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THE IMPACT OF RENEWABLE ENERGY ON VALUE-ADDED AND EMPLOYMENT IN NAVARRE

Spanish, International and Sectorial Economics

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ABSTRACT

This research quantifies the economic impact of solar FV and wind power in Navarre during the years 2010-2019 in terms of value-added and employment. The research starts with a brief description of the energy sector in Navarre, paying special attention to the development of wind and solar FV technologies. Then, input-output methodology is explained, as well as the data sources that will be used in the analysis. Estimations of direct, indirect and induced effects are made. Finally, the results from the investigation are presented and contextualized with information from the regional energy sector.

RESUMEN

Esta investigación cuantifica el impacto económico de las energías renovables solar y eólica en Navarra durante los años 2010-2019 en términos de valor añadido y empleo. El artículo comienza con una breve presentación del sector energético en Navarra, haciendo hincapié en el desarrollo de las tecnologías de interés. Seguidamente, se explica la metodología input-output que se empleará en el análisis, así como las fuentes de datos utilizadas. Se estiman los efectos directos, indirectos e inducidos. Finalmente, se muestran los resultados de la investigación y se contextualizan con información económica del sector energético.

Key words: Renewable energy, Input-Output analysis, Applied economics.

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1. INTRODUCTION

Since the year 1994, wind power started to develop in Navarre. From the year 2005 onwards, the solar FV sector started to gain importance as well. Installation stopped in the middle of the last decade, but it is expected to resume installation in the immediate future.

In the context of the upcoming climate crisis, a transition towards renewable energy sources is believed to be key, as greenhouse gas (GHG) emissions from burning fossil fuels are avoided. In the case of regions such as Navarre, with no deposits of fossil fuels, the development of renewables is also important for the sake of self-sufficiency. Apart from these reasons, the development of a renewable energy sector brings about positive economic effects. Indeed, a working paper published by the International Monetary Fund a month ago highlighted the economic impact of green investment, as it was estimated that the spending multipliers for clean energy projects were between two and seven times higher than those related to non-ecofriendly expenditure (IMF, 2021).

The aim of this research is to quantify the regional economic impact in terms of value-added and employment of the solar FV and wind technologies in Navarre. Jenniches (2018) thoroughly reviews the different methodologies in the economic literature that have been used to assess the regional economic impacts of renewable energy. Among the most common techniques, he finds employment ratios, supply chain analysis, input-output modelling, and computable general equilibrium (CGE) models. The main advantage of input-output modelling is that it accounts for all input flows of different industries, following an integrating approach. This is also accomplished in CGE models, but the data requirements exceed the scope of this analysis. Therefore, the impact of solar and wind power in Navarre will be analyzed using input-output methodology.

This methodology has been used to assess the regional impact of renewable energy in other parts of Spain. For example, Laplaza-Abadía and Simón-Fernández (2019) and Aixalá et al (2003) studied the impact in Aragon for different time periods; and Varela et al (2014) conducted a similar analysis in Galicia. The energy sector in Navarre and, in particular, the sector of renewable energy has already been studied: Faulín et al (2016) gave an account of the economic profile in the sector; López et al (2007) reviewed the recent evolution of different energy sources in the autonomous community; and the Government of Navarre (2016) published a report in which the impact on employment and value-added of the sector was analyzed for the years 2010 and 2014 through a company-based methodology.

This research builds upon previous research to complement their insights with a quantitative analysis of the economic impact. Not only do we calculate regional direct and indirect impacts, but also the induced effect of wind and solar FV technologies, which has been disregarded in other regional input-output studies.

The first section of the study describes the energy sector of Navarre in general and the solar FV and wind technologies in particular. This will be useful to contextualize the results. Input-output methodology is explained in section three. Results are presented next and, finally, the research ends with a brief conclusion.

2. THE ENERGY SECTOR IN NAVARRE

2.1. An overview of the sector

According to data from the Statistics Office of Navarre, the energy sector in Navarre accounted for 1,5% of total employment in the year 2005. In terms of value-added, the economic importance of the sector amounted to 5%. From that year, the sector has gained importance: in 2010, almost 2% of labor in the autonomous community was employed in the energy sector and it generated almost 7% of all value-added in the region. The most recent data (year 2019), shows that the sector has remained stable around the size of 2010: it employs 5.708 people and generated a value-added of 20 million euros. If we compare it to the industrial sector, we can see that it accounts for around 7% - 8% of employment and for 20% of industrial value-added. Productivity, measured as the ratio of value-added to employment, shows an increasing tendency: during the last decade, it has increased in 13%. The productivity of the energy sector is higher than the average of the industrial sector. More detailed information is presented in Table 1 and Table 2.

When we study energy, we need to distinguish between primary energy and final energy. Primary energy refers to the energy sources found in nature, without further processing or refinement for consumption. Final energy, on the other hand, refers to the energy that is used at the end points. The sources of primary energy can be divided into two broad categories, according to the nature of the natural resource form which energy is obtained: flow and stock. Stock resources can be quantified in an amount and the consumption of the resource today affects the amount of the resource left for tomorrow. According to how rapidly stock resources regenerate, they can be further classified into non-renewable (if a resource cannot regenerate fast enough; such as oil, natural gas, etc.) and renewable (if a resource is able to regenerate fast enough; this is the case of biomass). Opposite to stock resources we find flow resources, which are those for which present consumption of the resource does not have an effect on the amount that we can consume tomorrow. Examples of this are the sun or the wind: the use that we can make from the sun tomorrow is not limited by the use that we make of the sun today. For this reason, flow resources employed in energy production are commonly referred to as "renewable energy resources" (Field, 2016).

Table 1. Economic importance of the energy sector in Navarre in terms of employment.

	Employment	Share of total (%)	Share of industry (%)
2005	4350	1,46	6,09
2006	4582	1,50	6,40
2007	4616	1,46	6,12
2008	4828	1,53	6,38
2009	5222	1,74	7,35
2010	5492	1,86	7,86
2011	5341	1,82	7,67
2012	5213	1,86	7,96
2013	5185	1,91	8,26
2014	5155	1,88	8,13
2015	5301	1,88	8,15
2016	5402	1,88	8,16
2017	5443	1,84%	7,97%
2018	5517	1,82%	7,82%
2019	5708	1,83%	7,90%

Source: Own elaboration with data retrieved from the Statistics Office of Navarre (2019a).

Table 2. Economic importance of the energy sector in Navarre in terms of value-added.

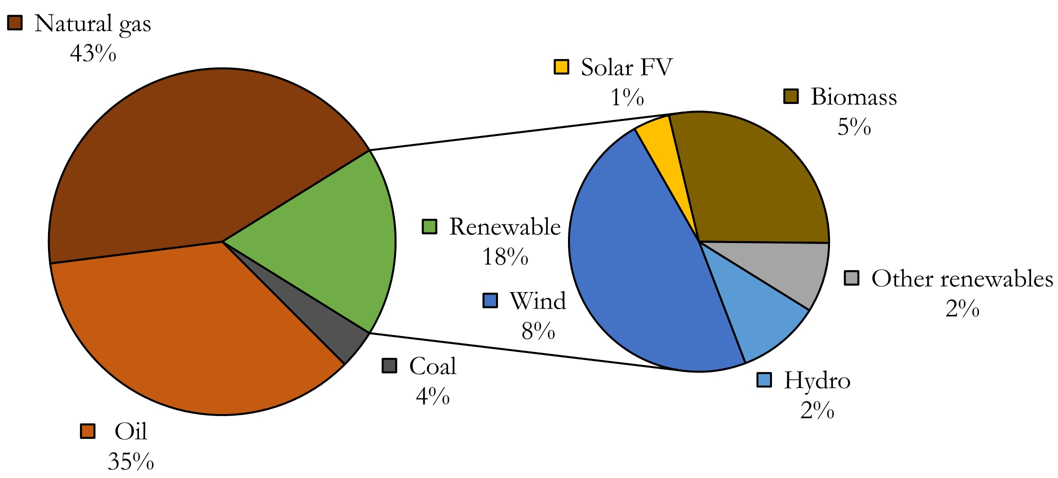
	Value-added (€)	Share of total (%)	Share of industry (%)
2005	14.388.362,38	4,99	16,91
2006	15.388.626,58	4,80	16,43
2007	16.609.694,90	4,89	16,75
2008	17.579.960,57	5,90	20,20
2009	17.184.509,79	6,18	21,90
2010	17.052.693,89	6,85	22,97
2011	17.352.606,22	6,99	22,84
2012	17.020.859,94	7,19	23,58
2013	16.687.083,10	7,07	22,73
2014	16.871.768,29	6,73	21,20
2015	17.395.454,35	6,90	21,68
2016	17.913.851,17	6,89	21,79
2017	18.591.992,88	7,10	22,64
2018	19.316.672,41	6,79	22,00
2019	20.100.018,15	6,85	22,27

Source: Own elaboration from data retrieved from the Statistics Office of Navarre (2019b).

According to this classification from natural resource economics, we can state that the majority of primary energy in Navarre comes from non-renewable resources (Government of Navarre, various years). According to the Energy Balances of Navarre, in the year 2010, for example, around 82% of primary energy proceeded from natural gas (43%), oil (35%) and coal (4%). The remaining 18% of primary energy is found in renewable sources, such as wind (8%), biomass (5%), hydro (2%), solar FV (1%) and others (2%), which include biogas, solar thermal, geothermal, etc. We can see that the variables of interest, solar FV and wind power, differ in importance. As share of primary energy, solar FV only accounts for 1%; wind power, instead, is the third most important source of primary energy.

All non-renewable sources of energy in Navarre are imported. This, combined with the fact that part of the biomass consumed in the central of Sangüesa[1] is also imported, leaves a self-sufficiency ratio of 14% in 2010, that is, the share of energy that Navarre was able to produce without drawing on external trade was only 14% of the primary energy used.

Figure 1. Sources of primary energy in Navarre in 2010.

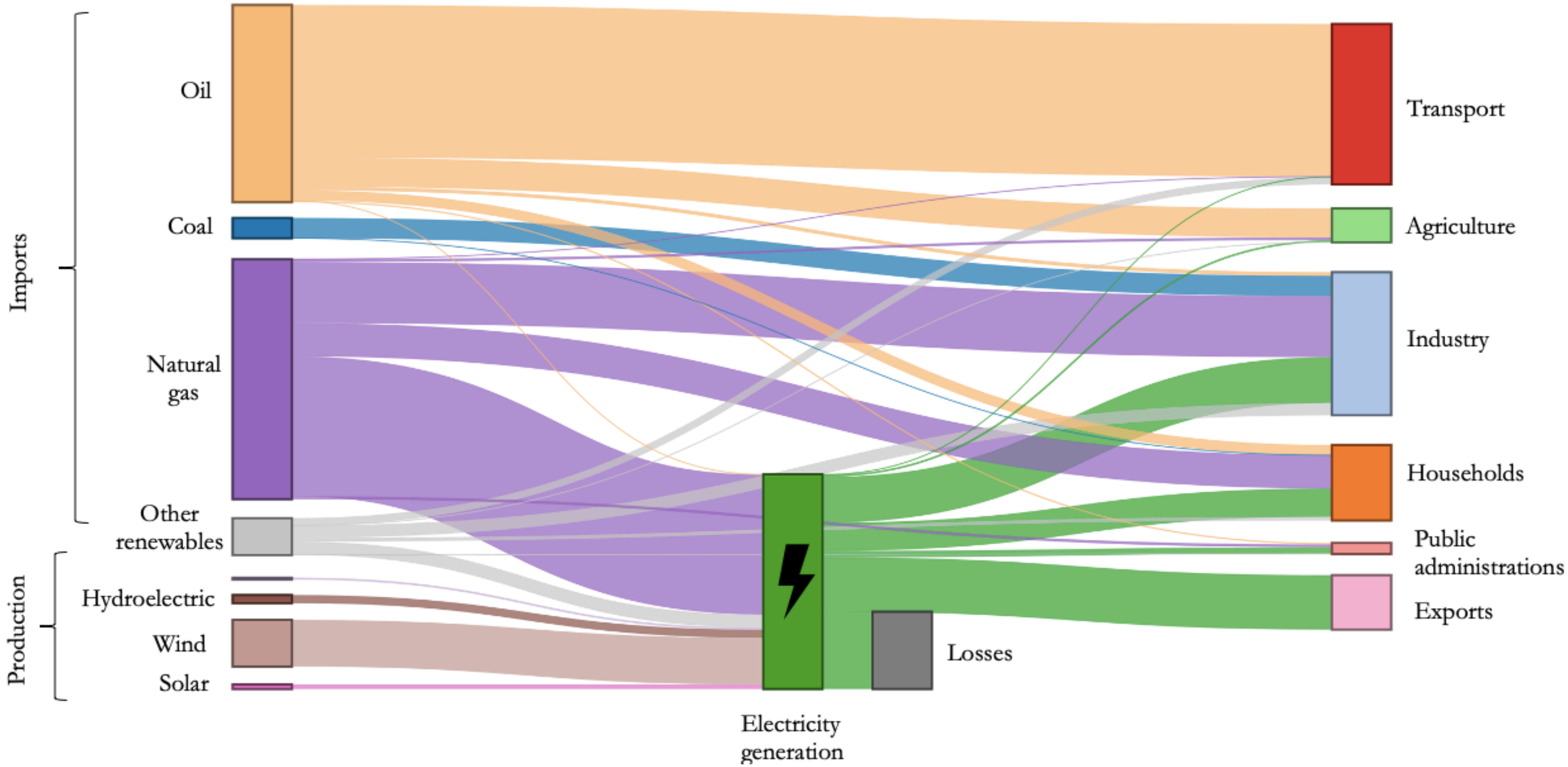


Source: Own elaboration with data from the 2010 Energy Balance (Government of Navarre, 2019).

