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Small-Scale Renewable Power Technologies are an Alternative to Reach a Sustainable Economic Growth: Evidence from Spain

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Abstract

Recent electricity management systems such as Smart Grids and Virtual Power Plants help to better integrate distributed generation renewable resources (RDG), such as photovoltaic, small hydro or micro wind in electricity markets. In this context, an important increase of small-scale power generation technologies is expected in Spain by 2020, according to the *Spanish Action Plan for Renewable Energy*.

This paper analyses the environmental and economic impacts of the massive integration of RDG in Spain for 2020 by using an Input-Output approach. The induced production and employment effects in every sector due to new RDG project investments as well as the CO_2 reductions attributed to a decline in conventional electricity consumption are estimated. The results indicate that investments in RDG based on photovoltaic and small-hydro have the greatest impact on employment generation. The RDG investments will lead to a decrease in emissions of 21.67 % in 2020 compared with 2013. The RDG technologies become an alternative to reach a sustainable economic growth in Spain.

In future research, a multi-regional input-output model and the study of the links between energy consumption, standard of living and consumption patterns will aid to delve deeper into the relationship between economic growth and the environmental impacts of small-scale renewable technologies.

Keywords: electricity distributed generation; input-output analysis; renewable energy.

JEL: C67 Input-output models, O13 Energy, Q5 Environmental Economics.

1. Introduction

The European Union has shifted significantly toward a more decarbonized energy system. In fact, the Europe 2020 Strategy (European Commission, 2010) established three key targets for 2020: a cut of 20% in greenhouse gas emissions (from 1990 levels), the boost of renewable energies in final energy consumption to 20% and the improvement in energy efficiency by 20%. The EU framework for climate and energy policies has gone far beyond the levels of these targets and, by 2030 the EU should cut greenhouse gas emissions by at least 40% compared with 1990 levels and increase the renewable energy generation and energy efficiency by at least 27%. The progressive milestones are in line with the Energy Roadmap 2050 (European Commission, 2011a) and Roadmap for

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moving to a competitive low carbon economy in 2050 (European Commission, 2011b). The EU aims to reduce emissions by 80% by 2050 and enhance clean technologies and low- or zero-carbon energy.

In this context, the expansion of renewable energy-based distributed generation (RDG) becomes an alternative for boosting the transition to a more climate-friendly and less energy-consuming economy. Although electricity generated from renewable energy sources (RES) may be variable in nature, the secure electricity supply and quality of service can be supported through the new electricity management systems and the expansion of smart grids, as the European Commission's Energy Roadmap has detailed. In fact, there is a renewed focus in European climate policy debates on strategies for decarbonisation (Sartor *et al*., 2017). The target of lowering domestic greenhouse gas emissions and transition to decarbonisation encompasses critical economic and policy implications and pushes reforms of the energy system underpinned by advances in renewable energy. Furthermore, the current electricity management system allows the aggregation of a portfolio of distributed generation resources under the concept of Virtual Power Plant (VPP). VPP is a multi-technology generation entity that operates as a unified system similar to a transmission-connected generator on the energy markets**.** VPP could reduce the imbalance costs and increase a reliable electricity supply compared to stand-alone RDGs units. Moreover, **s**mart grids can also help to better integrate renewable energy RDG. This context has produced a notable increase in distributed power generation whose deployment will continue to grow (Luo *et al*., 2015).

Spain represents a case study of significant wider interest as it is one of the countries with more locations with potential for the installation of distributed generation renewable resources（Bódis *et al*., 2014, Castillo *et al*., 2016）. So, knowing in advance how much the RDG investment in Spain can contribute, could encourage policy makers to invest in those suitable places. In Spain, it could be expected that distributed generation reaches more than half of the total installed electricity generation capacity by 2020, the major part of this generation being renewable-energy based and intermittent. (Dietrich *et al*., 2015). In fact, the *Spanish Action Plan for Renewable Energy 2011-2020* (Spanish Government, 2011) raises the installed capacity of small hydropower, photovoltaic or micro wind to 2,158 MW, 12,356 MW and 300MW in 2020, respectively. In 2014, 90% of 60,000 photovoltaic plants were connected to the electrical distribution grid in comparison with 10,000 plants that had been registered for 2006 (Álvarez and Castro, 2014). Currently, according to Eurostat data (Table 1), electricity generated by renewable energies represented more than 36% of all electricity generated in Spain in 2016. By technologies, Spain was the second largest producer of wind energy in Europe in 2016, with 48,893 GWh produced. China has the largest wind energy installed capacity with 145 GW, followed by the United States with 73 GW, Germany 45 GW, India 25 GW, Spain

23 GW and the UK 14 GW (World energy Council, 2016). With regard to solar energy generation, Spain was the third largest producer in Europe in 2016 with 8,033 GWh produced, Germany being the largest producer followed by Italy with 38,098 and 22,104 GWh, respectively. Spain was the leader in Concentrated Solar Power deployment with 2,362 MW installed capacity in 2016, followed by USA with 1,804 MW and India 454 MW (World energy Council, 2016). Moreover, in 2016, Spain was the fourth largest producer of mini-small hydropower with 4,996 GWh.

Table 1. Share of renewable energy in electricity and Gross electricity generation by technology in Europe 2016

	Share of renewable energy in electricity	Gross electricity generation by technology (GWh)							
		Total gross production	Solar Photovoltaic	Wind	Hydro <10MW	Hydro >10Mw	Pumped Hydro	Combustible Fuels	Nuclear
EU-28	29.6	3,255,050	85,694	293,804	43,298	300,326	30,059	893,435	812,993
Belgium	15.8	85,520	4	5,410	222	148	1,119	16,475	43,523
Bulgaria	19.2	45,277	1,386	1,425	1,035	2,908	626	18,127	15,776
Czech Republic	13.6	83,309	2,131	497	516	887	1,202	10,433	24,104
Denmark	53.7	30,522	0	12,782	19	0	0	12	0
Germany	32.2	649,119	38,098	78,598	4,887	15,484	5,588	279,753	84,634
Estonia	15.5	12,176	0	581	35	0	0	10,129	0
Ireland	27.2	30,418	0	6,149	106	575	292	21,196	0
Greece	23.8	51,405	3,930	5,146	722	4,821	22	27,426	0
Spain	36.6	274,779	8,033	48,893	49,96	30,596	3,470	80,530	58,633
France	19.2	556,184	4,169	20,240	6,048	53,337	4,846	34,819	403,195
Croatia	46.7	12,820	66	1,014	108	6,738	205	2,894	0
Italy	34	289,768	22,104	17,689	10438	31,432	1,825	93,213	0
Cyprus	8.6	4,887	94	226	0	0	0	4,455	0
Latvia	51.3	6,425	0	126	61	2,467	0	0	0
Lithuania	16.8	4,266	66	1,136	85	368	590	0	0
Luxembourg	6.7	2,196	0	101	108	0	1,413	112	0
Hungary	7.2	31,859	0	684	69	191	0	9,428	:
Malta	5.6	856	0	0	0	0	0	723	0
Netherlands	12.5	115,170	62	7,252	0	100	0	58,726	3,960
Austria	72.6	68,351	1,096	5,235	5642	33,673	3,081	5,973	0
Poland	13.4	166,635	0	12,588	906	1,231	482	4,170	0
Portugal	54.1	60,280	484	12,474	1291	14,413	1,186	21,912	0
Romania	42.7	65,103	1,626	6,292	1056	16,649	508	12,473	11,286
Slovenia	32.1	16,500	7	6	205	4,072	279	8	5,715
Slovakia	22.5	27,064	155	1	113	4,148	247	330	4,137
Finland	32.9	68,752	1	3,068	1101	13,663	0	4,199	23,203
Sweden	64.9	156,010	143	15,479	2996	59,012	119	23	63,101
UK	24.6	339,399	2,038	30,712	538	3,413	2,959	175,896	71,726

Source: Own elaboration from European Commission (2017): Eurostat database, http://ec.europa.eu/eurostat/data/database.

