An integrated economic-energy Computable General Equilibrium model of Portugal

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In recent years Portugal witnessed a major energy transition towards a high penetration rate of renewables, motivated by a policy of Feed-In Tariffs (FITs) and other subsidies. This strategy is part of the European environmental targets for 2020. In this thesis, a Computable General Equilibrium (CGE) static model was developed to assess the impact of that renewable energy policy in the Portuguese economy.

Portugal was modeled as an open economy whose two primary factors (Capital and Labor) were treated as imperfect markets. For Capital, a new piecewise function was introduced to create inefficiences in its sector mobility. Furthermore, each industry is capable of producing multiple goods – a rare feature for CGEs. In order to calibrate the model, a Social Accounting Matrix with data from the Portuguese National Statistics Institute was built and then altered using information from the National Energy Balance to include 13 Energy sectors, that represent specific technologies. A custom MATLAB project was used to solve the model, whose features, such as the production structure, behavioral parameters and the amount of goods, industries or factors can be altered freely.

Comparing the benchmark year with an alternative scenario without the FIT mechanism revealed that FITs were largely responsible by the shift towards renewable electricity, but they also induced a small loss in Gross Domestic Product. Hence, the model is able to quantify the tradeoff between the environmental benefits (resulting in better quality of life) and the loss of economic welfare caused by the FITs.

I. INTRODUCTION

Given the contemporany concern with climate change, the European Union (EU) decided to include environmental targets in Europe's 2020 agenda [7]. The main goal is to reduce CO_2 emissions by 20% (or 30% if possible) compared to 1990 mostly through the introduction of Renewable Energy Sources (RESs) and also by increasing Energy Efficiency thus reducing the total energy demand. Portugal has opted to introduce Feed-In Tariffs (FITs) in order to promote the growth of RESs, which should produce 31% of the total consumed energy and represent at least 45% of used electricity by 2020.

According to the FIT policy, Rede Eléctrica Nacional[1] (REN), the Portuguese grid operator, is required to purchase all the energy from RESs at a preset price regardless of the price of electricity in the Iberian Electricity Market (MIBEL). The FIT price depends on the used technology, for instance, Wind Parks are paid around 75€/MWh while Photovoltaic installations receive on average 257€/MWh.

However, as energy consumption and economic growth are often strongly correlated [8], Europe's environmental objectives may impair the wealth of its member states so the EU let each one chose how to reach its individual goals. The recently introduced FITs resulted in a drastic change of the Portuguese electricity mix and the economic structure. The major economic and environmental impacts were a slight decrease in Gross Domestic Product (GDP) and a large reduction in carbon emissions [11]. Also, since the rest of the economy purchases goods, namely electricity, from the energy sector, the other sectors also suffered some structural change.

A Computable General Equilibrium (CGE) model combines abstract General Equilibrium (GE) economic theory, expressed through equations, with realistic economic data to determine numerically the impact of an exogenous shock (such as the introduction of a FIT) in a set of endogenous variables such as prices, unemployment or green house gas emissions. The CGE static model has an initial scenario, often called Business as Usual (BaU) that represents reality without the introduction of the policy. Then, by changing one or some parameters, action known as introducing a *shock*, both scenarios can be compared to check the policy inefficiencies and how it can interfere with other measures [6]. The goal of this work is to build a hybrid static CGE of the Portuguese economy, with emphasis on the energy sector, that is capable of analyzing the simultaneous effects of the FIT mechanism on the economy and the environment, as well as other indirect outcomes.

II. ORIGINAL CONTRIBUTION

The purpose of this dissertation is to build a solid CGE modeling framework and use it to analyse the impact of

[1] National Electricity Grid

the FIT policy implemented in Portugal.

Constructing such a model requires the development of a system of equations capable of describing reality from an economic perspective. GE economic theory usually does not include non-clearing (or incomplete) markets, for instance unemployment rate and unused Labor. To introduce those concepts, a wage curve was incorporated into the model, as it was by Böhringer et al. [4], which had not yet been included into a CGE to study energy policies in Portugal. Moreover, a piecewise function was developed to account for Capital losses when it moves across production sectors. Also, unlike the usual practive, the production sectors are capable of simultaneously producing several different goods.

Bearing in mind that CGE models are calibrated to a benchmark period using actual data, a Social Accounting Matrix (SAM) was built to represent Portugal in 2010, with a total of 82 industries producing 88 goods. Then, the conventional energy sectors were replaced by 13 specific technologies and, after being converted into monetary flows, national energy interactions were added to the SAM. Nevertheless, due to computational constraints, both the non-Energy sectors and goods were reduced each to 10 items only.

In order to solve the set of equations that compose the model, i.e. to find new equilibria, a computational project was developed using MATLAB. This project is also capable of processing the large quantities of data necessary to calibrate the model and excute the calibration process according to the user's definitions. It is quite customizable as it can deal with a variable number of sectors, commodities and even the nesting structure can be easily specified.

