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# Trabajo Fin de Máster

# Evaluation of the economic and environmental impact of electric mobility development in Spain.

# Evaluación del impacto económico y medioambiental del desarrollo de la movilidad eléctrica en España.

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TÍTULO: Evaluación del impacto económico y medioambiental de la movilidad eléctrica en España.

RESUMEN: Los objetivos del Plan Nacional Integrado de Energía y Clima sitúan la cantidad de vehículos eléctricos en 5 millones para 2030 respecto a un parque automovilístico que podría superar en esa fecha los 30 millones en España. El cambio del vehículo de motor térmico a tracción eléctrica conlleva un cambio significativo para los sectores productivos en España, donde el sector de la automoción representa el 11% del PIB. Por un lado, los fabricantes de vehículos y sus proveedores deben hacer frente a modificaciones en su proceso productivo asociados al cambio tecnológico. Adicionalmente, otros sectores, como el energético, sufrirán dichos cambios. Por otro lado, la provisión de puntos de recarga eléctrica sustituirá parcialmente a las estaciones de combustibles fósiles. La industria automovilística española se relaciona con el resto de Europa y el mundo a través de importaciones y exportaciones de materiales y componentes que forman parte de la cadena de suministro para la fabricación de los vehículos. Además, el consumo por parte de la población de este tipo de vehículos dependerá de una serie de condicionantes, como el desarrollo de las infraestructuras adecuadas, pero también de otros factores económicos y sociales.

Este trabajo analiza los impactos económicos y medioambientales del desarrollo de la movilidad eléctrica en España. Para ello, se utiliza un modelo multisectorial input-output para España que recoge las relaciones intersectoriales e interregionales con el resto de Europa y el resto del mundo. La magnitud del impacto dependerá de la penetración de la movilidad eléctrica en España, de la intensidad de utilización de las industrias y de los cambios tecnológicos asociados en el horizonte de modelización. Esto viene dado tanto por el número de vehículos como por las infraestructuras necesarias. A este respecto, se estudian una serie de escenarios posibles en cuanto a la penetración en el mercado de la movilidad eléctrica para el horizonte de 2030 y 2050.

Más adelante, el análisis input-output se complementa con el diseño de un modelo de equilibrio general que permite flexibilizar las restricciones del modelo input-output con el fin de analizar distintos escenarios de medidas de política fiscal y de mercado de trabajo. El presente trabajo contempla el diseño del modelo, pero no cubre la completa validación del mismo y las conclusiones definitivas, que quedan como línea abierta de investigación.

TITLE: Evaluation of the economic and environmental impact of electric mobility in Spain.

ABSTRACT: The objectives of the National Integrated Energy and Climate Plan place the number of electric vehicles at 5 million by 2030 compared to a car fleet that could exceed 30 million on that date in Spain. The change from the thermal motor vehicle to electric traction entails a significant change for the productive sectors in Spain, where the automotive sector represents 11% of GDP. On the one hand, vehicle manufacturers and their suppliers must face changes in their production process associated with technological change. Additionally, other sectors, such as energy, will undergo such changes. On the other hand, the provision of electric charging points will partially replace fossil fuel stations. Spanish automotive industry is related to the rest of Europe and the world through imports and exports of materials and components that are part of the supply chain for the manufacture of vehicles. In addition, the consumption by the population of this type of vehicle will depend on a series of conditions, such as the development of adequate infrastructure, but also on other economic and social factors.

This work analyses the economic and environmental impacts of the development of electric mobility in Spain. To do this, a multisectoral input-output model is used for Spain that includes inter-sectoral and interregional relationships with the rest of Europe and the rest of the world. The magnitude of the impact will depend on the penetration of electric mobility in Spain, the intensity of use of the industries and the associated technological changes. This is given both by the number of vehicles and by the necessary infrastructure. In this regard, a series of possible scenarios are studied regarding the penetration of the electric mobility market by the 2030 and 2050 horizon.

Later on, the input-output analysis is complemented with the design of a general equilibrium model that makes it possible to relax the restrictions of the input-output model to analyse different scenarios of fiscal and labour market policy. The present work includes the design of the model, but not the complete validation and definitive conclusions that remain open as active research line.

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## 1. INTRODUCTION

Mobility is involved in a disruptive change integrating autonomous driving, connectivity, electrification and shared mobility. Any of these changes implies evolutions of technology and business models. The current crisis imposed by the pandemic has led to reinforce the objectives of the "EU Green Deal" (COM/2019/640), highlighting the importance of a green recovery with an economy more ecologic, digital and resilient. In this context, the changes in the automotive industry are accelerating significantly and will need the proper investments and political support. Electromobility is a key pillar to make mobility more sustainable, since it leads to lower tailpipe emissions and an improvement in the Life Cycle Assessment in relation to conventional powertrains using a thermal engine, mainly when coupled with low-carbon electricity sources. The transition to electric vehicles means a significant challenge for all the value chain, from the component suppliers to vehicle manufacturers, also including electricity providers and infrastructure. The demand of these vehicles will be determined by the consumer perception and acceptance, but also by the government policies that will push the new technology to fulfil environmental objectives and will ban the thermal engine powertrain for circulation and sell in different time steps. The scenario is moving very fast. A non exhaustive analysis shows the status of banning for different countries, where some developed and emerging countries, such as Japan, Germany, China and India, consider banning combustion engines by 2050, even before (McKinsey & Company, 2019).

This ban would affect normally to pure combustions engine vehicle, but the transition to pure electric vehicles (EVs) will be executed with the addition of different levels of hybridization in the powertrains. Hybridization has different levels (micro, mild, hybrid), with different combinations of interactions between the internal combustion engine (ICE) and the battery, that can have different voltages and be charged by the combustion engine or by plug-in. Thus, a transition pathway should lead to pure electric vehicles, known as battery electric vehicles (BEV) (icct, 2020), with high voltage and plug-in batteries for a proper autonomy and charging conditions depending on the use target. This transition must cope with $CO_2$ objectives for vehicles that are established for the automakers fleets (figure 1). It means that each automaker must have the proper mix of technologies and powertrain sizes to fulfil the regulations.

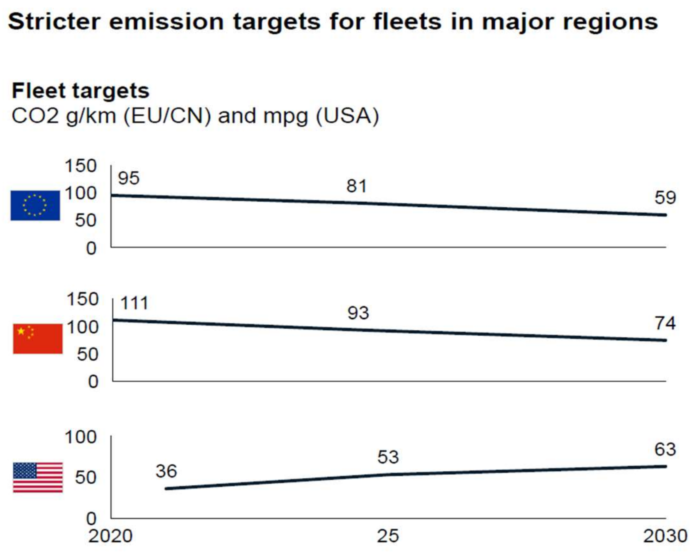

*Figure 1. Stricter emission targets for fleets in major regions (McKinsey & Company, December 2019)*

Additionally, in relation to the demand of vehicles, the current situation has led to several questions about previous and current trends of social organization: use of private vehicles versus shared mobility, ownership, homeworking, population distribution, etc. Nevertheless, the forecasts for car sales show an increase in the coming years. In the market share, the automakers are significantly ramping up the production of BEV's. It is estimated that they will need to sell up to 2.2 million EV units in 2021 alone, and they will launch around 300 new BEV's by 2025, with a strong focus on medium and large vehicles (McKinsey & Company, 2019). The following figure shows the recovery for the coming years in different regions (figure 2) and the next one shows how the share for different powertrains will be (figure 3).

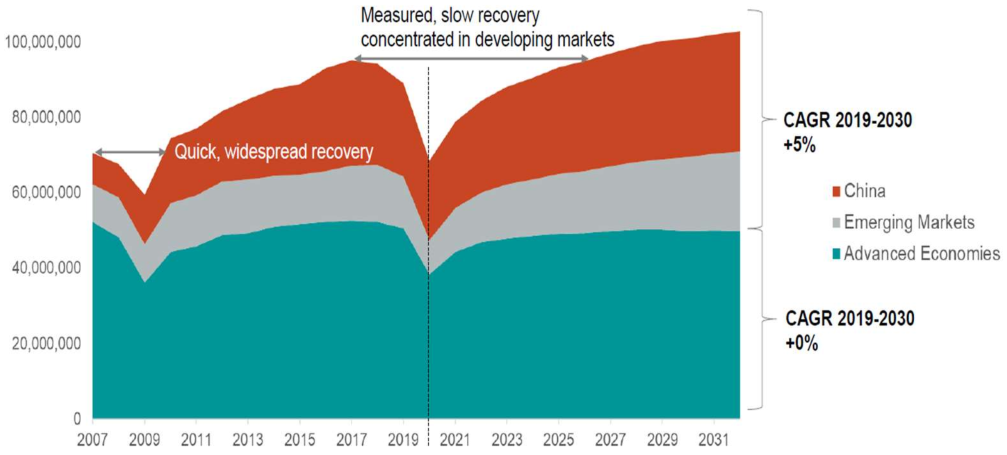

*Figure 2. Global production forecast, by production market (IHS Markit, November 2020)*

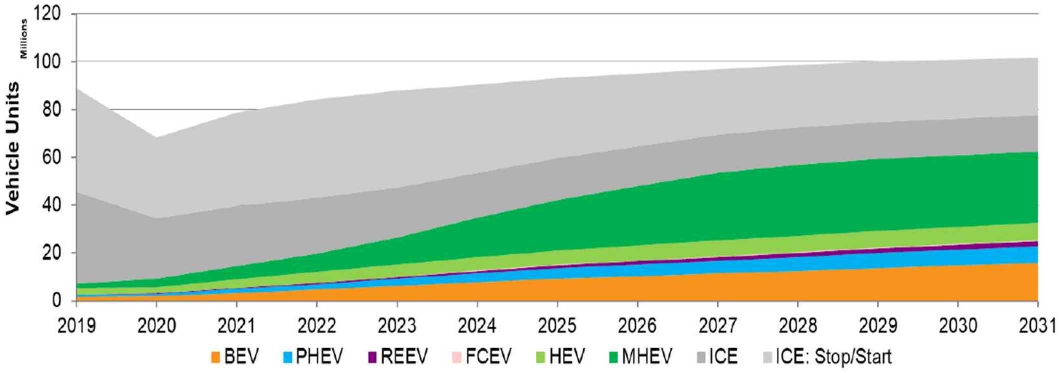

*Figure 3. Global production of alternative propulsion vehicles 2019 to 2031 (IHS Markit, November 2020) –BEV: Battery Electric Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, REEV: Range Extended Electric Vehicle, FCEV: Fuel Cell Electric Vehicle, HEV: Hybrid Electric Vehicle, MHEV: Mild Hybrid Electric Vehicle, ICE: Internal Combustion Engine)*

The investment of industry in the past years has increased significantly for the transition to a more connected and sustainable mobility. This investment has been made for the traditional automotive industry, and also there is a significant amount of newcomers and start-ups that are gaining relevance. Electric vehicles and batteries in particular have had a total investment in the industry of 33.3 billions from 2010 (McKinsey & Company, December 2019), showing the highest share apart from connectivity, automation and e-hailing services.