All around the world, renewable capacity will increase considerably in order to meet long-term climate goals. For example, the International Energy Agency forecasts that renewable energy will continue to show strong growth through 2022, with renewable electricity capacity forecast to expand by over 920 GW, an increase of 43% with respect to 2016 (International Energy Agency, 2017).

In this context of high growth of electricity generated by renewable sources, renewable energy-based distributed generation (RDG) can play a role in increasing electricity system flexibility, energy efficiency and foster the energy democracy in low income communities (Burke and Stephens, 2018). This article studies the expected environmental

and economic impact of the massive integration of distributed electricity generators from renewable sources (RDG) in Spain in 2020. In fact, we focus the study on small renewable technologies (micro and small hydropower, photovoltaic and micro-wind) as they can be more suitable for distributed generation. According to the classification given by El-Khattam and Salama (2004) wind and photovoltaic are different types of distributed generation from the constructional and technological points of view. Photovoltaic generation consists of independent panels that can operate individually down to very low-power ratings. In the same way each wind turbine can provide electricity as an individual. However, PV and wind technologies can also provide electricity as large power plants and as wind farms, respectively. Usually, wind farms aggregate large wind turbines but we study the effect of micro-wind which is mainly close to the load. Regarding PV, by analyzing the current geographical distribution of the PV installed capacity in Spain (available at https://www.esios.ree.es/es/mapas-de-interes/mapa-instalaciones-fotovoltaicas), it should be noted that PV installations are dotted around the country, so they are located close to the load and a lot of them are of a small size.
Moreover, most of the future deployment will be mainly driven by small-sized grid-connected PV systems for self-consumption and stand-alone systems for agriculture (The Spanish Photovoltaic Union, 2018) as a consequence of the future reduction of storage systems and the increase of electricity prices. Therefore an important share of new installed capacity for 2020 could be considered distributed generation.

The input-output (IO) methodology is used to study the environmental and economic impacts by integrating the economic and technical relations observed in the production system. The start-up of a set of generators involves a direct impact in aggregated demand of inputs for construction and operation, but also other induced effects on the economy. The input-output model makes it possible to detail trade-off between alternative technologies and their impacts on economic growth. The used procedure and methodology could be applied to any other country in the world in order to help them to decide their choice between different future RDG investment paths, according to the induced production and employment effects. Moreover, as Cai *et al.* (2017) stated "despite the official rhetoric, at the scholarly level the link between RES adoption and economic growth is still debated. While there is a sizable body of literature on the subject…studies generally produced results with a very coarse degree of aggregation in terms of industries and RES technologies". Some authors do not clearly define the type of RES technologies being assessed and study an aggregation of several technologies to an RES system (Jenniches, 2018). However, increasing attention is developing around the effects of separating electricity/distribution and generation and the introduction of renewable energy (Nakano *et al.*, 2017, Moretti *et al.*, 2017). Nowadays, there are few studies which have attempted the analysis of the socio-economic effects of the spread of power generation using the interaction of different types of microgeneration plants and other renewable energy sources. Small scale units of electricity generation are dispersive energies with geographical features. The efficient use of these energies requires a planned energy management system (Nakano *et al*, 2018). Only Nakano *et al.* (2018), Nakano *et al.* (2017), and Nakano and Washizu (2013) study the effect of a group of renewable energies for Japan. However, their level of disaggregation of small-scale units of electricity generation is limited, and they do not take into account the substitution effects among technologies. It should be noted that the deployment of RDG projects leads to new investments and an increase of renewable energy production, but also it is accompanied by an effect of substitution of the demand for conventional energies.

In Spain there are few studies disaggregating the electricity sector by joining several activities or technologies (Duarte *et al.*, 2017 or Cámara and Martínez 2017, among others); however, to the best of our knowledge, this is the first study quantifying the effect on the Spanish economy of a set of small-scale units of electricity generation based on different renewable sources. Micro hydropower (plants with installed capacity of less than 1MW, small hydropower (1-10MW), photovoltaic and micro-wind (plants with installed capacity of less than 100 kW) are the distributed generation resources considered in the present study.
Therefore, this paper tries to fill a gap found in the existing literature on the studies of socio-economic effects of small-scale units of electricity generation in Spain under an IO framework and forecasting in the short/medium term.

Thus, firstly, the analysis of this paper focuses on the specific disaggregation of the Spanish electricity generation according to production technologies of the latest available Spanish Input-Output table which refers to 2013. Secondly, by using the information related to renewable energy-based distributed generation (RDG), investment projects of the *Spanish Action Plan for Renewable Energy* for 2020, the analysis is extended to forecast the induced production and employment effects in every sector due to new RDG project investments as well as the CO_2 reductions attributed to a decline in conventional electricity consumption for a medium-term time horizon (2020).

The article shows how it is possible to quantify the environmental and economic impacts of the future massive integration of RDG with a high level of detail about possible small-scale renewable power technologies. The impact of each new MW of different RDG investment on employment, emissions and induced production at sectoral level in Spain is quantified by using an input-output approach. Considering the government predictions for small-scale renewable power technologies for 2020 in Spain, it seeks to identify the economic role of small-scale generation in the economy in upcoming years and realising the opportunities of each of these technologies for the electricity sytem and economic growth. Thus it enhances the scarce literature about contributing to environmental and economic objectives from different types of small-scale renewable generation due to changes in consumption patterns, the growth of decentralised energy and the deployment of smarter, more flexible solutions. The used procedure and methodology can be applied to any other country in the world to decide its choice between different future RDG investment paths, according to the induced production and employment effects.

This paper is divided into five more sections. Section 2 contains a literature review about the topic of this research. In Section 3, the procedure to disaggregate the Spanish electricity sector in the Spanish Input-Output table from the original supply and use tables is detailed. In Section 4, the methodology used to obtain the impact of RDG is presented. Section 5 presents the estimated impact of the distributed power generation renewable resources on the Spanish economy for 2020. Finally, the main concluding remarks and future lines of research complete the paper.

2. Literature review

Small scale renewable energy is contributing noticeably to future energy generation. Thus, the contribution of microgeneration for future low-carbon energy systems is promising, especially when they can shape a cluster of energy sources under Virtual Power Plants managed by Smart Grids. Extensive research about Smart Grids has been carried out around the world (See Moretti *et al*. 2017 for a review of environmental and economic impacts of Smart Grids). The American Recovery and Reinvestment Act of 2009 (ARRA) (Public Law 111-5) promoted the Smart Grid Investment Grant (SGIG) Program and the Smart Grid Demonstration Program (SGDP) to set up and assess smart grid and energy storage systems. In EU, EU–Platform SmartGrid (www.edsoforsmartgrids.eu/) has worked intensively on these issues and the number of distributed energy resources projects is non-negligible. Regardless, despite the increasing research on Virtual Power Plants the analysis about the effect of the massive integration of electricity distributed generators under the new electricity management systems is still scarce (see Dietrich *et al*. 2015 and Nosratabadi *et al*. 2017 for a comprehensive review of existing research). Moreover, there are few studies which have attempted the analysis of the socio-economic effects of the spread of power generation using the interaction of different types of microgeneration plants and other renewable energy sources.