Section III contains a description of the model's equations; Section IV presents the data and how it was processed; Section V the model's validation and Sections A and VII present the results and analysis, respectively. Finally, Section VIII contains some final remarks and an assessment of future works and possible improvements.

III. MODEL DESCRIPTION

Portugal is the main region being modeled in this CGE. It has 2 agents: 1 representative Household and 1 Government. They supply two primary production factors: Labor (L) and Capital or Assets (Capital (K) or A), receiving money in return. There are a total of s production sectors that create up to g different commodities. Goods and industries are both divided into 2 groups: Energy (E) and Material (or Non-Energy) Goods (Materials (M)), since they are going to be modeled into an slightly different manner.

In order to simplify the notation, all benchmark prices, including those related to imports and exports, were normalized to 1. Also, index i always refers to goods and sums over $1, \ldots, s$ and index j does the same for the production sectors $(1, \ldots, g)$.

A. Productive Sectors

The Productive Sectors, Firms or Industries transform inputs, a combination of goods and factors, into goods and services. For a certain productive structure, each firm tries to maximize its profits, which means it will try to produce as much output as possible while complying with a budget constraint.

After considering several options, the structure chosen for the group of sectors that are not involved in energy production is represented in Figure 1.

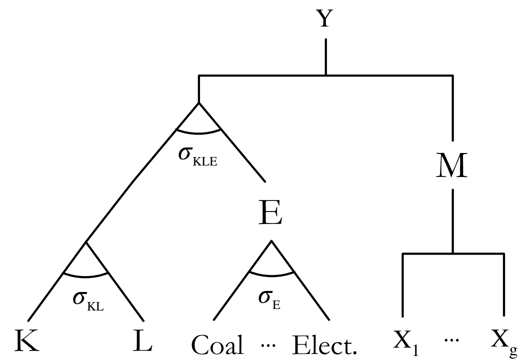

Figure 1. Productive structure of non-energetic sectors.

K and L were combined using a Constant Elasticity of Substitution (CES) whose elasticity value depends on the sector. The non-energetic M are also aggregated using a CES, but its elasticities are usually much smaller or even 0 in most CGE models, so a Leontief function was chosen. The E nest will be merged using a CES, but its elasticity is not relevant for most sectors as they only consume electricity. Finally, both the added-value-energy and the material composite goods are used in fixed proportions.

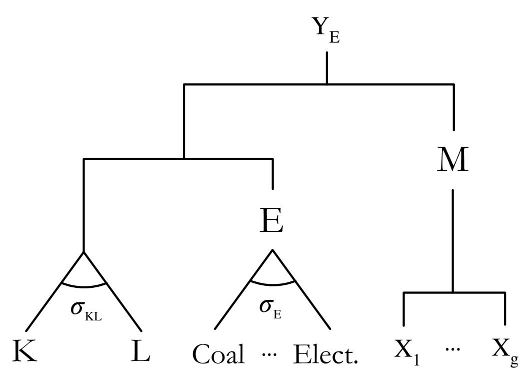

Figure 2. Productive structure of energetic sectors.

Figure 2 represents the productive structure of the Energy sectors. For these technologies, $\sigma_{\text{KL}} = 1$, $\sigma_{\text{E}} = 1$ and every other elasticity is zero.

The profit equation for each sector is:

$$\Pi_j^Y = Y_j r_j^Y - Y_j c_j^P (1 + t_j^P) - \delta K_j \tag{3.1}$$

Where the Depreciation of Capital has been modeled explicitly according to Equations 3.2a and 3.2b.

$$\delta K_j = \delta \bar{K}_j \frac{KS}{\bar{KS}} \tag{3.2a}$$

$$\delta KS = \sum_j \delta K_j \tag{3.2b}$$

The demand for each input can then be drawn from the profit equation.

$$X_{ij}^{\mathrm{IN}} = \frac{\partial \Pi_j^Y}{\partial p_i^A} \frac{-1}{1+t_j^P} \tag{3.3a}$$

$$L_j = \frac{\partial \Pi_j^Y}{\partial p_{\mathrm{L}}} \frac{-1}{1+t_j^P} \tag{3.3b}$$

$$K_j = \frac{\partial \Pi_j^Y}{\partial p_{\mathrm{K}}} \frac{-1}{1+t_j^P} \tag{3.3c}$$

The Capital resources that the firms demand aren't met by their own stock, instead they borrow assets from Households, the Government or the Rest of the World (RoW), such as property, money or others, which grant them a mixed income of interests and rents. Nevertheless, Capital reallocation has losses – not every unit of Capital can be repurposed and some turns into waste. This shall be portraid using variable that representst the percentage of unused capital.

