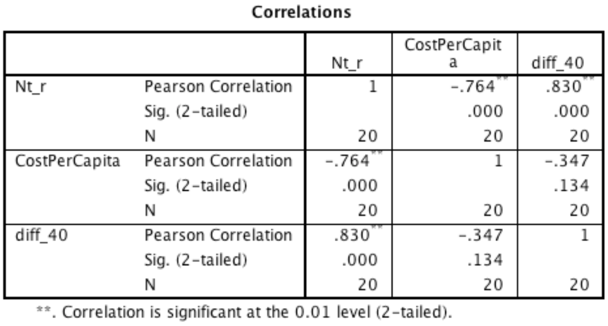


Figure 3: Scatter Plots of the relation between the maximum number of people contained in a regional community, the cost per capita and the years at 40% diffusion

The correlation analysis (Table 8), which is significant at the 0.001 level, confirms the trend visible in Figure 3. The correlation between the maximum number of people in a regional community and the per capita investment cost are negatively correlated (-0.764). It is a normal phenomenon happening in the investment communities: the rationale behind joining a community of people, in order to invest in a new electricity system, implies the necessity to decrease the investment cost, and, consequently, to reduce the risk of that investment. Therefore, according to formula ( 5 ), the fixed cost of MG decreases when the number of people in a community is high.

Conversely, the correlation between $N_{t,r}$ and the time horizon necessary to reach 40% regional diffusion is positive and strong (+0.83). This means that the more the people in a community, the longer the time to reach a certain degree of diffusion in that community. The theory explains this tendency by saying that the two moments of the diffusion process in organizations (“initiation” and “implementation”) need more time than if it was an individual adoption decision (Rogers, 2003). Since both correlations are strong, therefore, the diffusion model presented for the diffusion of Micro-Grids in Italy follows the theoretical assumption of this phenomenon.



**Correlations**

| | | Nt_r | CostPerCapita | diff_40 |
|---|---|---|---|---|
| Nt_r | Pearson Correlation | 1 | -.764** | .830** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 20 | 20 | 20 |
| CostPerCapita | Pearson Correlation | -.764** | 1 | -.347 |
| | Sig. (2-tailed) | .000 | | .134 |
| | N | 20 | 20 | 20 |
| diff_40 | Pearson Correlation | .830** | -.347 | 1 |
| | Sig. (2-tailed) | .000 | .134 | |
| | N | 20 | 20 | 20 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8: Correlation analysis: results

## 4.2 Discussion

### 4.2.1 Regional diffusion of MG

The first result discussion regards the diffusion and adoption of MG infrastructures at a regional level. The analysis performed in this work has four objectives: (i) to evaluate the duration of the process of diffusion of MG at a regional level; (ii) to foresee where (in which regions) the diffusion is more likely to happen; (iii) to identify the factors that influence the process; and (iv) to understand the mechanisms through which they influence it.

The baseline scenario simulates the diffusion process without any incentive. In Figure 4 the regional diffusion curves are reported.

