International Journal of
Sustainable Energy Planning and Management

A technology evaluation method for assessing the potential contribution of energy technologies to decarbonisation of the Italian production system

Elena De Luca*, **Alessandro Zini, Oscar Amerighi, Gaetano Coletta, Maria Grazia Oteri, Laura Gaetana Giuffrida, Giorgio Graditi**

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Lungotevere Thaon Di Revel 76, 00196 Rome, Italy

ABSTRACT

This paper aims to give a footprint of the development potential of energy technologies in Italy providing a synthetic and general view to support policy makers in energy planning. The approach focuses on the impact on climate, the potential in terms of R&D, the competitiveness of Italian companies and their diffusion on the territory. A reference Catalogue was realised in the framework of the 'Technical Board on Decarbonisation of the Economy', established by the Italian Presidency of the Council of Ministers. 36 datasheets, containing quantitative and qualitative information on Technology Readiness Level (TRL), efficiency, environmental and economic impacts and policy aspects were filled by 70 experts for each technology. Some data were extracted from the Catalogue – TRL, CO_2 emissions, developers, and centres of excellence – and further analysed and integrated with other information relating to the Italian production and innovation system collected from the National Enterprise Registry (ASIA). Companies and research centres are involved in development of technologies based on Renewable Energy Sources (RES) and Energy Storage (ES) with different levels of TRL and high potential for mitigating effects on climate. However, their distribution shows a rather inhomogeneous presence at territorial level.

Keywords:

Technology Evaluation;
Decarbonisation;
Technology Readiness Level (TRL);
Energy Planning;

URL: https://doi.org/10.5278/ijsepm.4433

1. Introduction

European Union member states are facing a challenge of climate change mitigation which makes it necessary to develop strategies for the transition to a low-carbon economy. This is consistent with the political 2030 objectives outlined in the European Green Deal [1–2]. The establishment of common objectives at an international level can lead to controversies [3]. The development of clean technologies will reduce production costs and thereby positively affect the reduction in greenhouse gas emissions and the abatement costs [4–5]. Specific features such as R&D, commercialization capabilities and product competitiveness could influence the market penetration of technologies as well as support schemes [6].

The sustainability of the energy system should be addressed by a multidisciplinary approach [7]. In this context, the energy planning is a branch of research oriented to draw a roadmap which takes into account technical, economic and societal issues. The terms of planning are determined by the ability to use mature

*Corresponding author - e-mail: elena.deluca@enea.it

technologies (short-term) and to adopt new ones (medium/long – term) [8].

An accurate technology evaluation should be addressed to the three conditions posed by the so-called energy 'trilemma'. The concept of energy 'trilemma', introduced in 2003 [9], brings out the complexity of balancing the three pillars of a sustainable energy system: decarbonisation, energy security and energy cost [10]. Energy security represents the energy supply side, the reliability of energy infrastructure and the ability to meet current and future demand. Energy cost is related to the accessibility and affordability of energy supply across the population. Decarbonisation encompasses the increase of the energy efficiency and the development of renewable and other low-carbon energy supplies to address the environmental concerns reducing greenhouse gas emissions [11].

Many studies seek to identify contrasts and possible trade-off between the different features of the 'trilemma' in order to facilitate the policy making process, the governance and the business decisions [12–13]. This approach could be applied to particular issues related to some technologies [14,15]. More precise information on the value of the different technologies could also allow an evaluation of their impact on employment, as already estimated for some single energy technologies [17].

In this framework the evaluation of energy technologies must be carried out in accordance with specific descriptors opportunely settled. 'Technology evaluation' is an issue widely recognized both in the research and industrial sectors [18,19]. Different models and indicators are currently proposed to this aim. In particular, input-output analysis, analytic hierarchy process, data driven approach and simulation models were proposed since the early seventies [20–24].

In depth energy planning could also contribute to design specific solutions to resolve the issues related to the excess of electricity produced by renewables in accordance with the decarbonisation goals [25]. Moreover, specific indicators tailored for developing countries are investigated to address energy planning supporting policy makers and energy experts [26].

This paper represents a feature of Italian analysis on the energy sector oriented to energy planning. It can be helpful for engaging stakeholders and facilitating the energy transition goals by providing an interpretation of data coming from the industrial and research system. Italy is making a great effort in energy planning which is leading to appreciable results in terms of the effectiveness of the policies. It has now become clear a general improvement by 1990 in particular in comparison with other European countries [27]. At national level, in addition to political decision makers, different stakeholders play a fundamental role in the energy transition with particularly regard to the Italian operators that can influence the development of such energy technologies [28].

In order to draw up the National Energy Strategy Plan, the Italian Presidency of the Council of Ministers set up the "Technical Board on the Decarbonisation of the Economy". The goal is to analyse the energy system from various stakeholders point of view and to evaluate the Italian policies in the energy-environmental field within the framework of EU regulation. Four Working Groups (WGs) have been established to achieve synergistic and complementary objectives (Annex A).

In this framework the "Catalogue of Energy Technologies" [29] was realised to draw the status of the technologies and their potential penetration in the energy market by the view of the energy transition.

Some relevant data contained in the Catalogue were analysed and elaborated using a statistical approach. An analysis was carried out on Technology Readiness Level (TRL), CO_2 avoided emissions and Italian companies and Centres of Excellence involved in production and/or R&D. The TRL, in particular, is a parameter to measure the state of a technology often used in the context of evaluating funding research projects. International literature adopt TRL with particular reference to the RES [30,31]. Moreover, TRL values were used in technology maturity assessment models designed to evaluate the implementation of manufacturing technologies [32].

Figure 1 shows the methodological scheme adopted by identifying four steps: data sources, parameters, analysis and evaluation. The dataset was enlarged with information collected by the National Enterprise Registry (ASIA) characterizing the companies active in the development of these technologies, assessing the territorial diffusion, the size class and turnover.

This study highlights peculiarities and issues related to the Italian energy sector suggesting strategies to support research and/or the domestic production chain. Italian companies and centres of excellence are involved in the development of technologies with different degrees of technological level with potential for mitigating effects on climate.

However, the mapping of companies and centres of excellence shows a distribution which is not always

