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Electricity and CO2 Emission Impacts of a Residential Electricity Demand Response Program in Spain

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ABSTRACT

Changes in electricity demand can bring substantial shifts in the production structure, costs, and level of emissions of electricity systems. However, the electricity sector is not the only one affected as these changes can create significant repercussions in other sectors and, consequently, in the whole economy. In this paper, the indirect effects of a reduction in household demand for electricity have been evaluated for the Spanish economy. A multisectoral static computable general equilibrium model is employed to achieve this objective. The results clearly point out the importance of assessing other sectors' behavior when assessing the consequences of promoting demand response policies, especially when dealing with pollutant emissions.

Keywords: Computable General Equilibrium (CGE), Emissions, Electricity Demand Response.

Impacto sobre la electricidad y emisiones de CO2 de un programa de gestión activa de la demanda eléctrica residencial en España

RESUMEN

Los cambios en los niveles de demanda de electricidad pueden implicar cambios sustanciales en la estructura de producción, costes y nivel de emisiones de los sistemas eléctricos. Sin embargo, el sector eléctrico no es el único afectado ya que estos cambios pueden crear importantes repercusiones en otros sectores y, por consiguiente, en toda la economía. En este trabajo se han evaluado los efectos indirectos de la reducción de la demanda de electricidad de los hogares para el mercado español. Se utiliza un modelo de equilibrio general aplicado (MEGA), multisectorial y estático para lograr este objetivo. Los resultados indican la importancia de evaluar el comportamiento de otros sectores al valorar las consecuencias de fomentar las políticas de gestión activa de la demanda eléctrica para el caso español, sobre todo cuando se trata de estudiar cambios en las emisiones de contaminantes.

Palabras clave: Modelo de Equilibrio General Aplicado (MEGA), emisiones, respuesta de la demanda de electricidad.

JEL Classification: C68, D58, Q4, Q51, L60

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1. INTRODUCTION[1]

Electricity systems currently face important challenges: the need to become more efficient in economic and energy terms, and also to reduce their environmental impact. An obstacle for achieving these objectives is peak demand, which involves considerable economic, environmental and technical inefficiencies, which in turn arise from the necessity of available infrastructure with a low utilization factor. The technologies applied to supply peak demand present higher variable costs and lower fixed costs. Moreover, nowadays these technologies are based in fossil fuels, which are usually highly polluting.

In this challenging context, Demand Response (DR) programs have gained importance in the last years as one of the options to smoothen and adjust the load profile and as a consequence decrease the need for inefficient, highly polluting technologies. DR programs intend to facilitate customers' reaction to the technical and economic needs of the electricity system. By receiving an efficient price or quantity signal, customers would have an incentive to reduce their consumption in periods where the production of electricity is more costly or polluting. In electricity markets, DR programs have two effects, reducing demand levels and/or shifting demand in time. Secondarily, DR programs could also have other advantages for the integration of renewable energy, distributed generation and electrical vehicles or in increasing customer's awareness of their consumption.

The evaluation of the impact of a DR program is then an important issue that goes side by side with the necessity to acquire an understanding about their consequences and about the correct signals that should be provided to consumers and productive sectors before actually engaging in its implementation. Borenstein et al. (2002) and Boisvert y Neenan (2003) started with this evaluation by showing an analysis of DR consequences in a theoretical way; however, quantitative measures are also necessary to evaluate the impact of such policies. In this field, the most usual approach adopted in the literature makes use of partial equilibrium models. Berg et al. (1983), Caves et al. (1984), Parks and Weitzel (1984), Hill (1991), Borenstein (2005), Andersen et al. (2006), Brattle Group (2007), Holland and Mansur (2008) and Conchado and Linares (2009a) evaluate the social or environmental costs and benefits of DR programs, through diverse models under the partial equilibrium paradigm.

However, the partial equilibrium approach disregards the impact of the interactions of variables concerning the other sectors of the economy, and deals with sources of linkages across markets exclusively exogenously. But, in order

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to evaluate policy interventions that affect a large number of markets simultaneously, these linkages cannot be neglected. DR programs are one of these cases because of the strong weight of the electricity sector in the determination of economic levels, its huge interrelation with other productive sectors, and its significant environmental influence. A general equilibrium approach is then necessary to address this issue correctly.

This study evaluates the impact of changes in the electricity demand of Spanish household electricity consumption and its consequences not only directly related to the electricity sector, but also to the entire national economy. For this, it makes use of a general equilibrium formulation that follows a similar structure to the works of Kehoe (1996) and Sue Wing (2004). Computable general equilibrium (CGE) models have been applied as tools to assist economic decisions since the early 1970s. Evolving from Leontief's 1930s multi-sector input-output models, CGE models have been presented as an alternative tool for economic evaluation since Johansen's (1960) seminal works. Shoven and Whalley (1992) and Kehoe et al. (2005) offer an overview of these models. There has been a rapid development of empirical CGE applications in a variety of policy issues, and also in energy and environmental issues (see Sue Wing (2009) and Rodrigues et al. (2011)).

However, despite its obvious importance, there is an absence of CGE empirical works that assess the economic impact of demand response programs. This paper intents to fulfill part of this gap by evaluating the demand reduction effects of DR programs, while additional research under work should be able to address the assessment of DR load displacement. In order to achieve this, the paper is structured as follows: section 2 presents results from a partial equilibrium analysis of DR that further in the article will be used as a comparative factor to the general equilibrium model. Sections 3 and 4 describe the general equilibrium model and present and analyze the results obtained in the study. Finally, section 5 provides the conclusions drawn from the study and points to possible future extensions.

2. THE PARTIAL EQUILIBRIUM MODEL

It is reasonable to assume that sending electricity consumers variable price signals might cause a shift in their consumption profile, in order to consume less in the most expensive hours and therefore reduce their electricity bill. As electricity prices are higher when demand is higher, peak-hour demand should suffer the largest effects from DR programs. Then, the direct result of DR programs would be to flatten the consumption profile by transferring peak demand to less expensive hours.

Considering a partial equilibrium analysis, the relocation caused by the change between the peak and off-peak consumption results in a different portfolio of technologies used on electricity production. The flattening of the consumption profile would avoid the need for peak-load technologies with low utilization factors. As the flexibility offered by peak units has usually as tradeoffs a higher operational cost and more pollutants emissions, DR programs could potentially cause a drop in production costs, electricity prices, and promote the utilization of relatively "cleaner" electricity technologies.

These effects have been estimated for the Spanish electricity market with the GEPAC model developed by Linares et al (2008). The model incorporates a detailed representation of the Spanish electricity sector encompassing the oligopolistic structure of the electricity market, carbon emission markets and tradable green certificates. The model provides optimal operation and investment decisions of production in the Spanish electricity market. In this case, the model has been run assuming a reduction in demand induced by DR programs of 6.61%, taken from Conchado and Linares (2009a and 2009b).

The results of the introduction of DR under a partial equilibrium perspective is promoting the flattening of the system demand, reducing the peak load and the use of peak technologies as 'Gas' and 'Fuel Oil', and also, in turn increasing the off-peak consumption. There are also changes in prices and pollutant emissions (the outcome of the partial equilibrium model can be seen in more detail in Table 2, Annex I).

However, as mentioned before, the question to be answered is what happens when the effects of the changes on demand and prices are evaluated in other economic sectors. This question can only be answered by a general equilibrium model, which would allow to endogeneize the indirect effects in order to provide a more complete analysis of the effects of a policy on the whole national economy. Next, we describe the CGE model used to measure the indirect effects of an increase of DR programs for the Spanish economy.

3. GENERAL EQUILIBRIUM MODEL

The CGE model represents a Walrasian static equilibrium, in the Arrow and Debreu (1954) tradition. It models a country (Spain) with two foreign regions (Europe and Rest of the World), two primary factors (capital and labor), two domestic agents (representative household and government) and 68 productive sectors. The whole set of equations and the definition of variables, parameters and sectors are displayed in the Annex II.

The data includes a Social Accounting Matrix (SAM), a set of elasticities, data on Spanish pollutant levels and some calibrated parameters. The SAM represents the macro-aggregates and input-output sectoral information of the

Spanish National Accounts for the year 2000[2]. The elasticities of substitution are taken from the standard source for CGE models: GTAP (Global Trade Analysis Project, Dimaranan (2007)). The sectoral pollutant levels were drawn from national estimations obtained from the Spanish national statistical database (from the 'Instituto Nacional de Estadística'). A description of the calibration procedure can be found in Dawkins et al. (2001). Basically the SAM provides information to calibrate ad valorem tax rates, transfers and some income levels, distributional and scale parameters, assuming the set of elasticities described above and some exogenous prices (see their definitions in Annex II).

Following the structure described by Robinson (1989), this Walrasian CGE model generates a set of equilibrium prices that clears markets under zero profits constraints for firms and maximizes household's utility. A consumer price index is used as numeraire. The CGE structure is briefly described below: we present the optimization problems from where the equations are obtained (see Annex II). Due to space constraints the mathematical derivations from the optimization problems to the equations in the model are not explained, but can be requested to the authors.

3.1. Productive sectors

Each productive sector j is described as a price-taker representative firm operating in a perfectly competitive market that chooses its production level (y_j). Firms maximize their profits (π_j). The price of the sector j output is denoted as p_j; the cost function (C_j) depends on p_j, the factor f price w^f, and y_j. These maximizations are constrained by technology, which is represented through a production function (φ_j) that implies the possibility of substitution among intermediate inputs (y_{ij}^{ll}) and primary factors (F_j^f). That is,

$$\textit{Max:} \qquad \pi_j = p_j y_j - C_j(p_j, w^f, y_j)$$

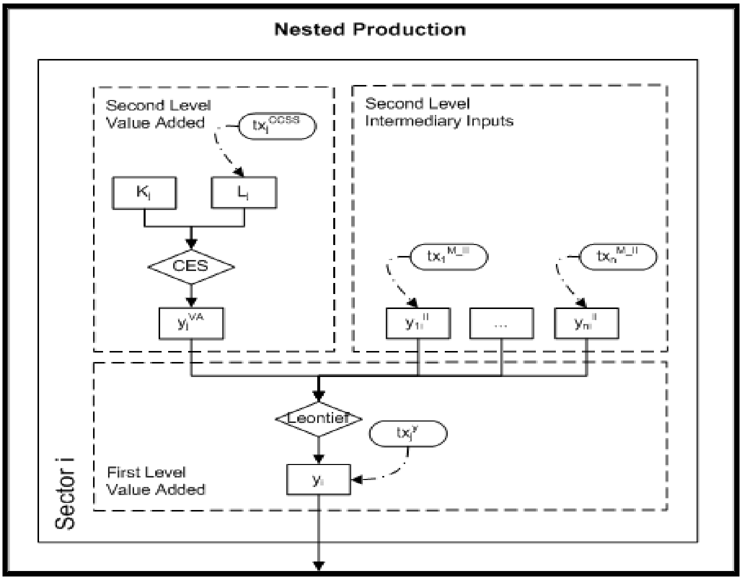
$$\textit{Subject to:} \qquad y_j = \varphi_j(y_{ij}^{ll}, F_j^f)$$

The production function is represented in this model through a series of nestings (see Figure 1). The first level of the production function stands for the effective production decision of each sector (y_j), and its technology is represented by a Leontief production function among a value added composite

[2] Most of the Social Accountability Matrix (SAM) data can be obtained at the 'Instituto Nacional de Estadística' webpage (http://www.ine.es). Special thanks are due to Helena Vieitez and Miguel Rodríguez, from Universidad de Vigo, by providing assistance in the data acquiring and by constructing the SAM utilized in this model.

