Title:

Impacts of the electric vehicle penetration in Spain: A dynamic EV-aware CGE model

Abstract

The European Green Deal aims to achieve the carbon neutrality in Europe for 2050. The transportation sector is an important contributor for this objective, where the efforts are focused on the electrification of the vehicle fleet. This electrification strategy involves an important conversion of the traditional automotive sector. The change in the powertrain from well-known combustion engines to electric motors and batteries brings new industries to the sector and a different distribution of imports and exports. The supply chain is highly affected due to the origin of raw materials and know-how of components of the electric powertrain. In this context, the aim of the present work is to analyse the impact of a massive penetration of electric vehicles with a dynamic approach up to the year 2050. To do it, a dynamic electric-vehicles (EV)-aware computable general equilibrium (CGE) model has been developed for the evaluation. This EV-aware CGE model is defined for the whole economy, establishing differences between Spain, rest of Europe and rest of the world. The case of Spain has been analysed isolated since this country is specifically sensitive to automotive industry change due the impact in its economy, given the fact that the automotive sector represents a significant percentage of the GDP. Moreover, most of the automotive sector in Spain is focused on manufacturing but there is no major technological centres so the risk can be more severe when analysing a change in the supply chain. The EV-aware CGE model designed reflects the behaviour and interactions of the economic agents (consumers, producers and public sector) so it is possible to measure direct and indirect effects of changes in behaviour of the agents and different economic policies. As a novelty, the dynamic EV-aware CGE model implements the selection of inputs for the production of electric vehicles, considering the necessary components of the production chain of the traditional automotive industry, and substitution by electric components, through elasticities of substitution. This extension works both on the production side and on the consumption side. The structures have been disaggregated in levels reaching the key sectors where the modifications are applied. The EXIOBASE database has been used as input data for the EV-aware CGE model for the year 2016, which 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. CGE models have been applied in the literature for the evaluation of this change in different regions of the world. However, there is not extensive work on the subject, and what is more, this work presents an extended horizon up to 2050 defining future scenarios and focused on regions where the traditional automotive sector has a significant weight in the overall economy. The scenarios simulated combine the change in demand by the main stakeholders, and also by fiscal policies that can be applied to promote the change. Additionally, we study the infrastructures required to address the development and accessibility of a network of public access for the supply of electric recharging points to enable the penetration of the most efficient and cleanest technologies in means of transport, as well as the development of measures to promote private access infrastructures for electric recharging in homes.

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Introduction

“EU Green Deal” (1) presents the green recovery of Europe with a economy more ecologic, digital and resilient. As for transportation sector, the objectives are focused on electrification of the car fleet. This represents an important challenge for the automotive industry, which is also facing other important advancements such as connectivity, autonomous driving and shared mobility. We are already facing a progressive replacement of traditional powertrains that will be further accelerated in the coming years. As for the direct comparison between electrified powertrains and combustion driven vehicles, the first has shown a positive impact on direct emissions as well as in the overall environmental footprint. Nevertheless the global effect of this change must be also evaluated in terms of economic and social impact. The disruptive change is affecting the automotive industry that must change the supply chain and production, since new components are coming and sometimes are replacing commodities from very well-known suppliers. New companies are appearing in this context and the existing ones must adapt to the new context.

Spain and Europe are highly concerned since the automotive industry accounts for 11% of Gross Domestic Product (GDP) for direct contribution for car and components production in Spain and 7% in the total EU GDP. In particular, Spain is the 9th vehicle producer of vehicles in the worlds and the 2nd in Europe (after Germany). A significant number of companies in the sector are big multinational companies with factories located in Europe, but with a highly globalized supply chain with many suppliers in Asia. 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.

There are 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 (2) 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 (3).

Germany uses PANTHA REI macroeconomic model implemented for economic-environmental forecasts and policy simulations (4). 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 (5) 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 (6) 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 addition to input-ouput and macroeconomic models, the General Equilibrium model is a powerful tool to represent the operation of the whole economy. In particular, for the increasing penetration of electric vehicles, it can help to understand the effects of demand change and policies application in the overall economy, covering social and economic impact. There is a number of publications in this subject. Schmelzer et al. (7) used a general equilibrium model combined with a discrete model to analyse the effects of the demand of electric vehicles in Austria. The results showed 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, (8) a CGE model was applied showing that the total industry output has a slight increase with the increase in the penetration of electric vehicles, 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. The impacts of road transport electrification in the EU have been recently evaluated with a CGE model (9), combining techno-economic assumptions with deployment scenarios derived by energy models. This study concludes that electrification leads to decrease costs for climate mitigation and evaluates also the shifts in employment considering skills and occupations, to analyse the socio-economic impacts of climate policy.