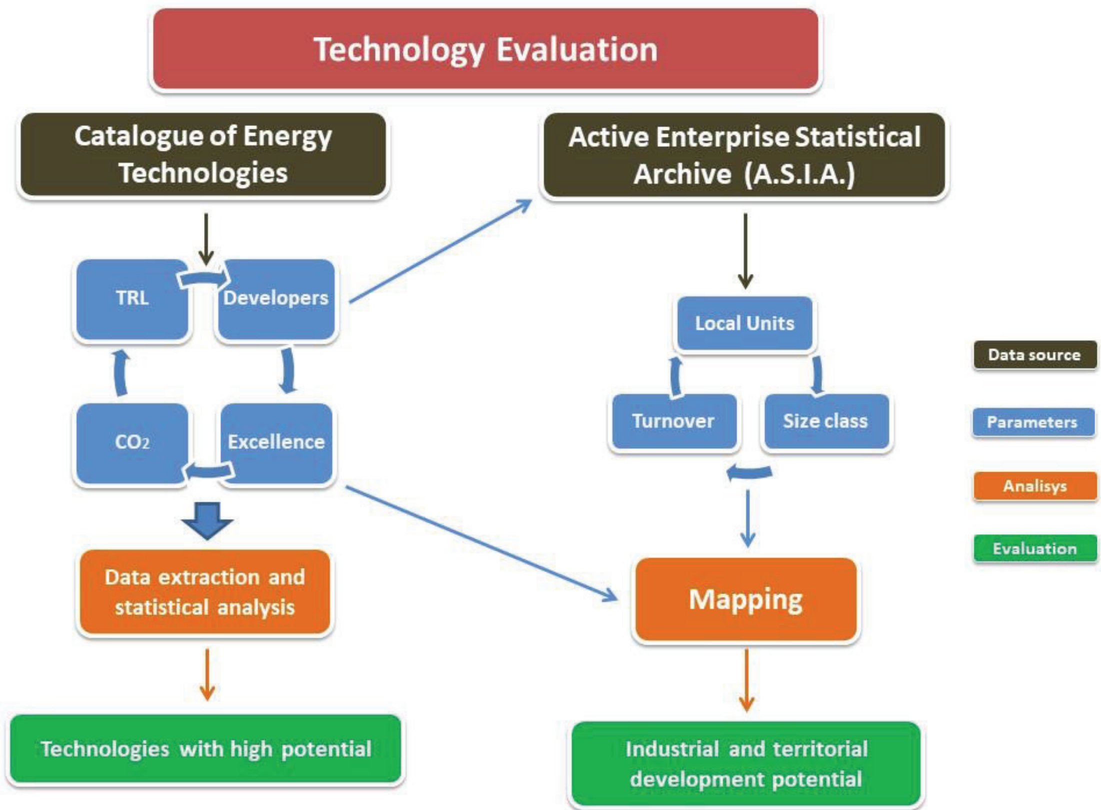

Figure 1: Methodological scheme followed by identifying four steps: data sources (brown), parameters selection (blue), type of analysis (orange) and evaluation (green)

overlapping with a rather inhomogeneous presence at a territorial level. This result could indicate the need of tailored policies and tools for a suitable spatial planning indicating possible synergies between different stakeholders [33].

The proposed methodology provides a description of the sector and useful elements to elaborate policy measures for the diffusion of energy technologies and could be repeated in other territorial context. In perspective, the technology evaluation could be integrated by the assessment of social indicators [34], with a special focus on the impact on job market and employment. The social aspects have been particularly considered to the extent that the job opportunities have been introduced as a pillar of the proposed energy quadrilemma [35].

2. Methods

2.1. Technology evaluation datasheet

The Catalogue is a result of a dialogue among 70 experts – from Research Institutions, Private Sector and representatives of Public Sector – who have built up a standard datasheet for technology evaluation.

The data and information reported in the datasheet are updated by 2017. Each technology is described by potential of decarbonisation and TRL value. TRL range starts from the emerging technologies, characterised by low TRL (TRL = 2), to those available in the market (TRL = 9) (Table 1).

The standard datasheet has been designed to be easily exported in a database to facilitate the data updating, through pre-set and length limited fields. In addition to technical information, such as the thermal/electrical efficiency of a conversion system and the average plant life, qualitative information such as technology development, sectoral impact, export and organizations involved in R&D and implementation has been collected (Annex B).

2.2. Statistical analysis

In order to illustrate the potential development of the energy technologies in Italy, some quantitative analyses have been carried out. The data matrices of TRL,

CO_2/MWh avoided emissions, the Italian companies involved in development of technology and Research Excellence Units (Table 2) have been elaborated by statistical tools.

Cluster analysis (https://www.r-project.org/, accessed by December 2019) was performed to make a classification based on TRL values and the number companies involved in each energy technologies.

The relation between TRL (medium value and range) and CO_2 avoided emissions has been displayed by a scatter plot diagram. Network analysis was performed to highlight the existing interconnections between Research Excellences and the technologies sorted by scatterplot with high potential of development in relation with CO_2 avoided emissions. The network graph has been produced by means of VOSviewer software (VOSviewer, Centre for Science and Technology Studies, Leiden University, The Netherlands, accessed by May 2019).

Table 1: Technology Readiness Level (TRL). The values varying from 1 to 9 describe in ascending order the technology state

TRL	Description
1	Compliance with the main principles
2	Technology Concept
3	Experimental test of concept
4	Technology validation in laboratory
5	Technology validation in industrial meaningful conditions
6	Technology demonstration in industrial meaningful conditions
7	Prototype system demonstrated in operative conditions
8	System completed and qualified
9	Real System tested in operative conditions (competitive production, product marketing)

Through the information related to the 'Developers' a reference database has been created with the Local Units of the companies, by elaborating the info available in ASIA – Council Regulation (EEC) No 2186/93 - which is a common framework for setting up statistical business registers. Then a regional geographical distribution of Local Units of Italian companies involved in development of technology and Research Excellence has been produced through the free open source software QGIS (https://www.qgis.org/it/site/ accessed by May 2019). Data related to the turnover and the number of employees of companies have been also collected and elaborated.

Finally, some geo-statistical tools have been used to explore the hypothesis of geographical concentration of the Research Excellence in the urban areas. To this aim, a map has been created by overlapping two different geographical layers. The first layer describes the degree of local urbanization through the urban clusters data (GEODATA-Eurostat), that is, groups of 1 km^2 contiguous cells, with a population density equal or higher 300 inhabitants/ km^2 and a total population of 5000 inhabitants, at least. The second layer represents the exact localization of the Research Excellence. Moreover, the statistical function Linhom Ripley L [36], has been used to test the hypothesis of concentration of the Research Excellence and to estimate the extent of an optimal value of their reciprocal spatial distance analyse.

Table 2: Description of the parameters taken from the catalogue and used as data source for the analysis

Parameter	Description
TRL	Data taken from the catalogue related with the Technology (or part of the process) Readiness Level, as resulting from the experts, on the basis of international review
$kgCO_2$/MWh avoided emissions	The potential mitigation, in terms of climate change emissions avoided ($KgCO_2$/MWh), with respect to the corresponding technology/process based on fossil fuels, is considered
Developers	Actors (companies, technology districts, joint enterprises, test laboratories, etc.) also in cooperation with research institutes, directly involved in the development (designing, implementation and maintenance) of technology or part of it (components) or in the technology industry. The actors may have their headquarters in Italy or they are branches of foreign companies, located on the Italian territory.
Research Excellence	Public Research Institutes (National research centres, Universities and laboratories) or private entities (consortia, enterprises, consulting companies) conducting high level research, in the technology sector. Such centres strengthen the national scientific base and support the creation of science-industry partnerships and the development of organizational strategies for national and international cooperation.

3. Results and discussion

Level of technology readiness and involvement of the Italian industry

The range between the minimum and maximum values of TRL detected recorded for each technology (Figure 2).

Such information should be considered as a proxy of the potential development of technologies [37]. In the case of a narrow range between 8 and 9 – as in 'Direct combustion of waste' or 'CAES Technology' – further innovation will be very limited. Instead, in the case of a wide range of TRL (2 to 9) – for different RES and Energy Storage Systems, even if some products are already available on the market, the technologies involved have a substantial margin of innovation, especially in component development, which may lead to increase efficiency and/or economic/environmental sustainability. In the case of low TRL, with a very narrow range – Flywheels, Solar Fuels, etc. – the involved technologies need additional efforts in research in order to enter the market.