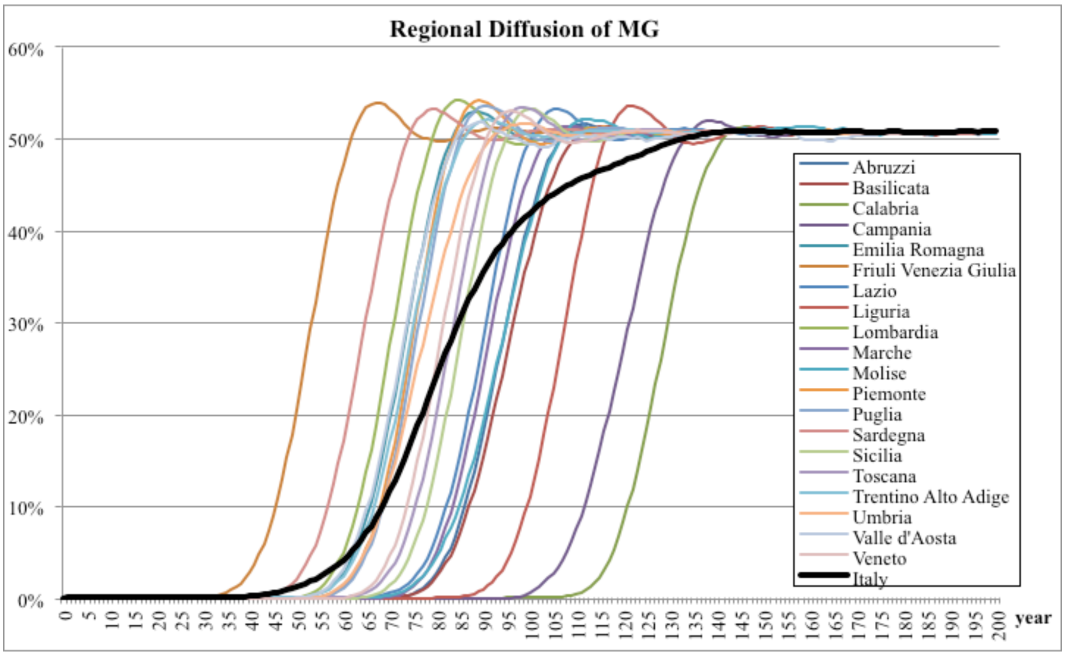


Figure 4: Regional diffusion of MGs, Baseline case

The individual regional curves also follow the S-shape trend. Every regional curve reaches a peak of diffusion, which is higher than the steady level in the maturity period of the time horizon. That peak is followed by a short decreased period; this is due to the fact that the investment duration is 20 years long and the model allows for substitution. The cumulative large number of people adopting the MG system in the take-off period simultaneously abandons that electricity system. These consumers might decide to substitute the MG: they start a new decision process by finding a new group of people willing to adopt once again the decentralised system. Hence, the combined desertion causes the short decrement in the diffusion curve, after the peak point. The second decisional phase, however, is faster than before, since MG has already achieved a certain degree of "visibility". After that transitory adoption moment, the regional steady state is reached at 50% diffusion.

The speed of diffusion, as Figure 4 shows, is very disparate among regions; even though the number of people participating in a community has a negative effect, it is still unknown what regional factors influence the diffusion, and what is their effect on that. In order to study this problem, a linear regression analysis has been performed. The dependent variable in the regression model is the years needed to reach a 40% level of diffusion at a regional level, while the independent variables are the regional electricity demand, the sum of wind and PV regional potential (expressed in hours) and the number of regional residents (expressed in thousand) considered in the structure of the agent-based model (see Table 6). In Table 9 the variables considered (normally distributed) in the regression model are summarized, while in Table 10 the results of regression analysis are reported.

| Region | diff_40% [years] | Demand [kWh/y] | Wind+PV [hours] | Population in 1000 |
|---|---|---|---|---|
| **Abruzzi** | 100 | 4913 | 1945 | 26 |
| **Basilicata** | 102 | 4497 | 2654 | 11 |
| **Calabria** | 134 | 2819 | 2790 | 40 |
| **Campania** | 126 | 3014 | 2481 | 116 |
| **Emilia Romagna** | 78 | 6242 | 2106 | 88 |
| **Friuli Venezia Giulia** | 57 | 8118 | 3596 | 24 |
| **Lazio** | 95 | 4077 | 2748 | 114 |
| **Liguria** | 112 | 4029 | 2121 | 32 |
| **Lombardia** | 75 | 6674 | 1789 | 198 |
| **Marche** | 97 | 4768 | 2263 | 31 |
| **Molise** | 100 | 4403 | 2923 | 6 |
| **Piemonte** | 79 | 5701 | 2214 | 89 |
| **Puglia** | 80 | 4597 | 3304 | 81 |
| **Sardegna** | 69 | 6728 | 2979 | 33 |
| **Sicilia** | 90 | 3836 | 3605 | 101 |
| **Toscana** | 88 | 5400 | 2190 | 74 |
| **Trentino Alto Adige** | 80 | 6406 | 2374 | 20 |
| **Umbria** | 84 | 6022 | 2630 | 18 |
| **Valle d'Aosta** | 78 | 7490 | 2546 | 2 |
| **Veneto** | 86 | 6060 | 1752 | 98 |

Table 9: Variables considered in the regression analysis

Coefficients[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 183.584 | 11.222 | | 16.359 | .000 | | |
| | Demand | -.012 | .001 | -.932 | -10.665 | .000 | .977 | 1.024 |
| | Wind_PV | -.010 | .003 | -.276 | -3.075 | .007 | .925 | 1.081 |
| | Population | -.083 | .033 | -.224 | -2.485 | .024 | .918 | 1.089 |

a. Dependent Variable: diff_40

Table 10: Regression analysis: results

The overall regression model is significant and explains 88% of the total variation in the dependent variable[11]. The three independent variables have a positive effect on the speed of diffusion since they, *ceteris paribus*, decrease the time needed to reach 40% diffusion of MG at regional level.