The paper is organized as follows. The following section describes the methodology and data used. The following one is dedicated to description and results, and finally the paper ends with conclusions and future actions to be carried out with the developed CGE model.

Methodology and data

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 (10). In relation to MRIO analysis, CGE removes the rigidities linked to the Leontief function. These rigidities can be relevant in the case of study given the nature of the technological change expected and the high price dependence of customer choices.

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 (11), another for transport services following Liu et Bohlin (12), and another one, as a novelty, for vehicle production sectors, see figure 8. A new sector is introduced to consider the production of electric vehicles apart from the sector “Manufacture of motor vehicles, trailers and semi-trailers”. This category considers production of combustion engine vehicles and includes the traditional automotive industry for components. Thus, the traditional industry maintains its balance of inputs, whereas the new category for electric vehicles introduces a new balance for products coming from traditional industry and products coming from the electric sector (“Manufacture of electrical machinery and apparatus”).

Given the importance of electricity supply for the increasing fleet of electric vehicle in the coming years, 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 1), 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 2, 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 also substitution for the demand of vehicles, splitting between combustion-powered and electric vehicles, under the category of land transport.

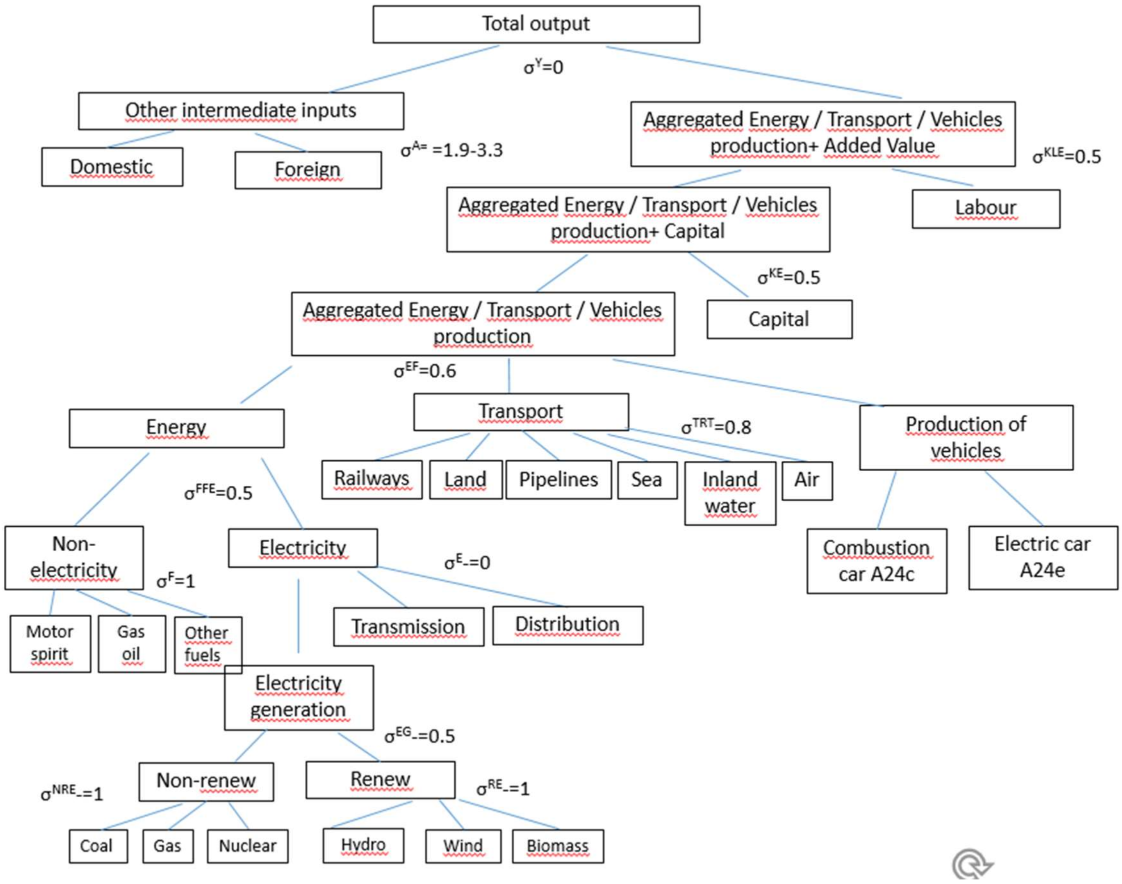

Figure 1: Nesting structure for production. Own elaboration

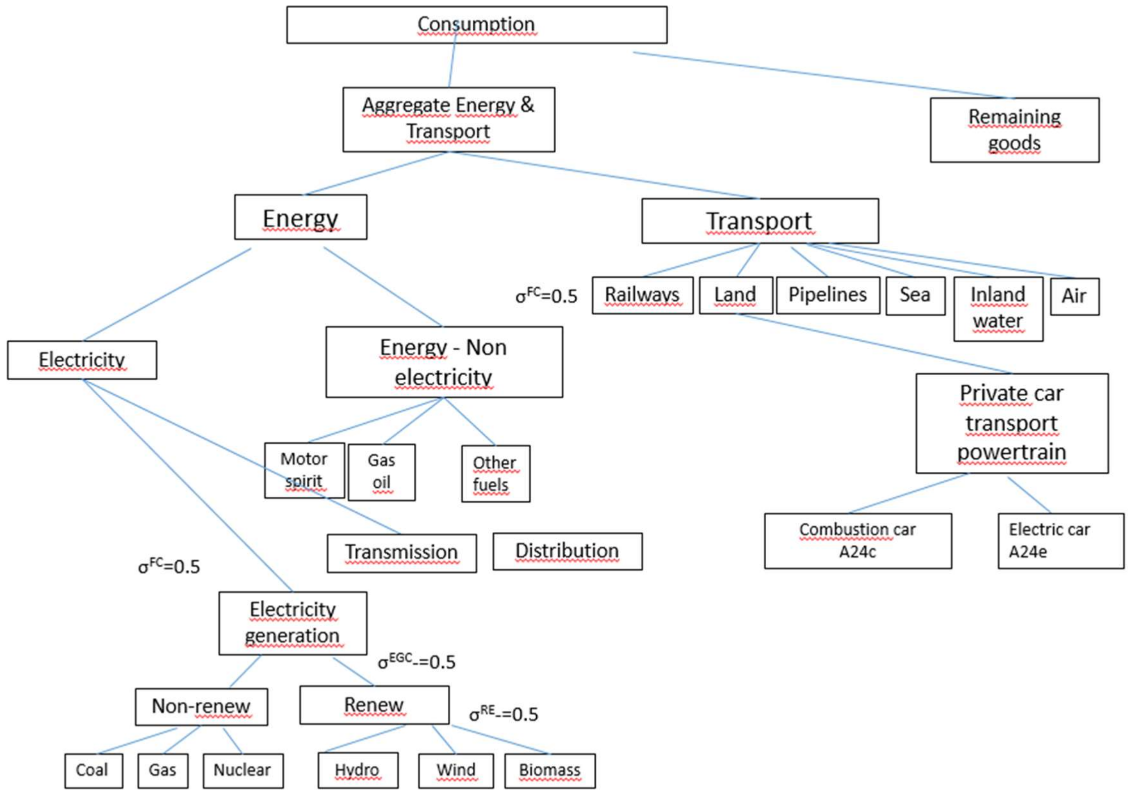

Figure 2: Nesting structure household consumption. Own elaboration

The considered elasticities are summarized in the following table:

Table 1. Elasticity parameters used in the model