(y_j^{VA}) and intermediate inputs (y_{ij}^{ll}). Some taxes on production burden final output (tx_j^{Y}) and intermediate inputs ($tx_j^{M\_ll}$) are considered at this stage. The second level divides the value added composite good (y_j^{VA}). It is represented by the aggregation of two primary factors (Labor, L_j, and Capital, K_j), combined through a constant elasticity of substitution function (CES). Social contributions burden (tx_j^{CCSS}) in labor expenditures are considered at this level.

Figure 1
Nested Production functions



Source: Own elaboration.

After solving the optimizing problem, it is possible to express the demand and composite prices for each productive factor and intermediate input (see Annex II for the equations description).

3.2. Representative household

We assume that private consumers in the model share homothetic and identical preferences, and as a consequence, they can be represented as a single representative household. Its objective is to choose a consumption bundle to maximize welfare, subject to a budget constraint. Welfare is represented by a utility function (U)[3] dependent on the final consumption of commodities in Spanish territory (d_i^H) and consumption in other countries (d_H^f), all subject to a budget constraint (Y^H). The household income consists of earnings of the representative agent's endowment of production factors ($\overline{L}^H$ and $\overline{K}^H$) and transfers from the government and abroad ($\overline{T}^{G\_H}$ and $\overline{T}^{f\_H}$). The second constraint states that the households spends in commodities all the not saved income, where $\overline{s}^H$ is the exogenous marginal propensity to save.

Max: $$U(d_i^H, d_H^f) = \sum_{i=1}^{n} \overline{\mu_i^H} . \ln d_i^H$$

Subject to: $$Y^H = w^L \overline{L}^H + w^K \overline{K}^H + \overline{T}^{G\_H} + \overline{T}^{f\_H}$$

$$\left(\sum_{i=1}^{n} d_i^H p_i^{Q\_H\_tx} \right) + d_H^f \overline{\varepsilon}^f \overline{p}_f^{average} \leq \left(1 - \overline{s}^H\right) Y^H$$

3.3. Government

The role of the public sector is twofold, i.e., owner of resources (e.g. from capital endowment, tax revenue and net foreign transfers), and purchaser of certain goods. Taxes consist of social contributions, value added taxes, other indirect taxes (production and product taxes), taxes on trade and direct taxes. The public sector also enters the model as a purchaser. The public sector expenditure includes both market goods (i.e., output that is disposed of in the market at economically significant prices) and non-market goods (i.e., output that is provided at prices that are not economically significant).This consumption is in goods fixed proportions. The macroeconomic closure of the public sector is represented by an endogenous public savings level.

3.4. External sector

We assume that goods are differentiated according to their origins (Spain, the European Union and the Rest of the World), following the Armington assumption, i.e., goods are imperfect substitutes. This allows for the possibility of intra-industry trade despite the assumption of exogenous world prices (i.e., the small country assumption, namely that Spain is price taker in international markets). The international trade in electricity for the Spanish economy represents a very small share in all the international flows, so those assumptions

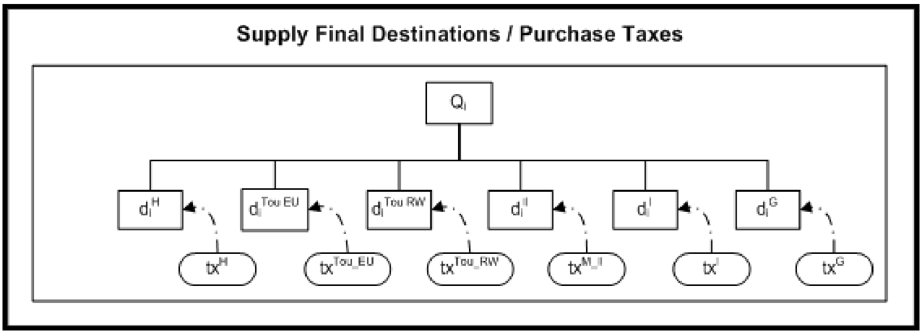
[3] The household preferences are described in the shape of an extended linear expenditure system utility function.

play a minor role in the quantitative results. Moreover, the imports and exports are considered exogenously given for the specific case of the electricity product because of the very limiting interconnection capabilities between countries, which are commonly used at their maximum capacity at the more sensible imports (exports) demanding periods of higher (lower) domestic prices.

3.5. Macroeconomic closure

The net production supplied in the domestic market (domestic production plus imports minus exports) has six destinations. The total sales within the country (Q_i) are partitioned among the final consumption from households (d_i^H), the consumption by foreign European tourists ($d_i^{Tou\_EU}$), the consumption by foreign tourists from the Rest of the World ($d_i^{Tou\_RW}$), the intermediate consumption of goods i demanded by the productive sectors (d_i^{II}), the investment goods demand (d_i^I), and the public sector consumption demand (d_i^G). Some taxes burden those demands, as displayed in Figure 2.

Figure 2
Final goods destination



Source: Own elaboration.

The foreign tourist demand decision is taken into account as follows. Their consumption decision depends of a fixed endowment of income in foreign currency, fully utilized in their expenditure decision through a fixed consumption share.

Finally, the model also assumes that all savings from households and government are spent on investment goods, at fixed investment shares for each sector.

4. CASE STUDY RESULTS

The assessment of the impact of DR programs in the Spanish economy is carried out through a comparative static analysis between the general equilibrium model results without DR programs and its results under a scenario of full penetration of electricity DR programs in the Spanish economy.

As mentioned before, DR programs flatten the system demand profile, reducing demand and production costs in peak hours. Regarding the Spanish economy, this result may be softened by indirect substitution and income effects on the electricity demand and on other sectors production decisions. The following subsections present the results of the simulation of the DR program. However, an important caveat should be explained before.

This CGE model as is formulated is only able to assess the reductions in electricity consumption caused by DR programs, and not the load shifting effect of peak demand displacement to cheaper hours. Therefore, the results presented are due solely to load reductions, and are not influenced by the shifting of load between peak and off-peak load levels. This shortcoming also implies that the influences of changes between fuel uses from changes in the electricity production technologies used are not analyzed, because the model is only capable of simulating fixed proportions reductions of the fuel use according to the reduction of electricity consumption. Research is under way to include the assessment of load shifting in the model.

Assuming this limitation, the results described below are the result of DR programs that produce domestic savings in electricity consumption corresponding to the maximal potential of penetration of DR programs, described in section 2. The estimated level of electricity demand savings corresponds to a decrease of 6.61% of the total household electricity consumption (Table 2, Annex I) and their consequences are evaluated below.

4.1. Analysis of demand response production impacts

Four Spanish structural factors are especially relevant in the analysis of this particular CGE study. The first factor is derived directly from the partial equilibrium analysis, and corresponds to the determination of which portfolio of technologies produces the electricity demanded. Its effect is the most straightforward of all of the effects that will be examined later. Sectors intimately linked to the electricity sector, as producers of intermediate inputs for the electricity process, will suffer a retraction in their production levels because of the reduction in electricity demand. Table 3 (Annex I) provides the list of sectors that might suffer more significantly this effect, such as the fuels producers (coal, gas, crude oil, coke and refining).

The additional three structural factors on the evaluation of CGE results are directly related with the effects only analyzed under a general equilibrium structure. The first of these effects is related to the use of electricity as an intermediate input on the production of other sectors; while the other two have an indirect influence character: they are related to each sector demand for production factors (capital and labor) necessary to obtain their final products.

In order to discuss these three effects it is necessary to analyze the total amount of electricity or production factors demanded by the industry (Figure 9, in Annex I) and the intensity with which the industry uses these factors (Figure10, in Annex I).

A decrease in household electricity demand allows the possibility of supplying the quantity demanded by the system with cheaper production technologies, reducing the production costs and, potentially, lowering electricity prices if the market is competitive enough. Taking as starting point the use of electricity as a productive input, the switch to a lower price level causes a drop in costs both in absolute and relative terms for sectors that use a significant amount of electricity in its production. In turn, these sectors would have an opportunity to convert these electricity bill savings into the growth of their own production or into the distribution of higher amounts of income between their owners[4].

Therefore, the more electricity intensive the sector is, the more indirect effects from diminishing electricity prices it will experience. Figure 9.A (in Annex I) describes the sectors most likely to be affected by this effect in absolute terms[5] while Figure 10.A (in Annex I) describes the same in relative terms[6].

[4] The households are also subject to a similar rebound effect that would undermine the effects of such demand response programs in the potential of promoting changes on the electricity demand levels. Nevertheless, as previously mentioned by this paper, the household electricity demand is exogenously given and by so, the analysis carried out in this research focus exclusively on the effects of DR programs in the productive and emitting sectors of the economy.

[5] The most affected sectors by this change in absolute costs are: transportation-related services – sales and repair of vehicles and fuels sales (40), transport by rail, land and sea (43) and manufacture of motor vehicles and trailers (36) –, electricity-intensive services – public administration (62), other business activities (55), post and telecommunications –, traditional industrial sectors – metallurgy (29), fabricated metal products (30) and chemicals (23) – and construction (39).