Another important task in this transition is the global supply chain that is now highly globalized and counts with China and other Asiatic countries for a high number of electric and electronic components due to technology know-how and cost. However, both the U.S and Europe are moving towards the localization of production for the most strategic components, such as the batteries in the case of BEV's. Currently there are many projects for mining, technology evolution and manufacturing capabilities to be developed locally.

In this context, Spain is highly concerned with this situation. According to date of 2019 (ANFAC, Annual Report 2019), the automotive industry accounts for 8,5% of Gross Domestic Product (GDP) (direct contribution for car and components production) and the 11% of GDP if distribution, insurance and finance are included. It also accounts for 9% of employment over the whole active population. Spain is the 9th vehicle producer of vehicles in the world and the 2nd in Europe (after Germany). The automotive industry (vehicles and components) represents 19% of total exports of Spain. A significant number of companies in this sector are big multinational companies with factories located in Spain, where production is the main activity and with a lower involvement in development and research areas.

The decarbonisation of mobility in Spain, that is, the transition to alternative powertrains, such as electric or hydrogen, is supported by several policies. These policies are directly related with the targets of the European Community for transport and sustainable development. There are also international initiatives for electric vehicles deployment

(Electric Vehicles Initiative, Global EV Pilot City Programme,…) (International Energy Agency, June 2020). As for public policies, the National Integrated Energy and Climate Plan in Spain (Plan Nacional Integrado de Energía y Clima –PNIEC 2021-2030) sets the goal of 5 millions of electric vehicles in 2030 (3 millions of passenger cars, and 2 millions of motorcycles, light commercial vehicles and buses). For that, there will be different incentives for promotion of these vehicles, together with increasing penalties for ICE vehicles (fiscal penalties or circulation restrictions). This goal is derived from the progressive decarbonisation objectives for the economy in the following decades that considers the emissions of vehicles with LCA, integrating the origin of the electricity source for the calculation of $CO_2$ emissions. This plan is included in the Long-Term Decarbonisation Strategy for 2050 (*Estrategia de Descarbonización a Largo Plazo 2050*) and is line with the communication from the European Commission to the European Parliament from December 2020 (Sustainable and Smart Mobility Strategy – putting European transport on track for the future). This latter settles the target of 90% reduction in the transport sector's emissions by 2050 with nearly all cars, vans, buses and heavy-duty vehicles with zero-emission. An intermediate evaluation in this strategy sets the quantity of zero-emission vehicles to be at least 30 million by 2030 on European roads.

The immediate future for powertrains is electric and the industry must be prepared in order to face the new challenges for the new technology. The shift of technology involves a change in the supplier chain and transfer between industries. On one hand, the current automotive industry must be prepared for the development and production of new components. On the other hand, other industries not traditional to the automotive market can enter with specific products for electromobility, and also newcomers and start-ups can offer advanced products for electric vehicles. The policies must take into account the provision for support to the companies and the whole sector involved in this transition. Besides, the balance between exports and imports must be considered, so the transition does not lead to an unfavourable balance to excessive imports due to the technology change.

In this context, this work analyses the impact of the technological and demand change associated with electric vehicles in the production chain, and in environmental, economic and social indicators. In order to consider the relationships between sectors along the full supply chain of the automotive industry, the spillovers and the total direct and indirect impacts, a multi-sectorial and multiregional input-output (MRIO) model is used. The use of this model enables to implement changes in the interrelation between industries representing a technological change in production and supply chains. At the same time, the demand can be modified to represent the impact of a new technology introduction. Second, a computational general equilibrium (CGE) model is used to analyse the impact of different policies, allowing for a higher flexibility (for instance different assumptions for technology, inputs substitution, responses to price changes) and alleviating some restrictions of the input-output model. The models cover the representation of a whole economy that permits to establish the impact for all sectors and regions represented in the model.

The main interest of this work is to analyse the impact of the development of electric mobility in Spanish industry and indicators, compared with the rest of Europe and the rest of the world. For that, different scenarios have been considered, in two different timeframes (2016-2030 and 2016-2050). The impact of the technological change in the automotive industry has been assessed complemented with a prediction in the demand for associated industry influenced by the generalized use of electric vehicles in 2050. To the best of our knowledge this is the first study analysing these technological transitions in an integrated multisectoral and multiregional framework. The work is structured as follows.

Sections 2 presents a brief review of the main results of previous literature. In section 3, the methodologies, both MRIO and CGE model, and the data used are described. Section 4 displays the results and finally, the section 5 shows the conclusions of the work.

## 2. LITERATURE REVIEW

The shift of car production from conventional (ICE) to electric powertrain has been assessed extensively, in the industrial ecology literature, in relation to environmental impact and LCA (Life Cycle Assessment) for the vehicle itself. The industrial ecology is based on the study of materials and energy flows within a clearly confined system. In these studies, the environmental burden is calculated when comparing one vehicle produced, used and the end-of-life for both powertrains. These works enable to discriminate the more critical phases and factors for each type of powertrain. The EV production is more intensive environmentally, but this can be compensated during use phase with the appropriate electricity mix, which will be more favourable as far as more renewable energy sources are used (Hawkins et al., 2012). There are also influencing factors of the use phase, such as the user, the infrastructure and surrounding conditions (Egede et al., 2015). When comparing with an ICE medium reference, the benefit of electrification is noticeable and favourable to EV’s, but depends significantly on the electricity production and the degree of electrification (Nordelöf et al., 2014).

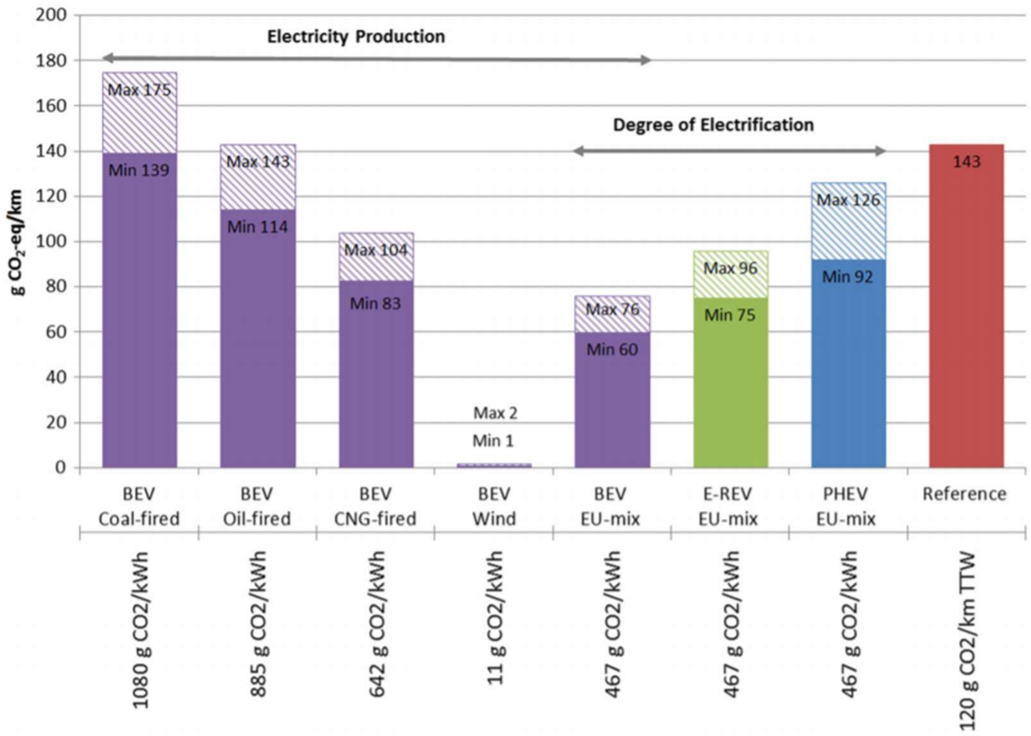

*Figure 4. Well-To-Wheel GHG emissions for different electricity production and degrees of electrification. Reference value for EU average electricity mix for the impact of degree of electrification / Reference vehicle corresponds to the 2012 EU fllet target for tailpipe emissions of sold cars (Nordelöf et al., 2014)*

The cost of the electric vehicles has been identified as a barrier for the implementation, since clean technologies need to be cost-efficient for a widespread introduction. The total cost of ownership (TCO) is a key target (Messagie et al, 2013). The research and advancement on the battery production chain will enable to reach parity in the coming years. The TCO must be balanced in a concept known as the Total Cost for Society that includes the costs generated by externalities such as climate change, air pollution or congestion (De Clerck et al., 2018)

In spite of the fact that LCA and environmental footprint analysis provide a significant insight for electric vehicles evaluation, it is also relevant to account for the aggregate of all the releases from the processes outside modelled systems (Gregori T., 2016). In this sense, EEIO (Environmental Extended Input-Output) and CGE (Computational General Equilibrium) model analysis can contribute further for evaluation and impacts. Moreover, these analyses enables to combine the environmental analysis with other economic and social evaluations. Despite the interest of the subject, it is still little studied in the economic literature, especially for the European industry and more in particular for Spain. There are abundant studies focusing on environmental impacts of alternative vehicle technologies, but the social and economic dimensions have not been investigated sufficiently.

