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GEEM: a policy model for assessing climate-energy reforms for Italy

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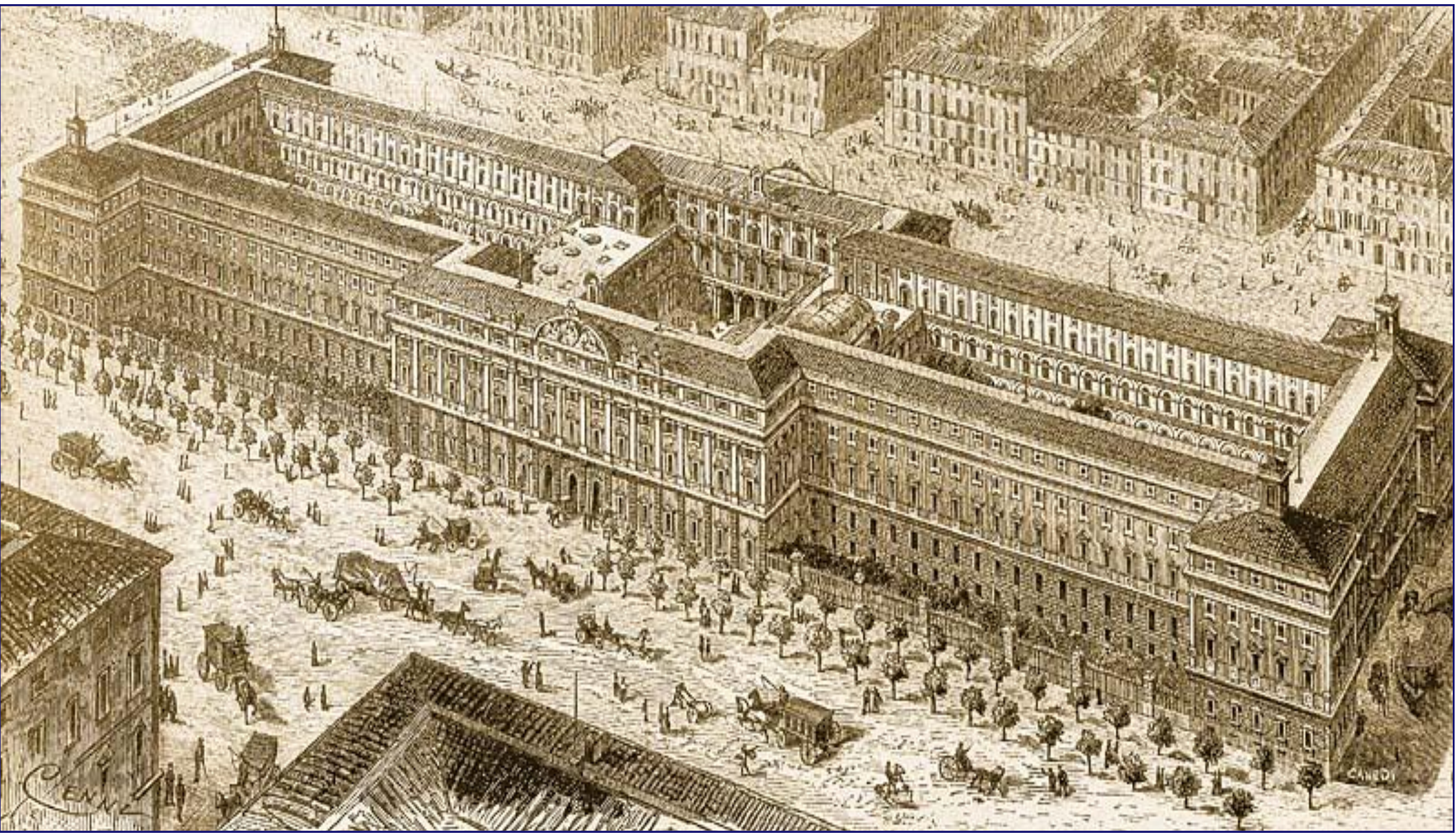

Working Papers

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GEEM: a policy model for assessing climate-energy reforms for Italy

Barbara Annicchiarico*, Susan Battles**, Fabio Di Dio§, Pierfrancesco Molina‡, Pietro Zoppoli•

Abstract

We build up a large scale, New Keynesian dynamic general equilibrium model embodying a cap on pollutant emissions, an electricity sector and fuel consumption to analyse climate-energy policies for the Italian economy. We consider several applications to illustrate how emission mitigation policies are likely to affect the economy. Our results show that a major trade-off may emerge between environmental quality and economic activity. However, we show how this potential trade-off can be effectively overcome by recycling the revenues from the sales of emission permits. Also, we find that the presence of an emission cap may significantly limit the expansionary effects of fiscal interventions as well as of policies aimed at fostering competition and productivity. Finally, a negative shock on gas and oil prices has a positive effect on the level of economic activity but is also found to increase investment in renewable sources.