An increase by 1 kWh in the regional demand independent variable, significant at the 0.01 level, reduces the dependent variable by 0.012, holding constant all the other independent variables. It means that each additional kWh demanded by the consumer reduces the speed of diffusion by about 5 days. In other words, the speed of MG diffusion is faster when the regional electricity demand is high. Why? People living in regions where the electricity demand is elevated, at the starting point of the simulation, pay a higher price for electricity than in regions where demand is lower, since the electricity price is the same at a national level. Moreover, the electricity price supplied from the national grid follows an increasing trend each time step (formula ( 1 ). For these reasons, along the years, the option to invest in Micro-Grids is more profitable for people living in regions where electricity demand and current costs are high.

Similar to the demand variable, the combined wind and PV regional potential variable positively affects the speed of regional diffusion. An increase by one hour in the regional potential affects the dependent variable by decreasing its value of 0.01 (four days). Micro-Grid diffusion, therefore, is strictly related to the renewable potential, because it reduces the variable cost of Micro-Grids. Moreover, since renewable sources receive national incentives (see Table 1) their individual profitability influences the MG profitability as well.

Lastly, population, significant at the 0.05 level in the regression model, also decreases the speed of diffusion. An increment by 1000 people at a regional level, *ceteris paribus*, decreases the number of years necessary to reach 40% diffusion by 0.083, which means about one month in time. This effect has two explanations, which recall the theoretical literature. In fact, the more the residents in a region, the higher the opportunity to develop what Rogers calls the "interpersonal communication channels". Moreover, the first MG adoption can be seen by more people, who are then willing to imitate those early adopters, confirming the centrality of "fashion effect" also in this diffusion study case.

To sum up, the regional diffusion and adoption of Micro-Grids in Italy is a process very susceptible to many variables. Firstly, since the adoption decision involves a community of final users, the speed of diffusion decreases along with the increase in the maximum number of people that can enter in that community, even though it reduces costs and profitability of the investment. Secondly, electricity demand, wind and PV potential and the number of residents influence positively the speed of regional MG diffusion. Moreover, the overall model presented is validated by means of the general result obtained by the simulation: the diffusion process and the regional adoption follow, respectively, an S-shape trend and a bell-shape curve. However, since the general Italian attitude towards more decentralized electricity system is not very high, the maximum rate of MG diffusion is about 50%.

Can a subsidy schema change this trend? To what percentage? The following section tries to answer these questions by simulating different subsidy scenarios at a national level.

### 4.2.2 National diffusion of MG: subsidy scenarios

The regulatory issue around Micro-Grids has a lack of policies able to push the diffusion of MGs towards national territories. The result of the regional analysis shows that the diffusion process in Italy is relatively slow since it will reach 30% diffusion after 85 years. In order to evaluate whether or not subsidies can be effective in accelerating the process of diffusion, four model configurations have been simulated. Each simulation represents an alternative scenario regarding a specific subsidy provided to the community in order to adopt MG. Starting from the baseline case, the other cases take into account subsidies, which start from €50,000 in the first and increase by €50,000 in subsequent

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[11] Rsquare=0.881. The assumption of homoscedasticity, linearity, no multicollinearity and normality of residuals are satisfied.

simulations (Table 11). The amount of subsidy received because of MG adoption, however, decreases together with the raising number of systems already adopted, as showed in formula ( 3 ). Figure 5 shows the diffusion curves under those scenarios.

| Scenario | SPt |
|---|---|
| Basecase | € - |
| Subs50k | € 50.000 |
| Subs100k | € 100.000 |
| Subs150k | € 150.000 |
| Subs200k | € 200.000 |