The current economic crisis of 2020 associated to the pandemic and the green recovery plan to be developed in the following years; together with the Dieselgate (Volkswagen emissions scandal) of 2015 have speed up the transition to electric cars, so the scenarios are being pushed due to political drivers. Anyhow, there are previous research programmes such as EV-STEP initiated in 2012 (Ghersi, 2017) to implement a systemic modelling approach to analyse widespread development scenarios for electric cars. This programme brings together a bottom-up liner optimization energy system (TIMES PanEU) and an economic general equilibrium model (IMACLIM) to evaluate the impact on the GDP for EU28. In the case of this study, this impact depends on the trade performance of the EU electric car industry. The penetration of electric cars also has an impact on electricity prices.

There is scarce literature on macroeconomics related to the change in transition of automotive industry to electrification. From the references found, most are focused on the effect for specific regions, as it is described below. Both MRIO and CGE models have been previously used.

As for MRIO, Sen et al. (2018) used the model with an extension to LCA model to calculate the material footprint to assess the material dependence of US to other countries. For that indicator, the manufacturing phase is dominant, and the main burden is the battery (65% of direct impacts). Onat et al. (2014) also applied combined MRIO and LCA previously, pointing out the low use of MRIO for global impact evaluation. They found that manufacturing phase is the most relevant for socio-economic impacts whereas operation is the dominant phase for environmental issues. In this study, electric vehicles show a clear improvement for emission costs and impact in human health. The study shows an increase in the income for low and medium skilled workers in the US, and the relationship between greenhouse emissions and GDP is the lowest when compared to other industries. Combined MRIO and LCA has been used also to assess the economic and environmental impacts of the battery itself (Sanfélix et al., 2016), when manufactured in Belgium and including trade data for 40 countries. This shows the relevance of some countries in the environmental performance proving the significance of indirect effects.

Shibusawa et Miyata (2017) applied national and multiregional input-output models for Japan. The conclusions show that hybrid electric vehicles produce positive effects from a macroeconomic perspective, whereas pure electric passenger cars result in negative effects. This negative effect is higher for areas with industries focused on mechanical sectors that should therefore change their production structure.

Leurent et Windisch (2015) used the MRIO for the analysis of the impact for the public finances in France, showing that the location of production of EVs and components will be very relevant (if EV's are produced domestic and not imported, mainly if they replace domestic combustion engine vehicle). They conclude that the incentive bonus for EV purchase are mainly justified by energy independence, domestic industry, and environmental quality. For a study in Russia (Kolpakov et Galinger, 2020) the increased share of electric vehicles leads to worsening of the macroeconomic indicators due to critical need of additional imports and the shortfall of natural gas or coal sale. This methodology is also used to evaluate interdependent economies, like China and Japan (Shibusawa et Xu, 2013). Japan depends heavily on the motor vehicle industry, and China expands rapidly in the sector of electric vehicles. In this context, the IO analysis is used showing a benefit for China due to the expansion of trade between the regions, in spite of the fact that EV case has a negative impact on Chinese economy. The study aims to examine how the relationship of competitive coexistence can be better built.

As for CGE models, there are also some applications in the literature. Schmelzer et al. (2018) also used a general equilibrium model combined with a discrete model to analyse the effects of the demand of electric vehicles in Austria. The results shows that the penetration highly depends on policies and that the investments into the charging infrastructure enhance economic growth, with noticeable environmental benefits beyond 2030. In the case of Toyohashi city, in Japan, (Khanam et al., 2011) a CGE model is applied showing that the total industry output has a slight increase, whereas the GDP in the automobile industry depicts a large rise. It leads to an increase of the GDP in the city and an increase in labour demand. In relation to sectors, the non-ferrous metal manufacturing industry is the one that gets a higher positive impact.

There are other multisectorial macro-economic models for specific economies that are based on input-output analysis and include climate and energy targets for 2030. E3ME (Energy-Environment-Economy Macro-Econometric model) was originally developed in Europe in the 1990s and has been used for high-profile policy assessments associated to decarbonisation of passenger car transport (European Climate Foundation, 2018). The results show significant potential benefits for energy dependence, gains in value added and employment and substantial benefit for grid synergies and for the consumer with a total cost of ownership of EVs converging at the fourth year. However, it also highlights the high level of investment required for infrastructure and the unbalanced evolution of employment, that will cause and adverse impact in the automotive value chain from 2030 (Stenning, 2018).

Germany uses PANTHA REI macroeconomic model implemented for economic-environmental forecasts and policy simulations (Meyer, 2005). PANTHA REI combines econometric methods in input-output modelling, and so depict the change of economic structures and interdependencies of the environment and the economy. It has been used for evaluation in automotive industry (Ulrich et Lehr, 2016) showing that the long term effects are found to be negative since the increasing demands in electrical industry is overcompensated by decrease of demand in the automobile industry and higher imports. Weakness of electronic industry and the lower productivity in this sector leads to a decrease of GDP from 2024 and a slightly negative or balanced employment effect from 2020. Another work from the same authors (Ulritch et al., 2020) illustrates the substitution of inputs within the automotive industry by inputs from the electrical engineering sector and an E-mobility scenario of six million e-vehicles by 2030 as target versus a reference scenario. In this case, the negative effects in vehicle production are offset by positive effects in energy technology production. The impact on employment is slightly positive in the short and medium term, and from macroeconomics it is shown that the share of imports and exports is crucial. In this work, the new coefficients for technological coefficients are derived from existing studies (Spath et al., 2012). This shift in sectors is calculated through a proxy that is the labour input to vehicle production for every technology extracted from an analysis of the vehicle electrification effects on employment in Germany (Bauer et al., 2018). By combining the percentage share and the labour input per type of powertrain, the shift in input coefficient at sector level can be calculated. In this case, the input coefficient for electrical machinery increases 2.6 in percentage by 2030, and the motor vehicle industry declines by -2.6 in percentage (Ulrich et Lehr, 2020). This is a relevant number to be taken into account for the present work.

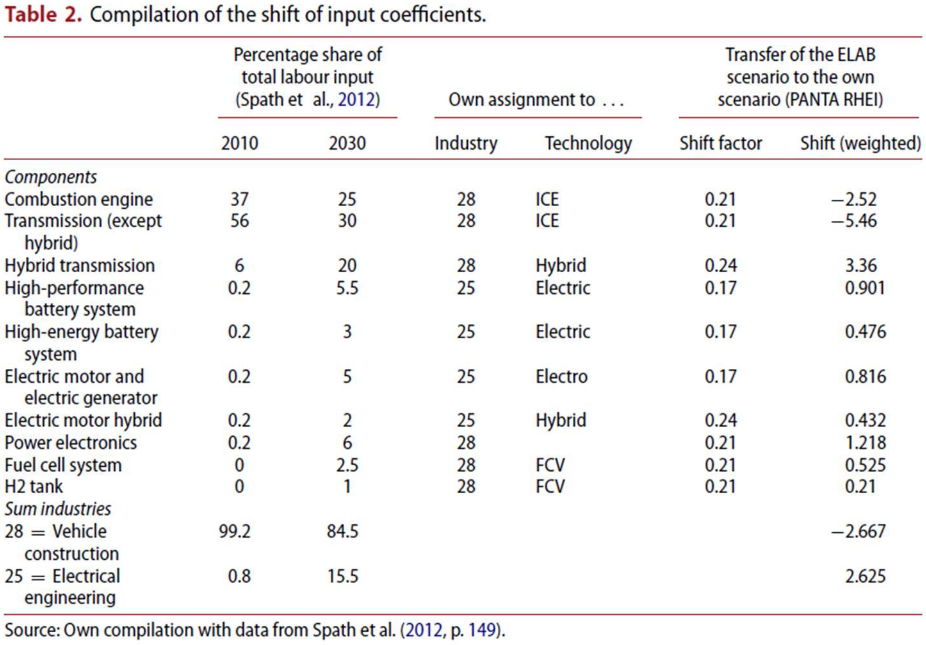

**Table 2.** Compilation of the shift of input coefficients.

| | Percentage share of total labour input (Spath et al., 2012) | | Own assignment to . . . | | Transfer of the ELAB scenario to the own scenario (PANTA RHEI) | |
|---|---|---|---|---|---|---|
| | 2010 | 2030 | Industry | Technology | Shift factor | Shift (weighted) |
| *Components* | | | | | | |
| Combustion engine | 37 | 25 | 28 | ICE | 0.21 | −2.52 |
| Transmission (except hybrid) | 56 | 30 | 28 | ICE | 0.21 | −5.46 |
| Hybrid transmission | 6 | 20 | 28 | Hybrid | 0.24 | 3.36 |
| High-performance battery system | 0.2 | 5.5 | 25 | Electric | 0.17 | 0.901 |
| High-energy battery system | 0.2 | 3 | 25 | Electric | 0.17 | 0.476 |
| Electric motor and electric generator | 0.2 | 5 | 25 | Electro | 0.17 | 0.816 |
| Electric motor hybrid | 0.2 | 2 | 25 | Hybrid | 0.24 | 0.432 |
| Power electronics | 0.2 | 6 | 28 | | 0.21 | 1.218 |
| Fuel cell system | 0 | 2.5 | 28 | FCV | 0.21 | 0.525 |
| H2 tank | 0 | 1 | 28 | FCV | 0.21 | 0.21 |
| *Sum industries* | | | | | | |
| 28 = Vehicle construction | 99.2 | 84.5 | | | | −2.667 |
| 25 = Electrical engineering | 0.8 | 15.5 | | | | 2.625 |

Source: Own compilation with data from Spath et al. (2012, p. 149).

*Figure 5. Evaluation of shift in factors for Germany industry (Ulrich et Lehr, 2020)*

## 3. METHODOLOGY AND DATA

This section presents the methodology addressed in the study. First, the multiregional and multisectoral input-output model, which is used to simulate different scenarios regarding technological changes form the production sides, and changes in demand. Additionally, this model is environmentally extended to study environmental impacts of these scenarios. Second, a Computable General Equilibrium (CGE) model is developed to study the transition scenarios of the EV.

### 3.1. The MRIO model

This work is based on a multiregional and multisectoral input-output model (MRIO) with a specific focus on Spanish economy and its relationship with the rest of Europe and the world. The fundamental purpose of the input-output framework is the analysis of the interdependence of industries and regions (Miller et Blair, 2009). Methodological choices have an influence on the evaluation results (Font Vivanco et al., 2016).