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]	σ^{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]	σ^{C}= 0.4-0.5
Transformation elasticity between:	
Exports and domestic goods[h]	σ^{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).

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. 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 (13). For balancing of quantities and prices, it is considered that the numeric price is the index for consumption in Spain.

In this case, EXIOBASE database has been used (14). 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.

A second version of the CGE model has been developed to include dynamic perspective to the static model given the fact that we are analysing the impact for year 2050. A recursive model has been used, that is a series of static models related to each period by exogenous and endogenous variables allowing annual updates (15). In this model prices in each period determines the decisions on production, consumption and investment. On the contrary, an intertemporal model is based on rational expectations of agents over an infinite horizon. The recursive model adds to the static model the following variables: depreciation rate, capital growth, rate of interest and rental price of capital together with initial values for the stock of capital, the initial investment and the return of capital.

Results

The static model has been tested with some basic scenarios to evaluate impact on the main economic indicators of changes that are caused by transport electrification or that could be used to promote this change based on taxes and subsidies that can be applied to fossil fuels and renewable-sourced electricity respectively.

First scenarios evaluated:

1) Final demand in households: 37% electricity demand increase in Spain and Europe, 17% in the rest of the world, and 80% fossil fuel for vehicle consumption reduction in Spain and Europe, 50% for the rest of the world.
2) Taxes impact: 10% penalty for fossil fuel use and 10% incentive for renewable energies. Applied only in Spain.