Table 11: Subsidy scenarios

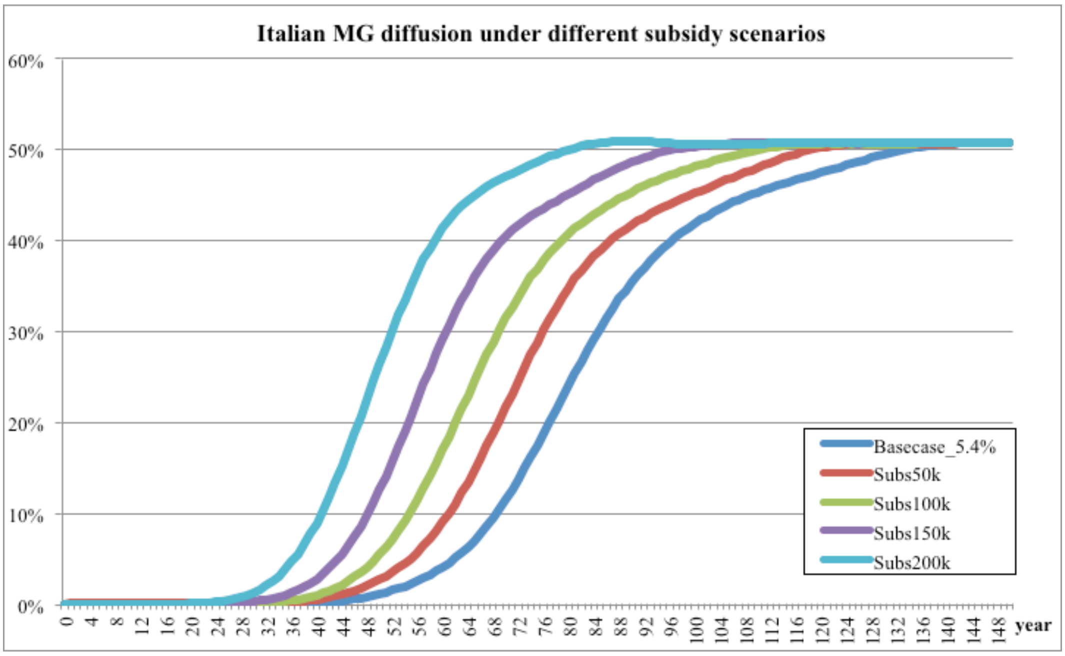

Figure 5: MG diffusion in Italy, under subsidy scenarios

Subsidies, according to Rogers (2003, p. 236), have the function to "increase the degree of relative advantage of an idea" for potential adopters. The advantage is, of course, in terms of lower expenditure compared to other options. In other words they allow the reduction of the initial cost of an innovation, which affect the rate of adoption, resulting in a more rapid progress. In Italy, the diffusion process of MGs follows this theoretical prerogative, where an elevated subsidy allows a faster diffusion. The curves resulting from each simulation show that the diffusion process starts earlier when the amount of subsidy is higher. However, the maximum rate of adoption is not increased compared to the baseline case. Its value remains at around 50% because the Italian attitude regarding the decentralized electricity infrastructure does not change along with subsidies ("green parameter" set at 5.4%).

In the previous paragraph, the relevance of the users' attitude is presented as the key factor influencing the maximum rate of adoption. Moreover, the nature of the social system affects it as well. In fact, in agreement with the classic diffusion theory, "critical mass" (Gersho and Mitra, 1975) is crucial, which usually occurs at 3-16% of the adoption process. This means that a subsidy scenario has to push adoption up to that percentage, and as soon as possible. In this crucial adoption phase (early adopters) the first Rogers' attribute (*relative advantage*) is determinant. Further, a second attribute has to be considered in the diffusion process: the *complexity* of the MG system is a factor influencing the slow adoption of that electricity infrastructure. This is a common result in eco-innovations diffusion (Ting *et al*., 2011). MG, also, cannot be experimented by potential adopters (*trialability*), but it can solely be *observable*; those attributes influence the rate of adopters. Therefore, the visibility of previously installed MGs is important as well as the *compatibility* of those electricity systems with potential adopters' values, past experiences and needs. Therefore, a way to increase the probability to rapidly diffuse an innovation is to incentivize early adopters.