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1 Introduction

In response to climate-energy issues and their effect on economic systems, many governmental and international organizations have been refining their policy models to better account for the interaction between economic and climate-energy policies. This growing effort reflects basically two concerns. First, a major awareness that macroeconomic performance and climate-energy policies are inherently intertwined, and that pursuing one objective without due consideration for the other may lead to achieving neither of the two. Indeed, social costs of negative externalities stemming from the production and the consumption of fossil fuel may impose heavy costs on both households and firms, with strong repercussions on economic activity as well.[1] Second, given the close interrelationship between macroeconomic performance and climate-energy policies, various macroeconomic policies, such as in the area of taxation, may need to be used in conjunction with environmental policies to the achievement of climate-energy targets. There is scope to better investigate how different policies interact, and what trade-offs they may give rise to, in order to better ascertain the appropriate policy mix required to reach environmental goals. In this respect, a full understanding of the impact of climate-energy policies through the use of fully-fledged models is highly desirable. Relevant models should include some realistic aspects, such as agents' expectations, imperfect price adjustments, real frictions and lack of perfect competition, in order to help us assess how general reform scenarios work under specific climate-energy constraints.

To explore the potential effects of climate-energy interventions within a unified approach we construct GEEM (General Equilibrium Environmental Model), a large-scale macroeconomic model designed for the Italian economy. In particular, we build up a dynamic general equilibrium (DGE) model specifically designed to capture the non-trivial interactions between climate-energy policies and the macroeconomic system in a fully microfounded set-up. Our model has four key features. First, the model embodies typical elements of the so-called New Neoclassical Synthesis, combining features at the heart of New Keynesian models, such as nominal rigidities in wages and prices, with features central to the Real Business Cycle (RBC) models, such as the systematic application of intertemporal optimization and of the rational expectations hypothesis in determining consumption, investment and factor supply decisions (e.g. Smets and Wouters, 2003, 2007; Galí and Gertler, 2007; Woodford, 2003, among others). This modeling approach represents a useful tool for policy analysis in a set-up able to match the dynamic linkages of the main macroeconomic variables, the interactions between rigidities on labour and product markets, and enables us to look into the effects of climate-energy policy interventions on economic performance in a consistent way. Second, the model incorporates an electricity sector distinguishing between fossil and renewable sources (RES). In this respect, GEEM is able to simulate, among other things, the dynamics of the most relevant economic variables in response to a progressive reduction in the emissions cap or an introduction of subsidies favouring the use of RES. Third, the model embodies a transport sector given by fuel consumption on the household side. Fourth, the intermediate-good and the electricity producing firms as well as the consumption of fuel produce GHG emissions. Nonetheless, the overall volume of GHG emissions is subject to an emission cap. The presence of such cap may thus give rise to major interactions with firm and consumer choices.

Given these features, GEEM can be used to analyze the response of the economy to a variety of standard shocks and policy interventions (e.g. technological changes, reduction in markups, fiscal reforms) under specific environmental policy regimes. This represents a significant strength of the

1. The internalization of negative externalities (i.e., GHG emissions) may instead trigger productivity improvements and innovation growth, thus fostering greenhouse gas emissions abatement and attracting investments in low-carbon technologies (see e.g. Porter and Van der Linke, 1995).

model and highlights its flexibility. Furthermore, with this simulation tool we are able to conduct a comprehensive analysis of the macroeconomic impact of climate and energy policies designed to tackle emissions directly and/or to induce a major use of clean energy sources. We are also able to study the effects of different shocks and the performance of policy interventions in other domains, independently of climate and energy instruments available to and effectively used by the policy maker. Thanks to this framework, the results obtained from the simulation of GEEM are consistent with and can be compared to those obtained from the main DGE models adopted by the European Commission for conducting economic policy evaluations and studying the impact of structural reforms (see, for instance, Ratto et al. 2009, Annicchiarico et al., 2013).