$$(K_C + K_G)(1 - u_K) + \bar{K}_{RoW} = \sum_j K_j \tag{3.4}$$

So, if the borrowed Capital in a firm is smaller than the benchmark value part of it is going to be destroyed.

$$u_K = \frac{\text{Lost Capital}}{K_C + K_G}$$
with,
$$\text{Lost Capital} = \frac{\sum_j \bar{K}_j - K_j}{e^{K_{mob}}} \quad \text{if} \quad \bar{K}_j > K_j \tag{3.5}$$

Likewise, the production of goods, both Domestic X_{ij}^D and Exported X_{ij}^X, come from the same profit function.

$$X_{ij}^D = \frac{\partial \Pi_j^Y}{\partial p_i^D} \tag{3.6a}$$

$$X_{ij}^X = \frac{\partial \Pi_j^Y}{\partial p_i^X} \tag{3.6b}$$

As for the Formation of Fixed Capital, the investment in each commodity i can be modeled according to its price.

$$I_i = \frac{\bar{p}_i^A \bar{I}_i}{p_i^A \bar{I}} I \tag{3.7}$$

Then the net change of capital stock in the total economy is the difference between investment and depreciation.

$$\Delta K = I - \delta K \tag{3.8a}$$

$$KS = \bar{KS} + \Delta K \tag{3.8b}$$

B. Households

Families also have their own budget equation, where income must balance consumption M and savings S. There are three main sources of income: wages and rents from lending assets and a foreign spending term that compensates any trades performed with the RoW. The latter is defined in the Trade subsection and can be negative. Furthermore, a Current Transfers ($\bar{CT}_C$) parameter was introduced to represent other flows which are not being modeled.

Wage income is obtained by renting Labor to the productive sectors, however, due to unemployment, there is a percentage of the Labor force that doesn't receive any money. The unemployment rate is directly related to the price of Labor through a wage curve [4]. The parameter ψ, usually negative, representes the wage elasticity with respect to the unemployment rate: an increase in wages leads to a change in unemployment proportional to ψ.

$$\frac{p_L}{\bar{p}_L} = \left(\frac{u_R}{\bar{u}_R}\right)^{\psi} \tag{3.9}$$

And the labor used by all the productive sectors must equal the employed labor.

$$L(1 - u_r) = \sum_j L_j + L_{RoW} \tag{3.10}$$

So, discounting both unemployment and taxes, the total wages are

$$\text{Income} = p_{\mathrm{L}} L(1 - u_r) + p_{\mathrm{K}} K_C (1 - u_K) \tag{3.11}$$

Therefore, the budgetary equilibrium for the consumers is defined as follows:

$$M_C + S_C = \text{Income } (1 - t^F) + \bar{CT}_C \tag{3.12}$$

And the savings ratio is computed as:

$$s_C = \frac{S_C}{S_C + M_C} \tag{3.13}$$

The consumption is spent acquiring the aggregate consumer good C

$$p_C C = M_C \tag{3.14}$$

With the following profit equation based on aquisition (or Armington) prices:

$$\Pi^C = p_C - \left[\sum_i \theta_i^C \left(p_i^A\right)^{1-\sigma_C}\right]^{\frac{1}{1-\sigma_C}} \tag{3.15}$$

So the individual demand for commodity i within the family's consumption basket is

$$X_i^C = -C\frac{\partial \Pi^C}{\partial p_i^A} \tag{3.16}$$

C. Government

The Government collects taxes on several transactions present in the economy, such as (i) goods: imported, exported or produced domestically (ii) revenues of each industry and (iii) Household income.

When being taxed, the domestically produced goods also include the exported variety.

$$\begin{aligned} T = &\sum_i \left(p_i^D X_i^D + p_i^X X_i^X + p_i^M X_i^M t_i^M\right) t_i^G \\ &+ \sum_j Y_j^P c_j^Y t_j^P \\ &+ \left[p_{\text{L}} L(1-u_r) + p_{\text{K}} K_C (1-u_K)\right] t^F \end{aligned} \tag{3.17}$$

The government also accumulates savings, so the government's budget balance is portrayed in Equation 3.18, where M_G indicates the value of its consumption basket.

$$S_G + M_G = T + p_{\text{K}} K_G + \bar{C}T_G \tag{3.18}$$

$$p_G G = M_G \tag{3.19}$$

The composite good is then aggregated using the following profit equation:

$$\Pi^G = p_G - \left[\sum_i \theta_i^G \left(p_i^A\right)^{1-\sigma_G}\right]^{\frac{1}{1-\sigma_G}} \tag{3.20}$$

So the Government demand for good i is

$$X_i^G = -G\frac{\partial \Pi^G}{\partial p_i^A} \tag{3.21}$$

D. Trade and Armington Goods

The Armington good is a CES of the domestic and imported varieties of a good, and the former also includes the Trade and Transport Margins (TTM) through a Leontieff coefficients. Taxes are also included in this sector, as a percentage of the base price, resulting in the profit Equation 3.22.