[6] The sectors most affected in relative terms (electricity-intensive sectors) are: primary industries – coal mining (4), non-metallic minerals (7) and crude petroleum and natural gas (5) – and traditional industrial sectors – manufacturing of cement, lime and plaster (25), glass (26), paper (21), rubber and plastics (24), metallurgy (29) and other mineral products (28).

The last two traditionally analyzed structural sources of influence in CGE models are the demand of the sectors for the production factors labor and capital. To analyze the effect that DR programs can produce through this aspect in the activity level of each specific industry it is necessary firstly to analyze the structure of the electricity sector itself. As shown in Figure 10.B (Annex I), the electricity sector (number “9” in the figure) can be classified as a capital intensive industry (the sixth most intensive in the economy), and at the same time as one of the most capital demanding sectors of the economy (it is the tenth most capital demanding sector as can be seen in Figure 9.B, Annex I).

As a consequence, a decrease in the demand for electricity implies a drop in the capital used by the power sector. As in the Spanish situation this sector is very important in relative terms (intensity) and in the absolute amount of the capital demanded by the whole economy, this drop in capital demand can create in turn significant effects. The shift in demand for capital lowers its price, which in turn benefits all other capital-intensive sectors and/or larger demanders of capital in the economy. Again, the savings generated by these sectors are reflected in increases of their own production.

Finally, the same mechanism can be used to evaluate the indirect effect which arises from the use of labor as productive factor. However, as can be seen in Figure 9.C and Figure 10.C (Annex I), the electricity sector is neither intensive nor great demander of labor, and therefore this last effect can be considered less significant in the analysis of the indirect effects of the implementation of DR programs.

The computation of the four previously described effects (the use of the product as an indirect input on the electricity production, and the demand intensity for electricity, capital and labor of sectors), summed up with their subsequent relationships suggest the forces acting on the economy in the relocation of income, purchases and sales for each sector of the Spanish economy as a consequence of DR programs. The production level resulting from this simulation can be described by the two figures presented below, in absolute terms (Figure 3) or in relative terms (Figure 4)[7].

As could be foreseen, all four previously described effects have influence on the results obtained by the CGE model simulation. However, only the first effect has the same direction as the decrease in electricity production originated from the DR program. All the other effects contribute to lessening this effect over the aggregate activity level of each sector.

As expected, the sectors where demand is closely linked to the level of production of the electricity sector have the first effect as the predominant one. Fuel suppliers for electricity are the sectors that are most negatively impacted

[7] See Annex II for the column numbers and sectors codes correspondence used on figures.

by the decline of electricity production. Coal mining (4), gas production (10), extraction of crude petroleum and natural gas (5) and coke, refining and nuclear fuels (8) are respectively the sectors that accompany the fall in production of the electricity sector. Here again, it is important to note the peculiarity that these effects reflect only proportional changes in the use of each technology in the original production of electricity, not reproducing any of the peak technology shifting effects promoted by a DR program.

Furthermore, even over these primarily affected sectors there is an influence of the three smoothing effects in the determination of their production levels. Nevertheless, it is in the other sectors that these indirect effects are more significant. The reduction of the price of electricity and capital have repercussions strong enough to offset the drops in the electricity sector demands in sectors such as: manufacturing of motor vehicles and trailers (36), construction (39), metallurgy (29), agriculture, livestock and hunting (1), Chemical manufacturing (23), other food industries (14), other business activities (55), sale and repair of motor vehicles and fuels (40), consequently promoting an increase in the activity level of these sectors.

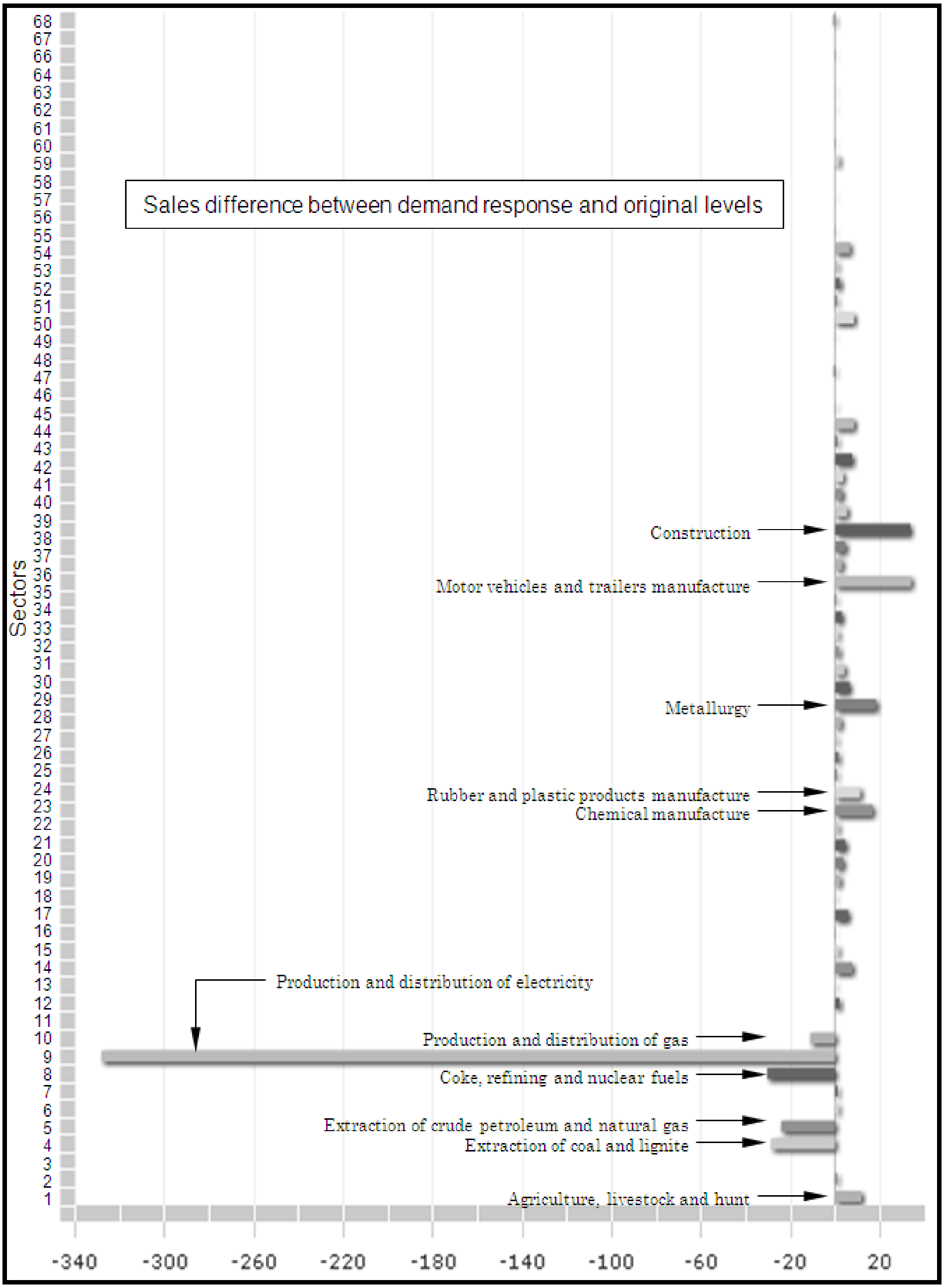
Prices are the second set of variables covered in the analysis. The simulation assumption of exogenously diminishing the electricity demand represents, in general terms, a negative displacement of the economy demand curves for products and production factors. This displacement generates a new equilibrium point where prices are expected to be inferior to the original ones. As shown in Figure 5, the capital rent and the wages obtained by the simulation are, respectively, 0.0543% and 0.025% lower than the original levels.

The electricity sector is capital intensive and this fact can explain the change in the rent of capital, which decreases in relative terms with respect to wages. This involves a redistribution effect of DR program in which workers are favored with respect to capital owners.

Whereby we assume competitive productive sectors structure, the productive sectors cost savings of lower capital and labor prices are transferred to their final product prices. As expected, the most capital intensive sectors present a superior price reduction[8]. The new product prices are in between 0.00039% and 0.048% lower than the original prices (see Figure 5 for magnitudes of each commodity price variation). Again, the product prices variation are bellow the upper limit represented by the capital prices variation because of the smoothing action performed by the imperfect substitution of externally produced goods, and the lower labor and intermediate inputs prices variation.

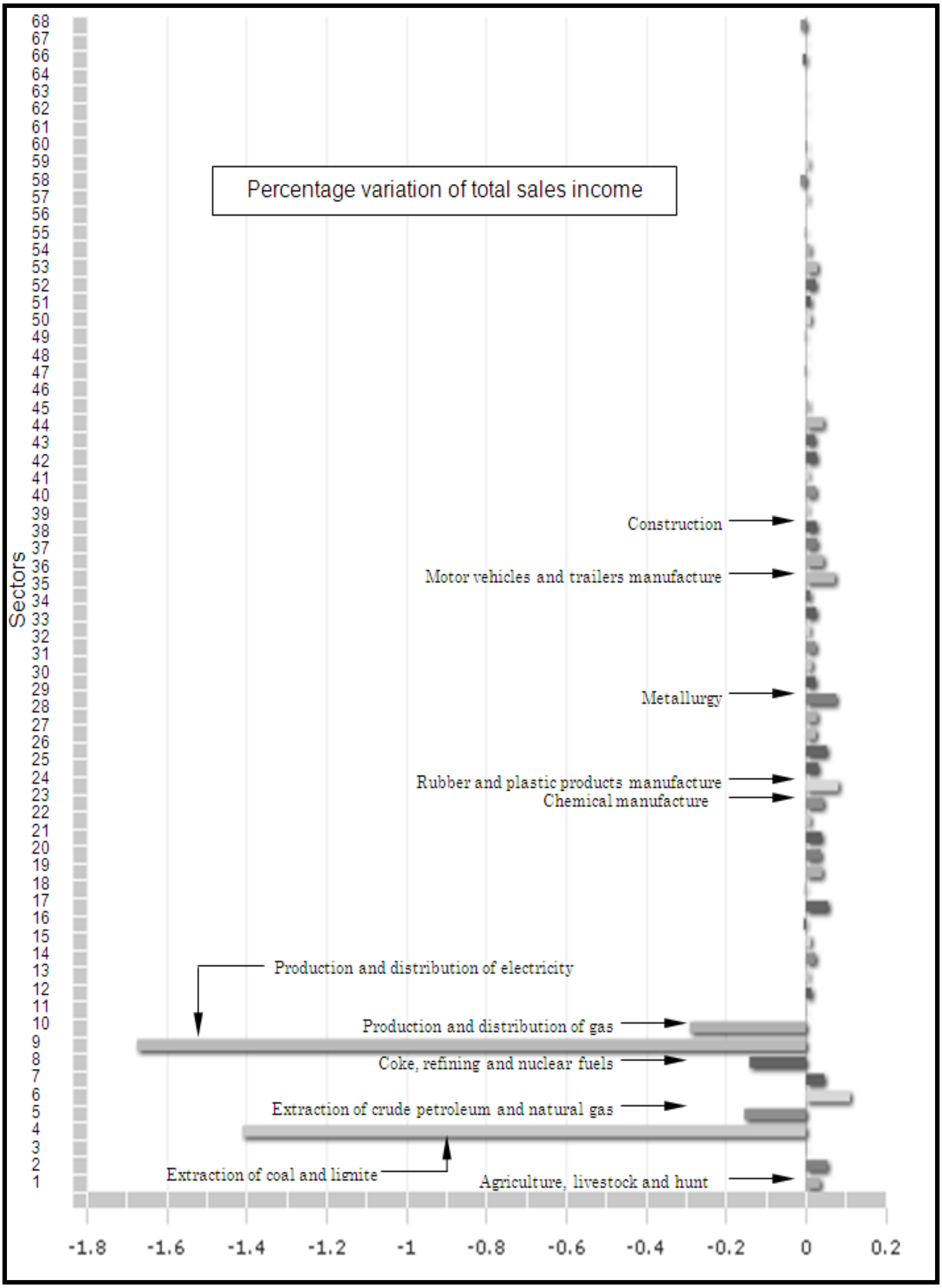
[8] Estate activities and imputed rent (51) and agriculture, livestock and hunt (1).