The most suitable subsidy scenario, in order to increase the speed of diffusion, seems to be the one with an incentive of €200,000. In fact, it allows reaching 26% diffusion of MGs in only 50 years, which is about half of the maximum adopters' share achievable in Italy. However, it is also the most expensive on the basis of the cumulative subsidy provided. At the end of the simulation period, it amounts to €70.12 billion, which results in a very expensive subsidy policy. Rogers affirmed that "once a level of, say, 20 percent adoption is reached in a social system, the economic incentive is discontinued" (Rogers, 2003, p. 238). In order to verify whether or not this assumption is met, simulations have been run under the most profitable subsidy scenario (€200k). In each simulation, the subsidy is provided until a certain rate of diffusion at national level is reached (Figure 6).

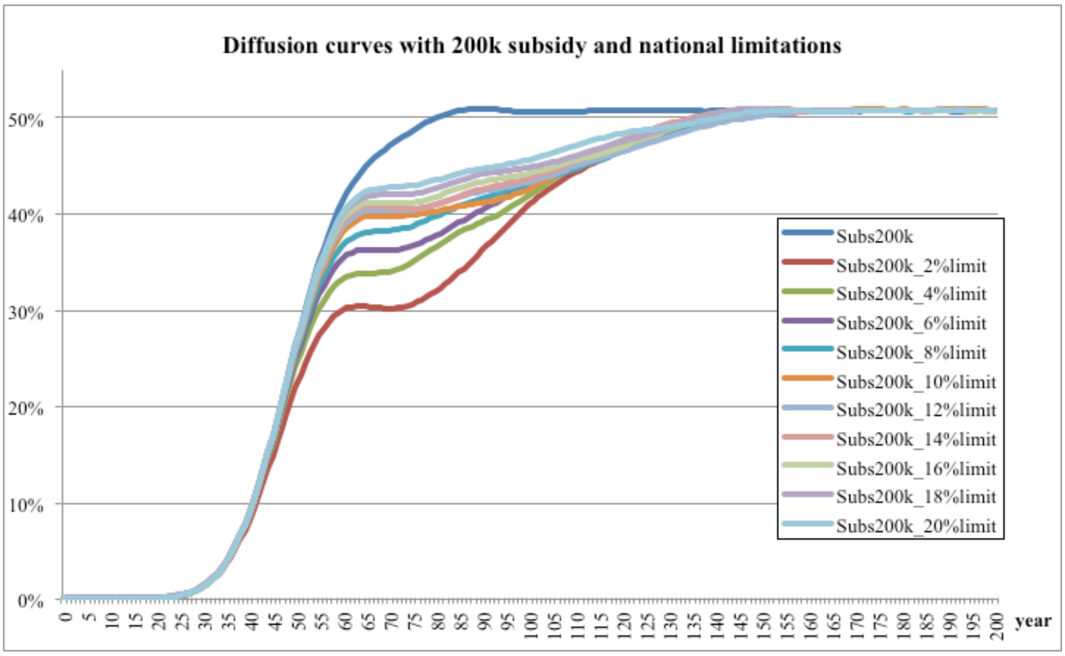

Figure 6: Diffusion curves with 200k subsidy and national limitations

The result of this simulation shows that the diffusion process follows, more or less, the Subs200k configuration until it reaches 30%; after that, depending on the limit set, each curve has a trend, which becomes faster every time the subsidy limitation increases. The rationale behind that is evident: the higher the amount of subsidy provided to adopters, the faster the adoption process. However, the diffusion process does not replicate the Subs200k line, even when the subsidy is provided until 20% diffusion at national level. This indicates that, even though the diffusion process is improved by means of subsidy in many regions (this is the reason why until 30% the curves are overlapping), there are some other regions where diffusion has not yet started or been fully accomplished (this explains the different and lower slope of the curves after 30% diffusion).

Therefore, we can conclude, that this policy is discriminatory against potential adopters in regions where the diffusion of Micro-Grids is strictly dependent on local factors. Moreover, even if the ten different subsidy scenarios simulated have lower cumulative subsidy expenditures (see Figure 7), the small improvement in the diffusion speed does not justify a more expensive subsidy schema.