Focusing on input-output methodology related methods such as social matrix accounting or multi-regional IO models, these are well established techniques to study economic effects of different energy sources. Ramos *et al.* (2013) review the substantial input-output literature about energy and economic structure. Lenzen *et al.* (2004) analyse issues related with greenhouse gases under the scope of input-output model and general equilibrium models. Moreover, Long *et al.* (2018) review studies in which country-scale emissions were calculated using IO analysis since 2001. Although the economic impact of renewable energy has usually been estimated by using IO, there are few attempts that consistently reveal socio-economic impacts of a wide range of microgeneration energy technologies (the analyses carried out by Nakano and Washizu 2013, Nakano *et al*. 2017, and Nakano *et al*. 2018 for Japan stand out).

Usually, the scarce literature on IO impacts of microgeneration energy technologies studies in isolation one of the micro technological options (see details in Table 2). Input-output life cycle assessment has been applied to analyse small hydropower schemes in India (Varun *et al.,* 2012) and in Japan (Hondo and Moriizumi, 2017). Varun *et al.* (2012) observed a reduction of relative GHG emissions in 2004-2005 related with the head and capacity of the small hydropower projects in India. Hondo and Moriizumi (2017) point out the induced employment opportunities in service sectors associated to the renewable projects. The positive IO impacts on the economy, employment and/or environment of photovoltaic plants are observed in several countries such as Spain in 2011 (Corona *et al.,* 2016), Arizona in 2012-2039 (Bae and Dall'erba, 2016) and Greece in 2010-2020 (Markaki *et al.,* 2013). The importance of the background of the economy is reported also for the wind power generation systems in United States, Brazil or Germany (Williams *et al.*, 2008 Lenzen and Wachsmann, 2004, Noori *et al.*, 2015). Nagashima *et al.* (2017) observed a positive net value of production and added valued of wind power for Japan in 2005, although some negative effects on conventional power exist. Moreover, IO based employment effects are concentrated mainly in solar and wind energy (see Cameron and Van Der Zwaan, 2015 and Hondo and Moriizumi 2017 for a review).

For a review of the environmental, social and economic impacts of different wind energy technologies, see Noori *et al.* (2015). It should be noted that few studies comment on micro-wind and, in general, they are oriented towards wind energy with a few exceptions covering the distinction between different types of wind turbines (Lenzen and Wachsmann, 2004, Noori *et al.*, 2015).

Table 2. IO studies analyzing the impact of RDG technologies

Authors	RDG included in the study	Time	Country	Methodology	Results
Hondo and Moriizumi (2017)	Small hydropower	2011	Japan	Renewable Energy-Focused IO Model	RES induce employment opportunities in service sectors.

Varun *et al*. (2012)	Small hydropower	2004-2005	India	Economic IO life cycle assessment (EIO-LCA)	Relative GHG emissions decreased with an increase in the capacity of the power projects.
Zhang *et al*. (2007)	Small hydropower	1992	China	EIO-LCA	Large hydropower is an efficient electrical source with relatively low GHG emissions compared with small hydropower.
Nakano *et al*. (2017)	Small hydropower, Solar, Wind power (land and offshore)	2005, 2030	Japan	Inter-regional IO analysis	The potential of residential solar power is large in regions that have metropolitan areas. The renewable energies with higher impacts are more expensive than conventional electricity.
Bae and Dall'erba, (2016)	Solar	2012-2039	Arizona	IO Multipliers, JEDI Model	The benefits of a new solar power plant with large utility scale go are positive under different models.
Markaki *et al*. (2013)	Solar	2010-2020	Greece	IO Multipliers	Employment is relatively higher in energy saving projects in building and construction.
Lenzen and Wachsmann (2004)	Wind	1995, 1997	Brazil and Germany	EIO-LCA	Identical wind technology can produce different economic impacts due to the supply chain of the studied economy.
Nagashima *et al*. (2017)	Wind	2005	Japan	Hybrid IO table	Wind power generation system supports reductions in energy consumption and CO_2 emissions.
Noori *et al*. (2015)	Wind	2009	USA	TBL-EIO (triple bottom line-Economic IO)	Socio-economic and environmental impacts of onshore wind turbines are higher than offshore wind turbines per kWwh electricity generation.
Williams *et al*. (2008)	Wind	2003-2004	US	IO Multipliers, JEDI Model	The local features are less important to the impacts associated to the operations and maintenance costs.

Source: Own elaboration.

In the case of Spain, small-scale distributed energy generation is expected to play an important role. The Spanish Institute for Energy Diversification and Saving (www.idae.es) and the Association of Renewable Energy companies (www.appa.es) issue reports about the situation and macroeconomic global impacts of renewable energy in Spain, including small-scale energy. However, there are few studies focusing on the economic and social impacts of promoting this distributed energy (Table 3 shows an overview of those studies).

Table 3. IO studies analyzing the impact of small-scale energy technologies in Spain

Authors	**RDG included in the study**	**Time**	**Methodology**	**Results**

Corona *et al.* (2016)	Solar	2011	Multiregional input-output (MRIO)	Taking into account the marginal technologies displaced, Concentrated Solar Power plant (CSP) results in net positive impacts on employment and the environment.
Duarte *et al.* (2017)	Solar	2013	Multi-sector input-output model, Social accounting matrix (SAM)	Spanish electricity system has a scarce connection with foreign power distribution grids. Solar demand predominates over supply.
Cansino *et al.* (2013) Cansino *et al.* (2014)	Solar	2013	CGE (Computable General Equilibrium)	Noteworthy socio-economic impacts: higher income, tax revenues and GDP.
Cámara *et al.* (2013)	Solar	2008 2020	SAM	CSP investments have positive impacts on sectors that in economic crisis merit attention.
Caldés *et al.* (2009)	Solar	2010	IO Multipliers	Notable impacts in terms of the increase of demand in goods and services and employment.
Cámara and Martínez (2017)	Solar, Small hydropower	2012, 2030	IO Multipliers	Positive impact in the territorial through employment and local tax revenues.
Cortés *et al.* (2015)	Solar	1995-2009	Environmental extended input-output model	Spain is one of the top per capita solar energy producers along with Japan and USA.

Source: Own elaboration.

Many authors have applied an input-output approach to study the Spanish electricity sector (Álcántara *et al.*, 2010, Tarancón *et al.*, 2010, Ramos and Moreno, 2013, Guerra, 2014, Cansino *et al.*, 2016a, among others) and greenhouse gas emissions (Labandeira and Labeaga, 2002, Tarancón and del Río, 2007, Llop, 2007, Tarancón and del Río, 2012, Cansino *et al.*, 2012 and 2016b, Demisse *et al.*, 2014). The economic impact assessments in Spain of RES has received a lot of attention (Caldés *et al.,* 2009, Cámara *et al.*, 2011, Cansino *et al.*, 2014, Cámara and Martínez, 2017, Duarte *et al.,* 2017, among others).

Focusing on microgeneration energy technologies, particular attention has grown around solar PV in Spain. The effects of this technology in economic and social terms are emphasized in several works (Corona *et al.*, 2016, Cansino *et al.,* 2013 and 2014, Cámara *et al.,* 2013, Caldés *et al.*, 2009, Cámara and Martínez, 2017, Cortés *et al.,* 2015, among others) with the exception of Duarte *et al.* (2017) who find that the generating and distribution electricity sectors are mainly highly capital intensive, but not relevant drivers of the economy.

Surprisingly, although Europe has a large tradition of Small Hydropower stations (SHP) and Spain is one of the main producers of SHP electricity in Europe together with Italy, France, Germany and Sweden (Manzano *et al.,* 2017), few attempts to study the economic and social input-output impacts of small and/or micro hydropower stations in Spain have been developed (Cámara and Martínez, 2017). Also, references to the analysis of potential effects of wind energy on the Spanish economy (Duarte *et al.,* 2017, Varela-Vázquez and Sanchez-Carreira, 2017, Cámara and Martínez, 2017, among others) do not consider a clear distinction of the micro-wind energy technology.