Figure 3
Total sales difference (DR minus original levels) at sectoral level



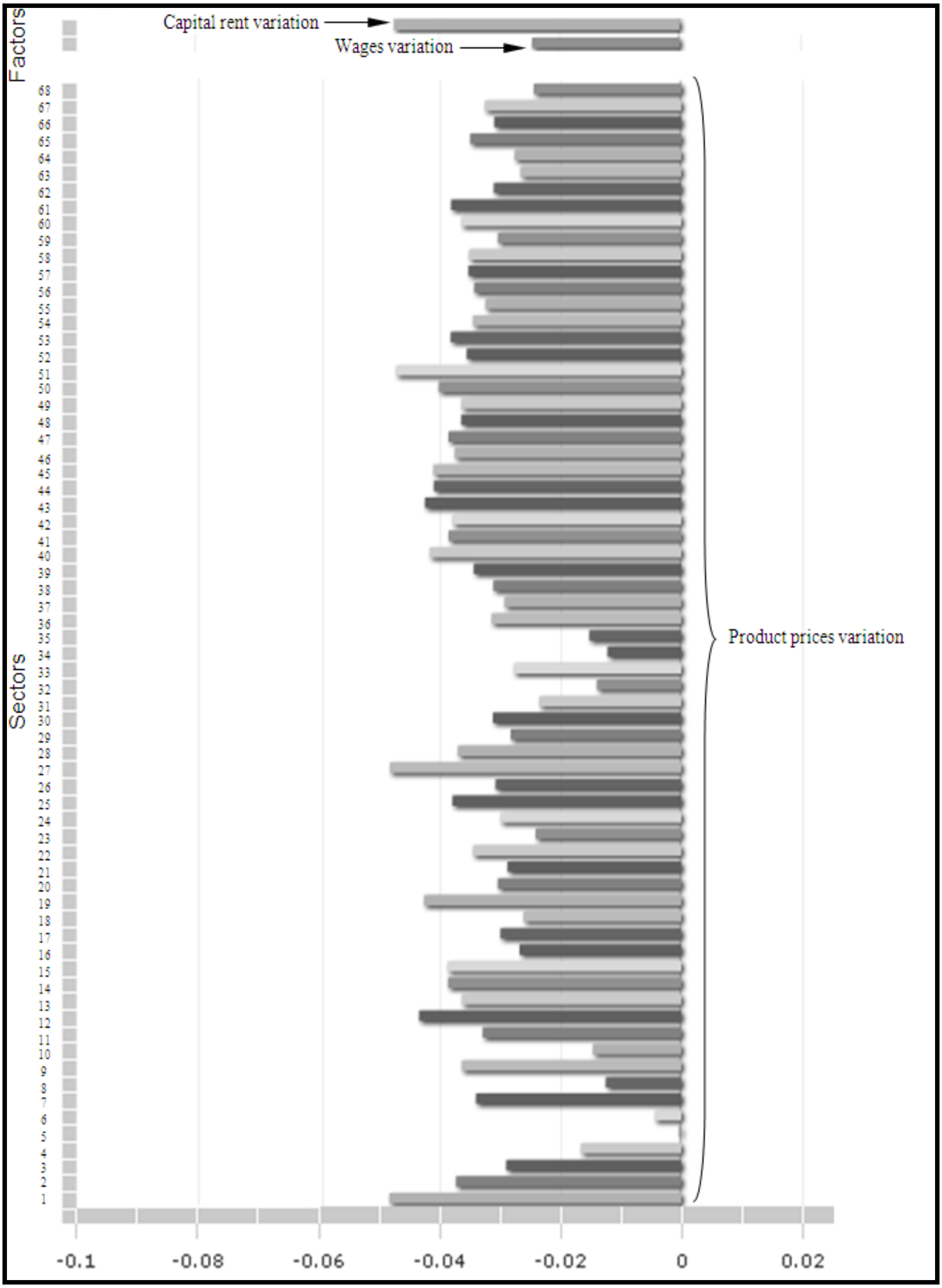
Source: Own elaboration. Unit: million of Euros.

Figure 4
Percentage variation of total sales difference (quantity x prices) at sectoral level



Source: Own elaboration. Unit: percentage.

Figure 5
Simulation results for prices variation



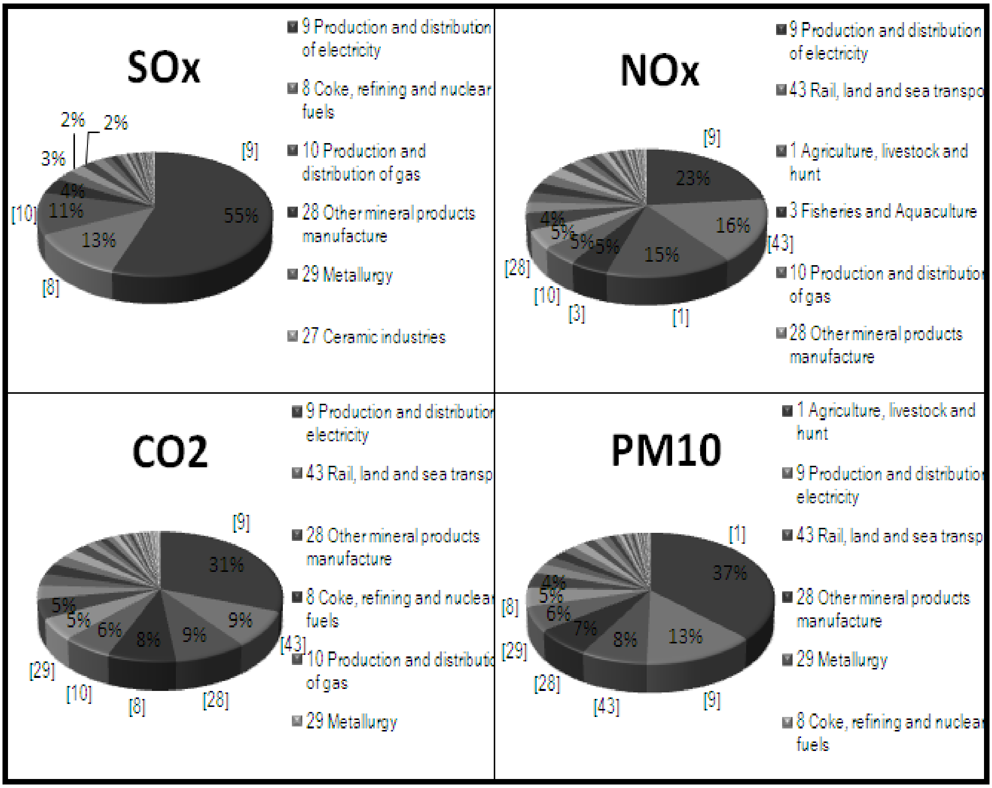
Source: Own elaboration. Unit: percentage.

4.2. Analysis of the impact of DR programs on pollutant emissions

The process to assess the impact of DR programs on pollutant emissions is described in this section. First, the differences between the quantities produced by each sector in the benchmark and in the simulated equilibrium are calculated. The original emissions quantities for each sector are then multiplied by the percentage change in the quantity produced in each sector of the economy to determine the new emissions levels.

The changes in pollutants levels promoted by the DR program can be evaluated under two distinct groups. The first group relates to pollutants whose production is directly related to the electricity sector. This group is outlined in Figure 6, where the electricity sector together with the associated fuel producers are responsible for 80% of emissions of SOx, 33% of NOx, 45% CO2 and 22% of total suspended particulates (TSP), according to 2000 data of the Spanish economy.

Figure 6
Pollutants with high production share of the electricity sector and associated fuel sectors



Source: Own elaboration. Unit: percentage.

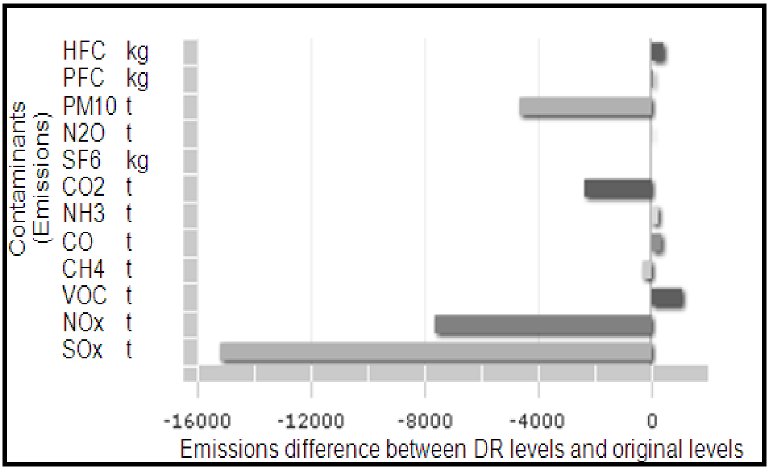
The second group corresponds to the remaining pollutants not significantly related with electricity production. Only 5% CH4, 4% CO, 2% of VOC, 2% N2O, and 0% other pollutants (NH3, SF6, PFCs and HFCs) are produced by sectors directly related to electricity production.