The sectors characterised by a wide range are affected by uncertainty and potential risk for investment due to the product technology configuration on the market. In fact, among the different technology solutions the spread of the TRL range indicates that the standard is not yet achieved by the industry, therefore, the evolution of the industry structure and the competitiveness of the sector cannot be forecasted. The cases of "Solar Thermodynamic" and the "Low Carbon Fuels" (TRL range 2-9) are typical examples. Although the products are already on the market for these technologies, a predominant standard does not exist yet and the margins for further developments and/or changes are still open. Instead, in the case of narrow ranges and high average TRL values (i.e. between 8 and 9), the sector is characterized by an improved definition of the technology; and the chance of substantial changes, both in technology and in the industry structure, will be relatively lower. The "Direct combustion of wastes" and the "CAES Technology" are related examples. In case of low average TRL value and quite narrow range, as for "Flywheels" and "Solar fuels", the technology is still at prototype level, quite distant to the market, and under development by public research institutes. Companies will be involved only after the phase of technical-commercial validation.

In order to support a possible classification a cluster analysis has been applied on TRL data – both range and average value – and the number of developers (Figure 3).

Three groups are identified:

- Group A includes technologies with specialization content
- Group B includes technologies with high potential of innovation;
- Group C includes innovative technologies with high degree of diffusion.

Group A includes technologies mainly characterized by a high TRL average value, narrow range and a limited number of companies involved, with the exceptions of "Illumination" and "Transparent thermal insulation," which include more than ten companies. Technologies based upon traditional sources, some storage systems, some RES (among which "Energy from marine currents", "Thermochemical conversion of biomass" – and "Illumination") and "Transparent thermal insulation"and energy efficiency technologies are included in this group. The technologies in Group A are basically standardized, and characterized by few companies. The structure and the international competitiveness of these companies should be deeply analysed in the frame of the national production system.

Group B includes 13 technologies characterized by a wide TRL range, and with the average value basically lower than the two other groups. Probably, the trade of these technologies is not yet consolidated, although some products are already available on the market. A deeper analysis would be needed to explore the variability in the number of the companies involved in several technologies.

Finally, Group C includes technologies that are mainly characterized by a high number of developers involved and basically have a medium-high level of readiness. Among these technologies, the "Solar Thermal" is the only one characterized by the TRL value variation remaining high, since a number of development programs for new systems and advanced high efficiency components are in progress.

More than 200 companies was recorded in the Catalogue, among these the medium-large size are involved in the development of more than one technology. More than a quarter of the total number of the companies examined, employ more than 250 workers and the total number of workers is more than 80,000. More than 30 % of the companies examined have sales revenues higher than 50 million €/year.

Table 3 synthetizes the information related to the size of the companies examined – in terms of total workers, class of workers, class of turnover and numerousness of