The methodology used in this model draws on the recent macro-environmental literature that makes use of the DGE framework to assess the impact of different climate and energy policies on economic activity.[2] In this respect, see the papers by Fischer and Springborn (2011), Heutel (2012) and Angelopoulos et al. (2013) who study environmental regulation in the presence of uncertainty through analyses based on RBC models. In particular, Fischer and Springborn (2011) analyze the business cycle properties of an economy hit by productivity shocks considering three environmental policies, namely an emission tax, an emission cap and an intensity target. They make use of a model where the level of the emissions generated by the economy depends on the quantity of a polluting intermediate input used in the production process, so that a reduction in emissions is obtained through factor substitution that, in turn, affects the level of output. In this framework the intensity target policy regime is shown to achieve the best results in terms of welfare, while the emission tax and the emission cap are found to be equivalent, though a cap system is found to generate lower volatility in output. Heutel (2012) studies optimal environmental policy in a RBC-type model where emissions are a byproduct of production and firms can decide to sustain the cost of emissions abatement without lowering their output. The decision on how much abatement effort to undertake depends on the level of emission taxes or the price of emission permits in the cap-and-trade scenario. In this framework optimal policy is found to be procyclical, so that the level of carbon emissions rises during expansions and decreases during recessions. However, optimal policy measures ultimately diminish the procyclicality of pollutant emissions compared to the no-policy case. Angelopoulos et al. (2013) consider a RBC model with two sources of uncertainty, namely technology shocks and emission intensity shocks and study the optimal environmental policy in this context. They show that the Ramsey planner, in an attempt to stimulate the economy, finds it optimal to cut taxes when a negative productivity shock occurs; however, when an adverse pollution shock materializes, it is optimal to increase taxes in order to finance abatement spending and thus mitigate the negative effects on the environment.

Other contributions in this direction include Annicchiarico and Di Dio (2015) and Dissou and Karnizova (2012). Specifically, Annicchiarico and Di Dio (2015) develop a closed economy model embodying characteristics of the New Neoclassical synthesis to study the business cycle under alternative environmental policy regimes (i.e. cap-and-trade, carbon tax, intensity target) and explore the role played by nominal rigidities in shaping the macroeconomic performance of the environmental policy regime adopted. By nesting New Keynesian aspects into a RBC-type model, they are able to explore the non-trivial interactions between pricing decisions and environmental policy in a simple unified framework. Dissou and Karnizova (2012) depart from the standard RBC setup, developing a multi-sector model in which, along with the good and service sector, there is an energy sector that supplies both polluting and clean inputs. In their model, uncertainty is due to sector-specific shocks,

2. For an overview of the macroeconomic approach to the study of environmental policy issues, see the survey by Fischer and Heutel (2013).

so allowing the authors to analyze the differences in the business cycle generated by sectoral shocks taken in isolation. They find that the source of uncertainty crucially influences the determination of the optimal policy. In the case of productivity shocks originating from the good and service sector, the emission tax and the cap perform in the same way, though using tax regimes involves a lower welfare cost than cap-and-trade in the case of productivity shocks stemming from the energy sector.

Only recently have large-scale DGE models been used for environmental policy analysis. On the grounds that models abstracting from the interaction between environmental policies and macroeconomic variables run the risk of overlooking important feedback effects in the economy, environmental policy papers have been increasingly approaching their issues from a macroeconomic perspective. Some examples include Conte et al. (2010) who explore the growth potential stemming from comprehensive environmental and innovation policy interventions through the use of the QUEST model; Bartocci and Pisani (2013) who evaluate the macroeconomic implications for France, Germany, Italy and Spain of taxing fuels for private transportation through the use of a DGE model; Buckowski (2010) who develops a multi-sector DGE model to assess climate-energy policies for Poland; Ganelli and Tervala (2011) who construct a fully-fledged open economy New Keynesian model designed for the study of the international transmission of environmental policy shocks.

To illustrate how GEEM can be used as a laboratory for policy analysis, in what follows we consider several climate-energy policy interventions and construct reform scenarios in the area of product market regulation and taxation. We use the model to study the cost and the effectiveness of specific policy climate-energy interventions as well as to consider more general interventions in different domains. We also analyze the effects of energy price shocks.