As mentioned in the previous section, the major effects of the reduction in the level of activity promoted by DR programs take place in the electricity sector and in the sectors most intimately connected to it as suppliers of production inputs. Therefore, it is clear that the electricity related sectors will induce the biggest changes in the emission of pollutants. Moreover, as in these sectors the use of their products as intermediate input for electricity is the predominant economic effect (as was shown in the previous section), these pollutants will follow the fall in the level of electricity production. As can be noted in Figure 7 and Figure 8, the decreases in the level of emissions in the economy under a DR program correspond to the pollutants listed in Figure 6. The changes on pollutants emissions are: -1.04% for SOx (-15,202 tonnes), -0.95% for CO2 (-2,364 tonnes), -0.66% for NOx (-7,640 tonnes) and -2.91 for PM10% (-4,651 tonnes).

Again, as seen previously, the less related with the electricity production a sector is, the higher the importance of the indirect effects on their production level. Some sectors, which have higher demand for factors and, at the same time, lower relation with the contraction of the electricity sector production would face a predominantly expansive effect due to the reduction of electricity bills or the change in factors price, potentially increasing their production. The increase in their production levels would increase their emissions levels, and, as some of them are responsible for emissions not related to the electricity sector, the increase in these sectors production could increase the global emissions levels of these non-electricity related pollutants.

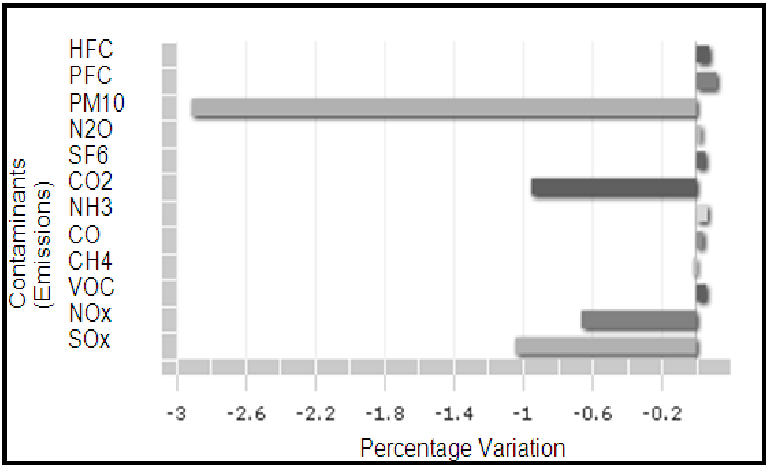
The pollutants belonging to the second group described above have their levels determined predominantly by the indirect effects of electricity, capital and labor price changes in the economy. The smaller change suffered by these sectors not directly related with the costs of production of electricity are translated to a smaller change in pollutant levels under the DR program. More importantly, their effect tends to be in the opposite direction of the contaminants previously described, i.e., they tend to present an increase in emissions levels as a consequence of the expansion of activity in these sectors. While CH4 emissions still present a small influence from the electricity production levels corresponding to a small decrease of 0.01% of emissions (-325 tons), all other contaminants increase their levels after the implementation of DR programs: N2O changes at 0.66% (19 tonnes), CO of 0.03% (346 tonnes), SF6 of 0.05% (4 kg), VOC of 0.05% (1082 tonnes), NH3 of 0.06% (240 tonnes), HFC 0, 07% (422 tonnes) and PFC of 0.11% (63 tonnes).

Figure 7
Difference of pollutants emitted in Spain with and without demand response increase



Unit: described in the graph.
Source: Own elaboration.

Figure 8
Percentage variation of the quantity of pollutants emitted in the atmosphere by Spain with DR programs



Unit: percentage.
Source: Own elaboration.

Furthermore, the comparison of the results obtained in the partial equilibrium and in the CGE simulation shows an indication of the benefits that a more comprehensive approach as the general equilibrium can promote when assessing pollutant emissions. Table 1 presents the relative results in pollutant emissions obtained by the partial and general equilibrium approaches for the implementation of a DR program.

Table 1
Comparison between partial equilibrium and general equilibrium results

		Partial equilibrium	General equilibrium
Pollutant	PM10_(particles)	-3,1%	-2,91%
	SOx	-1,8%	-1,04%
	CO2	-3,1%	-0,95%
	NOx	-2,9%	-0,66%
	CH4	-	-0,01%
	N2O	-	0,02%
	CO	-	0,03%
	SF6	-	0,05%
	VOC	-	0,05%
	NH3	-	0,06%
	HFC	-	0,07%
	PFC	-	0,11%

Unit: Percentage. The absence of numbers ('-') means that the model does not calculate the emission levels.
Source: Own elaboration.

The effect of the decrease of emissions obtained in the electricity sector is clearly maintained when evaluating the whole economy; however, the spread of DR effects to other sectors results in a reduction in the results obtained, especially in the cases of CO2 and NOx. In turn, DR programs promote, through the increase of activity of other sectors, an increase of emissions in smaller quantities for other atmospheric pollutants.

5. CONCLUSIONS

This paper presents a CGE model for the Spanish economy to estimate the impact of implementing electricity DR programs to flatten demand in peak hours. Demand response is seen by regulators as one of the main alternatives to face the problem of the increase in CO2 emissions (OFGEM, 2009). The model presented in this paper accomplishes a step in the analysis of the policy impacts of such an alternative as it underlines the importance of including the economic interactions between different sectors, i.e., the general equilibrium framework. Additional studies need to be done in order to understand better the impact of electricity sector policies on economic variables, and also to reduce the number of restrictive hypothesis, such as the assumption of proportional fuel decreases in relation to electricity demand levels, which could be eliminated by representing electricity production in a more detailed way, internalizing in the model the different production technologies used for each load block. Research is under way in this topic.

The analysis covers the changes in three variables: sales, prices and emissions. The sales changes generated by the DR program simulated drives a direct fall in the electricity demand (i.e., a fall in the output, given the market clearing in all markets). This reduced electricity demand lowers its own derived demand, including demand for intermediate inputs and primary factors. Fuels account for a high share of those intermediate inputs. Although, in general, non-energy sectors increase sales and they increase demand for their intermediate inputs, including electricity and fuels, the general equilibrium effects show a decrease in fuels sales given the relevant quantitative decline in electricity. Nevertheless the non-energy sectoral effects are of different size, with Motor vehicles, Metallurgy or Rubber and plastic products among the more expansionary sectors.

Prices are the second set of variables covered in the analysis. The electricity sector is capital intensive and this fact can explain the change in the rent of capital, which decreases with respect to wages. This involves a redistribution effect of DR program, with workers favored with respect to capital owners. Among the commodity prices the most capital intensive production techniques suffer the more intense relative prices variations as should be expected.

Finally, the impact of DR programs on pollutants emitted can be summarized in three main effects. First, the decrease in electricity demand reduces significantly the pollutants linked to electricity and fuel sectors. Second, the expansive effect on the other sectors output increases the emissions of pollutants not linked to electricity production. And third, a partial equilibrium analysis would overestimate the cut in emissions with respect to a more realistic general equilibrium framework, with relevant differences for some pollutants.

Those results highlight the general equilibrium approach as a way for the evaluation of the expected effects of DR programs. These programs are important in order to understand the different economic incentives created by the price signals. More importantly, these economic incentives do not concern only the electricity sector but also other economic sectors as a consequence of their relationship.

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Annex I

Table 2
GEPAC results to an increase in DR

		Initial value	DR scenario	
			New Level	Percentage
General Results	Household Demand (GWh)	60971	56943	-6,61%
	Total Annual Demand (GWh)	253384	249356	-1,59%
	Electricity marginal price (€/MWh)	54,67	52,97	-3,11%
Technology (Generation Mix)	Nuclear (GWh)	63037	63037	0%
	Carbon (GWh)	73895	71968	-2,61%
	Fuel oil (GWh)	1522	790	-48,09%
	Gas (GWh)	160	23	-85,63%
	Combined cycle (GWh)	38591	37378	-3,14%
	Biomass (GWh)	6416	6416	0%
	Cogeneration (GWh)	19254	19254	0%
	Mini-hydraulic (GWh)	4680	4680	0%
	Wind (GWh)	15996	15996	0%
	Solar (GWh)	18	18	0%
	Manageable Hydraulic (GWh)	17906	17906	0%
	Flowing Hydraulic (GWh)	11870	11870	0%
Emissions	CO2 (Mton)	96,33	93,37	-3,07%
	SO2 (Mton)	321,7	315,92	-1,80%
	NOx (Mton)	229,99	223,4	-2,87%
	Particles (Mton)	22,22	21,53	-3,11%

Units: described in the table

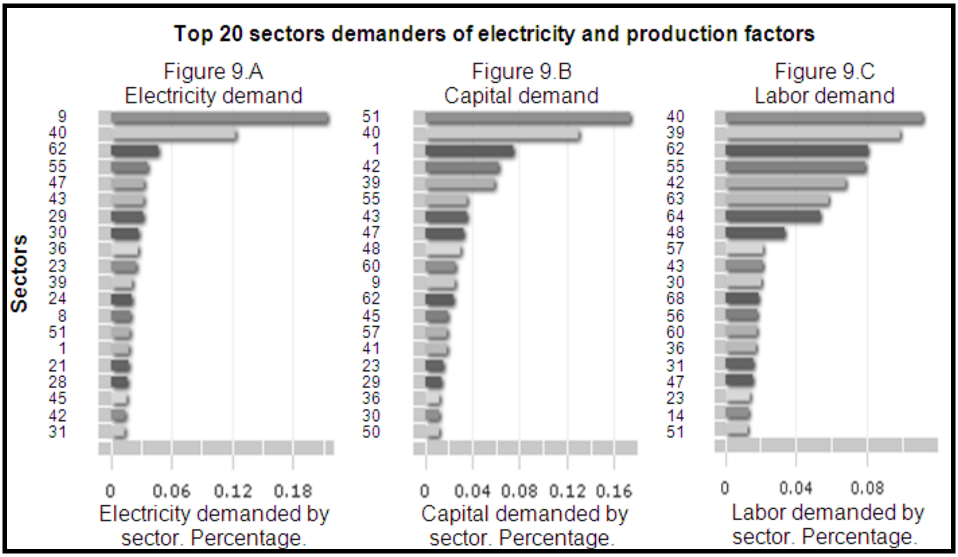
Source: Own elaboration based on Conchado and Linares (2009a and 2009b).