Our starting point is the representation of a closed global economy with *n* industries and *m* regions/countries, where **x** denotes the total output, and $x^r$ the total output generated by region *r*, and $\mathbf{Z} = (Z_{ij}^{rs})$ is *mn x mn* matrix of multiregional intermediate flows. Let us denote by **y** is vector *mn x 1* of total final demand of regions, where each element $y^r$ represents the worldwide final demand for products of the industry in country *r*, and **i** a unitary vector *mn x 1*.

$$\boldsymbol{x} = \boldsymbol{Zi} + \boldsymbol{y} \qquad (1)$$

We denote by **A** the matrix *mn x mn* of technical coefficients in this multiregional framework, where each element $a_{ij}^{rs}$ represents the volume of intermediate input *i* produced in region *r* that is used as input to produce one unit of output *j* in region *s*. Substituting **Ax** for **Zi**, the equilibrium equation can be expressed in terms of the so-called Leontief inverse matrix **L** as follows:

$$\boldsymbol{x} = \boldsymbol{Ax} + \boldsymbol{y} \rightarrow \boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y} \qquad (2)$$

$$\boldsymbol{x} = \boldsymbol{y} + \boldsymbol{Ay} + \boldsymbol{A}^2\boldsymbol{y} + \boldsymbol{A}^3\boldsymbol{y} + \boldsymbol{A}^4\boldsymbol{y} + \cdots. + \boldsymbol{A}^m\boldsymbol{y} \rightarrow \boldsymbol{x} = \boldsymbol{Ly} \qquad (3)$$

The representative element in **L**, $l_{ij}^{rs}$, represents all the production generated in sector *i* in region *r* to fulfil the demands of inputs incorporated in all the steps of the production chain and ending in the final demand of sector *j* in region *s*. In consequence, the elements in **L** capture the production embodied in all the economic flows linking sectors *i* and *j*, and regions *r* and *s* through the international supply chains.

Thus, the Leontief inverse (**L**) is the tool to link final demands in any region and sector (private and public consumption, investment, final exports) with all the production generated in the whole economy (across the global supply chain) to fulfil these final demands. In this sense, production, technology and final demand are sectorial and geographically connected in the MRIO framework.

Moreover, this MRIO can be extended to account for the inputs, resources and environmental impacts linked to the production in each region and sector (Wiedmann et al., 2007 and 2013, among others).

More specifically, if we denote by **W** a 1xmn vector of primary inputs or resources use (labour, value added, energy, water, CO2 emissions…), **Wi**=$W$ the total use of resources in the economy, and by **w** a vector of resources intensity, with $w_i^r = W_i^r / x_i^r$ being the use of resource in sector and country r per unit of output), we can write:

$$\boldsymbol{\varepsilon} = \hat{\boldsymbol{w}}.\boldsymbol{L}.\hat{\boldsymbol{y}} \tag{4}$$

Being ∈ the *nm* x *nm* matrix of resources embodied in the full supply chains associated to the final demand **y**. In this matrix, each element $\in_{ij}^{rs} = w_i^r L_{ij}^{rs} y_j^s$ shows the resource used in country r and sector i that to produce those inputs that directly and indirectly are associated to the final demand of sector j in country s. The sum of the elements in the row depict the total use of resources in that sector and country i, s. The sum of the elements in each column show all the resources in the global economy in the generation of all the inputs that are used to produce a given final demand. In this way, these columns capture the resources embodied in the full supply chain of product j consumed in country s.

Moreover, it holds that, $(\mathbf{i}'\boldsymbol{\varepsilon})\mathbf{i} = W$

On the basis of this model, different scenarios have been simulated to capture how technological change and demand shifts in a certain group of sectors will affect input supplies, production and primary inputs used anywhere.

The scenarios are introduced as technical changes $\Delta A_{ij}^{rs}$ introduced in 2030 and 2050 in the sectors of interest as well as different demand shifts $\Delta y_i^r$ linked to the progression of mobility options. The technical change involves a variation in the inputs consumed by the affected sectors (Ulrich, 2016). Moreover there is also modifications in the final demand (fuel and electricity sectors).

### 3.2. The CGE model for modelling electric vehicles

The MRIO presented above, extended with socioeconomic and environmental indicators, offers a first approach to the cross-sectoral effects of the changes technology through changes in production and inputs linked to different scenarios of development of mobility, showing the interdependence among sectors and countries and the impacts associated to these changes. However, different rigidities appear linked to the Leontief technology assumption (null sustituibility), the demand driven nature of the model, and the lack of circular quantity-price effects that could result relevant for the study of long-run effect in such dynamic process. In spite of the fact that MRIO analysis is a first step to understand the relationships between sectors, these rigidities can be relevant in our case. Mainly due to the nature of the technological change expected and the high price dependence of consumer choices.

A Computable General Equilibrium (CGE) model represents the whole economy, and the behaviour and interactions of the economic agents (consumers, producers and public sector). Thus, it is possible to measure direct and indirect effects of different economic policies as well of changes in the behaviour of the agents. For that, the model considers quantities and prices and considers that the offer equals the demand in the market (competitive and equilibrated markets). CGE model is one of the analytical tools that enable to integrate different parts of the economy in an overall system (Cardenete et al., 2012).

In comparison with partial equilibrium models, based on the *caeteris paribus* clause, MRIO and CGE models show explicit specifications for producers (such as firms) and consumers (such as households), and results for the whole economy. They also enable to design and evaluate impacts of technological change in the functions of consumption and production. In the case of CGE model, the results are obtained for prices and quantities simultaneously and endogenously. So, this is a tool very useful when evaluating economic, social and environmental policies as well as new scenarios, as the one related to the present study with the ramp-up of electric vehicles.

The CGE model is calibrated on the empirical database designed previously supporting the MRIO. A nesting structure is defined both for production and demand. For the production side, it is considered that producers minimise costs through a multi-level constant elasticity of substitution (CES). The nesting is done considering the relevant sectors for this analysis, based on a similar structure to the GTAP-E model for the energy aggregate (Burniaux et Truong, 2002), another for transport services following Liu et Bohlin, 2012, and another one, as a novelty, for vehicle production sectors, see figure 8. The production of vehicles is considered under the sector "*Manufacture of motor vehicles, trailers and semi-trailers*", independently of the powertrain used. This category also includes the traditional automotive industry for components, which is partly substituted by electric components ("Manufacture of electrical machinery and apparatus") for production of the vehicles. So, an elasticity is defined in order to represent this substitution. The value represents how the inputs can be varied to produce the output of production of vehicles. The shift in input coefficients for 2050 for the two sectors contributing to production in vehicles is 19.8%. The output does not vary. So, it is considered an elasticity of 0.19 between sectors.

The energy sector is further disaggregated in levels, splitting between non-electricity and electricity sector, and more in detail, for renewable and non-renewable energy. For all the levels, the corresponding elasticities are defined, as well as substitution factor for capital and labour use. Additionally, the Armington hypothesis is included through a set of sector elasticities in the production function (figure 6), to reflect the substitution between domestic and imported inputs for production. Also, a Constant Elasticity of Transformation (CET) is considered for substitution of exports, representing the producer decision on sell at home or export. In the demand, represented in figure 7, it is considered the substitution for the consumption of energy and transport sectors, with the same disaggregation than for production in energy sub-sectors. In this case, it has been considered that there is no substitution for the demand of the rest of sectors, including the demand of vehicles. This is due to the fact that the whole demand of vehicles is considered under the sector "*Manufacture of motor vehicles, trailers and semi-trailers*", as previously explained