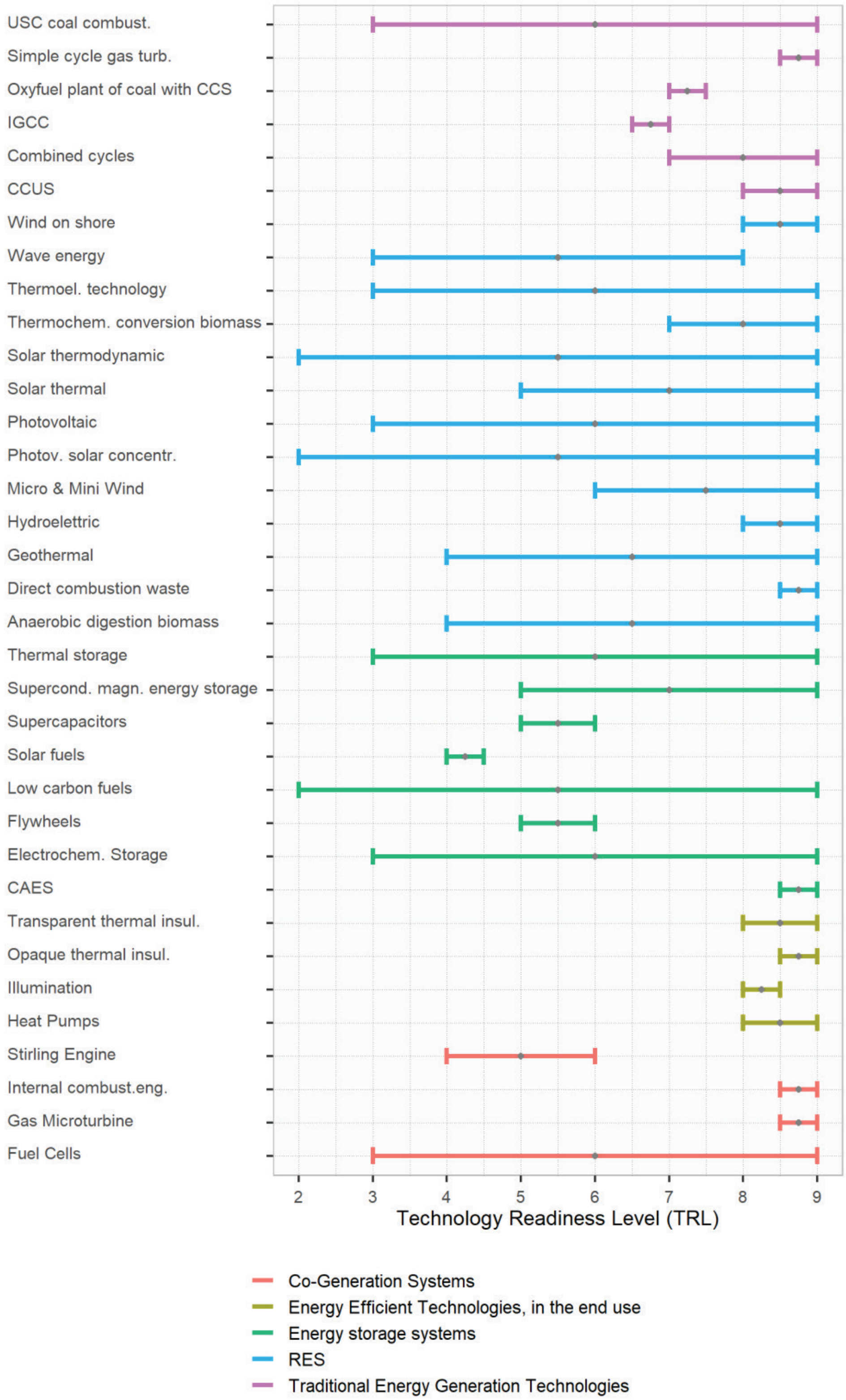

Figure 2: TRL range: minimum and maximum values detected for each technology

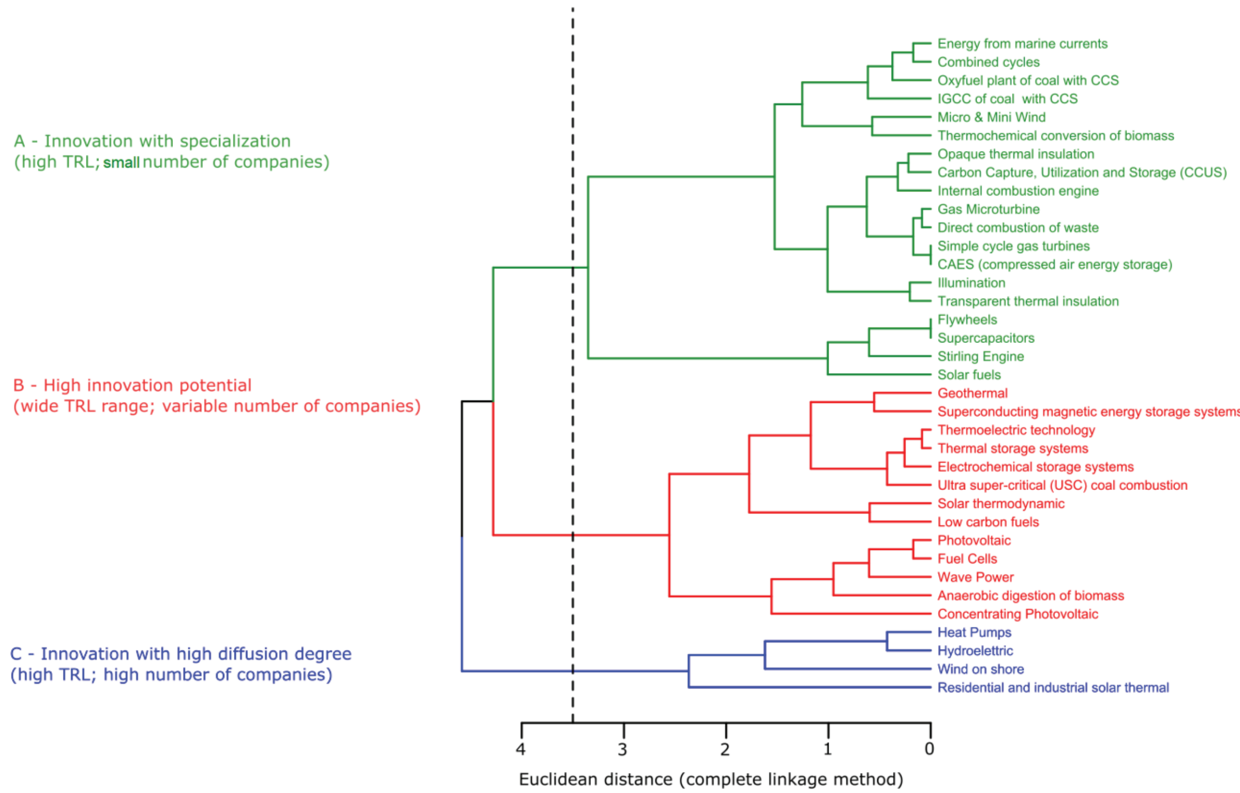

Figure 3: Technologies classification. Three groups are identified (A in green, B in red and C in blue) depending on the level of maturity

Table 3: Size characteristics of the companies examined, ordered by group of energy technologies

Group of technologies	Companies with more than 50 workers	Companies with sales revenue higher than 50M€/year	Number of companies	Total number of workers	Share of women employed
Renewable Energy Technologies	18,7%	24,5%	139	36.817	18,9%
Energy storage systems	26,7%	33,3%	15	4.771	23,5%
Co-generation systems	33,3%	37,5%	24	15.541	17,5%
Generation Technologies with fossil sources	57,1%	57,1%	7	18.645	26,2%
Energy efficient technologies	55,9%	70,6%	34	21.334	22,2%

actors – ordered in groups of technologies, as illustrated in Figure 2. In general, it is pointed out that the average size of the examined companies, in terms of number of workers, is higher than the average value in the manufacturing sector, as a whole, where the micro-small size companies (less than 50 workers) are the 97% of the total, versus the 0,3 % of large size companies.

The companies involved in the RES technologies are the most numerous and are characterized by an average size, in terms of workers and turnover, that is lower with respect the companies involved in the traditional sources generation and in end user energy efficient technologies. In fact, more than 80 % of the companies involved in the RES technologies are characterized by micro, small or medium sizes (less than 250 workers). Basically, similar data, in terms of size, are registered by storage and co-generation systems, although the number of companies is lower.

On the contrary, the most traditional sectors are characterized by large size companies, the most of them with a turnover higher than 50M €/year. The share of women employed, with respect the total number of workers, is an additional data examined, related with the impact on occupation (Table 6). This share is clearly quite low. It is widely recognized that the increase in the number of women employed in the energy sector could provide momentum to the transition process toward the low carbon economy, and several initiatives, in this direction, are put in place, also at international level [38].

3.2. Greenhouses emissions potential of mitigation

In order to assess the potential of innovation as a function of technology readiness and reduction of greenhouse emissions, the data on TRL and the quantity of avoided CO_2 (Kg/MWh) (when available) are compared. In the scatter plot of Figure 4, technologies are grouped into four categories. The width of the points corresponds to the range of TRL identified in the Figure 2.

Quadrant I groups technologies with high average TRL value and high CO_2 reduction potential, in particular 'Hydroelectric', 'Oxyfuel plant of coal with CCS' and 'IGCC carbon capture'. The 'Geothermal' and 'Anaerobic Digestion of Biomass' technologies, with the average TRL value of 6.5 are close to quadrant I but have margins of further technological development because they are characterized by wide TRL range. In order to facilitate the penetration of these technologies into the market, industry policies as well as actions at national and EU level, are needed to facilitate production and the use of low carbon technologies, without undermining the competitiveness of the national production system. Possible trade-offs in energy policy are well known and explored at theoretical level [39], as well as, the possible vulnerability of a "critical energy system" [40].

Quadrant II contains the technologies of interest from the point of view of the CO_2 emission reduction potential with a lower average degree of TRL than Quadrant I. Such technologies are characterized by a wide range of the TRL values indicating a high potential of further development. RES technologies are mainly located in this quadrant. In particular, the technology "Thermodynamic Solar", seems to be the technology with the highest potential until now, in terms of CO_2 emissions avoided, although it still needs a further technological development. In the frame of the Solar Energy, also the "traditional" technology "Photovoltaic" and the "Concentrating Photovoltaic" are located in this quadrant.

The quadrant III includes the technologies currently characterized by a lower potential of CO_2 emission reduction and the average TRL level still low. The storage and co-generation systems are represented in this quadrant together with a RES technology such as 'Wave power'. A further increase in the degree of technological readiness might have significant effects, in terms of efficiency with positive effects on mitigation of the greenhouse gases emissions.

Finally, the technologies included in quadrant IV, are mainly characterized by a high average TRL level with

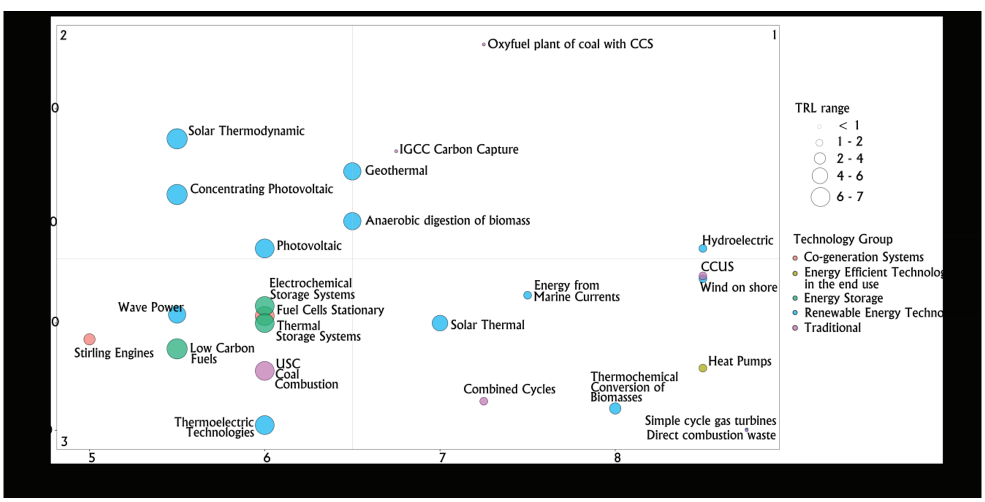

Figure 4: Scatter plot of energy technologies vs CO_2 emissions avoided (vertical axis) and TRL average value (horizontal axis). Four quadrants (I – IV) are identified placing the technologies in four categories according their degree of TRL and potential of mitigation of climate change effects. The bullet sizes correspond to the width of the range of TRL, identified in the Figure 2

the narrow range of the RTL values except for "Solar Thermal". The related markets are potentially mature, with a competitive structure basically defined. These technologies can be divided in two groups, according their potential of emission reduction: MEDIUM-HIGH for "Solar Thermal", "Wind on Shore", "Carbon Capture, Utilization and Storage (CCUS)" and "Energy from marine currents," with LIMITED for the others. For the first group the same indication for policies of Quadrant 1 could be valid.