Table 3
Intermediate Inputs used in the electricity production

		Share in the production of one unit of electricity
Intermediate Input	Production and distribution of electricity	28,00%
	Coke, refining and nuclear fuels	15,98%
	Extraction of coal and lignite	14,90%
	Production and distribution of gas	6,25%
	Other business activities	6,21%
	Sales and repair of vehicles and fuels	6,19%
	Fabricated metal products	3,71%
	Machinery and equipment	2,68%
	Manufacture of electrical machinery and apparatus	2,52%
	Others	13,56%

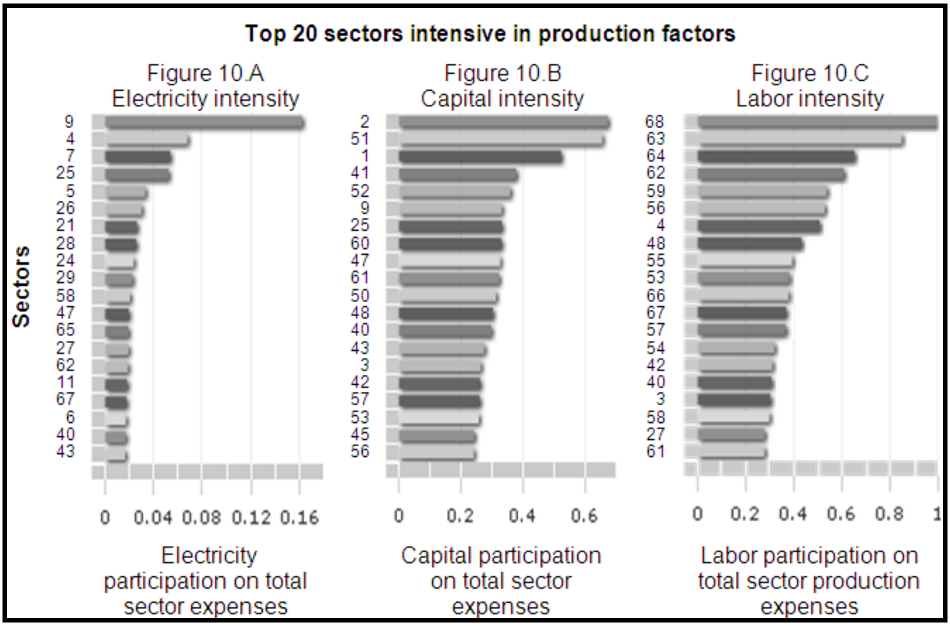
Unit: Percentage.
Source: Own elaboration.

Figure 9
Largest demanders of electricity and production factors in the Spanish economy



Each number in the column represents a different sector (see Annex II for a detailed correspondence). Unit: One ('1') corresponds to the total electricity or productive factors demanded by all productive sectors.
Source: Own elaboration.

Figure 10
Most intensive sectors in electricity and production factors in the Spanish economy



Each number in the column represents a different sector (see Annex II for a detailed correspondence). Unit: Percentage of electricity or production factor in the input expenses of the sector.

Source: Own elaboration.

Annex II

Model Description

Productive sectors:

1	Agriculture, livestock and hunt	35	Medical-surgical precision instruments
2	Forestry and logging	36	Motor vehicles and trailers manufacture
3	Fisheries and Aquaculture	37	Other transport equipment manufacture
4	Extraction of coal and lignite	38	Furniture and other manufacturing industries. Recycling
5	Extraction of crude petroleum and natural gas. Extraction of uranium and thorium	39	Construction
6	Extraction of metallic minerals	40	Sales and repair of motor vehicles, motor fuel trade, Wholesale and intermediaries, retail trade, personal effects repair
7	Extraction of non-metallic mineral	41	Accommodation
8	Coke, refining and nuclear fuels	42	Restoration
9	Production and distribution of electricity	43	Rail, land and sea transport
10	Production and distribution of gas	44	Air and space transport
11	Collection, purification and distribution of water	45	Auxiliary transport activities
12	Meat manufacture	46	Travel agencies activities
13	Milk manufacture	47	Post and telecommunications
14	Other food industries	48	Financial intermediation
15	Beverages manufacture	49	Insurance and pension
16	Tobacco manufacture	50	Auxiliary activities
17	Textile manufacture	51	Estate activities. Imputed rent
18	Clothing and fur manufacture	52	Renting of machinery and household services
19	Leather and footwear manufacture	53	Computing activities
20	Wood and cork manufacture	54	Search and development
21	Paper manufacture	55	Other business activities
22	Publishing and printing	56	Education of market
23	Chemical manufacture	57	Health and social services of market
24	Rubber and plastic products manufacture	58	Public sanitation of market
25	Cement, lime and plaster manufacture	59	Associative activities of market
26	Glass and glass products manufacture	60	Recreational, cultural and sports activities of market
27	Ceramic industries	61	Other personal services activities
28	Other mineral products manufacture	62	Public administration
29	Metallurgy	63	Non-market education
30	Metallic products manufacture	64	Non-market Health and social services
31	Machinery and equipment	65	Non-market public sanitation from public administrations
32	Office machinery and computers	66	Non-market associative activities from nonprofit institutions serving households
33	Electrical machinery and apparatus manufacture	67	Non-market recreation and culture activities
34	Electronic material manufacture	68	Employed persons by households

Variables and Parameters:

Parameters are differentiated from variables by a bar above the letter ($\overline{\alpha}$). Initial values are denoted by a 0 superscript (ex. p_i^0 , means the initial price for good i).

Variables:	
	Value Added Aggregation:
y_j^{VA}	Quantity of value added composite good produced by sector j
p_j^{VA}	Price of value added composite good of a specific sector j
K_j	Quantity of production factor capital utilized in a specific sector
p^K	Price of production factor Capital
L_j	Quantity of production factor labor utilized in a specific sector j
p^L	Price of production factor Labor (without social contributions taxes)
$p_j^{L\_tx}$	Price of production factor Labor (with social contributions taxes)
	Intermediate Inputs and Production Sector Aggregation:
y_{ij}^{II}	Quantity of intermediary input i utilized by a specific sector j
y_j	Quantity of the commodity produced by a specific sector j
p_i	Selling price of the commodity i (without foreign aggregations) (without production taxes)
$p_i^{y\_tx}$	Selling price of the commodity i (without foreign aggregations) (with production taxes)
	Imports Aggregation:
M_i^{EU}	Final goods i imported from Europe
M_i^{RW}	Final goods i imported from the rest of the world
D_i	Final aggregated imported and domestic produced supply of a specific good i
$p_i^{M\_EU}$	Price (in local currency) of imported goods i from Europe
$p_i^{M\_RW}$	Price (in local currency) of imported goods i from the rest of the world
p_i^D	Final Armington aggregated price of the good produced by a specific sector i
	Exports Disaggregation:
EX_i^{EU}	Final goods i exports to Europe
EX_i^{RW}	Final goods i exports to the rest of the world
$p_i^{EX\_EU}$	Price (in local currency) of exported goods i to Europe (without exportation taxes)
$p_i^{EX\_RW}$	Price (in local currency) of exported goods i to the rest of the world (without exportation taxes)

Variables (continued):	
$p_i^{EX\_EU\_tc}$	Price (in local currency) of exported goods i to Europe (with exportation taxes)
$p_i^{EX\_RW\_tx}$	Price (in local currency) of exported goods i to the rest of the world (with exportation taxes)
	Final Goods:
Q_i	Final aggregated supply of a specific good i to domestic market
p_i^Q	Price of domestic supplied good i
$p_i^{Q\_H\_tx}$	Household final purchase price (with taxes) of good i offered in the economy
$p_i^{Q\_G\_tx}$	Government final purchase price (with taxes) of good i offered in the economy
$p_i^{Q\_I\_tx}$	Investment final purchase price (with taxes) of good i offered in the economy
$p_i^{Q\_Tou\_EU\_tx}$	European tourists final purchase price (with taxes) of good i offered in the economy
$p_i^{Q\_Tou\_RW\_tx}$	Rest of the world tourists final purchase price (with taxes) of good i offered in the economy
	Destinations Balance:
d_i^H	Household domestic goods demand
$d_i^{Tou\_EU}$	Internal goods demand from European tourists
$d_i^{Tou\_RW}$	Internal goods demand from the rest of the world tourists
d_i^{II}	Intermediate inputs demand from productive sectors
d_i^I	Investment goods demand
d_i^G	Government goods demand
	Capital and Labor market clearing:
L^T	Total demand of the production factor Labor
K^T	Total demand of the production factor Capital
	Household Behavior:
$d_H^{EU\_Tou}$	Household consumption abroad in Europe (household tourism in Europe)
$d_H^{RW\_Tou}$	Household consumption abroad in the rest of the world (household tourism in the rest of the world)
Y^H	Representative household income level
E^H	Household expenditure
	Government Behavior:
Y^G	Government income level
E^G	Government expenditure

Variables (continued):	
	Savings-Investment:
S	Total savings in the economy
S^{H}	Household total savings
S^{G}	Government total savings
S^{EU}	Europe total savings (in foreign currency)
S^{RW}	Rest of the world total savings (in foreign currency)
I	Total Investment in the economy