Carbon is consumed in industrial settings directly in the same form as it is imported, as well as most of oil (99,8% of it), which is mainly used for transport and agriculture, and almost a half (41,7%) of natural gas, which is used for heating in the households and in industrial settings. Some of the primary energy needs to be transformed into electricity before reaching the end points for consumption. The rest of natural gas is employed in thermoelectric centrals that generate electricity. An overview of the energy system for the year 2010 can be seen in Figure 2. The general conclusions remain valid for the rest of the past decade, as no relevant changes have occurred in the period.

[1] The biomass power station in Sangüesa was opened in the year 2002 and runs on agricultural waste (mainly cereal straw) to generate electricity. Given its proximity to other autonomous community, Aragón, part of its inputs are imported (López et al, 2007).

Figure 2. Sankey diagram of energy flows in 2010 in Navarre.



Source: Own elaboration with data from the 2010 Energy Balance of Navarre (Government of Navarre, 2019).

As we can see, the main sources of electricity generation are natural gas, hydro, wind, solar FV and other renewables. However, this was not always the case. Until the 1980s, there were only two means of generating electricity: hydraulic and thermal by cogeneration. This was not a centralized activity. Lots of small hydroelectric stations were scattered throughout the territory, wherever natural conditions allowed such facilities to function. Conventional thermal generation, which generates electricity by moving turbines with steam from boiling water through the combustion of materials, were located in factories for self-consumption and sold any surplus of electricity to the grid. Demand for electricity was higher and, therefore, electricity needed to be imported to satisfy demand (López et al, 2007).

In order to increase the self-sufficiency ratio, Navarre started to develop renewable energy sources (based on wind, sunlight and water). The first step was to enlarge the capacity of hydroelectric stations. A refurbishment of stations that were becoming obsolete was carried out around the year 1995, which helped increase the generation of electricity. Additional megawatts of hydro power were installed continuously until the year 2000. Almost until that year, it was the main source of electricity in Navarre (López et al, 2007). In the present, hydroelectric plants count with a total of 254,8 MW installed (Government of Navarre, 2019).

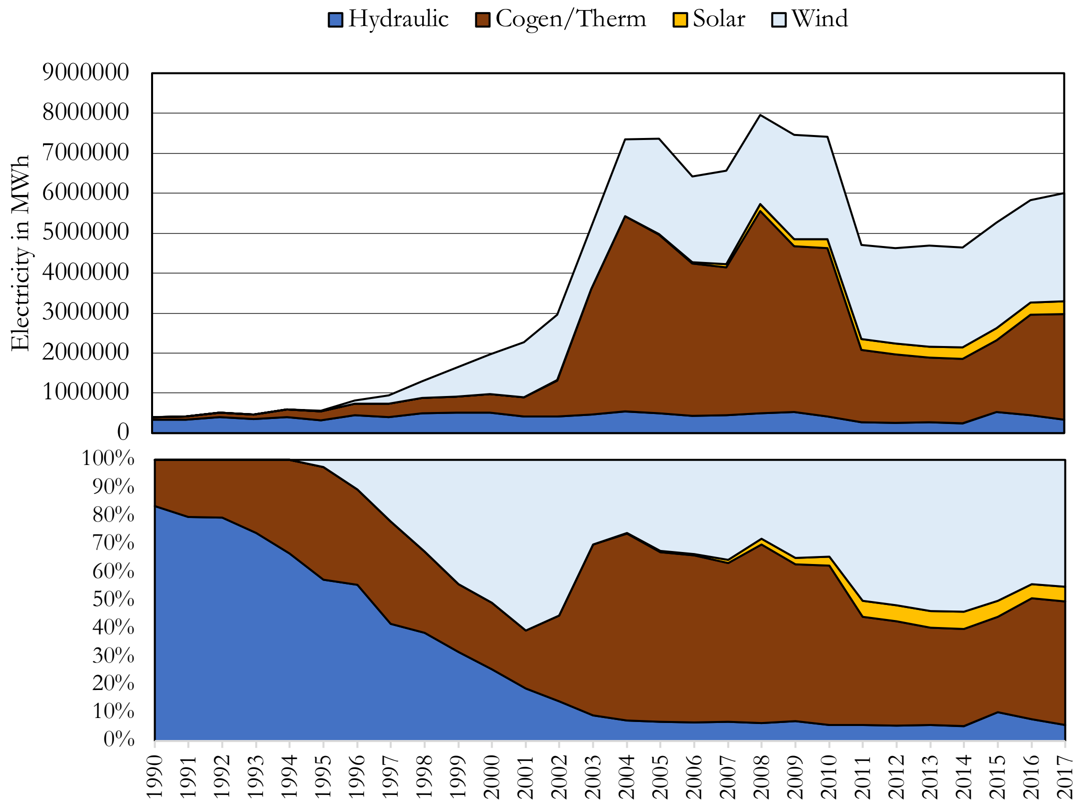
Wind power began to develop around the year 1994. It was stablished as the main pilar to achieve self-sufficiency. Installation took off rapidly, some years even doubling the cumulative installed power of the previous year. In terms of electricity generation, nowadays, total wind power capacity amounts to 1.028,60 MW (Government of Navarre, 2019).

Solar photovoltaic power is the least developed of the three. Its installation truly began in the year 2000, later than the others, and is not comparable to the capacity installed of wind power: as of the year 2019, only 162 MW of solar FV had been installed (Government of Navarre, 2019). The potential of the region continues to be unexploited.

At first it was thought that Navarre could achieve self-sufficiency solely by drawing energy from renewable sources, but eventually, combined-cycle power plants were installed. These are the power plants in Castejón, that produce electricity on the basis of combined cycles, which are more efficient than conventional thermoelectric plants. They began to operate in the year 2003 and became the main source of electricity in Navarre. At first they run on oil and later on natural gas (López et al, 2007).

Figure 3 shows how the primary energy source of electricity has evolved over the years in absolute and relative terms. Hydroelectric power is stable in absolute terms, but given the huge increase in electricity production, it has been losing importance in relative terms. It is noticeable how the installation of the combined-cycle plant in the year 2003 boosted the generation of thermoelectricity. The steady increase in wind power is also remarkable: even if it was not enough to achieve self-sufficiency, it is the factor that guarantees now that more than half of the electricity produced in Navarre is of renewable origin. Together with solar FV, they make up half of the electricity produced.

Figure 3. Evolution of the primary energy sources of electricity in Navarre 1990-2017.



Source: Own elaboration with data from Energy balances (Government of Navarre, 2003-2019) and the dataset from López et al (2007).

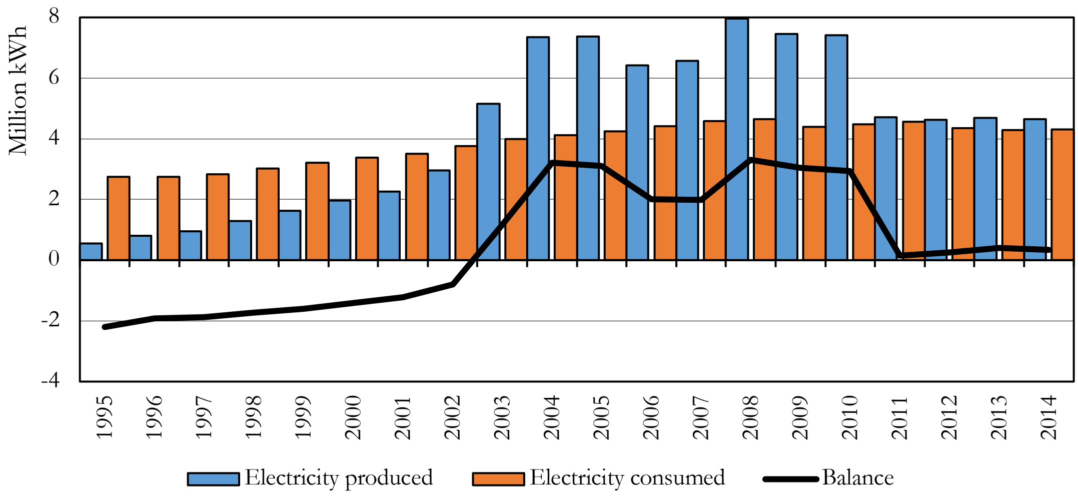
If we compare the electricity produced with the one consumed in the region, we can see that before the year 2003 Navarre needed to import electricity. From that year onwards, Navarre exports any surplus electricity. This can be seen in Figure 4[2].

As we can see, the current capacity of renewable energy sources alone is not enough to achieve independence from the external electric system. Nonetheless, they have been beneficial to the autonomous community in terms of value-added and employment. Moreover, it has consolidated a growing industrial sector of renewable energy in the region.

[2] Lack of available data on regional electricity consumption has made it impossible to offer a complete figure that tracks the evolution of the trend until the present.

The next section will focus exclusively on the development of wind and solar FV and on the sector that they operate in.

Figure 4. Electricity produced and consumed in Navarre from 1995 to 2014.



Source: Own elaboration with data from Energy Balances (Government of Navarre, various years), data from the Statistics Office of Navarre (2015a) and the dataset of López et al (2007).