3.3. R&D Potential in Italy

The profile of specialization for the Centres of Excellence seems to be influenced by the private/public character (Table 4). Even if, the private companies are active in all the technology classes, there are significantly involved in technologies based upon fossil sources (69%), while for what concerns the technologies related to the final users energy efficient, mostly the same share public/private is observed. These technologies are characterized by the highest average TRL value, as reported in Figure 2.

The different relative distribution of private and public actors, involved in the several technologies, can be related to several factors and should be further investigated, since, useful elements could emerge concerning the strengthens and weakness aspects of the national innovation system.

In order to consider the development of any single production chain, information on the industry structure, in time and at international level, are needed. The higher level of specialization for mature technologies of the private Research Excellence is not surprising because these technologies are supported by the managing approach, more "interpretative" rather than "analytical" [41]. From this point of view**,** the integration between private and public actors seems to be one of the keys to successful strategy.

The network analysis has been applied in order to stress the linkage between technologies with high potential of development in terms of environmental sustainability ad wide range of TRL (Quadrant II and III of Figure 4) and both public and private Centres of Excellence (Figure 5). This analysis allowed to identify the areas of research in which the research institutions are mostly involved and the legal status of institutions (public labelled in blue, private labelled in red). Each node is characterized by the position and width. A greater centrality in the graph and amplitude of the node indicate a greater number of connections (number of links to other actors and technologies) [42,43]. The nodes with similar ties can be grouped into different clusters. The proximity among nodes is not necessarily related to the existence of direct relation, (since such information is not inferable, exhaustively, from the Catalogue), but rather, it indicates a similarity in the technology interests. In this case, the dimension of the node and its position stands for the weight of the institution in the Italian research system. It is possible to deduce a public centres domain of expertise in Thermoelectric technologies (blue text prevalence) and a private centres one in Fuel Cells technologies (red text prevalence).

On these grounds it can be useful to divide the network into internally homogeneous groups, characterized by similar technological specialization. In such terms, any group may represent a synthetic picture of the segmentation of expertise and includes competitors and co-operative actors.

About the 42% of the Excellences, highlighted in the Catalogue, are represented in the graph, for a total of 114 ties. In the present analysis, four clusters of technology-actor relationship have been identified and represented by different colours (Figure 5). The group including the technologies "Thermal Storage", "USC Coal Combustion, "Thermodynamic Solar", "Electrochemical Storage", "Concentrator Photovoltaic" and "Stirling Engines", "Geothermal" and "Photovoltaic", is, the most extended (marked in yellow). The research centres CNR, ENEA, RSE and the University of Rome "La Sapienza", the Polytechnic of Milan, the University and the Polytechnic of Turin are tendentially positioned in the middle of this group having multiple areas of investigation. The other three groups appear to be less extended, likely, as an indication of the lower synergy existing among the technologies involved and the greater specialization of the actors, at least at the current status. In these groups, the "Anaerobic Digestion of Biomass" (marked in red), with a strong share of private actors, the "Thermoelectric Technologies" (marked in blue), with

Table 4: Profile of specialization for the Centres of Excellence by group of technology

	Public	Private
Renewable Energy Technologies	73%	27%
Co-generation Systems	62%	38%
Energy Storage Systems	61%	39%
Energy Efficient Technologies	50%	50%
Generation Technologies with fossil sources	31%	69%

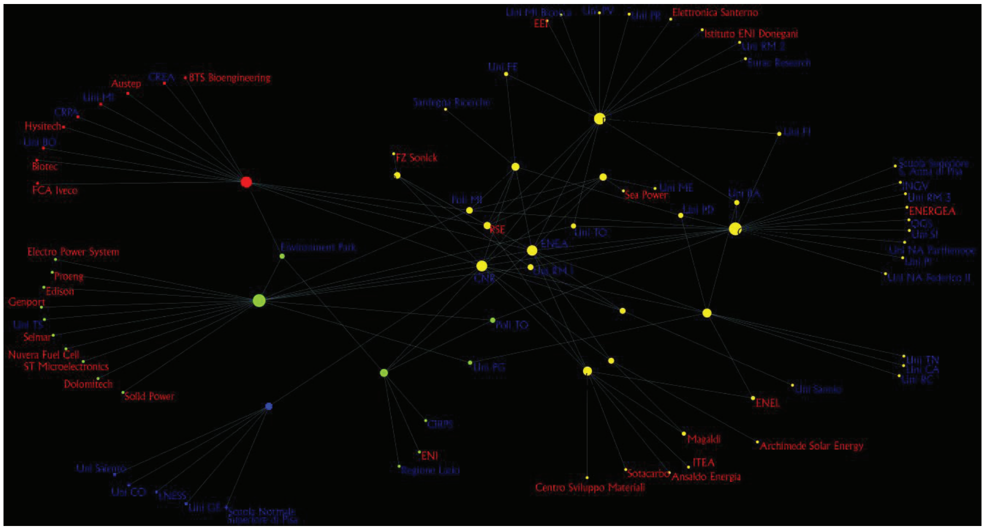

Figure 5: Network analysis performed on data of technologies with high potential of development (Quadrant II and III of Figure 4) and with both public and private Centres of Excellence (public entities are labelled in blue, private in red). A greater centrality and amplitude of the node indicate a greater number of connections. Four clusters of technology-actor relationship have been identified and represented by different colours