The present work aims to extend the literature, focusing on the impacts of different microgeneration power technologies in Spain under an IO framework and forecasting in the short/medium term. To the best of our knowledge, it is the first time in Spain that the focus has been placed on the detail of different types of microgeneration energy technologies and the impacts and interrelations with other sectors. This study considers the micro hydropower, small hydropower, micro-wind and photovoltaic technologies.

3. Disaggregation of the Spanish electricity sector

The level of sector aggregation of an IO table is key in the evaluation of the economic impact on the environment, especially if the environmentally sensitive sectors are aggregated (Lenzen, 2011). The Spanish Input-Output table includes only one sector referring to the electricity sector, so this sector needs to be disaggregated to study the effects of renewable energy-based distributed generation (RDG) on the economy.

The most recent symmetric Spanish Input-Output table published by the Spanish Statistical Institute is as of 2010. However, there is more recent information in the Input-Output framework. The latest Spanish Supply-Use tables at the time of writing this paper correspond to 2013. The Supply table presents the origin of the resources for goods and services. The Use table displays the use of those goods and services and the cost structure for the various industries.

Thus, a Symmetric Input-Output table can be compiled using the information of the Supply and Use tables without changing the value of the macro-economic aggregates (see details in methodology). With this option, we will obtain a Symmetric Input-Output table with the year of reference 2013.

This section describes the procedure to estimate the Input-Output table from Supply-Use tables and the procedure to disaggregate the electricity sector from the estimated IO table.

3.1. Conversion of the supply and use tables to an Input-Output table

The Symmetric Input-Output table is compiled by converting the Supply and Use tables into the Product Technology Assumption. The transformation is based on assumptions on the sales structure: it assumes that a commodity has the same input structure (United Nations, 1999).

Under this method, the construction of the Input-Output table from the Supply and Use tables was carried out in several steps. Using Product Technology Assumption, it can be established:

$$\mathbf{A}=\mathbf{P}\mathbf{C}^{-1} \tag{1}$$

where **A** is the technical coefficient matrix of the Symmetric input-output table and **P** and **C** are defined as:

$$\mathbf{C} = \mathbf{V}'\hat{\mathbf{g}}^{-1} \tag{2}$$

$$\mathbf{P} = \mathbf{U}\hat{\mathbf{g}}^{-1} \tag{3}$$

where **V** is the supply matrix, **U** is the use matrix and $\hat{\mathbf{g}}^{-1}$ is the vector of total sectorial output.

This process can produce negative values so, to solve that problem, hybrid technology and Almon's procedure can be applied. The methodology is commonly used in applied research to determine symmetrical Input-Output considering its economic interpretation. Product-by-product input-output tables for input-output analysis is believed to be more consistent of compilation (Jansen and Raa 1990).

Following this scope, the obtained Spanish Symmetric Input-Output table includes only one sector referring to energy: "Electricity, gas, steam and air conditioning". In the context of distributed generation under ensuing electricity management systems, it is relevant to disaggregate this sector. Several studies address the disaggregation of the electricity production sector (Shrestha and Marpaung, 2006, Lindner *et al*., 2013, Nakano *et al*. 2017, among others). Disaggregation entails the use of additional information sources. The data and estimation methods to disaggregate the *Electricity, gas, steam and air conditioning* sector are detailed below.

3.2. Data for the disaggregation

We proceeded to disaggregate the *Electricity, gas, steam and air conditioning* sector in three steps. The disaggregation of rows and columns of the energy reference sector is now detailed. The information requires splitting the subsectors, attending the sales of each industry (product) and the purchases of each industry, respectively.

Disaggregating rows is carried out in the following three steps. In the first step, the *Electricity, gas, steam and air conditioning* sector is split into two separate sub-sectors, *Production, transportation and distribution and commercialization of electrical energy* (NACE, 35.1) and *Production and distribution of gas, steam and air conditioning* (NACE 35.2, 35.3). With this aim, the information on sales of products, sales of merchandise and provision of services supplied by Industrial Companies Survey (Spanish Statistical Institute, 2014a) are used as proxies.

In a second step, Production, transport, distribution and commercialization of electricity are disaggregated according to *Industrial Companies Survey* micro-data about the same proxies.

In the last stage, the production of electricity is divided into the following technologies:

- Non-renewable: This includes the electricity produced by pumped hydro, power stations based on gas, coal, oil and nuclear.
- Renewables: This includes the electricity produced by *micro* (< 1MW), *small* (1-10MW) *non-pumped hydro power stations*, *micro-wind* (<100 kW), *photovoltaic* and the electricity produced by the *rest of renewable sources* (wind >100 kW, non-pumped hydro >10MW, concentrated solar power, biomass, municipal waste and geothermal). We would like to point out that our paper focuses on the impact of the small RDG according to the classification given by El-Khattam and Salama (2004). Thus, concentrating solar power (CSP) technology has not been studied separately as a small renewable technology, but it has been included in the *rest of renewable sources* because in the *Spanish Action Plan for Renewable Energy 2011-2020* (Spanish government, 2011) the figures for CSP show that the minimum rated power of this technology is mainly above the 50 MW mark. This could be attributed to the maturing of some of the technologies (mainly parabolic troughs, tower plants, and dish-based concentrators), which now allows for economies of scale and the building of larger power plants. The need for turbine-based energy conversion (mostly Rankine cycles) makes it a reasonable trend to up-size the plants to improve profitability. By contrast, *photovoltaic* generation consists of independent panels, which to some extent may also share components such as inverters or storage, but that can operate individually down to very low-power ratings.

To this end, gross electricity production is obtained from the Eurostat database (European Commission 2017). However, there is no separation of the gross electricity production of wind and hydro according to the capacity of the plants, so micro-wind data and the share of micro and small hydro in relation to the total of hydropower has been obtained from the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011). In order to obtain the net electricity production, all the consumption of power stations (10,370 GWh) and the electricity consumed by pumped hydro (5,960 GWh) reported by the Spanish Government (2013a) has been assigned to "non- renewable" technologies. In order to obtain the economic value of the net electricity production of "non-renewable" technologies, the final average purchase price of energy in the electricity market has been used (Red Eléctrica Española, 2013). The average price for "other renewables" has been calculated as a weighting average of the prices of renewable technologies using as weight the electricity produced by each technology.

It should be noted that the price regulation system was phased out through the Royal Decree 9/2013 of 12 July of 2013 (Spanish Government, 2013b), so the average price for 2012 has been used. Table 4, shows the economic value of the electricity production by technologies.

Table 4. Economic value of the electricity production according to technologies (2013)

Electricity Technology	Net Electricity production (GWh)	Economic Value (Thousands of €)
Non-renewable	157214	9069675.66
Renewables	115593	11095348.6
Hydropower	6315	552057.3
Micro Hydro	753	65827.26
Small Hydro	5562	486230.04
Micro-wind	17	1469.14
Photovoltaic	8327	3683115.37
Other renewable	100934	6858706.8
Total	272807	20165024.3

Source: Own estimations based on the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011).

Disaggregating columns is a similar process. The *Industrial Companies Survey* (Spanish Statistical Institute, 2014a) data and microdata about net purchases of raw materials, net purchases of other supplies, net purchases of goods, purchases and works carried out by other companies are used as proxies to first separate electrical energy and gas, steam and air conditioning and, then split production, transport, distribution and commercialization of electric energy. Finally, the production of electricity is separated in the mentioned technologies under some assumptions: purchases between these technologies are null, self-consumption appears in the main diagonal and the rest of the elements follow a structure similar to electric energy production.