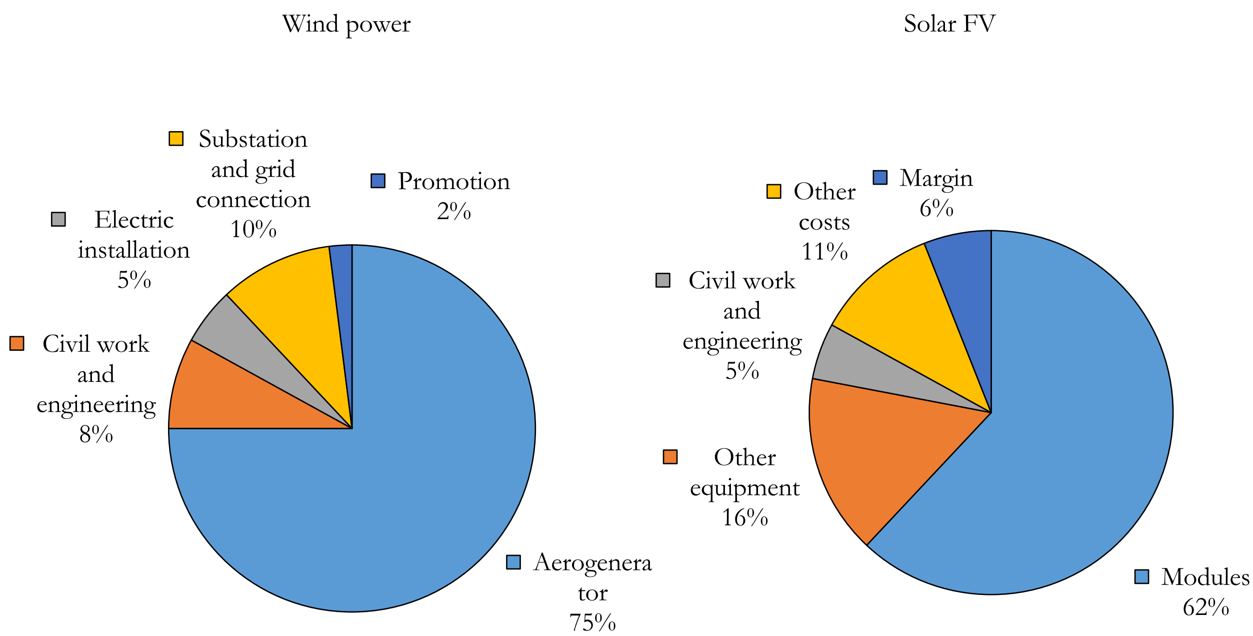
2.2. Solar FV and wind technologies during the last decade in Navarre

Regarding the development of the renewable energy sector in Navarre, there have been different public energy plans. The first energy plan (1995-2000, prolonged until 2005), the second (2005-2010) and the third (2010-2020) had the common objective of increasing energy self-sufficiency by increasing renewable capacity (Government of Navarre, 2010). As in the rest of Spain, the combined effect of introducing European directives regarding climate change and the consolidation of a European energy marker, and the quest for less external dependency favored the development of renewable energy sources.

The development of the wind and solar FV technologies during the period 2000-2010 was fostered under a very favorable regulatory framework: renewable energy sources were included in a special regime that guaranteed an extra prime for the sale of electricity (Real Decree Act 661/2007). This created a considerable incentive for the renewable energy sector to grow. After all, the installation of facilities to generate any type of energy, just like the installation of any other facility, has to do with the economic conditions of the sector: it is a business decision. It was profitable to invest in renewables under these conditions: by the beginning of the year 2010, 119,50 MW of solar FV power and 961,77 MW of wind power had been installed (Government of Navarre, 2009).

Another economic factor that should be taken into account is the costs. According to the "Plan for Renewable Energy" for the time period 2011-2020 (Instituto para la Diversificación y el Ahorro Energético - IDAE, 2011), estimated costs for the installation of a solar FV facility and of a wind farm were distributed in the following way (see Figure 5). The main component of wind power, to which 75% of the cost is attributed, is the aerogenerator. In the case of solar FV, the main part are the modules, which concentrate 62% of the installation costs. As we will see next, improvements in the production of these components are responsible for a large decrease in the cost of generating electricity using wind and solar FV power. Civil work and engineer is higher (as percentage of total cost) in wind than in solar FV. This will be relevant in the next section to determine the employment that the installation of these technologies generate in the economy.

Figure 5. Breakdown of the installation costs of solar FV and wind power in 2010.

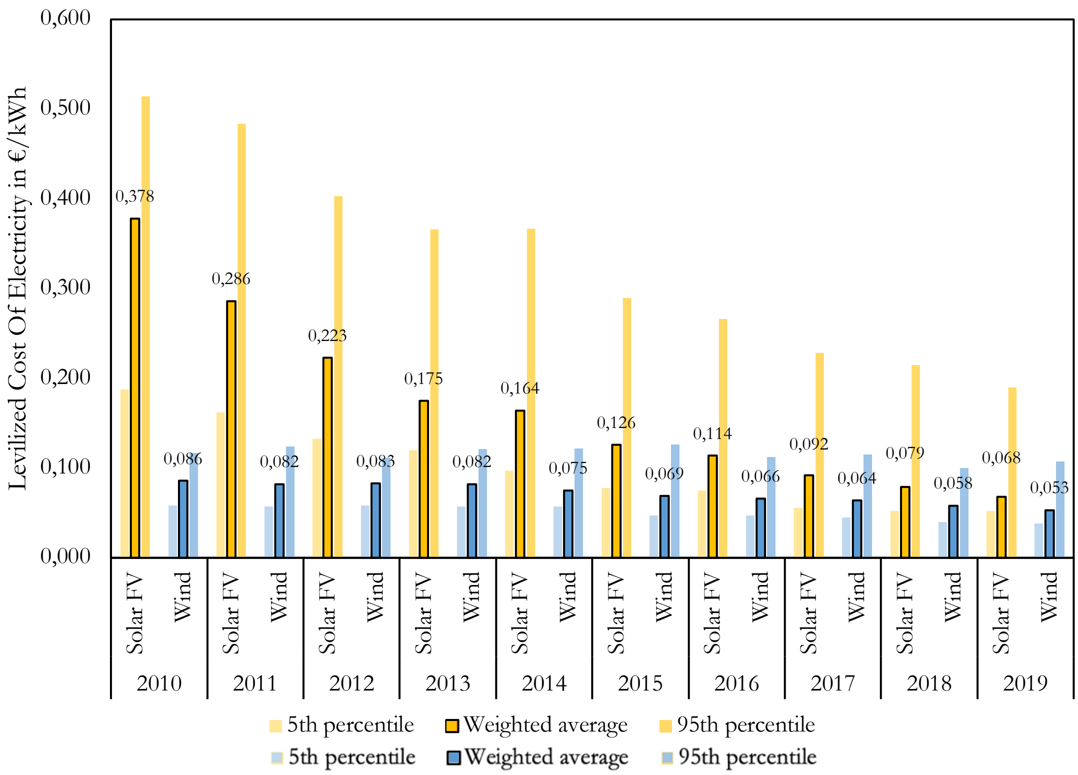


Source: Own elaboration with data from the PER 2011-2020 (IDAE, 2011)

Comparing the cost of producing electricity of two different technologies is not so straight-forward. When we need to compare the cost of producing electricity of different technologies, we make use of the analytical tool called "Levelized Cost Of Electricity" (LCOE). Basically, it takes into account all costs associated with the production of electricity (building, operating and dismantling the facility), bring them to the present time and allocate them over all the electricity that will be produced during the lifetime of the technology (Zweifel et al, 2017). This way, we can compare the cost of producing a kWh of electricity using different technologies. The fact that some technologies exhibit lower LCOE than others means that those technologies are more competitive.

During the recent years, wind and solar FV technologies have seen a sharp decrease in the annual LCOE. International data from the International Renewable Energy Agency (IRENA, 2020) are presented in Figure 6. As we can see, wind power has reduced the LCOE by 62% in the last ten years, while that of solar FV has been decreased by 82%. This has enabled 59% of new renewable energy installations to provide electricity at lower cost than the cheapest new fossil-fuel-powered alternatives, according to IRENA 2019 cost report. In the case of solar FV, the lower LCOE is the result of the decline in the price of modules of 90% during the last decade, derived from impressive learning rates in production; for wind, the same happens with the technological progress involved in the production of aerogenerators.

Figure 6. Evolution of the LCOE for wind and solar FV during the last ten year

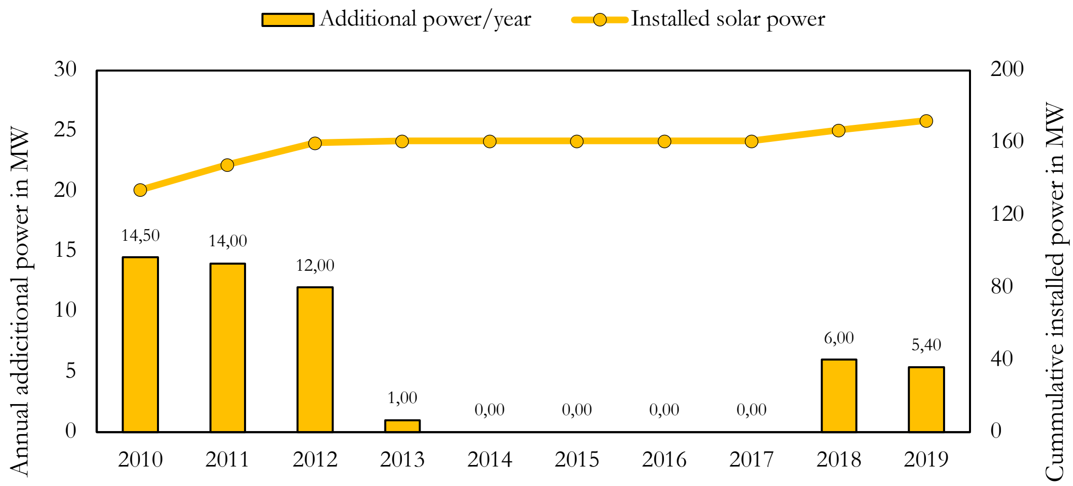


Source: Own elaboration with data from IRENA (2020).

However, when we look at the power installed during this period in the autonomous community of Navarre, we see that no new investments were made between the years 2014 and 2018 (see Figure 7 and Figure 8).

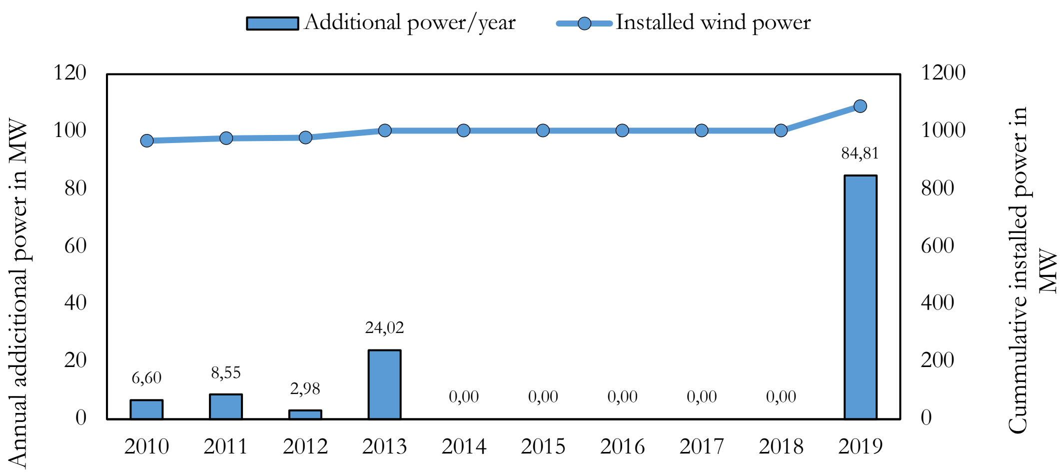
An explanation for the sudden drop in the investment is to be found in the change of the regulatory framework: the Real Decree Act 1/2012 of the year 2012, which modified the regulatory conditions of the Real Decree Act 661/2007, stated that the privileges attributed to renewable energy sources were to be suppressed. After this new piece of legislation was introduced, investment stopped. Moreover, because legislation in the sector is said to be volatile, regulatory uncertainty has been pointed out as a deterrent for further investments (Alenza, 2016).

Figure 7. Solar FV power installed in Navarre during the last decade.



Source: Own elaboration with data from Unión Española de Fotovoltaica - UNEF (2020) and the Government of Navarre (2019).

Figure 8. Wind power installed in Navarre during the last decade.



Source: Own elaboration with data from Asociación Española Eólica - AEE (2020).

Besides the installation of solar and wind farms, the region of Navarre counts with a larger sector involved in the supply chain of renewable energy. A report published by the Government of Navarre (2016) "Impact of renewable energy on employment and value-added in Navarre" quantified the employment of the sector around the number of 4.000

jobs. The annual turnover was estimated to be near three million euros in 2010 and around half of it in 2014. The main activity of these companies is to produce equipment renewable energy installations and, less importantly, the activities related to engineering, maintenance and production and promotion of the facilities. The companies of the sector, however, export materials for installations of other parts of Spain and of other countries of the world (the report highlights that this is due to some multinational companies that have an office in Navarre).