Our results show how GHG mitigation policies are likely to affect the economy. In general, a major trade-off may emerge between environmental quality and economic activity. However, we show how this trade-off can be effectively overcome by recycling the revenues from the sales of emission permits to reduce the burden of taxation on labour income. Tax shifts aimed at increasing the use of clean energy sources and/or reducing the consumption of fossil fuels, produce an important reallocation of emissions across sectors and are found to be expansionary. Policies aimed at fostering competition and productivity have positive effects on the level of economic activity, however the expansionary effects are mitigated by the underlying environmental policy that keeps the level of aggregate emissions fixed. Finally, a negative shock on gas and oil prices has a positive effect on the level of economic activity, as expected, but is also found to increase investment in RES.

The remainder of the paper is articulated as follows. Section 2 provides a short review about applied climate policy models. Section 3 provides a detailed description of the structure of GEEM. Section 3 describes the parametrization of the model and the solution strategy. Section 5 presents the scenarios specifically designed to illustrate some specific features of the model, while Sections 6 reports the results. Finally, Section 7 concludes.

2 Applied climate policy models: A review

Many institutions interested in the macro-environmental issues, such as universities, governments and international organizations, have devoted efforts to build large-scale models with different features according to the specific questions they answer and the peculiarities of the economic system under scrutiny.

The majority of these models have different characteristics but a common feature: they belong to the class of *general equilibrium* models. In turn, in this class two types of models stand out: *Dynamic General Equilibrium* (DGE) and *Computable General Equilibrium* (CGE) models.

Computable General Equilibrium models allow us to design a detailed representation of the economy under study including many, or at least the more relevant, economic sectors and geographical areas in order to estimate the impact of different policies at both aggregate and sectoral/territorial level. To be sure, the possibility to asses in which way each sector of the economy or geographical area is affected by the implementation of a specific policy is a valuable asset. Indeed, policy makers are usually interested to mitigate the costs or distribute the benefits of such policies across sectors looking at the inter-sectoral externalities. That is the reason why, so far, CGE models have represented the most popular tools to assess such policies although they also present not irrelevant drawbacks. First of all, CGE models need a great amount of resources in order to collect and manage the huge databases necessary to estimate all the elasticities and the other parameters for each sector included in the model. Furthermore, they lack the dynamic profile of the variables that plays a crucial role in policy evaluation.[3] In fact, CGE models take a picture of the state of the economy before and after the introduction of the policy but, they can say nothing of the transition path the economy goes through in reaching the new equilibrium. This is not a trivial matter when the transition implies, for instance, a long period of low growth or even recession.

In order to deal with this matter, *Dynamic General Equilibrium* models introduce the dynamic element deriving the inter-temporal optimal choices of rational agents. In this way, these models are able to describe how the economy reacts when is hit by shocks. Moreover, they introduce uncertainty so as the agent expectations of future variables may affect their optimal choices that in turn determine the dynamics of the economy. Despite that, this class of models can be easily converted into a deterministic setting introducing the assumption that the agents know in advance the emergence of a shock so as the uncertainty element is removed. The choice of a DSGE setting respect to the CGE stems from the importance to provide an instrument able to identify the final state of the economy after the introduction of the policy at hand as well as the time needed to reach it and the transition path followed by the main macroeconomic variables. Usually, DSGE models focus on the identification of the dynamic response of the most relevant aggregate variables to transitory as well as permanent climate-energy policy shocks. Nevertheless, it comes at price of being in the impossibility to disentangle the effects of the policy on each sector of the economy. One of the innovative features of GEEM is represented by the attenuation of such a trade-off by means of the development of a multi-sector framework. To this end, GEEM introduce the electricity sector along with the intermediate and final goods producers, so that it offers the possibility to control one of the most relevant sector when dealing with climate and energy policy.