The total installed capacity for PV is obtained from the Spanish Government (2013b), the hydro from REE (2013)- the share of micro and small hydro in relation to the total have been obtained from the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011), and the estimated micro wind from the same source. Table 5 shows the installed capacity by technologies.

Table 5. Installed Capacity according to technologies (2013)

RDG Technology	Installed Capacity (MW)
Hydropower	2058
Micro Hydro	263
Small Hydro	1795
Micro-wind	15
Photovoltaic	4711

Source: Own estimations based on the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011), Spanish Government (2013) and Red Eléctrica Española (2013).

4. Methodology

Using an Input–Output framework, some of the socio-economic impacts of RDG can be estimated. The Input–Output analysis has been widely used in environmental economics (Suh and Kagawa, 2009).

An Input-Output table describes the economic interconnections between sectors of the economy for a given period. Each row describes the output of each sector that is distributed to other sectors and final consumers; each column indicates the inputs necessary to produce the total output of the sector. The Input-Output model can be represented by the following equation:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{4}$$

where $\mathbf{x}$ is the vector of total output needed to satisfy the final demand, $\mathbf{y}$ is the vector of the final demand, $\mathbf{I}$ is the identity matrix and $\mathbf{A}$ is the matrix of technical coefficients. The Leontief inverse matrix $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ indicates the direct and indirect impact of a unit change in the exogenous final demand on the output of the industry.

By using the Input-Output model, the economic and environmental impact of RDG can be estimated as described in the following sections. The input-output model has commonly been applied to evaluate economic policies and to estimate impacts in the short and medium term. The main assumptions in the input-output model are (i) linear relations express the production process of each unit or sector, (ii) the Leontief production function assumes constant returns to scale (iii) changes in relative prices and possible substitution effects are ignored. For a more comprehensive overview of the strengths and weaknesses of IO models, see Miller and Blair (2009).

4.1. Procedure to estimate impacts on output and employment

One of the advantages of the Input-Output model is the capability to estimate how changes in final demand are transmitted and distributed in the economy through sectoral interrelationships (Eurostat, 2008). Thus, an increase in final demand for a particular product generates economy-wide changes: augment in the output of that product (direct effect) and increase in the demand of suppliers and so on (indirect effect).

Thus, the change in the output (Δx) due to an increase of the final demand (Δy) as a result of an increment in the renewable energy investments can be calculated as:

$$\Delta \mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \Delta \mathbf{y} \tag{5}$$

This model allows assessing the needs for total employment due to one unit change in final demand. The employment multipliers may evaluate in advance the employment impacts of economic policies destined to promote it by means of demand final increments, such as for example government expenditure, consumption or investment in a sector.

Direct employment coefficients estimate the relation between contracted employment and the production in an activity as:

$$n_j = \frac{l_j}{x_j} \tag{6}$$

where l_j is the employment (full time jobs) in sector j and x_j (monetary units) is the total output in sector j. In matrix terms:

$$\mathbf{l} = \hat{\mathbf{n}} x \tag{7}$$

where $\mathbf{l}$ is the contracted employment vector, $\mathbf{x}$ is the total output vector and $\hat{\mathbf{n}}$ is the diagonal matrix of direct employment coefficients. Considering that a change in the output will generate a change in employment:

$$\Delta \mathbf{l} = \hat{\mathbf{n}} \Delta \mathbf{x} \tag{8}$$

And substituting equation (5) for equation (8), the following expression is obtained

$$\Delta \mathbf{l} = \hat{\mathbf{n}} (\mathbf{I} - \mathbf{A})^{-1} \Delta \mathbf{y} = \hat{\mathbf{n}} \mathbf{K} \Delta \mathbf{y} \tag{9}$$

where elements of matrix $\mathbf{K}$, k_{ij}, are a measurement of created employment directly and indirectly in sector i when the final demand of sector j increases by a unit. The sum in j of the elements k_{ij} represents the total employment multiplier of a sector.

4.2. Procedure to estimate environmental effects over CO_2 emissions

Following Alcántara (1995), the total volume of emissions $\mathbf{E}$ (CO_2 equivalent) is calculated as:

$$\mathrm{E} = \mathbf{c}' \mathbf{x} \tag{10}$$

where $\mathbf{c}$ is the vector of sectoral direct emissions, $\mathbf{x}$ (nx1) represents (nx1) vector of total productions and **'** indicates the transposition of a vector. Then, according to equation (9), the sector total increase in emissions due to an increase in final demand can be determined as:

$$\Delta \mathbf{E} = \hat{\mathbf{c}} (\mathbf{I} - \mathbf{A})^{-1} \Delta \mathbf{y} \tag{11}$$

where $\mathbf{A}$ is the (nxn) matrix of technical coefficients, $\mathbf{y}$ (nx1) vector of final demand and $\hat{\boldsymbol{c}}$ is the diagonal matrix of sectoral direct emissions.

5. Results. Estimated impacts of the expansion of renewable energy-based distributed generation.

Europe 2020 -EU's growth strategy includes ambitious targets for boosting renewable energies - in final energy consumption. In the Spanish case, the Action Plan for Renewable

Energy 2011-2020 (Spanish Government, 2011) contains information related to electricity generation capacity investments by technologies for 2020. By using that information, the estimation of the impacts of the expansion of renewable energy-based distributed generation on the Spanish economy is carried out and presented in this section.
Longer-term predictions may not be feasible as the technological economic structure represented in an Input-Output table will change. Although some uncertainty can be associated to the sources of these forecasts, their reliability is adequate since the statistical information used comes from official organizations and the starting point of the prediction (year 2013) is not far from the final period (year 2020). The economic structure of a country remains stable, if moments not very distant in time are considered (Shishido *et al.*, 2000, Augustinovics, 1970, Jensen *et al.,* 1988, West 2000, Thakur, 2008 and 2010, among others).

In order to determine the impacts on the output, employment and emissions, it is necessary to account the monetary investment linked to the electricity generation capacity investments and the annualization of those monetary investments planned for 2020.

5.1. Investment for the installed capacity to 2020

The *Spanish Energy Efficiency Action Plan 2011-2020* (Spanish Government, 2011) gives forecasts regarding the gross electricity generation for 2010-2020 in Spain for the reference scenario and for the additional energy efficiency scenario (Table 6). Both scenarios share the same evolution about socioeconomic variables. The energy efficiency scenario includes new measures of energy efficiency that will be implemented from 2010 to make possible a reduction in the primary energy demand. The reference scenario does not include additional energy efficiency measures. The energy efficiency scenario is followed in this article. In EU, the Energy Efficiency Directive sets rules and obligations to help the EU reach its 2020 energy efficiency target and it is unrealistic to suppose that not one energy efficiency measure will be implemented in the studied period.
Moreover, the *Spanish Energy Efficiency Action Plan 2011-2020* also gives the energy consumed by pumping (12082 GWh) and consumption during generation (8968 GWh).

Table 6. Gross and net electricity generation for 2020 in Spain (GWh).

Electricity technologies	Gross	Net
Total	383634	362223
Non-Renewable	237193	216143
Micro Hydro <1MW (non-pumped)	843	843
Small Hydro 1-10 MW (non-pumped)	5749	5749
Micro wind (<100kW)	511	511
Photovoltaic	12357	12357
Other renewable	126620	126620

Source: *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011).

The evolution of the installed capacity of different electricity technologies is also offered. Table 7 summarizes the evolution for micro (< 1MW) and small (1-10MW)non- pumped hydro power stations, micro-wind (<100 kW) and photovoltaic, but also the estimated associated investment costs for each year.