What is the amount of labor and value-added of the sector that corresponds to the installation and maintenance of wind and solar FV power in Navarre? In view of the energy sector at large, how important are wind and solar FV technologies in comparison with the rest? What other impacts, besides the increase in energy self-sufficiency have these technologies had? Using input-output methodology, we try to give an answer to these questions in the following sections.

3. METHODOLOGY

Based on the work of Miler and Blair (2009) and of Muñoz, Iráizoz and Rapún (2016), what follows is a description of the input-output model and the specific applications thereof that will be used to examine the impact of solar and wind energy in the economy of Navarre.

3.1. Input-output table as an accounting document

The input-output framework dates back to the 1930s and was developed by Russian economist Wassily Leontief (1936). The basic idea is that input-output methodology allows a traceability of the product flows that take place among the different sectors of an economy. As an accounting document, input-output tables are an extension of the national accounts that address thoroughly interindustry transactions. Therefore, the data requirements for the construction of an input-output matrix are ultimately the sales and purchases of goods and services. Because of substantial measurement problems related to physical measurement of inputs and outputs, transactions are valued with prices and expressed in monetary units, even if this involves the complexities of changes in prices that might not reflect changes in the flows of physical inputs and outputs.

An input-output table has three distinct parts: the intermediate consumption table (in red in Table 1), the final demand table (in blue in Table 1) and the value-added table (in green in Table 1).

Table 3. Basic structure of an Input-Output table.

	1	2	…	n	$\sum_j x_{ij}$	C	G	K	E	D	X
1	x_{11}	x_{12}	…	x_{1n}	$\sum_j x_{1j}$	C_1	G_1	K_1	E_1		X_1
2	x_{21}	x_{22}	…	x_{2n}	$\sum_j x_{2j}$	C_2	G_2	K_2	E_2		X_2
…	…	…	…	…	…	…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nn}	$\sum_j x_{nj}$	C_n	G_n	K_n	E_n		X_n
$\sum_i x_{ij}$	$\sum_i x_{i1}$	$\sum_i x_{i2}$	…	$\sum_i x_{in}$							
L	l_1	l_2	…	l_n							
N	n_1	n_2	…	n_n							
T	t_1	t_2		t_n							
VA (L+N+T)	VA_1	VA_2	…	VA_n							
X	X_1	X_2	…	X_n							

Source: Own elaboration.

Intermediate consumption. This is the most distinctive part of the document, in comparison with other national accounting documents. This table accounts for the interindustry transactions. Economic activities are grouped into homogenous production units, economic sectors, and the intermediate consumption table quantifies the interdependence of the production processes of different economic sectors by registering the amount of intermediate consumption between every pair of sectors (in monetary units). It is expressed as a matrix that can be read horizontally and vertically:

- Vertically. Below a given economic sector, one can read vertically the distribution of the origin of intermediate consumption for that given economic sector. The amount x_{ij} is the amount of production from sector i that is incorporated to the production process of sector j. The sum of all intermediate consumption of a sector (sum of a column) indicates the total amount of intermediate consumption (valued in monetary units) that a given economic sector has employed.
- Horizontally. To the right of a given economic sector, one can read horizontally the distribution of how the production of a sector is employed as intermediate consumption for other sectors. The amount x_{ij} is the amount of production from sector i that is incorporated to the production process of sector j. The sum of a row indicates the production of a given economic sector that has been used by other sectors in the economy as intermediate consumption.

Final demand. This part of the document considers the final uses of the production of the different sectors (as opposed to the intermediate uses, that is, when the products are not incorporated into the production process of another sector). The final uses are individual consumption (C), collective consumption (G), gross capital formation (K) and exports (E). It is located to the right of the intermediate consumption part.

From these two tables, it is possible to derive a set of n linear equations (being n the number of economic sectors in which the economy is divided) that describe the different uses of the production of the different sectors in the economy:

$$x_{11} + x_{12} + \ldots + x_{1n} + C_1 + G_1 + K_1 + E_1 = X_1$$

$$x_{21} + x_{22} + \ldots + x_{2n} + C_2 + G_2 + K_2 + E_2 = X_2$$

…

$$x_{n1} + x_{n2} + \ldots + x_{nn} + C_n + G_n + K_n + E_n = X_n$$

These equations mean that production of a sector i (X_i) is distributed into intermediate uses ($x_{i1} + x_{i2} + \ldots + x_{in}$) and final uses ($C_i + G_i + K_i + E_i$).

Primary inputs. This last part of the table, located below the intermediate consumption table, accounts for other inputs necessary for the production process of each economic sector. These are the remuneration of the productive factors (labor, L, and capital, N), expressed by means of salaries and gross operating surplus, respectively, and government services (taxes, T).

From the primary inputs table and the intermediate consumption table, it is possible to derive a set of n linear equations that define the sources of the production of the n economic sectors in the economy:

$$x_{11} + x_{21} + \ldots + x_{n1} + l_1 + n_1 + t_1 = X_1$$

$$x_{21} + x_{22} + \ldots + x_{n2} + l_2 + n_2 + t_2 = X_2$$

…

$$x_{1n} + x_{2n} + \ldots + x_{nn} + l_n + n_n + t_n = X_n$$

These equations mean that production of sector j (X_j) comes from the following primary inputs: intermediate consumption ($x_{1j} + x_{2j} + \ldots + x_{nj}$) and added-value ($l_j + n_j + t_j$).

3.2. Technical coefficients

Assuming a production function that does not allow for the substitution of inputs (inputs are used in fixed proportions and isoquants have right angles), input-output analysis is based on the assumption that for increasing output of a given sector, inputs must increase proportionally.

This measure of proportionality between output and intermediate inputs is reflected in the technical coefficients (a_{ij}), which are calculated as follows:

$$a_{ij} = \frac{x_{ij}}{X_j}$$

In order to produce X_j units, economic sector j needs to purchase x_{ij} units of production from economic sector i as intermediate consumption. Likewise, to produce 1 unit of output, sector j needs to purchase a_{ij} units from sector i.

By the same token, the same fixed-proportions relationships can be derived between production of each economic sector and the rest of inputs that are needed for their production. These are called direct coefficients and the most common in economic input-output research are employment coefficients, value-added coefficients, CO_2 coefficients, energy coefficients, imports coefficients, etc. All of them are derived following the same procedure as that followed for the derivation of technical coefficients.

$$value\ added\ direct\ coefficient\ \overline{va}_j = \frac{VA_j}{X_j} \qquad employment\ direct\ coefficient\ \widehat{emp}_j = \frac{EMP_j}{X_j}$$

Usually, variables such as employment, energy or greenhouse gas emissions are measured in physical units. For labor it is common to use full-time employment equivalent units.

The interpretation of these other direct coefficients is the same as that of the technical coefficients. It informs us about how intensive in employment a given economic sector is: how many workers are needed to produce a unit of output. For example, in order to produce 1 unit of output, economic sector j needs to generate $\overline{va}_j$ units of value-added and employ $\widehat{emp}_j$ units of labor.

3.3. The demand model

The use of technical coefficients allows for interindustry transactions to be expressed as a function of sectorial output:

$$x_{ij} = a_{ij} \cdot X_j$$

Therefore, equations governing the uses of a sector's output (stated in 2.2) can be rewritten as:

$$a_{11} \cdot X_1 + a_{12} \cdot X_2 + \dots + a_{1n} \cdot X_n + D_1 = X_1$$

$$a_{21} \cdot X_1 + a_{22} \cdot X_2 + \dots + a_{2n} \cdot X_n + D_2 = X_2$$

...

$$a_{n1} \cdot X_1 + a_{n2} \cdot X_n + \ldots + a_{nn} \cdot X_n + D_n = X_n$$

Let **A** denote a square matrix of n rows and n columns whose elements are the technical coefficients of the n sectors; **X**, an n-column vector whose elements are the production of each sector; and **D**, an n-column vector whose elements correspond to the final demand of each economic sector; then, the above set of equations can be expressed in matrix form as follows:

$$\mathbf{A} \cdot \mathbf{X} + \mathbf{D} = \mathbf{X}$$

Notice that from here on, a bold capital letter will represent the corresponding matrix form of any variable.

This form of writing the equations brings us closer to orienting the data towards solving the question that input-output analysis mostly focuses on: how does the production of each economic sector has to change in order to satisfy a given increase in final demand.

In order to see how a given productive structure, defined by the above set of linear equations and always assuming a proportional production function, will respond to a specific vector of final demand, the following operations must be performed:

$$\mathbf{A} \cdot \mathbf{X} + \mathbf{D} = \mathbf{X}$$

$$\mathbf{D} = \mathbf{X} - \mathbf{A} \cdot \mathbf{X}$$

$$\mathbf{D} = (\mathbf{I} - \mathbf{A}) \cdot \mathbf{X}$$

Notice that **I** is an nxn identity matrix.

If we solve for X pre-multiplying by the inverse of (I – A), we will obtain the sectorial production in the economy associated to a given vector of final demand.

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{D}$$

It should be noticed that the system of n equations and n unknowns (the production of each economic sector), only has a solution if (**I** – **A**) is singular, that is, that an inverse matrix to (**I** – **A**) exists. $(\mathbf{I} - \mathbf{A})^{-1}$ is called the Leontief inverse matrix and it is a square matrix that contains total requirement coefficients (r_{ij}). An r_{ij} coefficient is the necessary increment in production of the sector i as a result of the increase in the final demand of the sector j in one unit.

The sum of the elements of a given column should be read as the increment in the production of the whole economy as a result of an increment in one unit of the final demand of the sector of that column. It is usually called 'output multiplier'. Following the same train of thought, the sum of the elements of a given row should be interpreted as the increase in production of a given sector as a result of all the sectors of the economy having their final demand increased in one unit.

The logic underpinning this model is that an increase in the demand of a given sector (ΔD_i) will require, in turn, an increase in the production of each of the other sectors whose productions are incorporated to the production of that sector. These other sectors will demand intermediate consumptions from other sectors as well, which will in turn need to demand other intermediate inputs, etc. The total requirements matrix gathers all of these effects.

The demand model starts by estimating the necessary increment in production that satisfies a given vector of final demand, but it can be used to estimate other variables in the economy that are linked to production in a proportional manner. For this purpose, the only additional information that is necessary are direct coefficients of other variables.

Following a proportional relationship, from a given final demand vector, it can be calculated the number of workers that need to be employed.

Let $\widehat{\boldsymbol{emp}}$ be an nxn diagonal matrix with employment direct coefficients as elements in the diagonal, then the algebraical expression for calculating employment generated in each economic sector is:

$$\widehat{\boldsymbol{emp}} \cdot (\mathbf{A} - \mathbf{I})^{-1} \cdot \mathbf{D}$$

The result is a column vector of n elements where every element is the employment generated in each sector as a consequence of a vector of final demand D.

As expressed above, the employment of each sector is computed as the increment of production in that sector resulting from the specific vector of final demand and translated into employment through the employment direct coefficient.

Likewise, the increment in production of each economic sector (derived from a given vector of final demand) can be translated into the value-added that will be generated in each economic sector as follows:

$$\widehat{\boldsymbol{va}} \cdot (\mathbf{A} - \mathbf{I})^{-1} \cdot \mathbf{D}$$

Where $\widehat{\boldsymbol{va}}$ is a diagonal square matrix whose elements are the value-added direct coefficients of the n sectors in the economy. The resulting column vector comprises the value-added that will be generated in each sector.

3.4. Impact analysis

A change in final demand introduces a series of successive impacts in the economy, as the productive structure stablishes a series of linkages among the economic sectors. In input-output methodology, impacts in the economy are categorized according to how immediate or distant their connection to the exogenous change is. We can distinguish three effects: direct, indirect and induced effects.

3.4.1. Direct effects

The direct effect refers to the immediate consequence of satisfying the vector of final demand. For every sector whose output needs to be increased to satisfy a given amount of final demand, there is a direct effect. Through the different direct coefficients, the initial output increment can be translated into other variables, such as employment, value-added, etc.