3 The model set-up

The model is a large-scale small open-economy DGE model. Consistently with the conventional New Keynesian models and in the spirit of the so-called New Neoclassical Synthesis, the model integrates a large variety of nominal and real frictions shaping the short- and the medium-run behaviour of the economy, while neoclassical features tend to prevail in the long run. In particular, the model has been designed to capture cost-efficiency issues and climate-energy policies, such as the reduction of greenhouse gas emissions (GHG), the increase in renewable energy production and energy efficiency. The model features seven types of agents: final good producers, intermediate good producers, a foreign sector (importing and exporting firms), an electricity sector, households-workers, monetary

3. There are a few examples of multi-period CGE models. In such models, however, agents have myopic and not rational expectations as they rely on the current conditions to make decisions, actually without taking into account the expectations on future developments of their current action.

and fiscal authorities. Furthermore, we assume that the overall emissions of the economy are subject to a cap. The government thus allocates the cap among the sectors (firms and households), according to a specific allocation rule. Households are assumed to receive the permits for free (grandfathering) while firms are assumed to buy allowances through an auction process. Nonetheless, firms cannot trade their permits in a secondary market.

In what follows we describe the main features of GEEM, emphasizing the key policy variables to be used in our simulation exercises. A simplified flow chart of the main relationships between the various sectors in the model is shown in Figure 1.

3.1 Final-good producers

Firms producing final non-tradable goods are assumed to be symmetric and to act under perfect competition. The representative firm producing the final non-tradable good E_t combines a bundle of domestically produced intermediate goods $Y_{H,t}$ with a bundle of imported intermediate goods $IMPF_t$ according to a constant elasticity of substitution (CES) technology:

$$E_t = \left[(1-\alpha_{IMPF})^{\frac{1}{\sigma_{IMPF}}} Y_{H,t}^{\frac{\sigma_{IMPF}-1}{\sigma_{IMPF}}} + \alpha_{IMPF}{}^{\frac{1}{\sigma_{IMPF}}} IMPF_t^{\frac{\sigma_{IMPF}-1}{\sigma_{IMPF}}} \right]^{\frac{\sigma_{IMPF}}{\sigma_{IMPF}-1}}, \tag{1}$$

where $\sigma_{IMPF} > 1$ is the elasticity of substitution between domestically produced and internationally produced intermediate goods, and α_{IMPF} represents the share of foreign intermediate goods used in the production of the final goods. Both $Y_{H,t}$ and $IMPF_t$, in turn, represent an aggregate of a continuum of good varieties indexed by $j \in [0,1]$ and $m \in [0,1]$, respectively:

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(j)^{\frac{\theta_{Y_H}-1}{\theta_{Y_H}}} dj \right]^{\frac{\theta_{Y_H}}{\theta_{Y_H}-1}}, \tag{2}$$

$$IMPF_t = \left[\int_0^1 IMPF_t(m)^{\frac{\theta_{IMPF}-1}{\theta_{IMPF}}} dm \right]^{\frac{\theta_{IMPF}}{\theta_{IMPF}-1}}, \tag{3}$$

where $\theta_{Y_H}, \theta_{IMPF} > 1$ denote the elasticities of substitution across the varieties of intermediate goods produced at home and abroad respectively.

At the optimum the following conditions hold:

$$Y_{H,t} = (1-\alpha_{IMPF}) \left(\frac{P_t}{P_{E,t}} \right)^{-\sigma_{IMPF}} (C_{Y,t} + I_t + G_t), \tag{4}$$

$$IMPF_t = \alpha_{IMPF} \left(\frac{P_{IMPF,t}}{P_{E,t}} \right)^{-\sigma_{IMPF}} (C_{Y,t} + I_t + G_t), \tag{5}$$

where we have used the fact that in equilibrium $E_t = C_{Y,t} + I_t + G_t$, with $C_{Y,t}$, I_t, and G_t, denoting consumption, investment and public consumption, respectively; P_t and $P_{IMPF,t}$ are the prices of domestic and foreign intermediate goods respectively and the price index $P_{E,t}$ is defined as

$$P_{E,t} \equiv \left[(1-\alpha_{IMPF}) P_t^{1-\sigma_{IMPF}} + \alpha_{IMPF} P_{IMPF,t}{}^{1-\sigma_{IMPF}} \right]^{\frac{1}{1-\sigma_{IMPF}}}. \tag{6}$$

The demand for each domestically produced variety and for foreign variety immediately follows. See Appendix A for more details.