Demand changes (%)

	SCENARIO1	SCENARIO2
HOUSEHOLD	10,27	4,53
GOVERNMENT	0,84	0,63
INVESTMENT	-30,50	-21,21
COMPANY	9,46	45,92

Changes in unemployment (%)

	SCENARIO1	SCENARIO2
UNEMPLOYEMENT	5,20	3,96

Change in total production (%)

	SCENARIO1	SCENARIO2
PRODUCTION	-6,98	-5,85

Per sector (with deviations higher than ±10%):

Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	**-20,39**	**-14,77**
Extraction processes- non metal	-15,95	-11,96
Manufacture of motor spirit (gasoline)	-39,31	-26,91
Manufacture ceramics, glass, mineral products	-16,60	-13,22
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	-13,34	-9,75
Aluminium production	-10,28	-7,57
Lead, zinc and tin production	-12,60	-9,66
Copper production	-13,16	-9,77
Precious metal and non-ferrous production	-10,25	-7,51
Casting of metals	-13,50	-9,66
Manufacture of fabricated metal products, except machinery and equipment	-11,83	-8,62

Manufacture of machinery and equipment	-18,90	-13,80
Manufacture of electrical machinery and apparatus	-10,95	-7,94
Production of electricity by hydro	-18,12	-19,54
Production of electricity by wind	-31,27	-28,53
Production of electricity nec, including biomass and waste	-25,32	-22,87
Transmission of electricity	-19,40	-17,46
Construction	-24,20	-17,67
Retail sale of automotive fuel	-15,06	-15,38
Transport via pipelines	-11,42	-11,00
Sea and coastal water transport	-12,72	-13,16
Inland water transport	-18,63	-18,90
Real estate activities	11,44	9,40
Computer and related activities	-15,59	-12,03

Other scenarios and dynamic calculations in process

Conclusions

In process to include other scenarios and dynamic calculations

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NOMENCLATURE

CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
EU	European Union
EV	Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
GDP	Gross Domestic Product
MRIO	Multi-Regional Input-Output
ROW	Rest of World
UK	United Kingdom
US	United States of America

REFERENCES

1. COM/2019/640 – The European Green Deal. Communication from the Commission to the European Parliament, The European Council, The European Economic and Social Committee and the Committee of the Regions.
2. European Climate Foundation, 2018. *Low-carbon cars in Europe: A socio-economic assessment*. Report from Cambridge Econometrics.
3. Stenning J., 2018. *Reviewing the impact of the low-carbon mobility transition on jobs. A report for the European Climate Foundation*. Report from Cambridge Econometrics.
4. Meyer B., 2005. *The Economic-Environmental Model PHANTA REI and its Application*. Paper presented at the Congress Environment and Science – Concepts and Strategic Goals for the Future, 2005, Tokyo
5. Ulrich P., Lehr U., 2016. *Economic effects of E-mobility scenarios – Intermediate interrelations and consumption*. Ecomod 2016, International Conference on Economic Modelling, Lisbon, Portugal.
6. Ulrich P., Lehr U., 2020. *Economic effects of an E-mobility scenario – input structure and energy consumption. 2020* Economic Systems Research, Vol. 32, N 1, 84-97. DOI: 10.1080/09535314.2019.1619522
7. Schmelzer S.,Miess M., Scasny M., Kopecna V., 2018. *Modelling electric vehicles as an abatement technology in a hybrid CGE model*. IES Working Paper, N 16/2018, Charles University in Prague, Institute of Economic Studies (IES), Prague
8. Khanam S., Miyata Y., Liu Y., 2011. *A Computable General Equilibrium Analysis of Electric Vehicle Society in Toyohashi City, Japan*. 2011. ERSA conference papers ersa11p1892, European Regional Science Association
9. Tamba M., Krause J., Witzel M., Ioan R., Duboz L., Grosso M., Vandyck T., 2022. *Economy-wide impacts of road transport electrification in the EU*. Technological Forecasting & Social Change 182 (2022) 121803. https://doi.org/10.1016/j.techfore.2022.121803
10. Cardenete M.A., Guerra A.I., Sancho F., 2012. *Applied General Equilibrium. An introduction*. Springer. ISBN 978-3-642-24745-3.
11. Burniaux J, Truong T. GTAP-E: *An Energy-Environmental Version of the GTAP Model*. GTAP Technical (Paper no. 16, Center for Global Trade Analysis, Purdue University, West Lafayette, IN), 2002.
12. Liu X, Bohlin L, *Effects from consistent internalization of external effects from transport and manufacturing – a CGE analysis for Sweden*, Working Paper 09/2012, Swedish Business School. 2012, ISSN 1403-0586.
13. Blanchflower, D.G., Oswald, A.J., 2005. *The Wage Curve Reloaded*. Discussion paper, IZA DP Nº 1665.
14. Stadler K., Wood R., Simas M., Bulavskaya T., de Koning A., Kuenen J., Acosta-Fernández J. *EXIOBASE3 – developing a time series of detailed environmentally extended multi-regional input-output tables*. J. Ind. Ecol. 2018; 22(3):502–515.
15. Sarasa C., 2014. *Irrigation Water Management: An Analysis Using Computable General Equilibrium Models*. Thesis Faculty of Economics, University of Zaragoza.