Given the information about the prediction of installed capacity of different electricity technologies, the associated investment costs shown in Table 7 have been estimated as follows: they have been calculated taking into account the decreasing trends in those costs (as a way to take into account the learning curve in the technologies).

Table 7. Evolution of the installed capacity and investment costs of different electricity technologies

Technology\year	2014	2015	2016	2017	2018	2019	2020
Micro wind							
New annual power (MW)	20	25	40	50	50	50	50
Accumulated power (MW)	35	60	100	150	200	250	300
Investment (€\kW)	2565.1	2408.7	2262.1	2124.6	1995.7	1874.9	1761.6
Total annual investment (thousands of €)	51301.6	60216.9	90482.4	106230.3	99786.6	93744.3	88077.8
Licences and fees	39848.2	46773.0	70281.6	82513.7	77508.6	72815.2	68413.8
Construction	7356.7	8635.1	12975.2	15233.5	14309.4	13443.0	12630.4
Electric connection	2775.1	3257.3	4894.5	5746.3	5397.8	5070.9	4764.4
Wind turbine	1321.7	1551.4	2331.1	2736.8	2570.8	2415.2	2269.2
Micro Hydro <1MW							
New annual power (MW)	2	2	3	3	3	3	3
Accumulated power (MW)	251	253	256	259	262	265	268
Investment (€\kW)	384.3	383.5	382.6	380.9	379.1	377.4	375.6
Total annual investment (thousands of €)	768.6	767.0	1147.9	1142.6	1137.4	1132.1	1126.9
Work of intake, channel and reinforced pipe	229.6	229.1	342.8	341.2	339.7	338.1	336.6
Other civil construction Works	103.7	103.5	154.8	154.1	153.4	152.7	152.0
Turbine	148.1	147.8	221.2	220.2	219.1	218.1	217.1
Generator	148.1	147.8	221.2	220.2	219.1	218.1	217.1
Installation	50.4	50.2	75.2	74.9	74.5	74.2	73.8
Industrial margin	88.9	88.7	132.7	132.1	131.5	130.9	130.3
Small Hydro 1-10 MW							
New annual power (MW)	28	33	32	32	27	27	35
Accumulated power (MW)	1731	1764	1796	1828	1855	1882	1917
Investment (€\kW)	384.3	383.5	382.6	380.9	379.1	377.4	375.6
Total annual investment (thousands of €)	10760.8	12656.2	12244.1	12187.9	10236.2	10189.2	13147.4
Work of intake, channel and reinforced pipe	3565.5	4193.5	4057.0	4038.3	3391.7	3376.1	4356.2
Other civil construction Works	1472.2	1731.5	1675.1	1667.4	1400.4	1394.0	1798.7
Turbine	1932.2	2272.6	2198.6	2188.5	1838.1	1829.6	2360.8
Generator	1932.2	2272.6	2198.6	2188.5	1838.1	1829.6	2360.8
Installation	644.1	757.5	732.9	729.5	612.7	609.9	786.9
Industrial margin	1214.6	1428.5	1382.0	1375.6	1155.3	1150.0	1483.9
Photovoltaic							
New annual power (MW)	249	273	300	331	363	400	440
Accumulated power (MW)	5143	5416	5716	6047	6410	6810	7250

Investment (€\W)	1.9	1.8	1.7	1.5	1.4	1.3	1.2
Total annual investment (thousands of €)	479942.4	484575.0	495258.6	508369.5	518679.2	531732.1	543400.0
Module	293162.7	298078.8	281190.0	287474.4	295084.6	301068.9	308645.5
Other costs (licenses and others)	50605.5	51454.1	51870.0	53029.3	54433.1	55537.0	56934.6
Investors	48860.4	49679.8	58695.0	60006.8	61595.3	62844.5	64426.0
Civil construction Works	26175.2	26614.2	30030.0	30701.1	31513.9	32153.0	32962.1
Structure	27047.7	27501.3	32760.0	33492.2	34378.8	35076.0	35958.7
Turnkey contractor profit margin	24430.2	24839.9	27300.0	27910.1	28649.0	29230.0	29965.6
Cabling	1745.0	1774.3	2730.0	2791.0	2864.9	2923.0	2996.6

Source: the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011) and own estimations from the Institute for Diversification and Energy Saving and the Boston Consulting Group (2011).

The annual investment cost for hydraulic energy has taken into account the decreasing trends of those costs by 1% from 2010 to 2015 and 2% from 2015 to 2020 (*Spanish Action Plan for Renewable Energy* 2011-2020, Spanish Government, 2011- p. 322).

Related to the investment cost in micro-wind, the *Spanish Action Plan for Renewable Energy* gives the investment cost related commercial turbines with rated power of 20 kW, 60 kW and 100 kW, so the investment cost in micro-wind has been calculated by using the average ratios of cost per kW of the different turbines. These ratios have been applied to the investment according to the learning curve published by the Spanish Energy Efficiency Action Plan 2011-2020 (Spanish Government, 2011 p. 248), that indicates that for plants p≤10kW, there will be a 7% annual reduction from 3500€/kW in 2011 and for plants 10kW<p≤10kW those costs will be reduced by 5% from 2700 €/kW in 2011.

In the same way, the annual investment cost for photovoltaic energy has been calculated by averaging the cost of outdoor flooring and rooftop photovoltaic installations and taking into account the decreasing paths in those costs.

5.2. Effects of distributed renewable energy sources

The demand growth of every new power generation technology entails the expansion of two expenditure items: operation and maintenance of installations and the likely construction and start-up of new installations to cope with the demand. Under Input-Output framework, the direct and indirected effects of an increment in RDG investments in the economic sector are calculated in terms of output, employment and emissions.

Table 8 presents the sectors with the greatest annual impact on the output due to an increase in the investments in RDG. In order to isolate the effects of investments in RDG, the rest of the sectors have remained at the same level as 2013.

Table 8. Output impact due to investment (€ million)

	2014	2015	2016	2017	2018	2019	2020
Mining and quarrying	12.48	25.33	39.12	53.57	68.06	82.71	97.57

Chemicals and chemical products	9.49	19.25	29.72	40.70	51.71	62.85	74.14
Small Hydro	11.44	24.89	37.91	50.86	61.74	72.57	86.55
Micro Wind	54.53	118.54	214.72	327.65	433.72	533.37	626.99
Photovoltaic	510.1	1025.27	1551.72	2092.11	2643.46	3208.68	3786.31
Electricity distribution and commercialization	62.91	127.60	197.04	269.82	342.81	416.62	491.46
Constructions and construction Works	10.02	20.33	31.40	43.00	54.63	66.39	78.32
Wholesale trade services, except for motor vehicles and motorcycles	13.95	28.30	43.70	59.84	76.03	92.40	109.00
Telecommunications services	10.18	20.66	31.90	43.68	55.49	67.44	79.55
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	11.53	23.38	36.10	49.44	62.81	76.34	90.05

Source: Own estimations.

We observe that although the major impact of the expansion of RDG occurs in their sectors themselves, that investment also impacts on other sectors such as chemicals and the chemical sector when producing materials such as silicon for photovoltaic modules, the business support service sector when installing power generation facilities and the distribution and commercialization electricity sector. Related to the distribution sector, it should be noted that the combination of new technology solutions (smart grids) help to better integrate renewable energy under distributed generation resources. Although microgeneration energy sources can play a role in the economy, they are rarely effective in isolation and the smart grids and virtual power plants can improve their performance. It is highlighted that micro-wind plants require significant initial investments in relation to their size and are less profitable than large turbine plants because all system components have decreasing costs in relation to their size (Valentine, 2011), so the same investment reached with medium and high size wind plants would produce less effect on Spanish output. Bortolini *et al.* (2014) present a complete technical and economic analysis of small wind turbines extended to five of the major European Union countries including Spain.