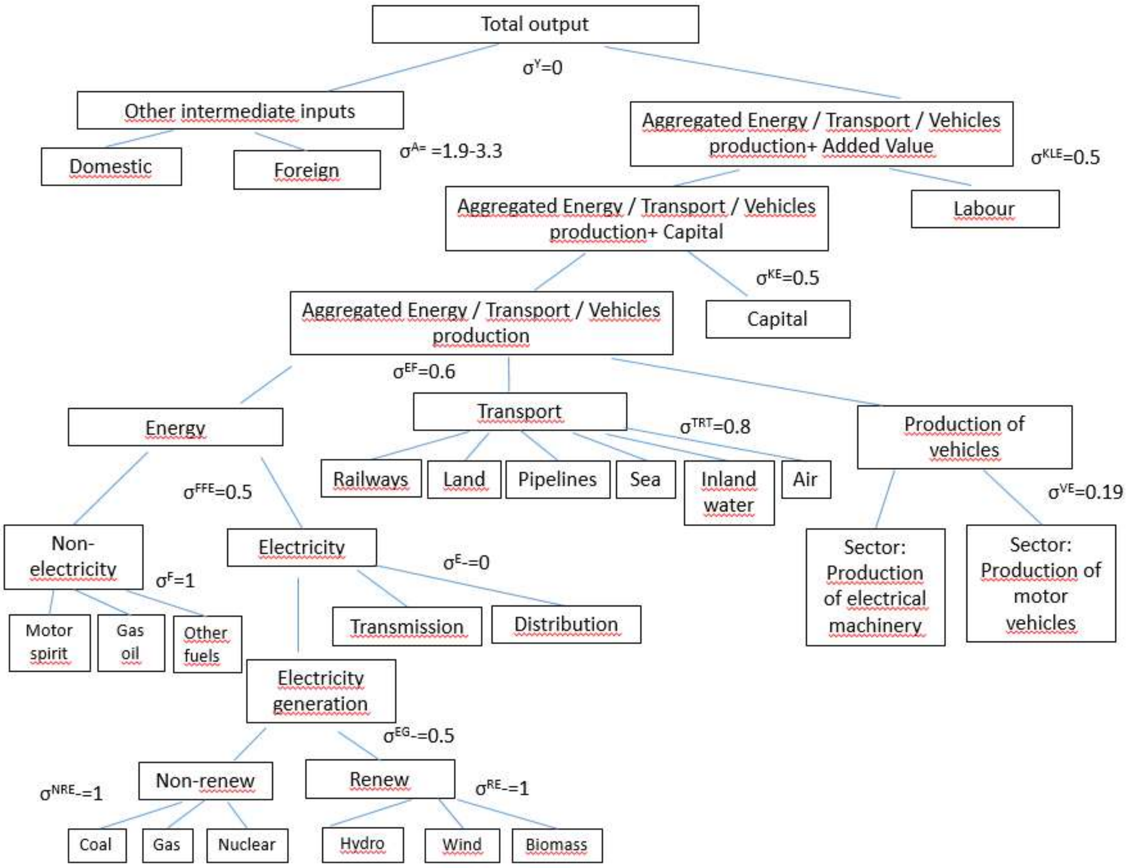

*Figure 6: Nesting structure for production. Own elaboration*

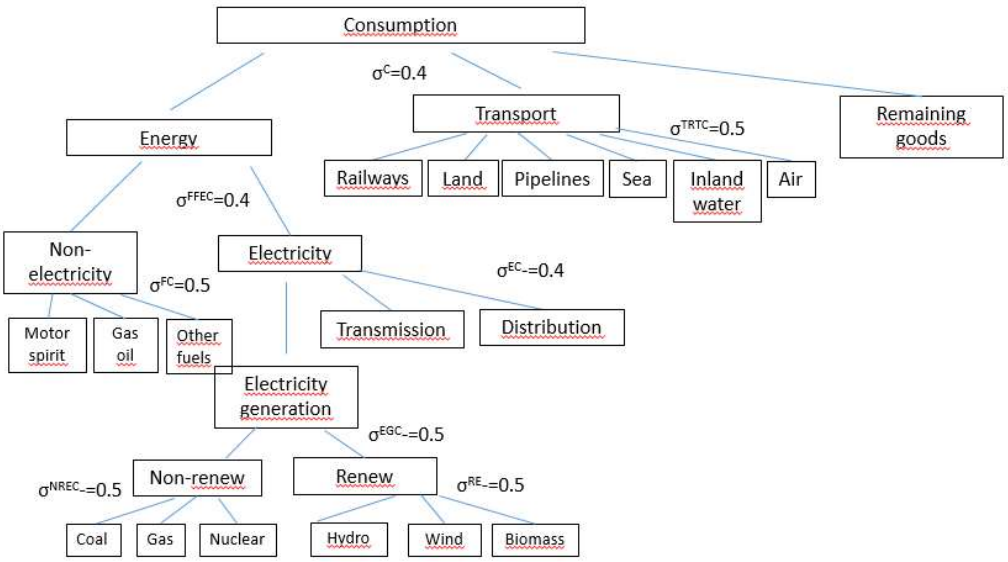

*Figure 7: Nesting structure household consumption. Own elaboration*

The considered elasticities are summarized in the following table:

| | |
|---|---|
| *Substitution elasticity between:* | |
| Intermediate inputs and value added | $\sigma^{Y} = 0$ |
| Labour and Capital-Energy aggregate (KLE)[a] | $\sigma^{KLE} = 0.5$ |
| Capital and Energy aggregate (KE)[a] | $\sigma^{KE} = 0.5$ |
| Energy /transport services/ vehicles [a] | $\sigma^{EF} = 0.6$ |
| Electricity and Fossil Fuels aggregate [a] | $\sigma^{FFE} = 0.5$ |
| Non electricity (fuels) [a] | $\sigma^{F} = 1$ |
| Electricity sector | $\sigma^{E} = 0$ |
| Electricity generation [c] | $\sigma^{EG} = 0.5$ |
| Renewable energies [d] | $\sigma^{RE} = 1$ |
| Non-renewable energies | $\sigma^{NRE} = 1$ |
| Transport services [e] | $\sigma^{TRT} = 0.8$ |
| Production of vehicles | $\sigma^{VE} = 0.19$ |
| Domestic and import goods [f] | $\sigma^{A}$= 1.9 - 3.3 (agriculture: 2.3, extraction and mining: 2, food: 2.2, textil: 3.3, wood:2.2, manufacture fuels and chemicals: 1.9, other manufactures and recycling: 2.8, electricity:2, services: 1.9) |
| Demand elasticity coefficients [g] | $\sigma^{C}$= 0.4-0.5 |
| *Transformation elasticity between:* | |
| Exports and domestic goods[h] | $\sigma^{T}$= 0.7 - 3.9 (agriculture: 3.9, manufacturing and recycling: 2.9, electricity:2, services 0.7) |

[a] Elasticity values by sectors from Burniaux and Truong (2002).
[b] Timilsina et a. (2011)
[c] Chi et al., (2002)
[d] Anson and Turner (2009)
[e] Liu and Bohlin (2012)
[f] Armington elasticities from Hertel (1997).
[g] Duarte et al (2016)
[h] De Melo and Tarr (1992).

*Table 1. Elasticity parameters used in the model*

The closure of the model must take into account the factor markets, that is, labour and capital. In this model, it is considered that labour is mobile between regions, whereas capital is mobile within Europe, including Spain, but not with the rest of the world. This not mobile with the rest of the world, though there is also mobility within this latter region as a whole. The model also includes a wage curve to consider unemployment. In the wage curve, a value of elasticity of -0.1 has been taken according to the last review for the US that can be also valid for other nations (Blanchflower et Oswald, 2005). For balancing of quantities and prices, it is considered that the numeric price is the index for consumption in Spain.

### 3.3. Data

In this case, EXIOBASE database has been used (Stadler et al, 2018). This database provides a time series of environmentally extended multiregional input-output from 1995 to 2016, including 44 countries (28 EU countries and other 16 major economies). The baseline situation has been extracted with 129 sectors and for three regions: Spain, rest of EU+28 and UK, and rest of the world (ROW) for the year 2016.

The EXIOBASE database presents a detailed number of sectors and environmental extensions, so it enables to take the appropriate activities under the production chain of interest. In particular for this work, the aggregation of sectors has been done according to the most relevant production chains and business for mobility. From 129 sectors, the aggregation process has resulted in 57 sectors. We pay special attention to 15 sectors that show a contribution for the sector of interest ("Manufacture of motor vehicles, trailers and semi-trailers") higher than 1% in the Spanish economy and the other 42 are considered due to potential relevance in the analysis.

The MRIO database provides information on intermediate sales between industries (inter-industry linkages) for the three regions considered along with final demand and primary inputs. The extensions of the database provide information for value added composition, employment, and environmental accounts as air emissions per sector and final demand and energy use and water accounts per sector.

# 4. RESULTS

## 4.1. Results from the MRIO model

### 4.1.1. Description of scenarios

Different modifications are considered in order to evaluate the changes in the car industry resulting from the ramp up of the EV market. Two main type of changes are taken into account: one related to technological change in the production of vehicles, and the other related to the change in demand. Both changes will be combined due to the increasing presence of electric vehicles. As for the change in demand, it will come mainly from an increase in electricity and decrease in traditional fuels. Besides, electricity sourcing is having a rapid evolution to renewable energy, so the energy mix is a factor to consider in the demand. In spite of the fact that the main interest in this work is Spain, the model is global and also the evolution of Europe and the rest of the world will be analysed due to high interdependence of regions.

- A change in the technology of production of the electric vehicles in relation to the conventional thermal engine models is addressed. This change in technology is modelled into the technical coefficient matrix **A** (equation 1) by increasing the weight of electrical inputs components and decreasing the weight of traditional components of the motor vehicle industry, following Bauer et al.(2018). Specifically, the input coefficient for electrical machinery increases 2.6 and the motor vehicle industry declines by -2.6 in percentage by 2030 (Ulrich et Lehr, 2020)-This change is considered for all the regions considered in the study. We assume a gradual transition in the evolution of the electric vehicles that is incorporated with a gradual evolution from 2030 to 2050 following the increasing implementation of electric vehicles in the market. In the literature (Ulrich et Lehr, 2020), it is stated that "the shift is not linear but is evolving in line with the EV market share changes over time".
- The impact of changes in final demand based on the increase in electricity and decrease in fossil fuel consumption is studied. The changes in demand for electricity and fossil fuel consumption have been taken from literature (International Energy Agency, 2020).
- Simultaneous change in technical coefficient matrix and final demand.

A crucial point in the analysis are the predictions in technical coefficients and in final demand for the period studied. These are found in literature for the year 2030 (as detailed below). But this is not the case for 2050. Therefore, it is needed to extend these changes up to 2050 in the different scenarios. The extension is done based on the evolution of EV market share. For Spain, the evolution of EV market share is calculated with a tool specifically designed by the OVEMS ("Observatorio del Vehículo Eléctrico y Movilidad Sostenible", Observatory of Electric Vehicle and Sustainable Mobility) of Comillas

University (Universidad Pontificia de Comillas) (Frías et al., 2019). One of the main inputs for the solver is the quantity of annual mileage in the country. It can be considered constant for the whole car fleet or can increase or decrease depending on social evolutions (big cities concentration, homeworking,…). Another relevant input is the percentage share of powertrains for 2050 that should be based on political drivers. The model takes into account the structure of new registrations and un-subscriptions of vehicles, the market acceptance of electric vehicles, an index for renewal of the fleet and the effect of the length of service. The tool calculates the quantity of passenger cars per powertrain based on the existing fleet (around 25 million in 2019), and the total consumption and emissions for this fleet. The target of 90% for CO2 emissions reduction could be reached by 2050 through strong fleet electrification (Krause et al., 2020). This scenario drives to a 2050 fleet composition for passenger vehicles as follows: 92.5% for BEV and 7.5% for PHEV (data calculated from Krause et al, 2020, considering 85% of passenger cars being small and medium cars of which 100% are BEV's, and the rest of large and SUV cars with 50% of BEV and PHEV). If these data are included in the model, considering constant annual mileage for the whole fleet and the existing car fleet, the evolution results in the following graphic.