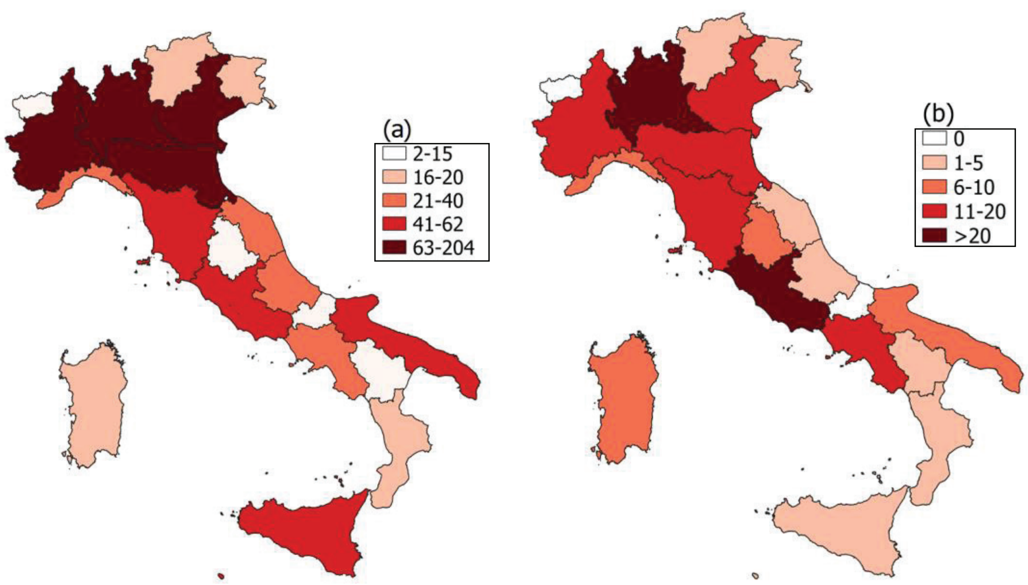

Figure 6: Regional mapping of the number of Local Units of Italian companies involved in development of technology (a) and Research Excellence (b)

the exclusive presence of public institutes, the connected “Fuel Cells” and “Low Carbon Fuels” (in yellow), are predominant, but more diversified in their interactions with the Excellences.

3.4. Territorial development potential

The maps of the Local Units of Italian companies (Figure 6a) and the Research Excellence (Figure 6b) involved in development of technologies show a territorial distribution that is not completely homogeneous. Both the companies and the Research Excellence are mainly concentrated in the central-northern regions of the country, although the Research Excellence are more widespread.

The regions with the highest number of local units of companies involved in development of technology are Piedmont, Lombardy, Veneto, and Emilia Romagna, typically the most industrialized regions of Italy (63–204 units). Instead, Tuscany, Latium, Apulia and Sicily show medium-high number of units (41–62) and Liguria, Marche, Abruzzo and Campania have a medium number of units (21–40). Friuli Venezia Giulia, Trentino Alto Adige, Sardinia and Calabria have medium-low number of units (16-20), while Val d'Aosta, Umbria, Molise and Basilicata have the lowest number of units (2–15). Latium, Campania, Sardinia, Umbria and Basilicata show a class of distribution of Research Excellence Units higher than for Local Units of companies, which could be due to scarce technology transfer at the local level as well as structural factors related to industrial and in market systems. This heterogeneity is based on economic dynamics that have been established since the earliest times of the country's industrial and technological development. Moreover, the Research Excellence localization is clearly related to the urban areas.

In Figure 7, the overlapping of two geographical layers is shown: the first layer, marked in blue, describes the degree of local urbanization, the second layer reports the localization of the Research Excellence, marked with red circles.

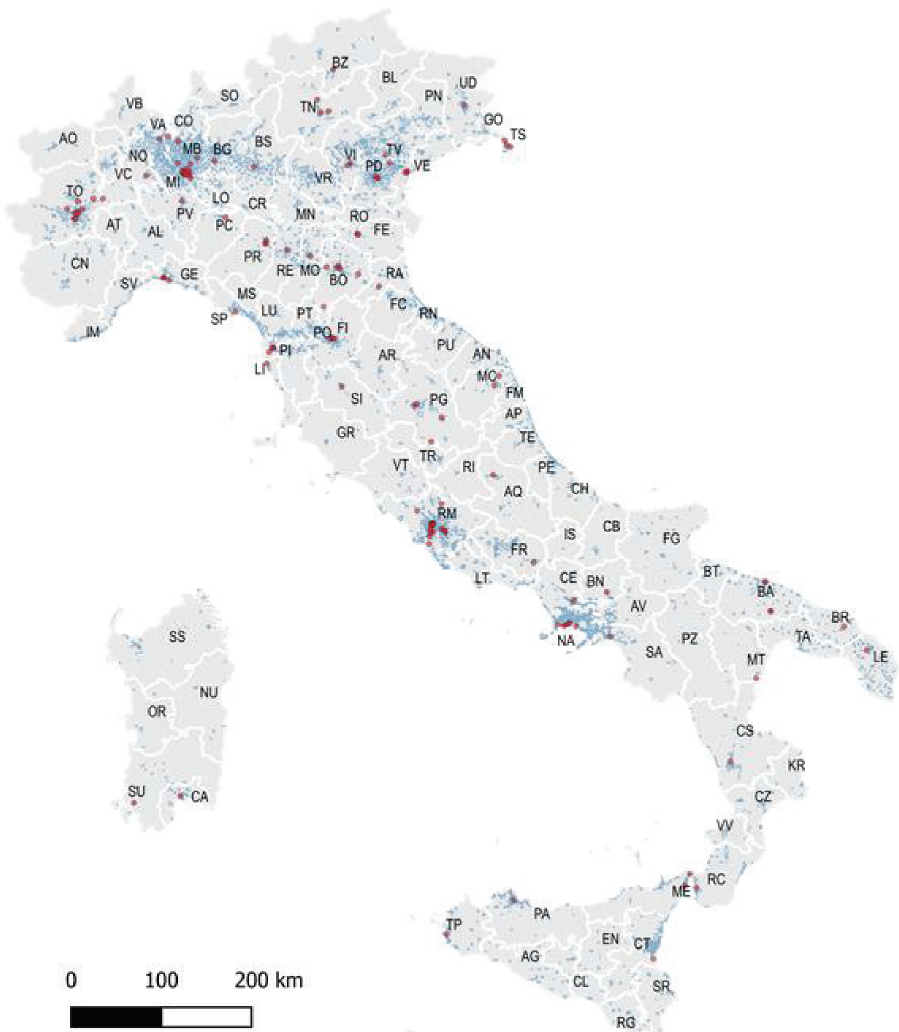

Figure 7: Mapping of the degree of urbanization at high resolution (blue areas) and localization of the Research Excellence (red circles)

This map suggests that the Research Excellence are mainly localized in mostly urbanized areas. This result is consistent with what is widely reported, in literature, about the factors driving the localization of the private enterprises and the innovation activities, in the field of the High Technology [44,45,46].

In Figure 7, two different spatial distributions of the Research Excellence are observed: the distribution is "like wildfire" in the most urbanized areas and "patchy" on the rest of the territory. Four clusters stand out among all: Milano, Roma, Torino, Napoli. Secondly, Trieste, Trento, Bolzano, the Emilia provinces and Venezia, Vicenza, Padova, Treviso are clusters characterized by lower extension with high density.

Pisa-Livorno and Firenze are lower density clusters too. In the southern regions some Research Excellence can be found, but they are concentrated in the Messina-Reggio Calabria and Bari provinces.

In order to investigate the possible tendency of the Research Excellence to be spatially aggregated the Ripley's L function has been used. The centres (red circles in Figure 7) are not randomly distributed but they tend to be relatively close each other's. Furthermore this analysis show a peak value for the interval about 15–40 km. This seems the optimal value extent for localization. Therefore,

it can be deduced that the Research Excellence may receive substantial advantages if they are aggregated in highly urbanized contexts. Such results seem to be explicable in the light of the "milieu innovateur" theory [47]. Such theory claims the context innovation in which common cognitive models work and the "unspoken knowledge" is transferred [48]. That is not simply matter of aggregation economies, but also the development of a common identity, in which the actors exchange information and reduce the risk of opportunism and uncertainty, so generating a collective learning process, in other words, using the "unspoken knowledge".

4. Conclusions

The 'Catalogue of the Energy Technologies' is a starting point for the assessment of technologies contributing to the process of energy transition.