$$\begin{aligned} \Pi_i^A = p_i^A - \Bigg[&\theta_i^D \left(\theta_i^{\text{Mar}} p_{\text{TTM}} + (1-\theta_i^{\text{Mar}}) p_i^D \frac{1+t_i^G}{1+\bar{t}_i^G}\right)^{1-\sigma_A} \\ &+ (1-\theta_i^D)\left(p_i^M \frac{1+t_i^G}{1+\bar{t}_i^G}\right)^{1-\sigma_A}\Bigg]^{\frac{1}{1-\sigma_A}} \end{aligned} \tag{3.22}$$

The TTM used in the Armington aggregation are provided by another sector which only uses of commodities as inputs, and thus has the following profit:

$$\Pi^{\text{TTM}} = p_{\text{TTM}} - \left[\sum_i \theta_i^{\text{TTM}} \left(p_i^A\right)^{1-\sigma_{\text{TTM}}}\right]^{\frac{1}{1-\sigma_{\text{TTM}}}} \tag{3.23}$$

This sector is supplied with TTM_i from each commodity i and produces the compound good TTM.

$$\text{TTM}_i = \text{TTM}\frac{\partial \Pi^{\text{TTM}}}{\partial p_i^A} \tag{3.24}$$

The total consumption of the Armington aggregate good k

$$A_i \frac{\partial \Pi_i^A}{\partial p_i^A} = \sum_j X_{ij}^{\text{IN}} + X_i^C + X_i^G + I_i + \text{TTM}_i \tag{3.25}$$

Which must balance in the production of domestic good k equations

$$X_i^D = \sum_j X_{ij}^D \tag{3.26a}$$

$$X_i^D = \frac{-A_i}{1+t_i^G}\frac{\partial \Pi_i^A}{\partial p_i^D} \tag{3.26b}$$

And the amount of imported good k

$$X_i^M = \frac{-A_i}{1+t_i^G}\frac{\partial \Pi_i^A}{\partial p_i^M} \tag{3.27}$$

For each Armington Good i, the used TTM are

$$X_i^{\text{TTM}} = -A_i \frac{\partial \Pi_i^A}{\partial p_{\text{TTM}}} \tag{3.28}$$

That also balance with the supply of TTM.

$$\sum_i X_i^{\text{TTM}} = \text{TTM} \tag{3.29}$$

To transform this model into a system with n equations and variables, it is necessary to set $s + 3g + 7$ variables as exogenous parameters defined outside the models' equations.

IV. DATA

2010 was chosen as the benchmark year and most of the necessary information came from the (Portuguese) National Statistics Institute (INE), which provided information regarding the productive sectors, the commercialized goods and also the Government and the Households. That information was organized into a SAM with 77 economic sectors, producing 82 non-energetic goods, and also 13 energy sectors that represent different technologies and generate mostly electricity, but due to computational restrains only the 10×10 (plus the energetic sectors and goods) aggregation was used.

Using the National Energetic Balance from 2010, a document elaborated by the DGEG containing the Portuguese energy fluxes – the energy equivalent of a SAM – it was possible to separate the energetic activities and goods from the rest. The original activity branches and products which were related to the energy fluxes: Electricity, gas, steam and air conditioning supply, Manufacture of coke and refined petroleum products and also Waste management were replaced by a set of specific energy-related sectors and commodities.

To calibrate some of the Energetic sectors it was necessary to use the data displayed in Table 1 concerning the Capital (K) and Labor (L) shares of RES and Fossil Fuel (FF) technologies that were retrieved from Proença and St. Aubyn [11], who claim to have determined their cost shares using data from the Markal-Times model of Portugal. It was assumed that geothermal energy has costs similar to solar power.

Technology	Capital (K)	Labor (L)	Fuel
Coal	0.29	0.32	0.39
Gas	0.11	0.10	0.79
Oil	0.08	0.09	0.83
Hydro	0.08	0.92	
Wind	0.21	0.79	
Solar	0.11	0.89	
Biomass	0.25	0.33	0.43

Table 1. Cost shares for energy technologies.

Due to the difficulty of determining elasticity parameters, it is common practice in CGE models to use values from relevant literature. Bearing this in mind, table 2 contains a summary of the parameters and their sources.

The sector specific values of σ_{KL} and σ_{KLE} as well as the Armington trade elasticities σ_{A} were gathered from the Global Trade Analysis Project (GTAP) database, the transformation elasticities come from Proença and St. Aubyn [11] and Böhringer et al. [4] also provided guidance when choosing the remaing values. The wage curve elasticity ψ was also corroborated by Robalo Marques et al. [12].