The small hydropower projects attract attention in Spain since water reservoirs are significant for water, food and energy security.

Mayor *et al.* (2017) point out the higher impacts per unit of energy produced of small hydropower projects in the Spanish Duero Basin, but at the same time report concerns about the cumulative environmental impacts in relative terms.We would like to point out that the obtained results on the effect of disaggregated renewable sources on different sectors depend on the available data about the disaggregated cost per activity involved in the investment (insurance, management, among others). In Spain, Ogayar *et al.* (2009)

developed different equations through which it is possible to approximate costs for the construction of new small hydroelectric plants, according to several different activities; however, the information required for its calculation was not available for the present study.

Extend the impact analysis to assess and quantify the impact on employment of the renewable energy investment established in Europe 2020 strategy, involves identifying direct employment coefficients in 2013 and 2020. The employment of the *Electricity, gas, steam and air conditioning* sector is split into *Production, transportation and distribution of electrical energy* (NACE, 35.1) and *Production and distribution of gas, steam and air conditioning* (NACE 35.2, 35.3), using data from the *Industrial Companies Survey* (Spanish Statistical Institute, 2014). In accordance, the employment of the electricity sector by technologies has been estimated using the ratios of each power technology production over the total power production as a proxy. The statistical information in this last step is provided by Eurostat (European Commission, 2017).
The estimations of direct employment to 2020 are based on the *Spanish Action Plan of Renewable Energy* (Spanish Government, 2011) forecasts. The estimations of direct employment and the share of that employment of the total employment of the Spanish economy by electricity sub-sectors are presented in Table 9.

Table 9. Estimation of direct employment (thousands of people)

	2013		2020	
Electricity sub-sectors	**Employment**	**% total employment**	**Employment**	**% total employment**
Micro Hydro (<1MW)	0.058	0.0013	0.054	0.0010
Small Hydro (1-10MW)	0.428	0.0099	0.369	0.0068
Micro-wind	0.001	0.0000	0.033	0.0006
Photovoltaic	3.24	0.0748	0.793	0.0147
Other renewable	6.033	0.1393	8.131	0.1506
Non-Renewable	7.978	0.1842	13.879	0.2571
Transport	1.576	0.0364	2.067	0.0383
Distribution and commercialization	16.614	0.3837	21.786	0.4036
Gas, steam and air conditioning	7.372	0.1703	6.871	0.1273
Total	43.3	100.00	53.983	100.00

Source: Own estimations based on the *Industrial Companies Survey* (Spanish Statistical Institute, 2014a). Energy Statistics: supply, transformation and consumption (European Commission, 2017) and the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011).

It should be noted that the deployment of RDG projects leads to new investments and an increase of renewable energy production, but also it is accompanied by an effect of substitution of conventional energy demand and thus a decrease in their employment.

Table 10 shows the losses of employment (only in the electricity sub-sectors) due to a substitution of conventional energies consumption by renewable energies, but also the percentage of that employment of the total employment of the Spanish Economy.

Table 10. Expected increase in total employment in 2020 with respect to 2013 (thousands of people). Electricity sub-sectors

Electricity sub-sectors	Change in total employment	% total employment
	Positive	
Micro Hydro (<1MW)	0.005	0.054
Small Hydro (1-10MW)	0.048	0.516
Micro-wind	0.033	0.355
Photovoltaic	0.366	3.935
Other renewable	0.000	0.000
Distribution and commercialization	0.247	2.783
Transport	0.030	0.323
	Negative	
Non-Renewable	-0.762	8.186
Gas, steam and air conditioning	-0.005	0.07

Source: Own estimations based on the *Industrial Companies Survey* (Spanish Statistical Institute, 2014a). Energy Statistics-supply, transformation and consumption (European Commission, 2017) and the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011).

Photovoltaic is the sector which is expected to grow more in employment. In fact, the *Spanish Action Plan of Renewable Energy* (Spanish Government, 2011) expects a significant growth in production which leads to this increase of almost 366 (3.93%) individuals. Distribution and commercialization also presents an important growth in the employment of 260 individuals (2.79%). On the other hand, the non-renewable energy sector has experienced a sharp decline in employment (569 individuals) due to the substitution of its production.

The direct employment of the rest of the sectors is specified in the IO table.

The total impact of RDG expansion on employment (direct and indirect) in different sectors of the economy appears in Table 11 (only sectors with growth in employment above the third quartile are shown). The construction sector increases its employment as it is directly involved in the enlargement of new plants. Additionally, business and management support services and wholesale trade services have also seen their number of employees increase in response to the upturn in economic activity, generated by the construction of new plants. In line with these results, Barros *et al.* (2017) highlight the potential of some renewables for high employment generation and Hondo and Moriizumi (2017) point out the indirect employment effect of renewables in the service sectors.

Table 11. Expected change in total employment in 2020 by sector (thousands of people).

Sector	Change total employment	% increase in total economy
Repair and installation services of machinery and equipment	0.163	1.754
Other professional, scientific and technical activities	0.199	2.144
Architectural and engineering activities; technical testing and analysis	0.197	2.120
Retail trade, except motor vehicles and motorcycles	0.236	2.533
Financial service activities, except insurance and pension funding	0.245	2.630

Electricity distribution and commercialization	0.260	2.795
Manufacture of fabricated metal products, except machinery and equipment	0.280	3.010
Constructions and construction Works	0.315	3.387
Legal and accounting services; services of head offices; management consulting services	0.329	3.534
Photovoltaic	0.366	3.933
Land transport services and transport services via pipelines	0.480	5.157
Wholesale trade services, except motor vehicles and motorcycles	0.985	10.586
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	1.519	16.329
Total Economy	9.301	100
Third quartile	0.119	

Source: Own estimations based on the *Industrial Companies Survey* (Spanish Statistical Institute, 2014a). Energy Statistics-supply, transformation and consumption (European Commission, 2017) and the *Spanish Action Plan* for *Renewable Energy* 2011-2020 (Spanish Government, 2011).

To determine the importance of the analyzed sectors, only the changes in the direct coefficients of these branches have been considered.
In order to account for the impact of RDG deployment on emissions, Europe 2020 targets are taken as references: greenhouse gas emissions to be reduced by 20% compared to 1990 and the share of renewable energy sources in final energy consumption to be increased to 20%.

The analytical framework that accounts for this impact is based on a hybrid model that combines magnitudes in physical units such as emissions and magnitudes quantified in monetary units such as the sectorial production. Data about the level of emissions has been obtained from Air Emission Accounts elaborated by the Spanish Statistical Institute (2014b). The methodology described in Section 4.2 has been applied to estimate the impact of RDG deployment on emissions. We have supposed several scenarios according to the share of RDG sources in final energy consumption: 5%, 10% and 20% as an upper limit.

Subsequently, new emissions have been calculated as of the Input-Output model and the ensuing reduction rates between 2013 and 2020 have been estimated. The main results are presented in Table 12.

Table 12. Expected CO_2-equivalent emission reductions in 2020 from 2013

Sector \ Scenarios	**Percentage of RDG sources in final energy consumption**

	5%	10%	20%
Mining and quarrying	0.15	0.32	0.67
Coke and refined petroleum products	0.07	0.14	0.31
Non-renewables	10.25	12.51	17.35
Gas. steam and air conditioning	0.28	0.56	1.20
Total economy	6.88	9.40	21.67

Source: Own estimations based on *Air Emission Accounts* (Spanish Statistical Institute, 2014b) and the *Spanish Action Plan for Renewable Energy* 2011-2020 (Spanish Government, 2011).