Algebraically, the direct effect is quantified as the product of the diagonalized matrix of direct coefficients and the vector of final demand. The specific algebraic expression for the calculation of the direct effect in employment and value-added are presented below:

$$\widehat{\boldsymbol{emp}} \cdot \mathbf{D} \qquad\qquad \widehat{\boldsymbol{va}} \cdot \mathbf{D}$$

3.4.2. Indirect effects

The initial increment of production that occurs in the sectors which are impacted in the first place by the exogenous change (direct effect) is passed on to other economic sectors via intermediate consumption. All the output that is generated as a result of this is called indirect effect. The calculation described in 2.3.2.1 and 2.3.2.2 refers to the total effect in terms of employment and value-added generation. Notice that the total effect comprises both the direct effect and the indirect effect. Therefore, in order to properly separate indirect and direct effect and avoid double-counting the effects, the direct effect needs to be subtracted from the total effect calculation showed above to get to the indirect effect.

3.4.3. Induced effects

There is a less common effect that input-output methodology allows us to quantify: the induced effect. The basis for this effect is that, as a result of families having their income increased (because of the increase in production necessary to satisfy all final and intermediate demand), their consumption increases as well and this generate additional economic effects.

We will follow the reading of D'Hernoncourt et al (2011) and Miller and Blair (2009) for its calculation.

Firstly, an extra matrix of technical coefficients needs to be created. The size of this matrix will no longer be nxn, but rather n+1 x n+1, as families will be included as another economic sector.

The extra row will be composed by a set of remuneration of employees coefficients.

$$re_j = \frac{RE_j}{X_j}$$

re_j informs as of how much employees in a sector are paid for each unit of output produced.

The extra column will quantify the spending of families in each economic sector. Therefore, the elements of this column will quantify how total spending of families is distributed among the different sectors. The elements will be:

$$c_j = \frac{spending\ of\ families\ on\ economic\ sector\ j}{total\ spending\ of\ families}$$

It should be noticed that the last element of the extra row and the last element of the extra column (the intersecting cell) will be left blank, as families receive no remuneration for their consumption and do not purchase goods and services from themselves.

Once the augmented matrix of technical coefficients is configured (**A'**), the procedure for the calculation of induced effects is similar to that of the indirect effects. Using a similar demand model and solving for the column vector of production (**X'**), we obtain:

$$\mathbf{X'} = (\mathbf{I} - \mathbf{A'})^{-1} \cdot \mathbf{D'}$$

Notice that the final demand vector (**D'**) will include an additional row (set to a value of zero) and that the resulting vector of production (**X'**) will as well include this extra row with its value set to zero.

With the same procedure as in the indirect effect, the output induced effect can be translated into other variables such as employment or value-added generation. The only difference lies in the fact that we will need to use a diagonal square matrix of direct coefficient, but of size (n+1) x (n+1), as an extra column and row should be added. They will be filled with null values. Let an ' sign denote this difference.

$$\widehat{emp}' \cdot (\mathbf{I} - \mathbf{A'})^{-1} \cdot \mathbf{D'} \qquad \widehat{va}' \cdot (\mathbf{I} - \mathbf{A'})^{-1} \cdot \mathbf{D'}$$

The induced effect calculation explained above includes the previous direct and indirect effects. Therefore, in order to avoid double counting, we need to subtract those from the induced effect.

3.4.4. Interior and total effects

The previous sections assume that no imports exist in the final demand vector. This is rarely the case in a globalized economy, and less even so in a regional economy. The interest of this study is to quantify the employment and value-added generation inside of the regional economy, so additional considerations need to be made. For this purpose, only regional demands are considered (that is, not including imports) and interior matrixes of technical coefficient and Leontief inverse are used. If total matrixes and total demands were considered, we would obtain the impacts that are produced outside of the region as well. In this case, as mentioned before, we only try to quantify the impacts that happen inside of the region.

3.5. Data and description of calculations

The aim of this work is to analyze the direct, indirect and induced effects of solar and wind energy in terms of employment and value-added generation in the economy of Navarre for the period 2010-2019.

For this purpose, we use the regional input-output table of the year 2010. The set of instructions that dictate how the table is prepared comes from the European Union regulation number 549/2013 and it stablishes that information should be gathered through an intermediate consumption survey. Specifically, for the elaboration of this table a stratified (according to the 2-digit CNAE economic activity) sample of 1.291 companies was surveyed (INE, 2015b). Impossibility of using more updated input-output information justifies the election of this data source.

The main difficulty of the analysis rests in the fact that these economic sectors (solar and wind energy) are not disaggregated from the rest of energy sectors in the input-output table. To overcome this obstacle, a series of procedures explained in the next section are followed.

As the research focuses on the impacts in the economy of Navarre, we use interior matrixes that disregard both the effects that take place in other regions of Spain and the effects that escape to the rest of the world through imports of intermediate goods and services.

Following the procedure of Varela et al (2014) and Simón et al (2009), who carry out a similar analysis for wind energy in the region of Galicia and Aragón, respectively, solar and wind energy create two kind of effects in the economy: temporary and permanent. The temporary effect refers to the process of installation of solar parks and wind farms; the permanent effects are the annual operating and maintenance activities. We will explain the procedures separately.

3.5.1. Temporary impact: installation of solar parks and wind farms

The main data requirements for the calculation of the economic effects derived from the installation of solar and wind energy generating facilities is the annual amount of money invested in these activities. For this, we use data on power capacity installed per year from UNEF (2020) and AEE (2020), which are measured in megawatts. For solar energy, data on auto-consumption installations has been complemented with data from the energy balances of the Government of Navarre (various years). Secondly, we value the cost of installation per megawatt using an estimate for the costs in 2010 from the PER 2011-2020 (IDEA, 2011) and assume that it has undergone a similar decrease as the one reflected by the annual data on costs from IRENA (2020). The data is shown in Table 3 and Table 4.

Table 3. Estimation of solar FV energy installation costs.

	Installed power (MW)	Additional power/year (MW)	Installation costs ($)/kW (world)	Costs as % of 2010	Installation costs of solar FV (€)/kW (Spain)	Value of Investment (€)
2009	119,50	(a)			(b)	(a)*(b)*1000
2010	134,00	14,50	2.934,05	1,000	2.530,00	36.685.000
2011	148,00	14,00	2.456,06	0,837	2.117,84	29.649.749
2012	160,00	12,00	1.862,64	0,635	1.606,14	19.273.628
2013	161,00	1,00	1.631,76	0,556	1.407,05	1.407.050
2014	161,00	0,00	1.475,14	0,503	1.271,99	-
2015	161,00	0,00	1.123,82	0,383	969,06	-
2016	161,00	0,00	1.021,49	0,348	880,82	-
2017	161,00	0,00	882,96	0,301	761,37	-
2018	167,00	6,00	753,79	0,257	649,99	3.899.923
2019	172,40	5,40	620,88	0,212	535,38	2.891.044

Source: Own elaboration with data from UNEF, the Government of Navarre (2010-2019) and IRENA (2020).

Table 4. Estimation of wind energy installation costs.

	Installed power (MW)	Additional power/year (MW)	Installation costs ($)/kW (world)	Costs as % of 2010	Installation costs of wind (€) /kW (Spain)	Value of investment (€)
2009	961,77	(a)			(b)	(a)*(b)*1000
2010	968,37	6,60	1.216,18	1,000	1.150,00	7.590.000
2011	976,92	8,55	1.209,94	0,995	1.144,10	9.782.051
2012	979,90	2,98	1.230,53	1,012	1.163,57	3.467.441
2013	1003,92	24,02	1.140,67	0,938	1.078,60	25.908.077
2014	1003,92	0,00	1.111,34	0,914	1.050,87	-
2015	1003,92	0,00	1.024,61	0,842	968,86	-
2016	1003,92	0,00	1.020,24	0,839	964,73	-
2017	1003,92	0,00	1.015,87	0,835	960,60	-
2018	1003,92	0,00	966,58	0,795	913,98	-
2019	1088,73	84,81	919,15	0,756	869,14	73.711.595

Source: Own elaboration with data from AEE (2020), the Government of Navarre (2010-2019) and IRENA (2020).

The next step is the creation of a final demand vector that can accommodate annual investments. In other words, we need to distribute the total annual cost into the different economic sectors, which are the ones from which inputs are demanded for the installation process. For this purpose, we replicate the same distribution from that of Laplaza-Abadía and Simón-Fernández (2019), who perform a similar analysis for wind and solar energy in Aragón. Their work links the distribution of costs to the different components that constitute a solar park and a wind farm. This procedure can be seen in other studies of similar characteristics and scope (Aixalá et al, 2003; Giménez, 2003; Varela et al, 2014, 2015). This distribution needs to take into consideration the percentage of imports. For this, we use data on imports intensity of the corresponding economic sectors, as the energy sector makes use of imports from those sectors. The distribution is shown below (Table 5) for solar and wind investment.

Table 5. Distribution of the installation costs among economic sectors.

Code	Economic sector	Solar FV (installation distribution)	Wind (installation distribution)	Share of installation demanded to the regional economy	Solar FV (interior installation distribution)	Wind (interior installation distribution)
15	Non-energy minerals	0,200	0,320	0,415	0,083	0,133
16	Metallic products	0,420	0,250	1,000	0,420	0,250
19	Machinery and electric equipment	0,270	0,330	0,054	0,015	0,018
29	Building materials	0,050	0,080	1,000	0,050	0,080
31	Wholesaling services	0,060	0,020	1,000	0,060	0,020
	Total	1	1	-	0,763	0,501

Source: Own elaboration with data from Laplaza-Abadía and Simón-Fernández (2019) and the Statistics Office of Navarre (2015).

Following the theory from sections 2.4.1, 2.4.2 and 2.4.3, direct, indirect and induced effects arising from the installation of solar and wind energy generating facilities are calculated.

3.5.2. Permanent effects: maintenance and operating of facilities

The main data requirements for the calculation of the economic impacts derived from operating and maintenance are the costs associated to these activities. The IRENA (2020) cost annual reports offer some estimations about the costs as a function of power capacity installed. For this case, we use the cumulative installed capacity from UNEF (2020) and AEE (2020). We value the O&M spending in 2010 with estimations from the PER 2011-2020 (IDEA, 2011) and adjust the costs in the same proportion as registered by IRENA (2020). Data is shown below.

Table 6. Estimation of solar FV energy O&M costs.

	Installed power (MW)	**O&M costs ($) /kW (world)**	**Costs as % of 2010**	**O&M costs (€) / kW (Spain)**	**Spending**
	(a)			(b)	(a)*(b)*1000
2010	134	26	1,000	47	6.324.800
2011	148	23	0,884	42	6.176.457
2012	160	22	0,861	41	6.502.301
2013	161	22	0,842	40	6.396.238
2014	161	21	0,822	39	6.249.535
2015	161	21	0,799	38	6.073.492
2016	161	20	0,780	37	5.926.789
2017	161	21	0,795	38	6.044.151
2018	167	19	0,741	35	5.843.324
2019	172	18	0,707	33	5.749.507

Source: Own elaboration with data from UNEF (2020), the Government of Navarre (2019), IDEA (2012), and IRENA (2020)

The case of O&M impact is different from the case of installation, as here we need to consider what part of O&M costs are distributed into value-added and intermediate consumption. For this, we assume the same distribution as that from the energy industry in Navarre. According to the data from the 2010 input-output table (Statistics Office of Navarre, 2015), intermediate consumption represents 63,16%, while value-added generation accounts for 36,83%.

Table 7. Estimation of wind energy O&M costs.

	Installed power (MW)	O&M costs ($) /kW (world)	Costs as % of 2010	O&M costs (€)/kW (Spain)	Spending
	(a)			(b)	(a)*(b)*1000
2010	968	52	1,000	45,00	43.576.650
2011	977	50	0,962	43,27	42.270.577
2012	980	48	0,923	41,54	40.703.538
2013	1.004	46	0,885	39,81	39.963.738
2014	1.004	44	0,846	38,08	38.226.185
2015	1.004	42	0,808	36,35	36.488.631
2016	1.004	41	0,788	35,48	35.619.854
2017	1.004	40	0,769	34,62	34.751.077
2018	1.004	38	0,731	32,88	33.013.523
2019	1.089	36	0,692	31,15	33.918.127

Source: Own elaboration with data from AEE (2020), the Government of Navarre (2010-2019), IDEA (2012), and IRENA (2020).