V. VALIDATION SCENARIO

In order to assess the validity of the model, the first scenario attempts to describe the year 2011. By comparing the simulated version with real data from that year, it should be possible to evaluate the GE model.

In this scenario, both the Household and Government Capital Stocks were set to their 2011 values. The Savings and the Available Labor were also altered to their respective 2011 values. Import and Export prices and tax parameters remained constant, except for the FITs, whose changes are represented in Table 3. The *numeraire* is the consumer price index p_{C} and a new equilibrium was found with $|\mathbf{y}_i| = 0.2823$.

First of all, Table 4 displays the Portuguese electricity mix, excluding imported electricity, in 2010, then the model's projections for 2011 and finally the real data from 2011.

In the imposed shock, only the wind power FIT was increased which should result in a growth of wind generated electricity. In fact, its projected share in the energy mix rose by 0.5%, matching the real share. On the other hand, hydroelectricity saw its production increased by 0.2% despite the FIT reduction as it is still a relatively cheap energy source. This projection is incorrect as the benchmark year was characterized by high rainfall and the model doesn't take pluviosity into account.

The FIT for photovoltaic and geothermal power suffered the highest cut, resulting in expected drops of 0.08% and 0.11% in their respective electricity share, which is contradicted by the data that shows a small increase in electricity production from both sources. There are severall explanations for this discreapancy: the already installed capacity was not reduced as it is difficult to repurpose the equipment; the FIT was already higher than the break-even point or there was a reduction of cost of installing these technologies due to technological improvements. Furthermore, the trends in the FF mix could not be predicted corretly as they depend on external factors not included in the model.

After the shock, the overall electricityconsumption increased by 0.65% and its price went down by more than 3%. These results are contradicted by DGEG's report of a 3% decline in consumption and a price hike of 3.8% in electricity tariffs. Even though some FITs were reduced and the total green electricity production was lower, the electricity price was increased to compensate the 'tariff deficit'. The conjunction of higher prices and austerity measures caused the electricity demand reduction wheres the model expected the opposite results.

Despite the growth of availabe Labor, the actual use of this factor droped significantly since the unemployment rate grew by 3.4%, increasing more than the real value: 12.7% in 2011. Also, with such a large rise in the amount of available Assets, the rents obtained from those were 2.3% lower.

Since the total tax revenue was kept constant, the tax on Household income decreased by 2.55% mostly through indirect effects: with smaller subsidies, the market distortions are lessened and the other sectors are more active – providing more tax money. The reduction in electricity costs was quite relevant. The direct subsidies to RESs actually increased from 870 to 1087 M€ as wind and hydroelectricity provided more energy than during benchmark year.

The GDP decreased by 1% relative to 2010, while the model foresaw a -1.79% reduction. The Compensating

	Elasticity	Value(s)
σ_{M}	Aggregation of Material inputs	0
σ_{E}	Aggregation of Energetic inputs	1 to 10
σ_{KL}	Aggregation of Capital and Labor	0 to 1.26
σ_{KLE}	Aggregation of Added-value and Energy	0 to 0.6
σ_{Y}	Final aggregation of inputs	0
η_{Y}	Disaggregation of industry good into several goods	−1
η_{X}	Disaggregation into domestic and foreign varieties	−2
σ_{A}	Armington aggregation of Domestic and Imported varieties	1 to 4.4
ψ	Wage curve elasticity	−0.1
σ_{C}	Consumer basket elasticity	0.2
σ_{G}	Government basket elasticity	0.2
K_{mob}	Capital Mobility	1

Table 2. Values of the external parameters (mostly elasticities) used in the model.

FITs	Benchmark (€/MWh)	Scenario (€/MWh)	Change
Hydro Power	91.07	88.88	– 2.4%
Wind Power	88.70	90.54	2.1%
Photovoltaic[a]	344.77	304.94	−11.6%
Geothermal[b]	344.77	304.94	−11.6%
Biomass	113.40	106.63	– 6.0%

[a] Also includes Tidal energy.
[b] ERSE combines the FIT for Photovoltaic and Geothermal electricity, but the data from the National Energy Balance provided by DGEG separates those two RESs, so they were processed as differents technologies with the same FIT.

Table 3. Control variables used in the first scenario – year 2011

	2010	Model	2011
Coal	13.7%	13.6%	24.5%
Natural Gas	31.6%	31.5%	27.8%
Oil	1.0%	1.0%	0.1%
FFs	46.3%	46.1%	52.4%
Hydro Power	30.6%	30.8%	23.1%
Wind Power	17.0%	17.5%	17.5%
Photovoltaic	0.40%	0.32%	0.53%
Geothermal	0.36%	0.25%	0.40%
Biomass	5.4%	5.1%	6.1%
RESs	53.7%	53.9%	47.6%

Table 4. Portuguese Electricity mix for 2010, the model's results for 2011 and also that year's real values for comparison.