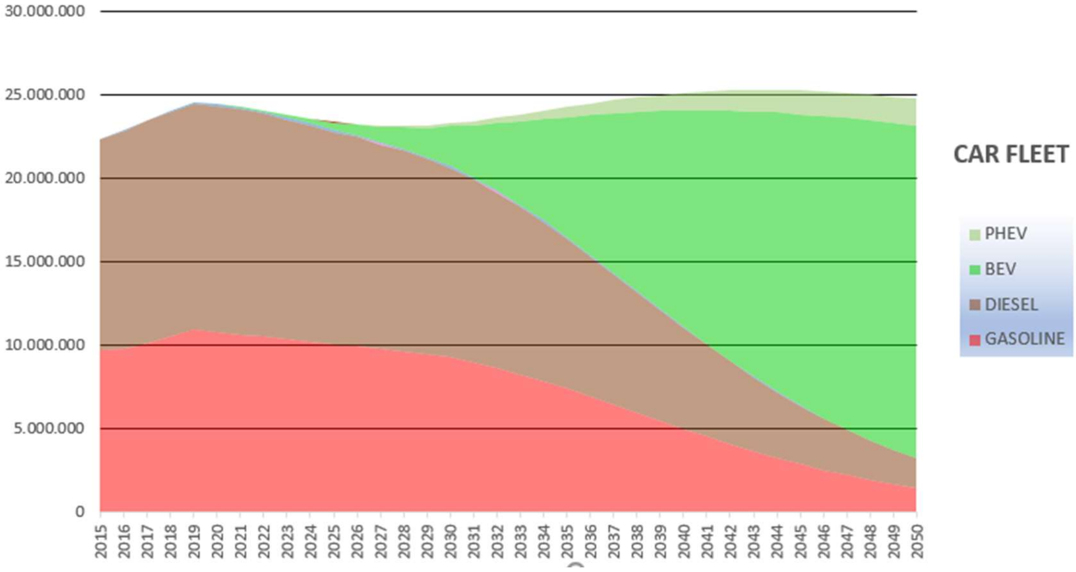

*Figure 8. Number of vehicles per type vs evolution in years (calculation with tool from OVEMS)*

As previously introduced, there are changes in technical coefficients and in demand. In this context, we assume that the change in the technical coefficients from 2016 to 2030 corresponds to a car fleet share change from 0.24 to 10.76%. In 2050, the car fleet share for electrified powertrains is 80.42%. If we assume an analogy with production (new and spare parts car products), the shift in technical coefficients would change from 2.6 percentage (increase and decrease in the corresponding categories) to 19.8%. The technical coefficients have been modified in the same values for all the regions, since the production and sale of vehicles are highly globalized.

As for the demand of electricity mix, it has been considered the change only for 2050, since from the existing information the change associated with the introduction of electric vehicles for 2030 is not significant and could be compensated with energy efficiency improvements (International Energy Agency, 2020). For 2050 a significant change is expected due to the ramp-up of electromobility. The categories that are considered to change are: production of electricity (by coal, gas, nuclear, hydro, wind and biomass and waste), transmission, distribution and trade of electricity. In this case, different considerations have been taken for Europe and the rest of the world, since this demand is directly related to the use of electric vehicles. Based on data for 2016 and 2030, and taking the same slope for electric vehicle introduction, the share for electrified powertrains in the rest of the world results in a value of approximately 35% for 2050. This value seems consistent if the rest of the world is taken as a whole, in spite of the fact that there will be very high differences between countries (China could achieve a level equal or even higher than Europe whereas other big countries such as India, Brazil and Russia would reach significant lower values). For that point, it is significantly relevant the energy mix considered (mainly the weight of renewable versus non-renewable sources for environmental effects). This is considered for variations in the scenario of demand modification.

From the available information on the share of electricity consumption attributable to EVs by region and scenario (International Energy Agency, 2020) a mean value is considered between the values for stated policies and sustainable development scenario. Considering the evolution of the car fleet for Spain (and assuming the same evolution for Europe), the share of electricity consumption is extrapolated to the 2050 scenario, and it is considered as the increase in the electricity demand. The rest of the world, apart from Europe, has been considered as a whole (even if there will be significant differences between countries and regions), and a mean value has been considered for extrapolation to 2050 electricity consumption. Thus, it is obtained that the electricity demand will increase by 37.12% in Spain and Europe, and 16.74% in the rest of the world associated with electric vehicles. The value for occidental regions is aligned with predictions in different references (McKinsey, 2018 / Mai et al., 2018).

The base case refers to an increase in electricity demand similar for all production sources. For Spain and Europe, it is reasonable to consider that all the increase in electricity demand by EV fleet is covered by renewable production. It has been considered for an additional evaluation that all this increase is with renewables with low emissions intensity (therefore leaving out biomass use). In the case of the IO table used, it corresponds to wind and hydro production sources. As for the rest of the world there are no common sustainable objectives, the increase in the electricity demand has been proportionally distributed in all the concepts. An additional evaluation considers including similar sustainability objectives for all the countries.

Oil displacement from EV fleet is translated for scenario definition with a modification in the demand in 2050 of different sectors: manufacture of motor spirit, manufacture of gas oil, the aggregated other fuels, and retail sale of automotive fuel. It is considered that the manufacture of motor spirit is exclusive for vehicle consumption, with a reduction of 80% for Europe (including Spain) and 50% for the rest of the world (International Energy Agency, October 2020). The definition of scenarios is a key topic for the later interpretation of results. For the construction of these scenarios it is possible to evaluate general trends, together with specific technological changes and demand modifications (Faber et al., 2006). In this case, the technological changes are done through adjustment of coefficients (variation on inputs for automotive industry), but without modifications of capital, labour and emissions per sector. The models aim to represent exclusively the changes due to the automotive industry, so no further considerations are taken into account. As for the demand, it represents the modification in the final demand by organizations, government and households that are the users of electric vehicles. The use of electric vehicles instead of internal combustion powered vehicles is basically in the consumption of electricity and fuels.

More specifically, based on the above, we obtain the following scenarios:

Scenario I. 2030: modification of technical coefficients (definition of matrix A2030)
Scenario II 2050: modification of technical coefficients (definition of matrix A2050)
Scenario III 2050: scenario II with demand modification (electricity and fuel) - base case and two additional evaluations for $CO_2$ emissions: The scenario III includes different cases for electricity production possibilities:

A. Base case: increase in electricity production with current production distribution.
B. Additional evaluation 1: Electricity increase only in low-intensive renewable sources for Europe (according to sustainability objectives)
C. Additional evaluation 2: Similar sustainability objectives for all the regions

#### 4.1.2. Results

Once scenarios are described, we analyse the impacts of these scenarios by studying a set of economic (production, value-added), social (jobs and wages) and environmental ($CO_2$ emissions) results obtained for the long-term analysis.

Results from Scenario I, II and III: Comparison of technological changes 2016-2030-2050, included base case for demand change

As previously introduced, the impact of changing the production process for the traditional automotive industry when changing to electric vehicles is translated into the technical coefficient matrix in the corresponding sectors. The traditional automotive industry is expected to decrease, whereas the one corresponding to electric components, is expected to increase, due to the production of new components, such as batteries, electric motors and other electric actuators integrated.

The following table shows the impact on total production, on traditional automotive sector and electric components sector for the three scenarios considered (scenario III with the base case for demand modification):

| | *Variation % 2016-2030* | *Variation % 2016-2050* | *Variation % 2016-2050 Demand* |
|---|---|---|---|
| ***Total production - Spain*** | 0.26 | -0.12 | -0.60 |
| ***Total production - Europe*** | 0.37 | -0.01 | -0.47 |
| ***Total production - ROW*** | 0.15 | -0.19 | -1.16 |
| ***Total production*** | **0.21** | **-0.14** | **-0.98** |
| ***Automotive sector - Spain*** | -0.38 | -6.08 | -6.21 |
| ***Automotive sector - Europe*** | -0.50 | -6.82 | -6.91 |
| ***Automotive sector - ROW*** | -0.96 | -8.92 | -9.02 |
| ***Total automotive sector*** | **-0.81** | **-8.23** | **-8.33** |
| ***Electric comp. Sector - Spain*** | 0.76 | 1.47 | 1.59 |
| ***Electric comp. Sector - Europe*** | 0.84 | 1.47 | 1.66 |
| ***Electric comp. Sector - ROW*** | 0.61 | 0.86 | 0.82 |
| ***Total electric comp. sector*** | **0.67** | **1.01** | **1.02** |

*Table 2. Impact of Scenario I, II and III in total production, traditional automotive and electric components sectors*

The results show that the effect up to 2030 is not that significant for the sectors under analysis (traditional automotive and electric component sectors), and even the total production is increasing. The effect in production for automotive industry can be noticed, but the impact is still low. The maximum contribution is a decrease in production of traditional automotive sector in the rest of the world of 0.96%, whereas the sector of electronic components is increasing, with the higher value for Europe of 0.84%. This can be due to the fact that most innovative technology is used in Europe, whereas there are more commodities in other regions, since automotive is a mature sector with high scale economies. Higher impact can be noticed for the calculation in 2050. The effect for total production is significant for scenario III, with a total reduction of 0.98%, and a balance unfavourable for the rest of the world. The impact in the two sectors considered in electromobility transition is not that dependant on demand, so there are similar values for scenarios II and III. The total decrease in traditional automotive sector reaches values of reduction of 9.02% for the rest of the world and 8.33% for total value. As for electric components sectors, the increase reaches the highest value for Europe with a 1.66%, whereas the increase for all the world is 1.02%. As explained before, there is an unbalance between Europe and the rest of the world that is increased with a higher deployment of electric vehicles. This could be explained by the weight of exports and delocalised production of commodities in low-cost countries that represent a high percentage in the rest of the world category. In the more industrialised countries, such as those of Europe, the most innovative sector (such as the electric components) could grow more than in other regions.

To highlight the importance of the effect in Spain, the category of "manufacture of motor vehicles…" has a weight of 4.05% in the total production (only overcome by food industry, real estate activities, hotels and restaurants, trade and construction, and two other conglomerate categories under the designation "other business activities", "other services"). This 4% contrast with a 3.08% in the rest of Europe and 2.35% in the rest of the world.

As for the industry of electric components, it is 1.02% of the total production in Spain, 1.31% in the rest of Europe and 1.42% in the rest of the world. Thus, the overall impact in the economy will be lower than that of the traditional automotive industry.

In scenario III, it is very relevant the impact for total production in the sector of fuels and electricity. It stands for the difference in total production between scenario II and III. As for fuels, and more in particular, the category motor spirit the decrease in production in all the regions is -37% (including the production for the different sector and the final demand), whereas in the rest of the world reaches a decrease of 33% (most important value given the fact that the countries out of Europe provide around 80% of this fuel). Besides, the impact in electricity production is also driven by the increase in the demand, and results show significant increases for the total production mainly for Spain and Europe, since the scenarios consider a high increase of final demand in these regions. In scenario III with base case of demand it has been considered that the increase in electricity final demand is equally shared between all the energy sources. So the final increase in total production is highly noticed for the considered renewable sources (hydro, wind and biomass), with values higher than 30% for Europe and values around 20% in Spain (except for wind, where the impact is lower than 10%). The fact that the impact is higher for Europe reveals the fact that the production of renewables is already more developed in Spain, so the impact of final demand is lower for the total production.