Therefore, direct effects are calculated using 36,83% of the O&M costs, in the same way as explained in section 2.4.1 but using the direct coefficients from the energy economic sector of the table. Indirect effects are calculated using the remaining 63,16% of O&M costs and assuming the following distribution of purchases to the rest of economics sectors. According to Cámara et al (2013), who disaggregated the Spanish energy sector into the different types of energies (in which we can find solar and wind) for the input-output table of the year 2010. From that document, it is possible to gather a distribution of the intermediate consumption that is involved in the operating of the solar and wind energy facilities. Such distribution, as well as the percentage of intermediate consumption that remains in the regional economy (obtained from the 2010 input-output of Navarre), is shown below (Table 8). Such coefficients are assumed to remain constant throughout the decade.

Table 8. Distribution of O&M costs into economic sectors.

Code	Economic sector	Solar FV	Wind	Share of regional	Solar FV (Nav)	Wind (Nav)
27	Water-related services	0,001	0,002	1,000	0,001	0,002
12	Chemical industry	0,003	0,000	0,001	0,000	0,000
17	Production of metallic products	0,393	0,684	0,204	0,080	0,140
20	Machinery	0,159	0,000	0,002	0,000	0,000
24	Other manufactures	0,103	0,157	0,109	0,011	0,017
29	Building material	0,205	0,046	1,000	0,205	0,046
31	Commerce and restauration	0,068	0,000	1,000	0,068	0,000
33	Transport and communication	0,021	0,000	0,784	0,016	0,000
47	Other services	0,046	0,110	1,000	0,046	0,110
	Total	1	1	-	0,427	0,315

Own elaboration with data from Camara et al (2013) and the Statistics Office of Navarre.

Following the theory from sections 2.4.1, 2.4.2 and 2.4.3, direct, indirect and induced effects arising from the installation of solar and wind energy generating facilities are calculated.

3.5.3. Nuancing the results

With data about the average distribution of the employment in every economic sector in terms of gender and occupation type (Statistics Office of Navarre, 2021), we can nuance the information obtained of the employment generated. In this way, we can offer a qualitative layer to the kind of employment that is generated and we can compare the employment generated by each type of renewable energy.

Likewise, with data about the sectorial distribution of the value-added generated in each industry, we can estimate how this variable is decomposed into salaries, gross operating surplus and taxes.

3.6. Limitations and assumptions

As explained above, input-output modelling gives us an approximation of the reality of the economy. In no case is it an exact picture of the economy and the results of this analysis should be examined bearing in mind the following limitations of the model:

- All effects derived from the substitution of inputs are disregarded.
- Every group of goods and services is only supplied by a given economic sector and all companies in the sector are supposed to be homogenous to one another.
- A fixed-proportions production function is assumed and there are no economies of scale or diseconomies of scale.
- External economies and diseconomies of scale are also disregarded, as the effect of producing simultaneously in various economic sectors is the same as the separate effects of producing independently.

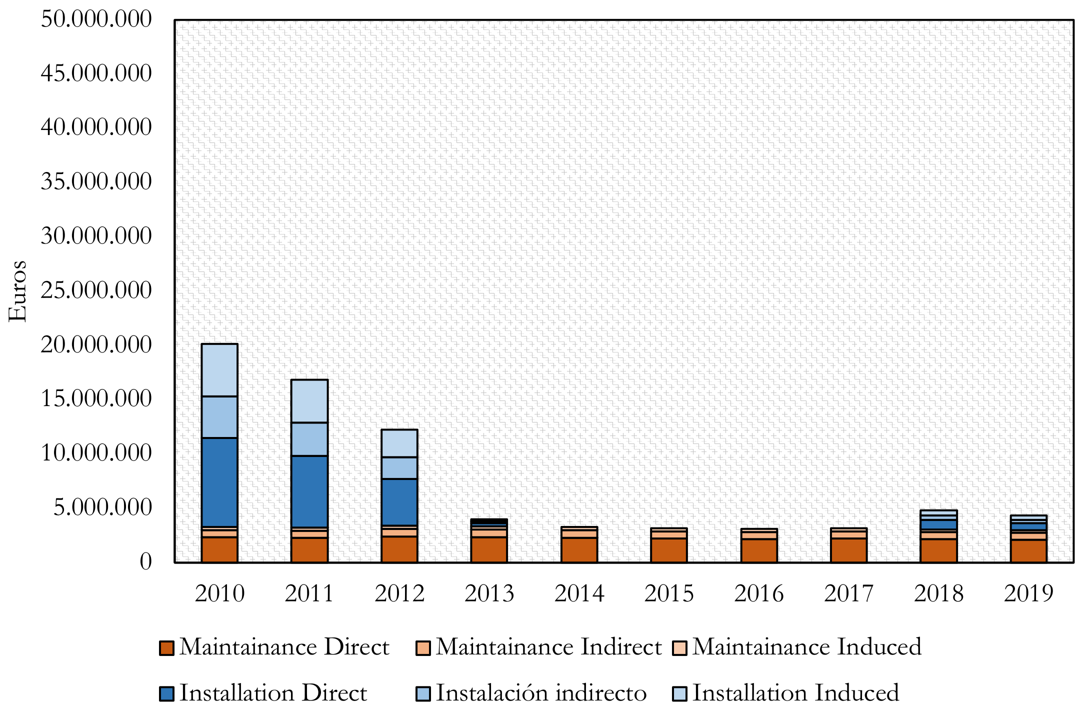
4. RESULTS

After computing the calculations explained in section 3, we obtained the following results. Firstly, we will state the results in terms of value-added generation for both technologies; secondly, in terms of employment. Both results are contextualized with the information provided in section 2, with data on the energy sector of Navarre.

4.1. Value-added generation

Figure 9 and Figure 10 show the impact in the economy of Navarre of wind and solar FV. In both cases, we can distinguish between the permanent (maintenance) and the temporary effect (installation). As maintenance depends on cumulative installed capacity, as opposed to installation, which depends on the annual marginal increments in capacity, it is a fairly stable magnitude. Even if the capacity grows over the years, value-added attributable to this activity is decreasing for both technologies: this has to do with the fact that O&M costs are decreasing due to technology improvements. Installation value-added generation is, on the contrary, intermittent and depends on the investment of each year.

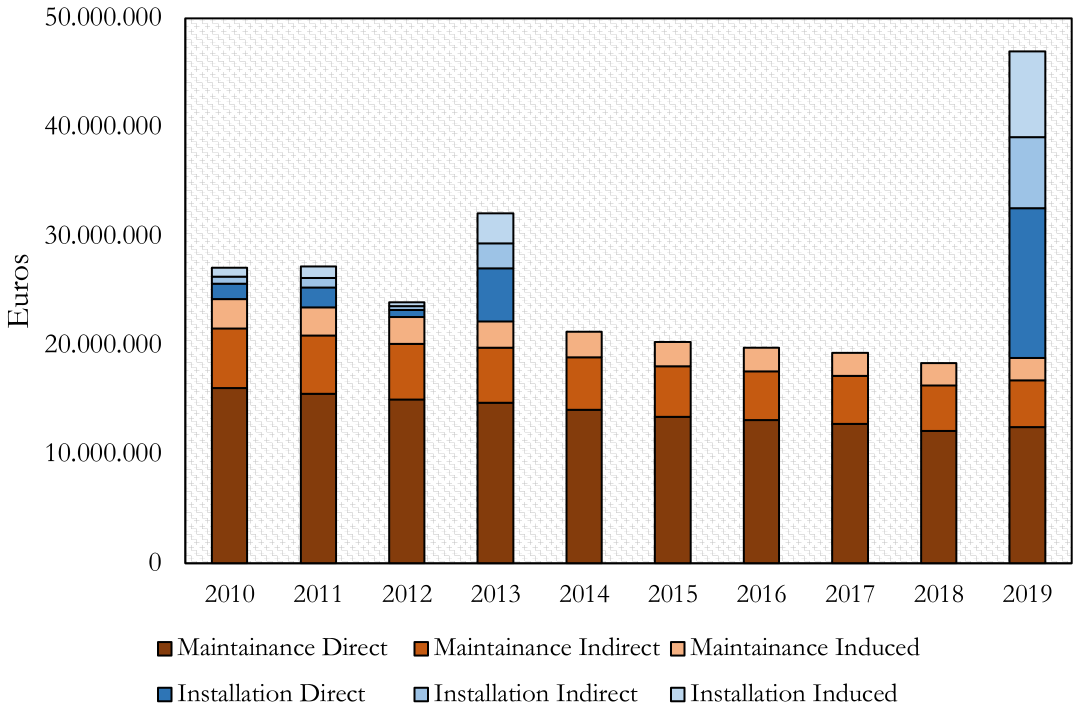
Figure 9. Value-added generation from solar FV in Navarre in 2010-2019.



Source: Own research.

Given the different state of development of the technologies (wind capacity is six times that of solar FV), it is not surprising to see that O&M value-added generation of wind is much higher that of solar FV. When looking at installation value-added, however, we can see that, for some years, solar FV contributed more than wind to value-added generation in the economy of Navarre.

Figure 10. Value-added generation from wind power in Navarre in 2010-2019.



Source: Own research.

We can also analyze the proportion of the different impacts. For every unit of value-added that is generated in the sector of renewable energy (direct impact), how much is generated in the rest of the economy through the linkages of the productive structure (indirect effect) and through the increase in income and consumption (induced effect)? These are called the pulling effects of a sector and are calculated as the indirect or induced effect over the direct effect. Because we assume that the proportion of investments and costs remain constant over the decade, the pulling effects remain also constant. Table 9 shows the pulling effects for installation and maintenance for both technologies. These numbers should be read as follows: for example, for every thousand euros of value-added that are generated in the renewables sector as a result of installation of solar FV, an indirect effect is produced of 467€ and a further induced effect of 592€ in the rest of the economy.

Table 9. Indirect and induced effects in value-added per unit of direct effect.

	Installation		**Maintenance**	
	Indirect	Induced	Indirect	Induced
Solar	0,467	0,592	0,298	0,119
Wind	0,475	0,576	0,343	0,166

Source: Own research.

It should be noticed that installation activities produce a stronger pulling effect in the economy than maintenance activities for both technologies. The pulling effects from wind power is higher than that of solar, and this difference is more obvious in the activity of maintenance. Finally, regarding the induced effect, we observe that in the case of installation, it is higher than the indirect effect, but in the case of maintenance it is lower.

Induced effect are diluted through the different economic sectors. Indirect effects, however, tend to concentrate on some particular sectors. If we look at the different economic sectors that are most affected by these activities, we see that the same five sectors concentrate almost a half of the indirect effect from the installation activities of both technologies. See Table 10. Table 10 shows the percentage of the total indirect value-added that is produced in each economic sector. Notice that only the five sectors most benefited by each technology are shown. These numbers should be read as follows: for example, 16,3% of all indirect value-added produced by the installation of wind power is created in the building sector.

Table 10. Installation indirect effect on value-added in different economic sectors (% of the total indirect effect).

Wind		**Solar**	
Building sector	0,163	Building sector	0,125
Energy sector	0,124	Energy sector	0,121
Transport sector	0,079	Metallurgy sector	0,077
Wholesaling sector	0,073	Transport sector	0,075
Metallurgy sector	0,056	Wholesaling sector	0,066

Source: Own research.

The indirect effect from maintenance activities is even more concentrated: in the case of both technologies, only five economic sectors hold 80% of the total indirect effect. This is presented in Table 11.