Calibrated parameters, elasticities and exogenous prices:	
	Numeraire:
CPI	Consumer Price Index
	Value Added Aggregation:
$\overline{\alpha}_j^{VA}$	Productivity parameter of sector value added composite good production function
$\overline{a}_j^{VA\_L}$	Share parameter of labor on value added composite good production function
$\overline{a}_j^{VA\_K}$	Share parameter of capital on value added composite good production function
$\overline{\sigma}_j^{VA}$	Elasticity of substitution between capital and labor productive factors
	Intermediate Inputs and Production Sector Aggregation:
$\overline{c}_{ij}^{II}$	Share parameter of intermediate composites inputs utilized on sector production function
$\overline{c}_j^{VA}$	Share parameter of value added composite input utilized on sector production function
	Imports Aggregation:
$\overline{\alpha}_i^{D}$	Productivity parameter of final aggregation supply good production function
$\overline{\alpha}_i^{D\_y}$	Share parameter of domestic produced supply on production function
$\overline{\alpha}_i^{D\_EU}$	Share parameter of European imports on production function
$\overline{\alpha}_i^{D\_RW}$	Share parameter of rest of the world imports on production function
$\overline{\sigma}_i^{D}$	Elasticity of substitution between domestic-European-rest of the world offer goods
$\overline{\varepsilon}^{EU}$	European exchange rate (direct quotation: 1 foreign currency unit = x home currency units)
$\overline{\varepsilon}^{RW}$	Rest of the World exchange rate (direct quotation: 1 foreign currency unit = x home currency units)
$\overline{p}_i^{EU\_M}$	International price of the imported goods from Europe
$\overline{p}_i^{RW\_M}$	International price of the imported goods from the rest of the world

Calibrated parameters, elasticities and exogenous prices (continued):	
$\overline{p}_i^{EU\_EX}$	International price of exported goods to Europe
$\overline{p}_i^{RW\_EX}$	International price of exported goods to the rest of the world
	Exports Disaggregation:
$\overline{\beta}_i^{EX}$	Productivity parameter of sector products composite good transformation function
$\overline{b}_i^{EX\_Q}$	Share parameter of final aggregation supply good on transformation function
$\overline{b}_i^{EX\_EU}$	Share parameter of European exportation on transformation function
$\overline{b}_i^{EX\_RW}$	Share parameter of rest of the world exportation on transformation function
$\overline{\sigma}_i^{EX}$	Elasticity of transformation between domestic-European-rest of the world supply goods
	Destinations Balance:
$\overline{\rho}_i^{Tou\_EU}$	European tourists fixed consumption share of national goods
$\overline{\rho}_i^{Tou\_RW}$	Rest of the World tourists fixed consumption share of national goods
$\overline{Y}^{Tou\_EU}$	Income of European tourists (in foreign currency)
$\overline{Y}^{Tou\_RW}$	Income of rest of the world tourists (in foreign currency)
	Household Behaviour:
$\overline{L}^{H}$	Representative Household initial endowment of labor
$\overline{K}^{H}$	Representative Household initial endowment of capital
$\overline{s}^{H}$	Representative Household marginal propensity to save
$\overline{\mu}_i^{H}$	Household marginal propensity to consume of domestic good
$\overline{\mu}_{EU}^{H}$	Household abroad marginal propensity to consume in Europe
$\overline{\mu}_{RW}^{H}$	Household abroad marginal propensity to consume in the rest of the world
$\overline{p}_{EU}^{average}$	Average price index of European goods in foreign currency
$\overline{p}_{RW}^{average}$	Average price index of rest of the world goods in foreign currency
	Government Behavior:
$\overline{K}^{G}$	Government initial endowment of capital
$\overline{d}_i^{G\_initial}$	Government initial demand for goods
	Transfers:
$\overline{T}^{G\_H}$	Transfers from Government to households
$\overline{T}^{H\_G}$	Transfers from households to Government
$\overline{T}^{EU\_H}$	Net transfers from Europe to households
$\overline{T}^{RW\_H}$	Net transfers from the rest of the world to households
$\overline{T}^{EU\_G}$	Net transfers from Europe to government

Calibrated parameters, elasticities and exogenous prices (continued):	
$\overline{T}^{RW\_G}$	Net transfers from the rest of the world to government
	Savings-Investment:
$\overline{TK}^{EU}$	Net capital transfers from Europe in foreign currency
$\overline{TK}^{RW}$	Net capital transfers from the rest of the world in foreign currency
$\overline{\theta}_i$	Share parameter of demand for investment goods
	Taxes:
$\bar{t}x_j^{CCSSE}$	Employer social contributions tax rate
$\bar{t}x_j^{CCSSH}$	Employee’s social contributions tax rate
$\bar{t}x_j^{y}$	Production tax rate
$\bar{t}x_j^{M\_II}$	Product tax over intermediate inputs sector goods purchases (import and specific taxes)
$\bar{t}x^{H}$	Product tax (IVA) over households purchases
$\bar{t}x^{G}$	Product tax (IVA) over government purchases
$\bar{t}x^{I}$	Product tax over gross capital formation
$\bar{t}x^{Tou\_EU}$	Product tax over European tourists purchases
$\bar{t}x^{Tou\_RW}$	Product tax over rest of the world tourists purchases
$\bar{t}x^{EX\_EU}$	European exportation product tax
$\bar{t}x^{EX\_RW}$	Rest of the world exportation product tax
$\bar{t}x^{D}$	Direct tax amount paid by households to government
	Numeraire:
$\overline{\mu}_i^{CPI}$	Weight of the good on the consumer price index

Equations:

Type	Descriptions	Model Equations
Production Sector Equations – Value Added Aggregation	Value added production function by sector (CES)	$y_j^{VA} = \overline{\alpha}_j^{VA}\left(\overline{a}_j^{VA\_L}\left(L_j\right)^{\frac{\overline{\sigma}_j^{VA}-1}{\overline{\sigma}_j^{VA}}} + \overline{a}_j^{VA\_K}\left(K_j\right)^{\frac{\overline{\sigma}_j^{VA}-1}{\overline{\sigma}_j^{VA}}}\right)^{\frac{\overline{\sigma}_j^{VA}}{\overline{\sigma}_j^{VA}-1}}$
	Labor capital transformation function	$\frac{L_j}{K_j} = \frac{\left(\overline{a}_j^{VA\_L}\right)^{\overline{\sigma}_j^{VA}}\left(p^K\right)^{\overline{\sigma}_j^{VA}}}{\left(\overline{a}_j^{VA\_K}\right)^{\overline{\sigma}_j^{VA}}\left(p^{l\_tx}\right)^{\overline{\sigma}_j^{VA}}}$
	Price of value added composite goods	$p_j^{VA} = \frac{p_j^{L\_tx}L_j + p^K K_j}{y_j^{VA}}$

Equations (continued):

Type	Descriptions	Model Equations
Production Sector Equations – Intermediate Inputs and Production Sector Aggregation	Demand for value added composite goods to produce the sector output	$y_j = \frac{y_j^{VA}}{\bar{c}_j^{VA}}$
	Demand inside the sector for intermediary inputs to produce the sector output	$y_j = \frac{y_{1j}^{II}}{\bar{c}_{1j}^{II}} = \ldots = \frac{y_{nj}^{II}}{\bar{c}_{nj}^{II}}$
	Unitary cost function to production on each sector	$p_j = \frac{p_j^{VA} y_j^{VA} + \left(1 + \bar{t}x_j^{M\_II}\right)\sum_{i=1}^{n} p_i^{Q} y_{ij}^{II}}{y_j}$
	Production price with taxes	$p_j^{y\_tx} = p_j\left(1 + \bar{t}x_j^{y}\right)$
International Accounts – Import Aggregation	Armington production function aggregation of imports and domestic produced goods (CES)	$D_j = \bar{\alpha}_j^{D}\left(\bar{a}_j^{D\_y}\left(y_j\right)^{\frac{\bar{\sigma}_j^{D}-1}{\bar{\sigma}_j^{D}}} + \bar{a}_j^{D\_EU}\left(M_j^{EU}\right)^{\frac{\bar{\sigma}_j^{D}-1}{\bar{\sigma}_j^{D}}} + \bar{a}_j^{D\_RW}\left(M_j^{RW}\right)^{\frac{\bar{\sigma}_j^{D}-1}{\bar{\sigma}_j^{D}}}\right)^{\frac{\bar{\sigma}_j^{D}}{\bar{\sigma}_j^{D}-1}}$
	Domestic produced goods and imports from Europe transformation function	$\frac{y_j}{M_j^{EU}} = \frac{\left(\bar{a}_j^{D\_y}\right)^{\bar{\sigma}_j^{D}}\left(p_j^{M\_EU}\right)^{\bar{\sigma}_j^{D}}}{\left(\bar{a}_j^{D\_EU}\right)^{\bar{\sigma}_j^{D}}\left(p_j^{y\_tx}\right)^{\bar{\sigma}_j^{D}}}$
	Domestic produced goods and imports from RW transformation function	$\frac{y_j}{M_j^{RW}} = \frac{\left(\bar{a}_j^{D\_y}\right)^{\bar{\sigma}_j^{D}}\left(p_j^{M\_RW}\right)^{\bar{\sigma}_j^{D}}}{\left(\bar{a}_j^{D\_RW}\right)^{\bar{\sigma}_j^{D}}\left(p_j^{y\_tx}\right)^{\bar{\sigma}_j^{D}}}$
	Price of the CES aggregation (D) between domestic (y) and importation (M) goods supply	$p_j^{D} = \frac{p_j^{y\_tx} y_j + p_j^{M\_EU} M^{EU} + p_j^{M\_RW} M^{RW}}{D_j}$
International Accounts – Export Disaggregation	Transformation production function of exports and domestic Armington goods supply (CET)	$D_j = \bar{\beta}_j^{EX}\left(\bar{b}_j^{EX\_Q}\left(Q_j\right)^{\frac{\bar{\sigma}_j^{EX}+1}{\bar{\sigma}_j^{EX}}} + \bar{b}_j^{EX\_EU}\left(EX_j^{EU}\right)^{\frac{\bar{\sigma}_j^{EX}+1}{\bar{\sigma}_j^{EX}}} + \bar{b}_j^{EX\_RW}\left(EX_j^{RW}\right)^{\frac{\bar{\sigma}_j^{EX}+1}{\bar{\sigma}_j^{EX}}}\right)^{\frac{\bar{\sigma}_j^{EX}}{\bar{\sigma}_j^{EX}+1}}$

Equations (continued):