The following table collects the information of the impacts in total production higher than 10% (increase or reduction) for scenario III, base case for demand. The difference in the impact for different regions depend highly on economy structure. Apart from the impacts described above, it can be observed, for example, that the extraction of crude will have an impact in Europe and the rest of the world, but not for Spain, since most of the crude is imported. Another important impact is in the retail sale of automotive fuel. With the exception of the extraction is crude, all the contributions shown in this table with impacts higher than ±10% are corresponding to sectors where the final demand has been modified. The table reflects how the final demand change impact in the total production (consumption by other sectors with the addition of final demand).

| | ***Spain*** | ***Europe*** | ***RoW*** |
|---|---|---|---|
| ***Extraction of crude petroleum and services related to crude oil extraction, excluding surveying*** | <±*10%* | -23.92 | -20.67 |
| ***Manufacture of motor spirit (gasoline)*** | -64.20 | -49.90 | -32.94 |
| ***Other fuels (petroleum, gas, nuclear)*** | -18.93 | <±*10%* | -28.88 |
| ***Production of electricity by hydro*** | 22.70 | 35.88 | <±*10%* |
| ***Production of electricity by wind*** | <±*10%* | 33.99 | 11.73 |
| ***Production of electricity nec, including biomass and waste*** | 21.86 | 36.03 | 10.18 |
| ***Transmission of electricity*** | <±*10%* | 10.88 | <±*10%* |
| ***Distribution and trade of electricity*** | 13.55 | 16.84 | <±*10%* |
| ***Retail sale of automotive fuel*** | -33.23 | -41.02 | -54.23 |

*Table 3. Sectors with an impact in total production higher than 10% (increase or decrease) / Scenario III / base case for demand – apart from traditional automotive industry and electric components sectors*

As we have seen, most of the change in the parameters is driven by the demand. Apart from the sectors that have been modified according to the different scenarios, there are others affected. The effects can be extracted from the comparison of input-output matrices from 2016 to 2050. In this case, the base case of demand has been considered.

Output (differences higher than 1% of variation) / Net effect

| | *Spain* | *Europe* | *ROW* |
|---|---|---|---|
| ***Extraction of crude petroleum and services related to crude oil extraction, excluding surveying*** | <±*1*% | -25.88 | -22,08 |
| ***Gaseous fuels-extraction and production*** | -3,49 | -1,42 | -1,49 |
| ***Lead, zinc and tin production*** | <±*1*% | <±*1*% | -2,38 |
| ***Casting of metals*** | -2,94 | -1,59 | -1,10 |
| ***Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories*** | -1,69 | -1,13 | -1,57 |
| ***Transport via railways*** | <±*1*% | <±*1*% | -1,06 |
| ***Transport via pipelines*** | -8,11 | -4,41 | -4,22 |
| ***Sea and coastal water transport*** | -1,31 | -1,25 | -2,44 |
| ***Inland water transport*** | -1,31 | -1,08 | -3,14 |
| ***Waste treatment*** | <±*1*% | <±*1*% | -1,07 |

*Table 4. Sectors with an impact in total production higher than 1% (increase or decrease) / Scenario III / base case for demand – apart from traditional automotive industry and electric components sectors*

### Employment

Of course, the decrease or increase in final production drive a direct impact in employment for the industries where the final demand is highly modified. However, as this work intends to evaluate the structural change due to transition to electromobility, the effect in employment has been evaluated in detail for the sectors directly affected by the technological change, in particular for the traditional automotive industry, which is the target for this study. The intention is not just to evaluate the order of magnitude (that should be similar to the impact in production), but to understand how this impact is divided between different skills and how it affects wages and number of people employed in the sector. So, scenarios I and II have been considered.

Moreover, the automotive industry has an important weight in Spanish workforce percentage, who represents 4.11% of employment (number of hours), that goes up to 6.21% for medium-skilled workers. For the number of people, it is translated into a 4.53% of employment– considered inside the category of "manufacture of motor vehicles"-. In

Europe the total number of hours for this industry accounts for 3.91% of the total, whereas for the rest of the world this percentage drops to 2.75%. A structural difference with Europe is that in Spain the relative percentage of low-skilled workers in the traditional automotive industry is higher, being quite equilibrated with medium-skilled workers. For Europe, the highest amount of workers in the automotive industry is in medium-skilled workers.

The impact in overall employment is an increase of 0.06% for 2030 and -0.40% for 2050. As for the traditional automotive industry, it means an increase of 0.03% for 2030 and a decrease of 6.51% for 2050. As the present work is focused on industries related to automotive sector, the values of impact are detailed below for both time frames.

The impact on the level of employment for the traditional automotive sector can be evaluated for the three levels of skills in the MRIO table. The tables below show the values of impact for 2030 and 2050.

| | *Variation % 2016-2030 Low-Skilled* | *Variation % 2016-2030 Medium-Skilled* | *Variation % 2016-2030 High-Skilled* |
|---|---|---|---|
| ***Employment - Spain*** | 0.69 | 0.60 | 0.88 |
| ***Employment - Europe*** | 0.57 | 0.58 | 0.69 |
| ***Employment - ROW*** | -0.54 | -0.53 | -0.45 |
| ***Total employment automotive*** | **0.13** | **0.03** | **-0.06** |

*Table 5. Impact in employment for 2030 in traditional automotive industry (scenario I)*

| | *Variation % 2016-2050 Low-Skilled* | *Variation % 2016-2050 Medium-Skilled* | *Variation % 2016-2050 High-Skilled* |
|---|---|---|---|
| ***Employment - Spain*** | -3.69 | -8.31 | -5.57 |
| ***Employment - Europe*** | -4,66 | -4.25 | -4.47 |
| ***Employment - ROW*** | -8.80 | -8.53 | -8.04 |
| ***Total employment automotive*** | **-6.23** | **-6.49** | **-6.89** |

*Table 6. Impact in employment for 2050 in traditional automotive industry (scenario II)*

This variation is very remarkable for 2050. However, the impact for 2030 is not that significant. The impacts up to 2030 could be marginal due to small adjustments in production, with a slight positive impact for Spain and Europe and negative for the rest of the world. This indicates a trend that is confirmed for 2050 where the gaps between the regions are higher, with a difference for the rest of the world higher than 2 percentage points for low and high-skilled workers (e.g. -8.04% vs -5.57% in Spain and -4.47% in Europe for high-skilled workers). An exception is the medium-skilled workers, where the percentage impact in Spain (8.31%) is similar to the rest of the world (because these workers represented a 6.21% of total medium-skilled workers in Spain).

As for wages (M€) and numbers of persons employed, the effect is:

| | *Variation % 2016-2050 Low-Skilled* | *Variation % 2016-2050 Medium-Skilled* | *Variation % 2016-2050 High-Skilled* |
|---|---|---|---|
| ***Wages - Spain*** | -4.30 | -9.13 | -6.98 |
| ***Wages - Europe*** | -4.72 | -4.34 | -4.54 |
| ***Wages - ROW*** | -8.15 | -8.29 | -8.00 |
| ***Total Wages automotive*** | -6.79 | -6.79 | -7.12 |

*Table 7. Impact in wages for 2050 in traditional automotive industry (scenario II)*

| | *Variation % 2016-2030* | *Variation % 2016-2050* |
|---|---|---|
| ***People - Spain*** | 0.88 | -6.93 |
| ***People - Europe*** | 0.84 | -4.53 |
| ***People- ROW*** | -0.35 | -7.77 |
| ***Total People automotive*** | -0.10 | -7.13 |

*Table 8. Impact in people for 2050 in traditional automotive industry (scenario II)*

As shown in table 4, Spain is significantly more affected than the rest of Europe as for the number of people employed in this industry (more direct than indirect jobs).

Quantitatively, this reduction of 6.93% means a reduction of 50000 people in the sector for 2050.

If the people of number employed is measured for all the sectors, taking into account the employment changes in the traditional sectors, but also the changes along the supply chains and new demands of employments, the total numbers would be as follows:

| | *Variation % 2016-2030* | *Variation % 2016-2050* |
|---|---|---|
| ***People - Spain*** | -0.21 | -0.64 |
| ***People - Europe*** | 0.00 | -0.24 |
| ***People- ROW*** | 0.81 | -0.29 |
| ***Total People ALL SECTORS*** | 0.73 | -0.29 |

*Table 9. Impact in people for 2050 for all sectors (scenario II)*

Emissions $CO_2$/ Different scenarios for demand (scenario III, with demand A, B, C)

The emissions impact is considered only for scenario III, due to the modifications in fuel and electricity consumption. For the emissions it is important to distinguish the source for electricity generation. So, evaluation 1 and evaluation 2 sub-scenarios are compared to scenario III with base case for demand modification. The embodied emissions are the emissions included in the consumption of a region (own consumption and imported goods) whereas the direct emissions are those that are generated directly for the production in this region (independently if it is consumed in the region or exported). For the tables below the effect in total emissions is the same, but the distinction between regions gives the idea of where the emissions are produced (direct) and consumed (embodied). It is relevant to see the difference in the European region, where embodied reductions are lower than direct ones. It is because the imports from other regions add emissions that are not accounted for in the regional production. On the contrary, the difference between embodied and direct emissions is not that high for the rest of the world, since the dependence on imports is considerable lower (much higher volume of production in the region).

Effect only for emissions due to production (not operation of vehicle) – *Embodied-*

| | ***Variation % 2016-2050 Base case*** | ***Variation % 2016-2050 Evaluation1*** | ***Variation % 2016-2050 Evaluation2*** |
|---|---|---|---|
| ***Emissions- Spain*** | 0.16 | -1.08 | -1.07 |
| ***Emissions - Europe*** | 0.66 | -0.48 | -0.48 |
| ***Emissions - ROW*** | 0.01 | 0.02 | -1.95 |
| ***Emissions Total production*** | 0.12 | -0.07 | -1.71 |

*Table 10. Impact in embodied emissions (scenario III / base case – evaluation 1 – evaluation 2)*

Effect only for emissions due to production (not operation of vehicle) – *Direct-*

| | ***Variation % 2016-2050 Base case*** | ***Variation % 2016-2050 Evaluation1*** | ***Variation % 2016-2050 Evaluation2*** |
|---|---|---|---|
| ***Emissions- Spain*** | -1.08 | -2.23 | -2.23 |
| ***Emissions - Europe*** | 0.16 | -0.97 | -0.97 |
| ***Emissions - ROW*** | 0.13 | 0.15 | -1.85 |
| ***Emissions Total production*** | 0.12 | -0.07 | -1.71 |

*Table 11. Impact in direct emissions (scenario III / base case – evaluation 1 – evaluation 2)*

This is the evaluation due to technological change and demand, but in addition, the emissions for the vehicle in operation must be taken into account (it widens the approach to Life Cycle Analysis use, that would also consider disposal and recyclability).