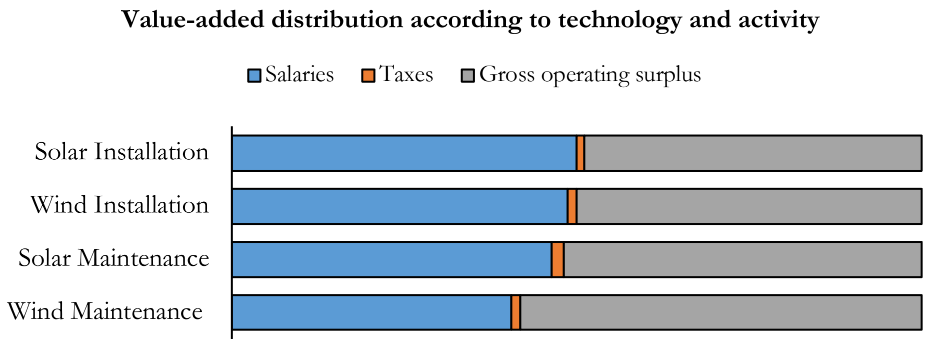
Table 11. Maintenance indirect effect on value-added in different economic sectors (% of the total indirect effect).

Wind		**Solar**	
Architecture and engineering services	0,323	Building sector	0,427
Metallic products sector	0,257	Wholesaling sector	0,144
Building sector	0,156	Metallic products sector	0,101
Other manufactures sector	0,048	Architecture and engineering services	0,097
Wholesaling sector	0,032	Transport sector	0,037

Source: Own research.

Value-added can also be studied according to its distribution. Figure 11 shows how the total value-added (that is, the sum of direct, indirect and induced value-added) is distributed among employee compensation, taxes and gross operating surplus. Only proportions are presented here for a better comparison, quantitative information is included in Annex 8.2.

Figure 11. Distribution of value-added generation according to technology and activity.



Source: Own research.

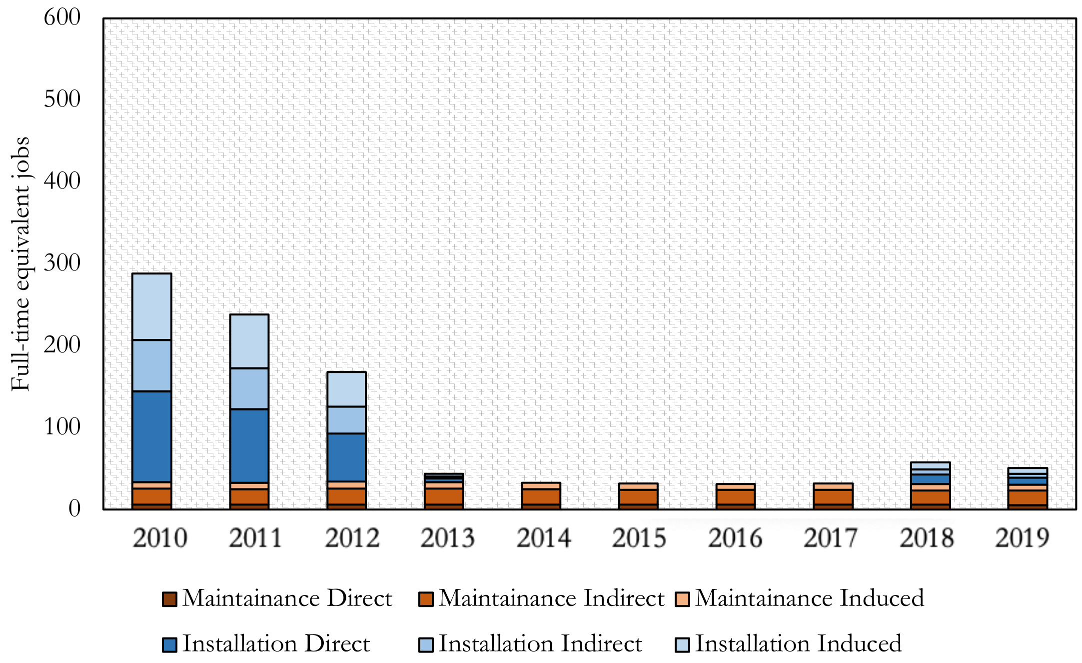
As we can see, the value-added from installation activities flows to employee remuneration in a higher proportion than in the case of installation activities. This is true for both technologies, but is more evident in the case of wind power.

Finally, value-added generation can be compared to the physical power capacity that is installed or maintained in the first place. For solar FV energy, every 1 MW in the year 2010 created a value-added of 1.161.419€ for the installation and 24.648€ for its maintenance. In the year 2019, due to the cost reduction that occurred along the decade, these numbers decreased to 245.770€ and 17.416€, respectively. In the case of wind, every 1 MW installed created a value of 438.836€ for the installation and 25.014€ for its maintenance. In the year 2019, the effects were lower: 331.660€ and 17.317€, respectively. As we can see, the effect the effect for maintenance has become similar for both technologies, which resembles Figure 6 (the decrease in the Levelized Cost Of Electricity for both technologies).

4.2. Employment generation

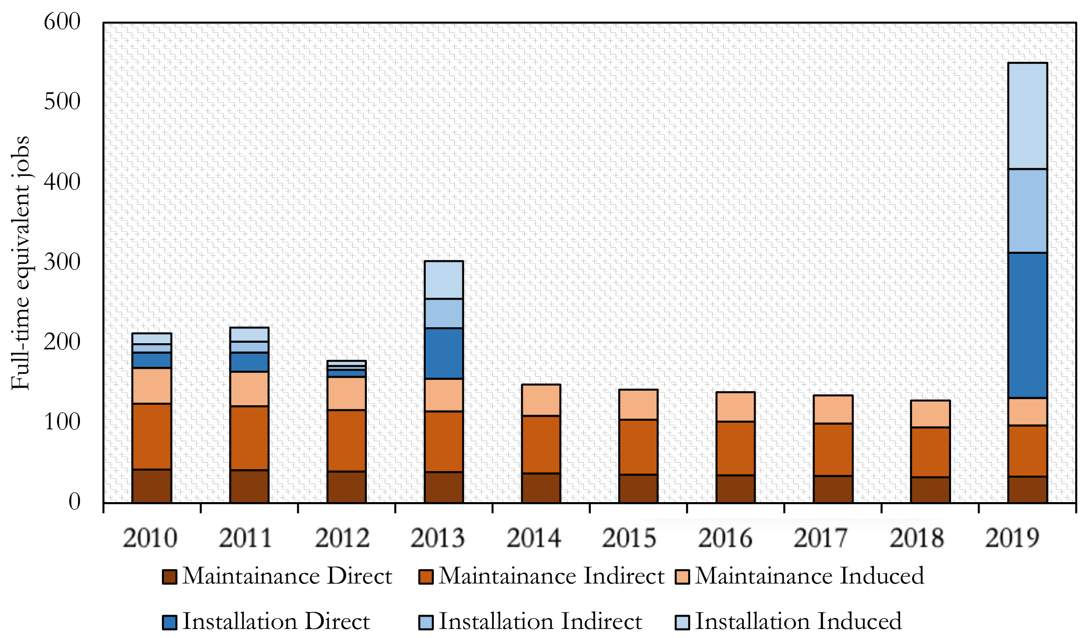
Figure 12 and Figure 13 show the impact of solar FV and wind power in Navarre during the last decade in the regional employment.

Figure 12. Employment generation from solar FV in Navarre in 2010-2019.



Source: Own research.

Figure 13. Employment generation from wind in Navarre in 2010-2019.



Source: Own research.

Following the same logic as with value-added generation in the previous section, employment derived from installation exhibit an intermittent pattern and its impact depends heavily on installed capacity. Employment from maintenance is constant (though decreasing because of progressive increase in productivity). A remarkable feature of employment generation that is diametrically opposed to the results from value-added generation, is that maintenance activities create very low direct employment, compared to indirect and, even, induced employment. This is shown in Table 12. Both technologies show similar results for the activity of installation, but solar FV has a greater effect regarding maintenance than wind power.

Table 12. Indirect and induced effects in employment generation (as % of direct effect).

	Installation		**Maintenance**	
	Indirect	Induced	Indirect	Induced
Solar	0,564	0,731	3,112	1,300
Wind	0,579	0,732	1,944	1,056

Source: Own research.

If we look at the economic sectors that most benefit in terms of employment from the installation of these renewable energy technologies, we obtain the following picture (see Table 13). As in the case of value-added, almost half of the indirect effect is concentrated in five economic sectors. It should be noticed that the economic sector "Safety and research activities" appears in terms of employment, but does not in terms of value-added.

Table 13. Installation indirect effect on employment in different economic sectors (as % of total indirect effect).

Wind		**Solar**	
Building sector	0,149	Building sector	0,112
Transport sector	0,110	Transport sector	0,102
Wholesaling sector	0,080	Safety and research activities	0,084
Safety and research activities	0,078	Wholesaling sector	0,071
Storage and transport related activities	0,047	Metallurgy sector	0,061

Source: Own research.

If, in turn, we look at the indirect impact of maintenance activities, we obtain the following results (see Table 14). The results are somewhat similar to the ones obtained in the analysis of value-added generation.

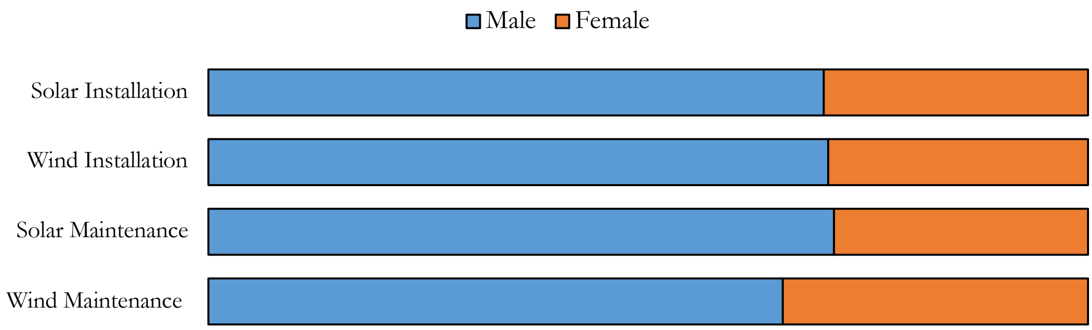
Table 14. Maintenance indirect effect on employment in different economic sectors (as % of the total indirect effect).

Wind		Solar	
Metallic products sector	0,303	Building sector	0,392
Architecture and engineering services	0,209	Wholesaling sector	0,158
Building sector	0,154	Metallic products sector	0,111
Other manufactures sector	0,066	Architecture and engineering services	0,059
Safety and research activities	0,042	Transport sector	0,051

Source: Own research.

In order to get more nuanced results, we look at how total employment (direct, indirect and induced) is distributed among gender and occupation. This is presented in Figure 15. Only proportions are analyzed here for a better comparison, absolute numbers can be found in Annex 8.1.

Figure 15. Employment distribution according to gender.

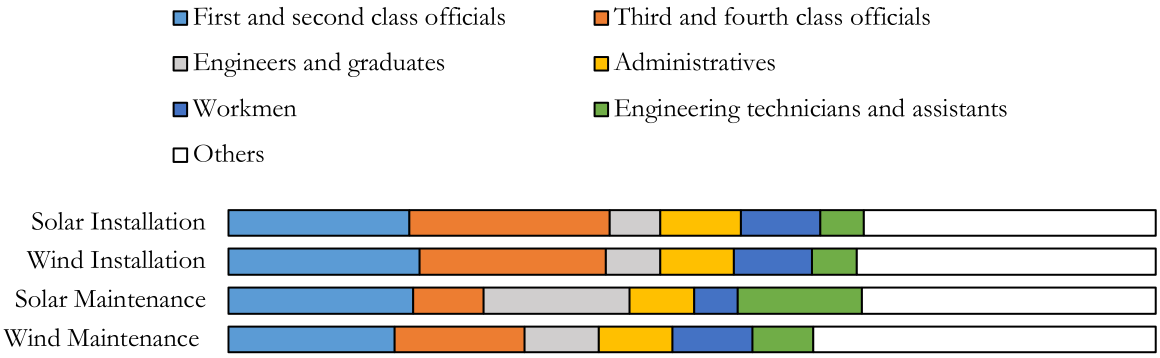


Source: Own research.