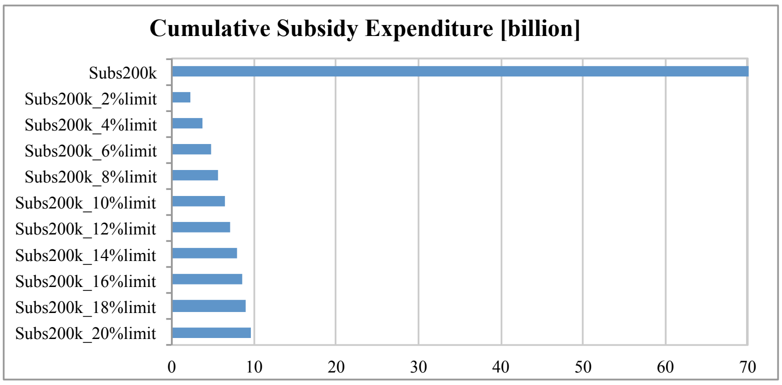

Figure 7: Cumulative subsidy expenditure under the 200k subsidy and different limitations

Two additional scenarios have been simulated, then, in order to orientate subsidy at a regional level. In fact, the limitations of the subsidy have been set at the regional diffusion rate, rather than at the national level. The result (Figure 8) shows that stopping subsidy at 1% regional diffusion allows having a curve very close to the Subs200k scenario, and that at 5% the curve is exactly matching the scenario without limitation. This happens because each region can benefit from the subsidies provided, contrary to the previous subsidy scenario where only the some of them could. Moreover, the cumulative subsidy expenditure are much lower than the previous case shown in Figure 7: in fact, in the Subs200k_1%reg it amounts to €2.14 billion while in the Subs200k_5%reg to €5.76 billion.

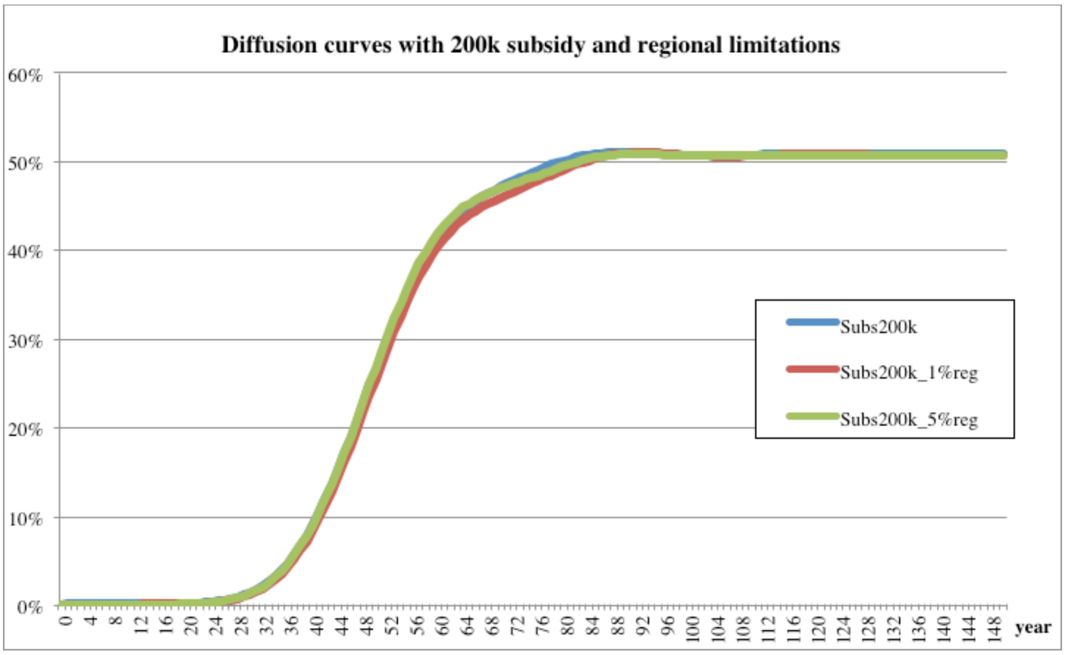

Figure 8: Diffusion curves with 200k subsidy and regional limitations

In conclusion, the last two scenarios simulated suggest that a regulation focussing on electricity generation, aimed at the diffusion and adoption of new innovations and systems, might be more effective if it is regional-based rather than national-based. The reasons are mainly demographic, climatic and related to electricity demand, which are very heterogeneous along the Italian territory. All the three cited elements are factors influencing diffusion at a regional level and a subsidy policy has to take them into account.