This analysis has been done exclusively for the case of Spain, with the calculated distribution of vehicles types previously presented. The number of vehicles are considered constant as the mileage in Spain: 2.86 $10^{11}$km/año (*“Observatorio del Vehículo Eléctrico y Movilidad Sostenible”,* Observatory of Electric Vehicle and Sustainable Mobility).For that analysis, the well-to-wheel greenhouse emissions for different type of vehicles: g$CO_2$/km (Nordelöf et al., 2014) have been considered.

According to data calculated for emissions in an overall approach of Life Cycle Assessment for vehicles (Nordelöf et al., 2014), the emissions for the different powertrains would be:

- Electric vehicle: Mean 60 g$CO_2$/km (for electricity production with energy mix 190 g$CO_2$/kWh), considered as conservative scenario / Minimum value approx. 2 g$CO_2$/km (if most sustainable energy mix is considered for electricity generation: 11 g$CO_2$/kWh), considered as sustainable scenario.
- Diesel vehicle: 145 g$CO_2$/km

| | ***Variation 2016-2050 Case1*** | ***Variation 2016-2050 Case2*** | ***Variation 2016-2050 Case3*** |
|---|---|---|---|
| ***Reduction in emissions due to operation of vehicles (g$CO_2$/km)*** | 2.43 $10^{13}$ | 4.08 $10^{13}$ | 5.50 $10^{13}$ |

*Table 12. Reduction in emissions of operation of the vehicle in Spain (Case1: conservative / Case2: sustainable approach (Nordelöf et al. 2014) / Case3: calculation OVEMS tool)*

If these emission in operation are added to the embodied emissions of production the real variation in emissions can be calculated. For 2050 it has been considered the base case for demand, where variation was 0.16% for CO2 emissions in Spain (embodied emissions, table 10). So, there was even a slight increase.

| | ***Total emissions 2016*** | ***Total emissions 2050*** | ***Variation % 2016-2050*** |
|---|---|---|---|
| ***Case1*** | 2.85 $10^{14}$ | 2.61 $10^{14}$ | -8.39 |
| ***Case2*** | 2.85 $10^{14}$ | 2.44 $10^{14}$ | -14.22 |
| ***Case3*** | 3.00 $10^{14}$ | 2.46 $10^{14}$ | -18.17 |

*Table 13. Total reduction of emissions in Spain (embodied + operation emissions) (Case1: conservative / Case2: sustainable approach (Nordelöf et al. 2014) / Case3: calculation OVEMS tool)*

So, even if the energy mix for production itself is not corresponding to a sustainable scenario, the fact of introducing electric vehicles plays an important role for overall $CO_2$ reduction. The value of 0.16% changes to a minimum of reduction of -8.39% that goes up to -18.17% if the electric vehicles count with specific chargers fed with renewable energy. What is more, if the scenario III with evaluation 2 is considered, the reduction in emissions increases around 1 percentage point for the variation.

### 4.2. Results from the CGE model

In the MRIO analysis, the technological and demand changes linked to electric vehicle market penetration have shown the impact on productive structure, consumption and the associated effects in employment and emissions. However, in this analysis the changes are always exogenous (including inputs substitution), without possibility of introducing policies or drivers generating the changes. CGE enables to evaluate different politic, technological or fiscal policies, showing the global effect and taking into account prices and quantities changes. The generation of a general equilibrium model with disaggregation for the sector of interest (automotive) and with the relationship between regions (Europe and rest of the world) is fully innovative. This work involves and additional work for elasticities estimation between productive sector and space and market factors substitution, as well as later uncertainty evaluations. So, the results presented in this work must be understood as preliminary in a research line that is being initiated.

The scenarios for the CGE modelling are based on 2050 projections, that is, similar to scenario III in the MRIO model. The electrification of automotive industry is represented by a modification of demand by households. The modification of demand is similar to the evaluation 1 of scenario III of MRIO model where it is assumed that all the increase in electricity for electric vehicle consumption comes from renewable sources, and with a decrease in petrol consumption as motor spirit. Also a comparison with a fiscal policy of increasing the rates for fuel consumption and providing grants for renewable energy is evaluated (assumed as a decrease of taxes). Both for demand and taxes, the changes have been applied only in Europe, including Spain. Thus, the values shown are calculated with an increase of electricity demand of 35% and decrease in motor spirit demand of 80% (demand from households), and an increase of 30% for motor spirit taxes and a reduction of 10% for renewable electricity.

|  | *Variation % CGE demand* | *Variation %-CGE demand+petrol tax* | *Variation %-CGE demand+petrol tax + renewables grant* |
|---|---|---|---|
| ***Total production - Spain*** | -5.75 | -3.91 | -1.67 |
| ***Total production - Europe*** | -4.04 | -1.69 | -0.38 |
| ***Total production - ROW*** | -4.32 | -2.15 | -0.30 |
| ***Total production*** | -4.28 | -2.07 | -0.34 |

Table 14. Impact with CGE modelling for total production

In this case, there are substitution relationships between sectors represented in the nested structure for production and consumption. These relationships determine the increase and decrease of the sectors for the different scenarios.

Nevertheless, the most interesting information from CGE model is to compare the different policies for electrification of the automotive industry. In the case of the modification of only demand, it would correspond to the imposition of vehicle sale by means of ban of internal combustion engine. This would determine the composition of car fleet. If there is no specific bans and impositions, a way to act on the consumers behaviour is through the fiscal policies. In the case of cars, an increase of tax of petrol and decrease of electricity taxes could be effective. The tax on petrol consisted of an increase of 30% in relation to the existing tax to de-promote the use, instead of banning (represented in the second case in the table). The third case adds to the second scenario a decrease in taxes for renewable sources (considered in -10%), to incentive the use of electricity and promote the sale of electric vehicles. In general, taxes applied in CGE models involve production decrease except if the taxes are used to invest in particular sector or agents. In the production decreased obtained, it could point out the need for restructuring the economy as a consequence of the changes implemented.

With the CGE model constructed so far, a first approach shows that a fiscal policy could be more effective if a goal is to maintain global production level. Banning could have a disincentive effect for overall production. It must be also noticed that the overall effect is higher than for the MRIO model, so transmission effect throughout sectors is higher with substitution and elasticity parameters included.

In the case of CGE modelling, and once the scenarios and parameters are validated, we will be able to extract other data additional to MRIO model such as impact in prices and rates of unemployment. The analysis per sector will be relevant and should be used for the evaluation of results.

## 5. CONCLUSIONS

In this work, the impact of electrification for automotive industry has been evaluated by means of the use of multiregional input-output database. The main objective is to assess the impact for Spanish industry, and compare with the position of this industry in relation to Europe and the rest of the world. The policies announced so far establish limitations in the use and banning of internal combustion engines vehicles, but most of these policies are referred to 2030 horizon. It is important to analyse more future impacts, given the fact that industries need to be prepared and, what is more, the general scenario should be predicted in order to define the proper policies in the coming years.

For that, the main contribution of this work has been to calculate the impacts not only for 2030 (for which extensive predictions can be found) but for a longer horizon up to the year 2050. The assumptions in the change of production and in the evolution of demand had to be calculated. The evolution of vehicle fleet has been calculated with a specific tool designed by the Observatory of Electric Vehicle and Sustainable Mobility of Comillas University. This evolution determines how the production chain in the automotive industry changes for 2050. The changes in the industry have been extrapolated from a literature value that shifts the inputs of the traditional automotive industry introducing a higher share for electric components. The changes in demand had been also inferred from changes in 2030.

When only production shift is included, the impact on general macroeconomic indicators is limited. In fact, for 2030 the total production increases, and the maximum effect is a decrease in the traditional automotive industry of -0.81%. However, in 2050, when the production shift includes the higher number of electric cars produced, the overall effect in the global economy is almost -1%, confirming previous works that found negative long run effects (Ulrich et Lehr, 2016). For the particular sectors, the effect goes up to -8.23% for the traditional automotive industry and with an increase in the electric component sector of +1.01%. For these sectors, there is no significant difference when including the changes in demand of electricity and fuel. For Spain, the impact in these industries is in line with Europe. In relation to the rest of the world, the effect of decrease is higher for the traditional automotive and shows a lower increase for electric components sector. It is understandable because many of the current components for vehicles have become commodities and externalized in low cost countries. If the change in demand is included, the main sectors affected are those related to fuels production and to electricity. This effect was expected. However, the calculated values enable to weight the importance in relation to the economies of countries (Spain) or regions.

In the case of Spain, with a significant unemployment rate, it is important to analyse the impact of the electrification transition. Besides, the distribution of the employment is relevant for Spanish economy, since there is a gap of skills demanded by industry. The traditional automotive industry has a significant weight of 4.11% or the total employment in Spain. The calculation for the 2050 horizon shows a significant effect of the transition that leads to the maximum decrease in employment for medium-skilled workers of -8.31%. When the overall reduction is applied to the number of people, it means around 50000 people less in this industry for 2050 in Spain.

The extension of the multiregional input-output database with $CO_2$ emissions enables to calculate the changes in emissions for the transition. The reduction in emissions is only really noticeable when there is an strategy for the use of electricity to feed the electric cars, that is, that the electricity comes from renewable sources. In that case, the overall reduction reaches 1.71% but only if similar sustainability goals are considered for all the countries. Otherwise, the impact of electrification by itself stands for only -0.07%. In Spain, the reduction reaches levels of 1.08 and 2.23% for embodied and direct emissions respectively. This reduction does not consider the operation of the vehicle. If this is considered, the impact in Spain leads to a reduction from 8.39 to 18.17% depending on the source of electricity used when added to embodied emissions. This is a significant reduction to take into consideration.

Up to the knowledge of the author of this work, this is the first time that MRIO model has been used to assess the impact of electromobility transition in Spain. In spite of the fact that several assumptions have been made, the numbers justify the continuation of the work for further analysis and proper policy actuations.

A complementary activity initiated in the framework of this study is to include a CGE model to include flexibility in the relationships of MRIO model. A detailed global economy has been modelled, considering the same geographical regions. The results obtained so far must be taken as preliminary, since the definition of parameters and scenarios are under process of validation. A goal for continuation of this work will be to analyse fiscal and other policies, and model the whole economy with the proper relationships between sectors and factors. Detailed conclusions need the assessment and evaluation of parameters, sensitivity and uncertainty studies.

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