As we can see, every activity and technology creates employment that is mainly masculine; a slight increase in female employment can be found in the maintenance of wind facilities.

It is interesting to see that for the activities of installation, first and second class official, and third and fourth class officials comprise a half of the employment generated. In maintenance-derived employment, it stands out the higher share of employment that is generated among engineers and technicians. This is true for both technologies, but more evident in the case of solar FV.

Figure 16. Employment distribution according to occupation level.



Source: Own research.

Finally, in physical terms, we calculate that for every 100 MW of solar FV capacity installed in the year 2010, a total of 1.758 full-time equivalent would have been created and another 25 for their maintenance. At the end of the decade, these numbers had decreased to 372 and 18, respectively. In the case of wind power, for every 100 MW installed, a total of 652 full-time equivalent jobs would have been created and another 17 in concept of maintenance. In 2019, these numbers were 493 and 12, respectively. This shows that solar FV is more labor intensive than wind power.

4.3. Contextualization

If we compare the results obtained in this section to the ones presented at the beginning of section 2, we obtain Table 15 and Table 16. We can see that the impact is more prominent when compared to the rest of the energy sector in terms of employment than in terms of value-added generation, but relatively more important in terms of value-added when compared to regional value-added and the industrial sector.

Table 15. Value-added from wind and solar FV in context (in %).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Share of regional VA	0,23	0,21	0,18	0,18	0,13	0,12	0,11	0,11	0,11	0,20
Share of industry	0,76	0,68	0,59	0,59	0,41	0,38	0,36	0,34	0,34	0,66
Share of energy sector	3,31	2,99	2,49	2,58	1,93	1,75	1,66	1,52	1,55	2,96

Source: Own elaboration with data from the research and the Statistics Office of Navarre (2019b).

Table 16. Employment from wind and solar FV in context (in %).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Share of regional emp.	0,12	0,11	0,09	0,09	0,05	0,05	0,04	0,04	0,04	0,13
Share of industry	0,51	0,46	0,38	0,39	0,21	0,20	0,19	0,18	0,19	0,58
Share of energy sector	6,43	6,06	4,74	4,76	2,60	2,42	2,32	2,27	2,47	7,34

Source: Own elaboration with data from the research and the Statistics Office of Navarre (2019a).

It can be observed that there is a difference between the years in which more capacity is installed (2010, 2011, 2012, 2013 and 2019) and those in which it is not (2014-2018): in the best year (2019) wind and solar made up 7,34% of energy employment, 2,27% in the worst year (2017). This is consistent if we bear in mind Figure 1 and Figure 2, in which the relative importance of each primary energy source is depicted. Wind and solar are, at most, a 9% of primary energy used in Navarre in 2010, it follows that the employment that they generate is around that number. In the years in which no installation takes place, the relative importance is much lower than that, which means that, because of how these particular technologies operate, not as much employment is needed for its operation (compared to the rest of other energy sources in Navarre).

Compared to the data from the report of the impact of renewable energy in Navarre (Government of Navarre, 2016), in which it was stated that for the years 2010 and 2014 the renewable energy sector created around 4.000 jobs, we can see that the results of the research are much lower than that. In 2010, we obtained a total employment of around 500 full-time equivalent jobs; in 2014, the number was reduced to around 350 as a result of lower additional capacity installed in that year. Therefore, our conclusion is that the renewable sector in Navarre has grown past the regional needs of the sector and is driven now to a considerable extent by external demand and participation in external value chains.

5. CONCLUSION

The first conclusion that we can extract from the results of the analysis is that wind and solar FV technologies exhibit a peculiar pattern: they generate much more impact (both in terms of value-added and employment) in the process of installation than in the production of electricity. Once installed, the economic impact decreases.

Both technologies produce a similar effect in the economy during the installation phase (they affect mainly industrial sectors related to building, transport, wholesaling, etc., create a quantitatively similar indirect effect, etc.), but have slightly different effects in the operating phase. While solar FV creates higher indirect employment related to O&M, wind power generates more indirect value-added.

In general terms, the results from the analysis of the impact of wind and solar power in the economy of Navarre fall into line with the general outline of the energy sector. At first, it may seem paradoxical that these sources of energy, which account for 10% of primary energy, represent a sensitively smaller share in terms of value-added (around 3%) and employment (around 7%). However, when we think of the peculiar nature of wind and solar FV technologies commented before (installation produces a greater impact than operations), the results appear more reasonable.

It is expected that in the immediate future renewable power will resume installation so that GHG emissions are limited. The results of this research suggest that the economic impacts that this shift towards renewable energy will entail should be consider carefully, as when the installation phase is complete, the permanent effects in the economy will be lower.

Finally, regarding methodological issues, there is no denying that input-output methodology exhibits certain limitations. They are acknowledged and should be taken into consideration when interpreting the results. Be that as it may, studies found in the literature apply the very same methodology for similar purposes and obtain valid conclusions.

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8. ANNEXES

8.1. Employment by gender and occupation level of different technologies and activities

Employment of solar FV power installation by gender and occupation level.

	(%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Male	0,700	178	144	94	7	0	0	0	0	19	14
Female	0,300	77	62	40	3	0	0	0	0	8	6
Total	1,000	255	206	134	10	0	0	0	0	27	20
No consta	0,167	42	34	22	2	0	0	0	0	5	3
Ingenieros, licenciados, alta dirección	0,054	14	11	7	1	0	0	0	0	1	1
Ingenieros técnicos, ayudantes titulados	0,047	12	10	6	0	0	0	0	0	1	1
Jefes administrativos y de taller	0,031	8	6	4	0	0	0	0	0	1	1
Ayudantes no titulados	0,022	6	4	3	0	0	0	0	0	1	0
Oficiales administrativos	0,087	22	18	12	1	0	0	0	0	2	2
Subalternos	0,038	10	8	5	0	0	0	0	0	1	1
Auxiliares administrativos	0,058	15	12	8	1	0	0	0	0	2	1
Oficiales primera y segunda	0,195	50	40	26	2	0	0	0	0	5	4
Oficiales tercera y especialistas	0,216	55	44	29	2	0	0	0	0	6	4
Peones y asimilados	0,085	22	18	11	1	0	0	0	0	2	2
Trabajadores menores de 18 años	0,000	0	0	0	0	0	0	0	0	0	0
Total	1,000	255	206	134	10	0	0	0	0	27	20

Employment of solar FV power maintenance by gender and occupation level.

	(%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Male	0,711	24	23	24	24	23	23	22	23	22	21
Female	0,289	10	9	10	10	9	9	9	9	9	9
Total	1,000	33	32	34	34	33	32	31	32	31	30
No consta	0,117	4	4	4	4	4	4	4	4	4	4
Ingenieros, licenciados, alta dirección	0,157	5	5	5	5	5	5	5	5	5	5
Ingenieros técnicos, ayudantes titulados	0,134	4	4	5	4	4	4	4	4	4	4
Jefes administrativos y de taller	0,026	1	1	1	1	1	1	1	1	1	1
Ayudantes no titulados	0,077	3	2	3	3	3	2	2	2	2	2
Oficiales administrativos	0,070	2	2	2	2	2	2	2	2	2	2
Subalternos	0,023	1	1	1	1	1	1	1	1	1	1
Auxiliares administrativos	0,074	2	2	3	2	2	2	2	2	2	2
Oficiales primera y segunda	0,199	7	6	7	7	7	6	6	6	6	6
Oficiales tercera y especialistas	0,076	3	2	3	3	2	2	2	2	2	2
Peones y asimilados	0,047	2	2	2	2	2	1	1	1	1	1
Trabajadores menores de 18 años	0,000	0	0	0	0	0	0	0	0	0	0
Total	1,000	33	32	34	34	33	32	31	32	31	30

Employment of wind power installation by gender and occupation level.

	(%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Male	0,705	30	39	14	103	0	0	0	0	0	294
Female	0,295	13	16	6	43	0	0	0	0	0	123
Total	1,000	43	55	20	147	0	0	0	0	0	418
No consta	0,177	8	10	3	26	0	0	0	0	0	74
Ingenieros, licenciados, alta dirección	0,058	3	3	1	9	0	0	0	0	0	24
Ingenieros técnicos, ayudantes titulados	0,048	2	3	1	7	0	0	0	0	0	20
Jefes administrativos y de taller	0,030	1	2	1	4	0	0	0	0	0	12
Ayudantes no titulados	0,022	1	1	0	3	0	0	0	0	0	9
Oficiales administrativos	0,080	3	4	2	12	0	0	0	0	0	33
Subalternos	0,037	2	2	1	5	0	0	0	0	0	15
Auxiliares administrativos	0,057	2	3	1	8	0	0	0	0	0	24
Oficiales primera y segunda	0,206	9	11	4	30	0	0	0	0	0	86
Oficiales tercera y especialistas	0,201	9	11	4	29	0	0	0	0	0	84
Peones y asimilados	0,084	4	5	2	12	0	0	0	0	0	35
Trabajadores menores de 18 años	0,000	0	0	0	0	0	0	0	0	0	0
Total	1,000	43	55	20	147	0	0	0	0	0	418

Employment of wind power maintenance by gender and occupation level.

	(%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Male	0,653	111	107	103	101	97	93	90	88	84	86
Female	0,347	59	57	55	54	51	49	48	47	44	46
Total	1,000	169	164	158	155	148	142	138	135	128	132
No consta	0,203	34	33	32	31	30	29	28	27	26	27
Ingenieros, licenciados, alta dirección	0,080	14	13	13	12	12	11	11	11	10	11
Ingenieros técnicos, ayudantes titulados	0,066	11	11	10	10	10	9	9	9	8	9
Jefes administrativos y de taller	0,030	5	5	5	5	5	4	4	4	4	4
Ayudantes no titulados	0,029	5	5	5	4	4	4	4	4	4	4
Oficiales administrativos	0,080	13	13	13	12	12	11	11	11	10	10
Subalternos	0,040	7	7	6	6	6	6	6	5	5	5
Auxiliares administrativos	0,067	11	11	11	10	10	9	9	9	9	9
Oficiales primera y segunda	0,179	30	29	28	28	27	25	25	24	23	24
Oficiales tercera y especialistas	0,140	24	23	22	22	21	20	19	19	18	18
Peones y asimilados	0,087	15	14	14	13	13	12	12	12	11	11
Trabajadores menores de 18 años	0,000	0	0	0	0	0	0	0	0	0	0
Total	1,000	169	164	158	155	148	142	138	135	128	132

8.2. Value-added distribution of different technologies and activities

Tech.	Activity	Distribution	(%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Wind	Installation	Salaries	0,487	1410382	1817712	644324	4814268	0	0	0	0	0	13697170
		Taxes	0,013	38006	48982	17363	129730	0	0	0	0	0	369098
		Gross operating surplus	0,500	1447933	1866107	661479	4942444	0	0	0	0	0	14061847
	Maintenance	Salaries	0,405	9809224	9515223	9162478	8995947	8604819	8213691	8018127	7822563	7431435	7635063
		Taxes	0,013	308506	299260	288166	282928	270627	258326	252175	246025	233723	240128
		Gross operating surplus	0,582	14104604	13681863	13174654	12935200	12372800	11810400	11529200	11248000	10685600	10978396
Solar	Installation	Salaries	0,500	8422657	6807405	4425110	323050	0	0	0	0	895399	663766
		Taxes	0,011	187659	151671	98593	7198	0	0	0	0	19950	14789
		Gross operating surplus	0,489	8230267	6651911	4324032	315671	0	0	0	0	874946	648605
	Maintenance	Salaries	0,463	1529644	1493767	1572572	1546921	1511441	1468865	1433385	1461769	1413199	1390510
		Taxes	0,018	60956	59527	62667	61645	60231	58534	57120	58252	56316	55412
		Gross operating surplus	0,518	1712261	1672102	1760315	1731601	1691885	1644227	1604511	1636284	1581915	1556517