### 4.2.3 MGs and the environmental benefits in Italy

This last section focuses, firstly, on the environmental benefits that a MG system could have and, secondly, on the "green" attitude of consumers, in order to understand how they could affect the process of adoption and diffusion.

As discussed at the beginning of this paper, decentralized electricity systems have the very likely potential of improving national environmental performances, by installing renewable sources, producing electricity from them and using that production for self-consumption. Therefore, Micro-Grids have a clear advantage in the reduction of losses compared to the national grid, where electricity transmission is not efficient to increase the penetration of renewable sources and to make areas or buildings quasi-independent in terms of electricity production and consumption. Those three features of the MG infrastructure can help a country to address its environmental concerns. In Italy, according to the baseline case, the energy mix obtained by adopting MGs sees, on average, an increment of the renewable power installed (wind and PV power together) by 6.3 MW per year. Therefore, on average, for each year of the time horizon simulated, 7,097 tonnes of CO2 are avoided by installing micro wind turbines and the photovoltaic panels within the MG system[12].

However, the yearly environmental benefit, generated through the installation of new Micro-Grids, is related to the users' attitude to invest in decentralized electricity systems. In the model, the willingness to shift towards the new electricity infrastructure has been represented in a parameter called "green" and set at 5.4%. This value reflects how much electricity production has been used for self-consumption in Italy in 2012. This percentage denotes that the majority of Italian consumers prefer to maintain the electricity supply from the national grid, even though, while the electricity price increases, the MGs present clear advantages in terms of economic savings. In order to evaluate the influence of the "green" factor in the model, a simulation has been run setting a different value. We assume a value 50% higher than the value set in the Baseline configuration; that is 8.1%. The outcome of this simulation (Figure 9) suggests

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[12] The value has been computed by multiplying the parameter of the CO2 avoided by renewable electricity production (Bechis and Marangon, 2011) with the renewable electricity produced in MGs. This last value, on yearly average, is the net amount of new wind and PV installed capacity in new communities multiplied by the Italian average of functioning hours for both sources.

that a higher "green" attitude allows a faster diffusion process and, what is more important, with a higher rate. Moreover, this higher elevated individual "green" attitude allows the avoidance of 8,147 tonnes of CO2 per year, which confirms the fact that the global GHG emissions problem could be partially solved at the citizen level.

Therefore, we can conclude by saying that MG adoption and diffusion is very much linked to people's interest in decentralized electricity systems and to their readiness to produce electricity for self-consumption. The higher those characteristics, the faster and deeper the diffusion. And, moreover, since diffusion concerns individual decisions, people are always the main actors of this process.