Variation increased by 0.30% and the Real Consumption grew by 0.32%. However, these parameters don't incorporate the impact of future investments or the health benefits drawn from the lower CO_2 emissions.

To sum up, despite the lack of a parameter to control the availability of resources, the changes in a FIT has a direct impact on the technology it represents. Nevertheless, the model doesn't predict correcly the impact of the policy in the electricity price and demand, an effect that is propagated to other economic sectors. As for other economic indicators, such as GDP and unemployment, the results are coherent with the real data from 2011. Concerning investment and capital depreciation, there were no relevant changes in the variables, which means the model is not accurately representing this aspect of the economy.

VI. RESULTS

Since the FIT mechanism had already been implemented in the benchmark year, in order to evaluate the impact of the FITs the second scenario simulates the Portuguese economic and energetic sectors without those tarrifs. The system could not reach a new equilibrium under the desired tolerance with the parameters used in the previous scenario – namely, the low Energy aggregation elasticity, so this parameter was increased to 10, in compliance with [17].

The control variables were the same as in the previous scenario but all of them retained their benchmark values, excluding the FITs, that were completely removed. The consumer price index p_{C} remained the *numeraire* and the new equilibirum was found with $|\mathbf{y}_i| = 0.6813$.

Without any FIT wind, photovoltaic and geothermal power would have almost no representation in the electricity sector, in the same way those technologies were not used in the early 2000s. The projected decrease in hydroelectricity corresponds to the dismantlement of many small to medium sized hydric power plants (< 10MW) as only large hydro power is viable without a FIT – matching once again the portuguese energy mix before the introduction of this policy. As for biomass, its share in the electricity mix would also be higher since before the introduction of the FITs, biomass and co-generation

	2010	Model	Change
Coal	13.7%	18.6%	4.9%
Natural Gas	31.6%	43.8%	12.2%
Oil	1.0%	3.1%	2.1%
FFs	**46.3%**	**65.5%**	**19.2%**
Hydro Power	30.6%	24.4%	-6.2%
Wind Power	16.97%	0.03%	-16.95%
Photovaltaic	0.40%	0.01%	-0.39%
Geothermal	0.36%	0.01%	-0.35%
Biomass	5.4%	10.0%	4.7%
RESs	**53.7%**	**34.5%**	**-19.2%**

Table 5. Portuguese Electricity mix in the scenrario without FITs and differences from the benchmark year 2010.

were already used to produce electricity, so a large decline was never expected. Overall, the price of electricity would have decreased by 1.74% resulting in a consumption growth of 13.38% – still, it is important to recall that these variables were not correct in the previous scenario.

In this scenario, the use of Labor would increase as the expectations for the unemployment rate are a fall from 10.8% to 10.7%, accompanied by a small wage increase of 0.1%. Assets would also provide higher earnings in this scenario as their rental price increased by 0.5%.

The tax burden on Households decreased by 3.13%, which is expected since the Government was no longer supporting the FIT scheme and kept the same level of tax revenue. This increase in income led to improved Welfare: compensating variation (or utility) increased by 2.35% and the real consumption grew 2.33%. Still, GDP would have decreased by -6% (from $172,859$ to $162,488$ M€) as Portugal would be much mode dependent on imported Fossil Fuels.

Relative price and activity changes are shown in Tables 6 and 7. The farming, extracting and manufacturing sector (Sector code 1) would have profited the most from the reduced energy price, with an activity rise of 21.2%. On the other hand, retail, commerce and transportation (code 4) are the most damaged activity (down by 12.5%) as the latter relies a lot on imported fuels and the increasing demand created a price hike.

Good [a]	Price (%)	Good	Price (%)
1	6.07	OL	309.65
2	4.35	NG	60.98
3	0.61	DE	13.39
4	-4.22	TE	18.49
5	0.38	HE	-52.20
6	2.67	WE	-99.93
7	1.26	PV	-99.55
8	2.10	GT	-99.51
9	0.95	BE	16.93
10	2.18	HT	39.14
CO	70.88	BM	134.60
PL	362.36		

[a] List of Goods in Table 11

Table 6. Relative commodity price changes from the benchmark year in the No FITs Scenario.

Sector[a]	Activity (%)	Sector	Activity (%)
1	21.16	OR	552.8
2	7.77	TE	30.9
3	0.55	HP	-56.5
4	-12.45	WP	-100.0
5	-6.65	SP	-100.0
6	2.57	GT	-100.0
7	-0.27	EG	26.3
8	7.73	BM	27.8
9	0.62		
10	5.21		

[a] List of Sectors in Table 12

Table 7. Relative sectorial activity changes in the No FITs Scenario from the benchmark year.

VII. SENSITIVITY ANALYSIS

The sensitivity analysis is used to test the impact of key parameters in the model and in the results.