The obtained results show that under 20% scenario emissions decrease 21.67 % in 2020 compared with 2013 levels. The greatest emission reductions are found in mining and quarrying, coke and refined petroleum products, gas, steam and air conditioning and non-renewable sectors.

6. Conclusions

An important increase of small-scale renewable power-based generation technologies is expected in Spain by 2020. In fact,the *Spanish Action Plan for Renewable Energy 2011-2020* (Spanish Government, 2011) raises the installed capacity of small hydropower, photovoltaic or micro wind to 2158 MW, 12356 MW and 300MW till 2020, respectively. Economically, the investment in these technologies can originate relevant induced effects in the economy. Thus, we study the economic impact of renewable energy-based distributed generation technologies (RDG) on the Spanish economy for 2020 by using an Input-Output approach and the data of the Spanish Action Plan for Renewable Energy 2011-2020 under the energy efficiency scenario.

There may be discrepancies between the *Spanish Action Plan for Renewable Energy 2011-2020* and the real data. Prediction of the electric power system is difficult due to its stochastic nature. The electricity system is marked by incomplete information and uncertainty. The electric power industry unveils relevant changes with respect to management, technology progress, consumer behaviour, industry configuration and government policy.

Institutionalized legal insecurity, retroactive measures, the current regulation for the grid connection of large-scale energy infrastructure (Spanish Government 2015) and a lack of grid expansion plans were some of the barriers causing the observed stagnation of renewables in Spain (López and Steininger, 2017). After the stoppage of the growth of renewables in Spain in 2012, the Spanish electricity system is currently undergoing important changes that can give a boost in the fight against climate change, foster the ecological transition and try to reach the objectives of the Spanish Energy Efficiency Action Plan in record time. The Government promoted in 2017 the installation of 8,700 MW of renewable energy (UNEF, 2018). In July 2017, more than 5,000 MW of photovoltaic and wind power were awarded. The latest auctions for the installation of renewable energy in Spain highlight the possibilities of this sector (Donoso, 2017) and an encouraging scenario for the upcoming years (UNEF, 2018, Jäger-Waldau, 2017). The ambitious agreement on the transition to clean energies within the European Union for 2030 should strengthen investors' certainty (European Commission, 2018). Additional energy efficiency policies in Europe can contribute to achieving the objectives marked in the Spanish Action Plan for Renewable Energy 2011-2020.

Under this approach, the direct and indirect effects of an increment in RDG investments in the economic sector are calculated in terms of output, employment and emissions.The existing Spanish Input-Output tables do not include RDG so it is necessary to disaggregate the existing sector "Electricity, gas, steam and air conditioning" before forecasting the induced production, employment and CO_2 emission effects in every sector due to new RDG project investments. These impacts have been calculated given the information about the path of installed capacity of different electricity technologies from 2014 to 2020. The associated investment costs should be estimated for each year. They have been calculated taking into account the decreasing paths in those costs.

Beyond the possible bias of scenarios with respect to the real data, the methodology offers a general tool for measuring impacts. The method offers multipliers of changes due to a unit increase in final use. The exposed results in the paper are for the whole economy, but implicitly, the results can be obtained for unit increase in final demand, and then they can be appropriate for other scenarios of evolution of small-scale renewable energies.

The estimated impact on the output by sector shows that major impacts are expected in the RDG sectors themselves, but RDG investment also impacts on other sectors such as chemicals and the chemical sector, the business support service sector and the distribution and commercialization of electricity sector.

With regard to the effect of the development of RDG on employment, it has been shown that it directly generates jobs in the energy sector (at the operation and maintenance stages) but also indirectly induces jobs in other sectors such as the construction sector (at the investment stage) and other sectors such as services, as other studies have also highlighted (Corona *et al*., 2016; Nagashima *et al.,* 2017, among others). The photovoltaic sector is that with the highest direct employment expected growth. Cartelle *et al.* (2017) point out that some renewables -such as photovoltaic or mini-hydro, among others, are still the options with the highest direct employment generation. Moreover, the construction sector increases its employment as it is directly involved in the enlargement of new plants, but also business and management support services and the wholesale trade services sectors.

Regarding the impact of RDG deployment on emissions, our obtained results show an expected emissions reduction in the economy as a whole of 6.88% and 21.67 % from 2013 to 2020 if the share of RDG sources in final energy consumption increases to 5% and 20% respectively. Those estimated environmental, output and new job benefits in the economy are relevant and help the transformation to not only lower-carbon economy but also to achieve a prosperous nation. It should be pointed out that distributed energy resources reduce transmission and distribution network investment needs which have not been taken into account in this study as only capacity investment has been considered.

Related to the distribution sector, it is worth highlighting that new technology solutions help to better integrate renewable energy under distributed generation resources. Although microgeneration energy sources can play a role in the economy, they are rarely effective in isolation and the smart grids and virtual power plants (VPP) can improve their performance. The aggregation of distributed generation resources based on renewables under the VPP concept could reduce the imbalance costs contributing to EU2020 engagement and increase a reliable electricity supply compared to stand-alone RDG units. With regard to VPP, we would like to point out that the current Spanish Royal Decree 413/2014 (Government of Spain 2014) allows the participation of renewable power technologies in other electricity markets as in the provision of ancillary services plants, providing that the power is equal to or higher than 5MW, it being possible to reach that power by the aggregation of several RDG units. As shown, the increment of RDG contributes to tonnes of CO_2 avoidance annually. However, it would be possible that they could have negative effects on other environmental issues. A further step of our research could be to take into account other environmental impacts besides emissions. For example, wind turbines generate several environmental impacts (see Zerrahn 2017 for a literature of wind power externalities) such as a deterioration of the aesthetic quality of landscapes, for that reason a study of the environmental impact of the installation of new plants is sometimes required in order to obtain the license for the installation.
Related to small hydro, Valero (2012) provided a characterization of the water quality status in a river stretch around a small hydro plan situated in northwest Spain, for four years after its construction and showed that the plant caused an adverse effect on the ecosystem and biological quality of the water over a period of two years (Manzano-Agugliaro *et al.* 2017 summarized an overview of social aspects and environmental issues of small hydropower and its research trends in Europe).

Regarding the implication of the results of this research for other countries in the world, we would like to highlight that the obtained results with IO methodology are conditional to the economic structure of each country and its electricity supply characteristics. Thus, results could be useful for other countries with similar characteristics to Spain. In this sense, Eurelectric (2018) indicates that the different point of departure of EU countries in terms of energy mix, economic situation and industrial activities will imply different pathways and levels of effort of the decarbonisation process. However, the procedure and methodology we have used could be applied to any other country in the world in order to help them decide their choice between different future RDG investment paths, according to the induced production and employment effects they have.

In future research, a multi-regional input-output model will add more precision to the impact analysis regarding the consequences of international trade and the relevance of imports as other authors have pointed out (Machado *et al*., 2001, Mongelli *et al*., 2006, Nakano *et al*., 2018). The use of a multiregional input–output model makes it possible to register, not only the domestic impacts directly and indirectly generated in the country, but also the effects generated abroad (Cui, *et al.,* 2015, Markandya *et al*., 2016). Globalization has increased the fragmentation of the supply chains around regions where extraction of raw materials and manufacturing of components can take place in some countries and distribution and/or consumption in others. Changes in the energy mix of some countries can benefit other countries, enabling economic and social environments for the production of renewable energy-related goods and services. In that sense, RDG deployment has an impact on national economies, but also on other economies when including spillovers and supply chains of regions whose multi-regional input-output model we could quantify in future work. Likewise, the study of the link between energy consumption, standard of living and consumption patterns can help to delve deeper into the relationship between economic growth and environmental impacts (Duarte *et al*., 2010, Cellura *et al*., 2011; Graham, 2017).

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