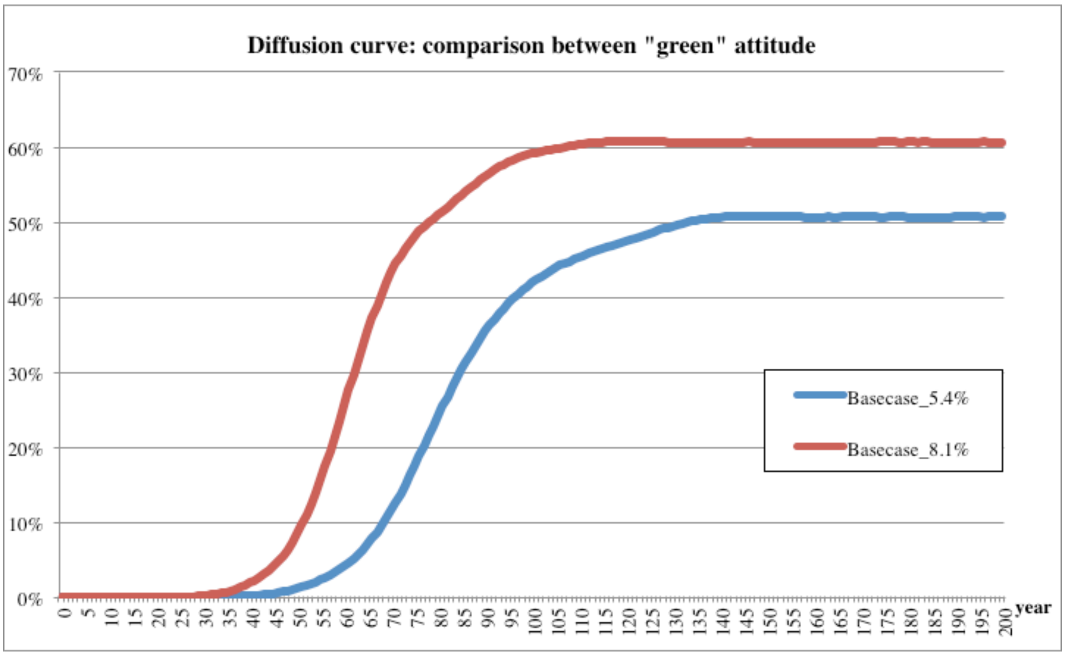

Figure 9: Diffusion curve under two different "green" attitudes

## 5 Conclusions

This work analyses the adoption and diffusion of Micro-Grids (MGs) in Italy by considering regional factors.

MGs are decentralized electricity systems working quasi independently from the national centralized grid. This new infrastructure involves a cluster of technologies functioning together in order to supply electricity to a limited number of users living in the same neighbourhood. The components of the structure of MG considered in this study are renewables energy sources (RES), such as micro wind turbines and photovoltaic panels, and biomass-based micro-cogenerators.

There is a broad literature on decentralized electricity systems, covering research fields related to eco-innovations: technological, environmental and regulatory. From a technical point of view, the whole array of elements concerning MGs seems ready for a wide implementation, and, consequently, for the accomplishment of the transition from a centralized to a more decentralized electricity system. But this shift has not yet started. The Italian electricity supply infrastructure, indeed, is totally based on the national grid even if it presents high inefficiencies (in 2010, losses in the transmission system amount for 6.2% of net electricity production) and is highly import-dependent (83.8% of fuel was imported in 2010 and 15% of electricity was imported in 2011).

The agent-based model formulated and simulated in this study shows that the adoption and diffusion of MGs in Italy would depend on three main aspects: regional specificities, subsidies and people's attitude.

The main conclusion of this work con be summarised as follows:

1. Given the high heterogeneity of Italian regions in terms of electricity demand (mean: $\mu$=5290 and standard deviation: $\sigma$=1434 kWh/y per capita), renewable potential ($\mu$=2551 and $\sigma$=540 functioning hours per year) and population ($\mu$=3 and $\sigma$=2.5 million of residents per region), the relative MG diffusion differs a lot from one place to another ($\mu$=91 and $\sigma$=19 years to reach 40% of diffusion rate). On average, it determines a slow overall diffusion and at a low rate (50% maximum).

2. The model, then, shows that in the Italian MG case study, subsidy can definitely accelerate the process of diffusion (38 years less to reach a level of diffusion of 40% compared to a scenario without subsidies), when they have no limitations. However, the cumulative expenditure under this scenario is quite important (€70.12 billion). When limitations are set to the subsidies until a certain rate of national diffusion, even if the cumulative expenditure decreases considerably, the duration of the diffusion is higher. Conversely, when limitations are set to the subsidies until a certain rate of regional diffusion, we observe a modest cumulative expenditure and a better trend in terms of speed, compared to the national-based subsidy scenario.
3. The diffusion of innovation is strictly related to the decision phase, when a consumer decides to adopt or reject a new technology. The user's cognitive decision, moreover, is influenced by his attitude concerning the opportunity to adopt a new infrastructure permitting the production of electricity for self-consumption. Therefore this parameter is crucial in the diffusion model. The higher the "green" attitude of the consumer, the faster and deeper the diffusion. What is more important, since MGs are eco-innovations, because they involve wind turbines and PV panels, a higher attitude in favour of MG results also in a relevant reduction of CO2 emissions.

Therefore, in national contexts aiming at intruding new decentralised electricity systems for the substitution of or integration with the existing centralised infrastructure, policy-makers should consider different aspects. Firstly, higher renewable potential and elevate electricity demand might be favourable factors to boost diffusion of MG. Furthermore, a policies aiming at incentivising transition towards centralised infrastructures would be more effective if tailored to regional specificities, instead of being national-based. Nevertheless, when the ownership of MG concerns consumers only, their "green" attitude plays a crucial role. When it is low, diffusion is slow and does not reach the whole population. Therefore, it is also important to put in place policy strategies that can increase people willingness to invest in more sustainable and environmental friendly energy infrastructures.

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