The Catalogue gives a snapshot at year 2017 and provides important information on technologies with high decarbonisation potential, although still in the development phase, not only in terms of climate mitigation but also in industrial development.

Such important initial effort should be followed by a continuous updating, through a validation process of the collected information.

This study, starting from data and information extracted from the Catalogue suggests a methodological approach to identify instruments suitable for facilitating the spread of the energy technologies.

The analysis has been carried out to assess the different levels of the potential of the energy technologies, in particular:

- technological readiness and involvement of the Italian industry,
- impact on climate,
- R&D activities,
- distribution on the national territory.

The attempt to correlate the TRL with the potential of reduction of greenhouse gases emission, as well as, the relationship with the Research Excellence, private companies and the presence on the territory represents the novelty of the proposed approach.

The analysis of the data collected shows that RES and Energy Storage Systems have a high potential of development in Italy. Research has facilitated the market penetration of some specific technologies, involving several sectors of the Italian Industry, like SME.

The network analysis highlighted the central role played by Research Institutions and Universities in the development of energy technologies as well as the numerous connections between centres of excellence and the most promising technologies, in some cases belonging to more specialized sectors with few entities involved. A steady dialogue between research institutions and industry, supported by conditions to re-launch both sectors, is necessary to achieve decarbonisation targets and economic growth. The spatial distribution of companies involved in R&D activities and Centres of Excellences confirms this need.

Probably, greater support to technology transfer will enhance local industrial development. Such support could be achieved through specific financed calls for proposals for consortia of public and private subjects aimed to increase the TRL of technologies tested in research institutes by local companies and/or new start-ups.

The implementation of a system of data collection on the enterprises involved in the development of energy technologies can fill the information lack on current and historical databases. Patents an investments in R&D energy technologies are additional data sources useful to estimate the degree of innovation in the national economy system, also in comparison with the international trend. Moreover, the update of the Catalogue should be planned to include the emerging technologies such as "Liquid Air Energy Storage (LAES)" and "Power to gas".

This study could have the following policy implication particularly addressed for the Italian concerns:

- it contributes to adopt industrial policies to encourage a new entrepreneurship in the energy sector;
- it helps to identify and train new professional skills who are not currently present on the market;
- it can be useful to set up actions to enhance the national supply chains increasing the dialogue between different developed regions (Calabria, Campania, Puglia, Sicilia and Basilicata) eligible for funding under the Commission Implementing Decision (EU) 2016/1941;
- it can support the public policy makers in identifying the territorial policies to contribute to the achievement of the objectives set by the Italian Integrated National Energy and Climate Plan (PNIEC);
- it could favour an organic management of research in the energy sector improving the effectiveness financial resources allocation.

Acknowledgements

This paper belongs to an IJSEPM special issue on *Sustainable Development using Renewable Energy Systems*[49]. Special thanks go to Marcello Capra, Italian Delegate for SET PLAN at the Italian Ministry of Economic Development (MiSE), and to Riccardo Basosi, Italian Delegate for SET PLAN at the Italian Ministry of University and Research for their support for the topic of the study.

References

[1] von der Leyen, U., A Union that strives for more. My agenda for Europe. Political guidelines for the next EU Commission 2019–2024. European Union, 2019. http://doi.org/10.2775/018127

[2] Helm, D., The European framework for energy and climate policies, Energy Policy (64) (2014) 29–35 https://doi.org/10.1016/j.enpol.2013.05.063

[3] Cooper, M., Governing the global climate commons: The political economy of state and local action, after the U.S. flip-flop on the Paris Agreement, Energy Policy (118) (2018) 440–454. http://doi.org/10.1016/j.enpol.2018.03.037

[4] Aggarwal, P., Vyas, S., Thornton, P., Campbell, B.M., Kropff, M., Importance of considering technology growth in impact assessments of climate change on agriculture, Global Food Security (23) (2019) 41–48. http.s://doi.org/10.1016/j.gfs.2019.04.002

[5] Maas, R., Grennfelt, P., Towards Cleaner Air. Scientific Assessment Report 2016. EMEP Steering Body and Working Group on Effects of the Convention on Long-Range Transboundary Air Pollution, Oslo (2016) http://www.unece.org/fileadmin/DAM/env/lrtap/ExecutiveBody/35th_session/CLRTAP_Scientific_Assessment_Report_-_Final_20-5-2016.pdf

[6] Kim, S.K., Lee, B.G., Park, B.S., Oh, K.S., The effect of R & D, technology commercialization capabilities and innovation performance. Technol. Econ. Dev. Econ. (17) (4) (2011) 563–578. https://doi.org/10.3846/20294913.2011.603481

[7] Ferreira, P., Soares, I., Johannsen, R.M., Østergaard, P.A., Policies for new energy challenges, International Journal of Sustainable Energy Planning and Management (26) (2020) 01–04. https://doi.org/10.5278/ijsepm.3552

[8] Prasad, R.D., Bansal, R.C., Raturi, A., Multi-faceted energy planning: A review, Renewable and sustainable energy reviews (38) (2014) 686–689. https://doi.org/10.1016/j.rser.2014.07.021

[9] E.ON, 2008. Carbon, Cost and Consequences. E.ON UK publication.

[10] Boston, A., Delivering a secure electricity supply on a low carbon pathway, Energy Policy (52) (2013) 55–59. https://doi.org/10.1016/j.enpol.2012.02.004

[11] WEC, World Energy Trilemma Index 2016. Benchmarking the sustainability of national energy systems(2016) London EC3V, United Kingdom. https://www.worldenergy.org/assets/downloads/Full-report_Energy-Trilemma-Index-2016.pdf

[12] Gunningham, N., Managing the energy trilemma: The case of Indonesia, Energy Policy (54) (2013) 184–93. https://10.2139/ssrn.2342925

[13] Oliver, J., Sovacool, B.K., The Energy Trilemma and the Smart Grid: Implications Beyond the United States, Asia & the Pacific Policy Studies (4)(1) (2015) 70–84. https://doi.org/10.1002/app5.95

[14] Parkes, G., Spartaru C., Integrating the views and perceptions of UK energy professionals in future energy scenarios to inform policymakers, Energy Policy (104) (2017) 155–170. https://doi.org/10.1016/j.enpol.2016.11.019

[15] Rehner, R., Mc.Cauley, D., Security, Justice and the Energy Crossroads: Assessing the Implications of the Nuclear

Phase-out in Germany, Energy Policy (88) (2016) 289–298. https://10.1016/j.enpol.2015.10.038

[16] Táczi, I., 2016. System Effects of Intermittent Renewable Generators (Wind, Solar) – Balancing, ERRA, Budapest, Hungary. https://erranet.org/wp-content/uploads/2016/03/Position-Paper_System-effects-of-intermittent-renewable-generators_final_2016_eng.pdf

[17] Felici, B., Corrias, P., Baldissara, B., Amerighi, O., Tricoli, C., 2015. L'impatto occupazionale delle fonti energetiche rinnovabili in Italia: il fotovoltaico. Un approccio bottom up sul metodo dell'employment factor, applicato alle fasi della catena del valore http://openarchive.enea.it/handle/10840/6814.