Type	Descriptions	Model Equations
International Accounts – Export Disaggregation (continued)	Final goods supply and exports to Europe transformation function	$\frac{Q_j}{EX_j^{EU}} = \frac{\left(\bar{b}_j^{EX\_RW}\right)^{\bar{\sigma}_j^{EX}} \left(p_j^{Q}\right)^{\bar{\sigma}_j^{EX}}}{\left(\bar{b}_j^{EX\_Q}\right)^{\bar{\sigma}_j^{EX}} \left(p_j^{EX\_RW\_tx}\right)^{\bar{\sigma}_j^{EX}}}$
	Final goods supply and exports to RW transformation function	$\frac{Q_j}{EX_j^{RW}} = \frac{\left(\bar{b}_j^{EX\_EU}\right)^{\bar{\sigma}_j^{EX}} \left(p_j^{Q}\right)^{\bar{\sigma}_j^{EX}}}{\left(\bar{b}_j^{EX\_Q}\right)^{\bar{\sigma}_j^{EX}} \left(p_j^{EX\_EU\_tx}\right)^{\bar{\sigma}_j^{EX}}}$
	Price of the CET disaggregation of Armington aggregation (D) between exports (EX) and final goods (Q) supply	$p_j^{Q} = \frac{p_j^{D} D_j + p_j^{EX\_EU} EX_j^{EU} + p_j^{EX\_RW} EX_j^{RW}}{Q_j}$
IVA prices	Final purchase price for households (with taxes) of the good offered in the economy	$p_i^{Q\_H\_tx} = p_i^{Q}\left(1+\bar{t}x_i^{H}\right)$
	Final purchase price for government (with taxes) of the good offered in the economy	$p_i^{Q\_G\_tx} = p_i^{Q}\left(1+\bar{t}x_i^{G}\right)$
	Final purchase price for investment (with taxes) of the good offered in the economy	$p_i^{Q\_I\_tx} = p_i^{Q}\left(1+\bar{t}x_i^{I}\right)$
	Final purchase price for European tourists (with taxes) of the good offered in the economy	$p_i^{Q\_Tou\_EU\_tx} = p_i^{Q}\left(1+\bar{t}x^{Tou\_EU}\right)$
	Final purchase price for rest of the world tourists (with taxes) of the good offered in the economy	$p_i^{Q\_Tou\_RW\_tx} = p_i^{Q}\left(1+\bar{t}x^{Tou\_RW}\right)$
Destinations Balance Equations	Balance equation of possible final goods destinations	$Q_i = d_i^{H} + d_i^{Tou\_EU} + d_i^{Tou\_RW} + d_i^{G} + d_i^{I} + d_i^{II}$
	Balance equation of intermediate inputs sales and demand	$d_i^{II} = \sum_{j=1}^{n} y_{ij}^{II}$
	European tourists demand for goods in national territory	$d_i^{Tou\_EU} = \frac{\bar{\sigma}_i^{Tou\_EU}\, \bar{\varepsilon}^{EU}\, Y^{Tou\_EU}}{p_i^{Q\_Tou\_EU\_tx}}$
	Rest of the world tourists demand for goods in national territory	$d_i^{Tou\_RW} = \frac{\bar{\sigma}_i^{Tou\_RW}\, \bar{\varepsilon}^{RW}\, Y^{Tou\_RW}}{p_i^{Q\_Tou\_RW\_tx}}$

Equations (continued):

Type	Descriptions	Model Equations
Household Equations	Household income	$Y^H = p^L \overline{L}^H + p^K \overline{K}^H + \overline{T}^{G\_H} + \overline{T}^{EU\_H} + \overline{T}^{RW\_H}$
	Household domestic goods demand	$d_i^H = \frac{\overline{\mu}_i^H \left[\left(1-\overline{s}^H\right)\left(Y^H - \overline{T}^{H\_G} - \overline{tx}^D\right)\right]}{p_i^{Q\_H\_tx}}$
	Household consumption abroad in Europe (household tourism in Europe)	$d_H^{EU\_Tou} = \frac{\overline{\mu}_{EU}^H \left[\left(1-\overline{s}^H\right)\left(Y^H - \overline{T}^{H\_G} - \overline{tx}^D\right)\right]}{\overline{\varepsilon}^{EU}\, \overline{p}_{EU}^{average}}$
	Household consumption abroad in the rest of the world (household tourism in the rest of the world)	$d_H^{RW\_Tou} = \frac{\overline{\mu}_{RW}^H \left[\left(1-\overline{s}^H\right)\left(Y^H - \overline{T}^{H\_G} - \overline{tx}^D\right)\right]}{\overline{\varepsilon}^{RW}\, \overline{p}_{RW}^{average}}$
	Household Expenditure	$E^H = \left(\sum_{i=1}^{n} d_i^H p_i^{Q\_H\_tx}\right) + d_H^{EU\_Tou}\overline{\varepsilon}^{EU}\,\overline{p}_{EU}^{average} +$ $d_H^{RW\_Tou}\overline{\varepsilon}^{RW}\,\overline{p}_{RW}^{average} + \overline{T}^{H\_G} + \overline{tx}^D$
	Household total savings	$S^H = \overline{s}^H\left(Y^H - \overline{T}^{H\_G} + \overline{tx}^D\right)$
Government Equations	Government income	$Y^G = p^K \overline{K}^G + \overline{T}^{H\_G} + \overline{T}^{EU\_G} + \overline{T}^{RW\_G} + \overline{tx}^D +$ $\sum_j \overline{tx}_j^{CCSSE} L_j p^L + \sum_j \overline{tx}_j^{CCSSH} L_j p^L + \sum_j \overline{tx}_j^{y} y_j p_j +$ $\sum_j \left(\sum_i \overline{tx}_j^{M\_II} y_{ij}^{II} p_i^Q\right) + \sum_i \overline{tx}^{EX\_EU} EX_i^{EU} p_i^{EX\_EU} +$ $\sum_i \overline{tx}^{EX\_RW} EX_i^{RW} p_i^{EX\_RW} + \sum_i \overline{tx}^H d_i^H p_i^Q +$ $\sum_i \overline{tx}^G d_i^G p_i^Q + \sum_i \overline{tx}^I d_i^I p_i^Q + \sum_i \overline{tx}^{Tou\_EU} d_i^{Tou\_EU} p_i^Q +$ $\sum_i \overline{tx}^{Tou\_RW} d_i^{Tou\_RW} p_i^Q$
	Government expenditure	$E^G = \left(\sum_i d_i^G p_i^{Q\_G\_tx}\right) + \overline{T}^{G\_H}$
	Government domestic goods demand	$d_i^G = \overline{d}_i^{G\_initial}$
	Government total savings	$S^G = Y^G - E^G$

Equations (continued):

Type	Descriptions	Model Equations
Labor and Capital Market Clearing	Price of production factor Labor (with social contributions taxes)	$p_j^{L\_tx} = p^L\left(1+\bar{t}x_j^{CCSSE}+\bar{t}x_j^{CCSSH}\right)$
	Labor total quantity	$L^T = \sum_j L_j$
	Capital total quantity	$K^T = \sum_j K_j$
	Labor market clearing	$\bar{L}^H = L^T$
	Capital market clearing	$\bar{K}^H + \bar{K}^G = K^T$
Savings-Investment Equations	Total savings in the economy	$S = S^H + S^G + \bar{\varepsilon}^{EU} S^{EU} + \bar{\varepsilon}^{RW} S^{RW} + \bar{\varepsilon}^{EU}\overline{TK}^{EU} + \bar{\varepsilon}^{RW}\overline{TK}^{RW}$
	Europe total savings (in foreign currency)	$S^{EU} = \left[\left(\sum_i \frac{p_i^{M\_EU} M_i^{EU}}{\bar{\varepsilon}^{EU}}\right) + \left(d_H^{EU\_Tou}\, p_{EU}^{average}\right)\right] - \left[\left(\sum_i \frac{p_i^{EX\_EU\_tx} EX_i^{EU}}{\bar{\varepsilon}^{EU}}\right) + \left(\sum_i \frac{p_i^{Q\_Tou\_EU\_tx} d_i^{Tou\_EU}}{\bar{\varepsilon}^{EU}}\right) + \frac{\bar{T}^{EU\_H}}{\bar{\varepsilon}^{EU}} + \frac{\bar{T}^{EU\_G}}{\bar{\varepsilon}^{EU}} + \overline{TK}^{EU}\right]$
	Rest of the world total savings (in foreign currency)	$S^{RW} = \left[\left(\sum_i \frac{p_i^{M\_RW} M_i^{RW}}{\bar{\varepsilon}^{RW}}\right) + \left(d_H^{RW\_Tou}\, p_{RW}^{average}\right)\right] - \left[\left(\sum_i \frac{p_i^{EX\_RW\_tx} EX_i^{RW}}{\bar{\varepsilon}^{RW}}\right) + \left(\sum_i \frac{p_i^{Q\_Tou\_RW\_tx} d_i^{Tou\_RW}}{\bar{\varepsilon}^{RW}}\right) + \frac{\bar{T}^{RW\_H}}{\bar{\varepsilon}^{RW}} + \frac{\bar{T}^{RW\_G}}{\bar{\varepsilon}^{RW}} + \overline{TK}^{RW}\right]$
	Investment demand for each good	$d_i^I = \frac{\bar{\theta}_i I}{p_i^{Q\_I\_tx}}$
	Savings equals to investment	$I = S + WALRAS$
Additional Price Equations	Final goods exportation to Europe prices (in local currency)	$p_i^{EX\_EU} = \bar{\varepsilon}^{EU}\, \bar{p}_i^{EU\_EX}$
	Final goods exportation to the rest of the world prices (in local currency)	$p_i^{EX\_RW} = \bar{\varepsilon}^{RW}\, \bar{p}_i^{RW\_EX}$

Equations (continued):

Type	Descriptions	Model Equations
Additional Price Equations (continued)	Final goods exportation to Europe prices with taxes(in local currency)	$p_i^{EX\_EU\_tx} = p_i^{EX\_EU}\left(1+\bar{t}x^{EX\_EU}\right)$
	Final goods exportation to the rest of the world prices with taxes (in local currency)	$p_i^{EX\_RW\_tx} = p_i^{EX\_RW}\left(1+\bar{t}x^{EX\_RW}\right)$
	Final goods importation from Europe prices (in local currency)	$p_i^{M\_EU} = \bar{\varepsilon}^{EU}\,\bar{p}_i^{EU\_M}$
	Final goods importation from Europe prices (in local currency)	$p_i^{M\_RW} = \bar{\varepsilon}^{RW}\,\bar{p}_i^{RW\_M}$
	Consumer price index	$CPI = \sum_i \left(\bar{\mu}_i^{CPI}\,p_i^{Q}\right)$