Table 8 displays the electricity mix for several pairs of capital mobility and energy aggregation elasticity – the original scenario had $K_{mob} = 1$ and $\sigma_{\mathrm{E}} = 1$. The hydro and the wind power shares increase in all the considered possibilities. As the contrains become more relaxed with higher the parameters, the more their share increases. Similarly, biomass, photovoltaic and geothermal power have their share reduced in all cases. On the other hand, the behaviour of FFs is simple to understand: either they all increase or they all decrease in proportion to their original share. The main scenario was chosen for its forecast of the wind power share, which is the closest to the real value of 2011.

Regardless of those parameter values, the price of electricity decreased and its consumption increased – more details in Table 9. As for the unemployment rate, it grew in every scenario, ranging from 13.20% to 14.79%. The same happened to the welfare indicators and the change in GDP. Overall, just by changing these two parameters there is no large impact on the results described in Section V.

While the *high* sensitivity simulation was made by increasing every Arminton elasticity by 33%, the *low* version was executed by decreasing every trade elasticity parameter by 33%. Table 10 list some of the major variables in Scenario 2011 (labeled *normal*) and their respective *high* and *low* counterparts.

The trading section has a relatively large impact on some variables: noticeably wages, rents and the price of electricity, with repercussions to the rest of the system. Still, the electricity mix, the GDP and the welfare in-

Capital Mobility (K_{mob})	2010	0	0.5	1	2	0	1	2	1	2011
Energy Elasticity (σ_E)		1	1	1	1	2	2	2	5	
Coal	13.68	13.67	13.65	13.63	13.61	13.77	13.74	13.71	13.17	24.46
Oil	1.02	0.99	0.99	0.99	0.98	1.01	1.02	1.02	0.89	0.10
Natural Gas	31.61	31.55	31.50	31.46	31.41	31.81	31.72	31.67	30.25	27.81
FFs	**46.31**	**46.21**	**46.14**	**46.08**	**46.00**	**46.59**	**46.47**	**46.40**	**44.31**	**52.38**
Hydro Power	30.59	30.62	30.72	30.80	30.89	30.71	30.95	31.06	31.23	23.09
Wind Power	16.97	17.42	17.45	17.47	17.50	17.91	17.99	18.02	19.24	17.46
Photovaltaic	0.40	0.32	0.32	0.32	0.32	0.00	0.01	0.01	0.16	0.53
Geothermal	0.36	0.25	0.25	0.25	0.25	0.00	0.01	0.01	0.10	0.40
Biomass	5.36	5.19	5.13	5.08	5.03	4.77	4.58	4.50	4.95	6.14
RESs	**53.69**	**54.69**	**53.86**	**53.92**	**54.00**	**53.41**	**53.53**	**53.60**	**55.69**	**47.62**

Table 8. The resulting electricity mix of scenario 2011 for different values of capital mobility and energy aggregation elasticity.

Capital Mobility (K_{mob})	0	0.5	1	2	0	1	2	2011
Energy Elasticity (σ_E)	1	1	1	1	2	2	2	
Electricity Price (%)	-2.08	-2.65	-3.09	-3.55	-3.93	-4.92	-5.31	3.8
Electricity Demand (%)	0.67	0.66	0.66	0.63	9.02	11.35	12.27	-3

Table 9. Simulation of 2011: electricity price and demand for different values of capital mobility and energy aggregation elasticity.

	low	*normal*	*high*
Unemployment	10.38%	10.66%	11.04%
Wages	0.40%	0.13%	-0.22%
Rents	-0.33%	0.53%	1.15%
GDP (M€)	161,400	162,488	165,593
Electricity Price	2.8%	-1.7%	-3.2%
Electricity Domestic Use	0.9%	13.4%	17.2%
Compensating Variation	0.77%	2.35%	1.35%
Real Consumption Change	0.77%	2.33%	1.30%

Table 10. Simulations of the scenario No FITs with different values of Armington Import and Export elasticities.

dicators maintain their regular trends. Either doubling or halving the Wage Curve Elasticity (ψ) did not result in any significant changes in the unemployment rate ($\leq 0.1\%$) or the nominal wage ($\leq 0.03\%$) .

Other than changing the porportions of the goods in the consumer basket, σ_C doesn't seem to have any major repercurtions on other variables.

VIII. CONCLUSIONS

Climate change is one of the key issues of the XIXst century. To prevent it, we are heading torwards sustainable development, so that we can meet the needs of the present without compromising the ability of future generations to meet their own needs. Aligned with the EU's goals, Portugal has shifted towards green electricity with the introduction of a FIT mechanism, but what was the ecomic impact of its policies?