[18] Cho, J., Lee, J., Development of a new technology product evaluation model for assessing commercialization opportunities using Delphi method and fuzzy AHP approach, Expert Systems with Application (40) (13) (2013) 5314–5330. https://doi.org/10.1016/j.eswa.2013.03.038

[19] Hsu D.W., Shen Y.C., Yuan B.J., Chou C.J., Toward successful commercialization of university technology: performance drivers of university technology transfer in Taiwan. Technolical Forecasting and Social Change (92) (2015) 25–39. https://doi.org/10.1016/j.techfore.2014.11.002

[20] Carter, A.P., Technological Forecasting and Input-Output Analysis. Technological Forecasting (1) (4) (1970) 331–345. https://doi.org/10.1016/0099-3964(70)90011-6

[21] Auer, P., Advances in Energy Systems and Technology Vol 2 (1979) Academic Press, New York. ISBN: 978-1483175454

[22] Saaty, T. S., Decision making with the analytic hierarchy process, International Journal of Services Sciences (1) (2008)83-98. https://doi.org/10.1504/IJSSCI.2008.017590

[23] Noh, H., Seob, J., Yoob, H.S., Leea, S., How to improve a technology evaluation model: A data-driven approach, Technovation (72-73) (2018) 1–12. https//doi.org/10.1016/j.technovation.2017.10.006

[24] Malcev, N.V., Shaybakova, L.F., Evaluation of the Innovative Activity Efficiency While Developing the Sectoral Technology Policy in the Region. In: Solovev D. (eds) Smart Technologies and Innovations in Design for Control of Technological Processes and Objects: Economy and Production (2020) Far East Con Smart Innovation, Systems and Technologies 858–868. https://doi.org/10.1007/978-3-030-15577-3_79

[25] Prina, M. G., Moser, D., Vaccaro, R., Sparber, W., EPLANopt optimization model based on EnergyPLAN applied at regional level:the future competition on excess electricity production from renewables, International Journal of Sustainable Energy Planning and Management (27) (2020) 35–50. https://doi.org/10.5278/ijsepm.3504

[26] Razmjooa, A.A., Investigating energy sustainability indicators for developing countries, International Journal of Sustainable Energy Planning and Management (21) (2019) 59–76. https://doi.org/10.5278/ijsepm.2019.21.5

[27] Martinez Fernandez, P., deLlano-Paz, F., Calvo-Silvosa, A., Soares I., An evaluation of the energy and environmental policy efficiency of the EU member states in 25-year period from a Modern Portfolio theory perspective, International Journal of Sustainable Energy Planning and Management (26) (2020) 19–32. https://doi.org/10.5278/ijsepm.3482

[28] Di Nucci, M. R., Russolillo, D., Energy Governance in Italy. Path Dependence, Policy Adjustments and New Challenges for Sustainability. In: M. Knodt, J. Kemmerzell (eds.), Handbook of Energy Governance in Europe (2019), Springer Nature. ISBN: 978-3-030-43249-2

[29] Sanson, A., Giuffrida, L.G., 2017. Decarbonizzazione dell'economia italiana. Il Catalogo delle tecnologie energetiche. ENEA, Rome, Italy. ISBN: 978-88-8286-349-4.

[30] European Commission, Technology Readiness Level: Guidance Principles for Renewable Energy technologies - Final Report. EUR 27988 EN. European Commission B-1049 Brussels (2017) https://op.europa.eu/en/publication-detail/-/publication/d5d8e9c8-e6d3-11e7-9749-01aa75ed71a1

[31] ARENA, Technology Readiness Levels for Renewable Energy Sectors. Australian Government, Australian Renewable Energy Agency (2014) https://arena.gov.au/assets/2014/02/Technology-Readiness-Levels.pdf

[32] Reinhart, G., Schindler, S., A strategic evaluation approach for defining the maturity of manufacturing technologies, Word academy of Sciences, Engineering and Technology. International Journal of Industrial and Manufacturing Engineering 4 (11)(2010) 1291-1296. https://pdfs.semanticscholar.org/6a8b/d380554b001350edeb69758560f79ebfd217.pdf?_ga=2.241643972.737455282.1585562498-662110384.1585562498

[33] Camagni, R., Regional Competitiveness: Towards a Concept of territorial capital», in Capello, R.; Camagni, R.; Chizzolini, B., and Fratesi, U. (eds.), Modelling Regional Sce narios for the Enlarged Europe: European Competitiveness and Global Strategies (2008)33–48, Berlin, Springer Verlag. https//doi.org/10.1007/978-3-540-74737-6

[34] Carrera, D.G., Mack, A., Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts, Energy Policy (38) (2010) 1030–1039. https://doi.org/10.1016/j.enpol.2009.10.055

[35] Olabi, A.G., Energy quadrilemma and the future of renewable energy, Energy 108 (2016) 1–6. https://doi.org/10.1016/j.energy.2016.07.145

[36] Baddeley, A., Rubak, E. Turner, R., Spatial Point Patterns: Methodology and Applications with R. Chapman and Hall/ CRC Press (2015) ISBN 9781482210200

[37] Giuffrida, L.G., De Luca, E., Sanson, A., Il catalogo delle tecnologie energetiche, AEIT ½ (2019) 38-43. https://www.aeit.it/aeit/edicola/aeit/aeit2019/aeit2019_01_cisa/aeit2019_01_riv.pdf

[38] IEA, Status report on Gender Equality in the Energy Sector (2019) https://webstore.iea.org/status-report-on-gender-equality-in-the-energy-sector

[39] Gracceva, F., Zeniewski, P., A systemic approach to assessing energy security in a low-carbon EU energy system, Applied Energy (123) (2014) 335–348. https://doi.org/10.1016/j.apenergy.2013.12.018

[40] Cherp, A., Jewell, J., The concept of energy security: beyond the four AS, Energy policy (75) (2014) 415–421. https://doi.org/10.1016/j.enpol.2014.09.005

[41] Lester, R.K., Piore, M.J., Innovation. The missing dimension, Cambridge (Mass.) (2006) ISBN 9780674019942

[42] Mascarenhas, C., Ferreira, J., Marques, C., University–industry cooperation: A systematic literature review and research agenda. Science and Public Policy 45(5) (2018) 708–718. https://doi.org/10.1093/scipol/scy003

[43] Doleck, T., Lajoie, S., Social networking and academic performance: A review, Education and Information Technologies 23(1)(2018) 435–465. httpsdoi.org/10.1007/s10639-017-9612-3

[44] Krugman, P., Urban Concentration: The Role of Increasing Returns and Transport Costs, International Regional Science Review, 19 (1-2) (1996) 5–30. https://doi.org/10.1177/016001769601900202

[45] Rosenthal, S. S., Strange, W. C., Evidence on the nature and sources of agglomeration economies, Handbook of regional and urban economics 4 (2004) 2119–2171. https://doi.org/10.1016/S1574-0080(04)80006-3

[46] Lazzeroni, M., High-Tech activities, system innovativeness and geographical concentration insights into technological districts in Italy, European Urban and Regional Studies, 17(1) (2010) 45–63. https://doi.org/10.1177/0969776409350795

[47] Aydalot, P., Milieux Innovateurs en Europe, GREMI, Paris. (1986)

[48] Camagni R., Technological change, uncertainty and innovation networks: towards a dynamic theory of economic space, in R. Camagni (ed.) Innovation networks: spatial perspectives, Belhaven-Pinter, London(1991) https://doi.org/10.1007/978-3-319-57807-1_4

[49] Østergaard PA, Johannsen RM, Duic N. Sustainable Development using Renewable Energy Systems. Int J Sustain Energy Plan Manag 2020;29. http://doi.org/10.5278/ijsepm.4302.