In this thesis a CGE model was built with the purpose of assesssing that impact. There are three basic pillars to CGE modelling: the set of equations, parameter calibration and finding a numerical solution. In Chapter **??**, the first scenario, a small leap from the benchmark year (2010) to the *shock* year (2011) was used to asses the qualities and flaws of the model.

In term of equations, the Capital mobility piecewise function successfully controled this primary factor. In Table 8, we can see that higher Capital Mobility led to lower shares of Photovoltaic and Geothermal in the electricity mix as they became less attractive with the FIT reduction and lower Capital mobility prevented the Capital from reallocating as easily.

The Labor market included a wage curve, which was not present in other CGEs applied to Portugal. Indeed, the introduction of the unemployment rate in the model suggests it would be slightly lower without the FITs.

Also, the depreciation of capital is usually supported by the investors instead of the industrial sectors and this experiment did not demonstrate any additional insights from that alteration as most values did not change. These expressions (Equation 3.2a) should be either revisited or removed entirely from the model.

Still, the system that was created has its merits: it's a hybrid CGE that can process sectors with multiple outputs, whereas most models have each sector producing only one type of output and require more data treatment. The introduction of a piecewise function to model Capital mobility was a success, yey the depreciation of capital failed at presenting interesting results.

As a fundamental part of the modelling tool's construction, plenty of data was gathered and built into a SAM matching the model's equations. The energy fluxes from the National Energy Balance were transformed into monetary flows and incorporated into the SAM in order to represent with detail 13 energy technologies. The elasticity parameters were obtained through a literary review, as is commonplace in the field. Calculating new Portuguese specific elasticities would be enough work for a separate thesis.

However, the computational side of this work restricted the ambitious goals set in the beginning, considering that there is enough data to simulate 77 economic sectors, producing 82 non-Energy goods, and also 13 energy sectors that represent different technologies, but due to computation time restrains the non-Energy sectors and goods were only represented in the 10×10 aggregation.

The project that was developed to calibrate and solve the model was able to serve its purpose, although the code can be improved in several aspects. It was built with some flexibility, so it can be expanded to include more sectors, goods, factors and agents. Even the customization of the production structure is quite simple. Also, the algorithm created to compute the Jacobian numerically using analytical expressions succeeded in greatly reducing the computation time – one of the largest problem faced when trying to find new equilibria.

In term of results, the analysis was performed using a static CGE model, so it does not incorporate important dynamic effects, such as the 'Tariff Deficit' or technological development. And even as a static model, it could be improved in several fronts. One of the major issues in the first scenario, which was used for validation, was the lack of control over pluviosity, solar or wind availability. This problem can be solved by including more specific factors in the production of renewable electricity, yet these require careful calibration and are hard to grasp in economical terms.

The simulation of the Portuguese economy without the FIT mechanism in place shows that these policies were largely responsible by the shift towards using RES to generate electricity. Without them, the Government could have saved directly more than 4,000M€, but the dissociation from FFs also provided some economies. In fact, the results pointed to a smaller GDP in the scenario without the FITs. In contrast, the welfare indicators are biased towards higher well-being without the FIT policy in place, however they do not account for health improvements and other intangible enhancements in the quality of life obtained from it.

Despite the similarities, Proença and St. Aubyn's work predicts a smaller impact on the Portuguese economy. Major differences arise from the description of Portugal's production structure as in this thesis we propose sectors capable of generating multiple outputs.

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Appendix A: List of Sectors and Goods

Code	Industry
1	Agriculture, Forestry and Fishing
2	Mining, Quarrying, Manufacturing and Waste Related Activities
3	Construction Activities
4	Retail, Transportation, Accomodation and Food and Beverage Services
5	Information Services
6	Insurance Financial Services
7	Real Estate Activities
8	Professional, Scientifical, Technical and Business Support Activities
9	Public Administration, Education and Health
10	Other Activities, such as Sports, Arts and Social Work
CO	Coal and Lignite
PL	Petroleum
NG	Natural Gas
OL	Refined Oil
DE	Distributed Electricity
TE	Termoelectricity
HE	Hydroelectricity
WE	Wind Electricity
PV	Photovoltaic Electricity
GT	Geothermal Electricity
BE	Biomass Electricity
HT	Heat
BM	Biomass

Table 11. List of Goods

Code	Industry
1	Agriculture, Forestry and Fishing
2	Mining, Quarrying, Manufacturing and Waste Related Activities
3	Construction Activities
4	Retail, Transportation, Accomodation and Food and Beverage Services
5	Information Services
6	Insurance Financial Services
7	Real Estate Activities
8	Professional, Scientifical, Technical and Business Support Activities
9	Public Administration, Education and Health
10	Other Activities, such as Sports, Arts and
OR	Oil Refinery
TE	Thermoelectric Power
HP	Hydro Power
WP	Wind Power
SP	Solar Power
GT	Geothermal
EG	Electric Grid
BM	Biomass

Table 12. List of Sectors