3.2 Intermediate-good producers

The intermediate goods sector is made up of a continuum of monopolistically competitive producers. This sector can be identified as the manufacturing sector. The production function for the typical firm is of the following form:

$$Y_t = A_t d(M_t)\left[\rho_{VA}{}^{\frac{1}{\theta_Y}} VA_t^{\frac{\theta_Y-1}{\theta_Y}} + (1-\rho_{VA})^{\frac{1}{\theta_Y}} EL_t^{\frac{\theta_Y-1}{\theta_Y}}\right]^{\frac{\theta_Y}{\theta_Y-1}}, \tag{7}$$

where A_t represents total factor productivity (TFP), VA_t is the value added, EL_t represents electric energy, ρ_{VA} is the share of value added used in the production of the intermediate good, while $\theta_Y > 1$ is the elasticity of substitution between value added and electricity.[4] Furthermore, $d(M_t)$ represents a damage function, mapping the stock of carbon dioxide in the atmosphere to the economic damage on productivity. The functional form follows Golosov et al. (2014) in the adaptation of Annicchiarico and Di Dio (2016):

$$d(M_t) = e^{-\phi(M_t-\overline{M})}, \tag{8}$$

where M_t is the world stock of emissions, $\overline{M}$ is the pre-industrial stock level of emissions and ϕ is a positive parameter measuring the intensity of this negative externality.[5].

We assume that EL_t is a bundle that aggregates a continuum of varieties indexed by $i \in [0,1]$ according to

$$EL_t \equiv \left[\int_0^1 EL_t(i)^{\frac{\theta_{EL}-1}{\theta_{EL}}} di\right]^{\frac{\theta_{EL}}{\theta_{EL}-1}}, \tag{9}$$

where $\theta_{EL} > 1$ denotes the elasticity of substitution across different varieties of electricity generation. As we will see, pro-competitive policy interventions in the electricity sector will be introduced into the model by increasing the parameter θ_{EL}. Given EL_t, the representative firm determines its demand of the single variety i minimizing total expenditure $\int_0^1 P_{EL,t}(i)EL_t(i)di$. Hence, the demand of the variety i is $EL_t(i) = \left(\frac{P_{EL,t}(i)}{P_{EL,t}}\right)^{-\theta_{EL}} EL_t$, with $P_{EL,t}$ being the ideal price index of electricity.

The value added VA_t is produced combining capital K_t and labour L_t according to the following CES technology:

$$VA_t = \left[\rho_{K_{VA}}{}^{\frac{1}{\theta_{VA}}} (u_t^K K_t)^{\frac{\theta_{VA}-1}{\theta_{VA}}} + (1-\rho_{K_{VA}})^{\frac{1}{\theta_{VA}}} L_t^{\frac{\theta_{VA}-1}{\theta_{VA}}}\right]^{\frac{\theta_{VA}}{\theta_{VA}-1}}, \tag{10}$$

where $\theta_{VA} > 1$ is the elasticity of substitution between capital and labour, u_t^K is the rate of utilization at which capital is utilized and $\rho_{K_{VA}}$ represents the share of capital used to generate the value added. Moreover, L_t represents a CES aggregate of two labour inputs, namely labour supplied by two different types of unionized workers, related to Ricardian (L_R) and non-Ricardian (L_{NR}) households:

$$L_t = \left[\rho_{L_R}{}^{\frac{1}{\sigma_L}} (ef_{L_R} L_{R,t})^{\frac{\sigma_L-1}{\sigma_L}} + (1-\rho_{L_R})^{\frac{1}{\sigma_L}} (ef_{L_{NR}} L_{NR,t})^{\frac{\sigma_L-1}{\sigma_L}}\right]^{\frac{\sigma_L}{\sigma_L-1}}, \tag{11}$$

4. It is worth noting that Y_H (see equation 2) represents the domestic absorption of production, while Y denotes total production. In fact, $Y_H = Y - EXP$, with EXP denoting exports.

5. Damages from climate change include, among other factors, loss of life, deterioration in the quality of life, and depreciation of the capital stock. These damages should also include any resources used to prevent disasters and, more generally, to lessen the impact of climate change on humans and human activity. See Golosov et al. (2015) for further details.

where $\sigma_L > 1$ is the elasticity of substitution between labour inputs supplied by Ricardian and non-Ricardian households respectively, ef_{L_R} and $ef_{L_{NR}}$ are the efficiency parameters for, respectively, Ricardian and non-Ricardian labour while ρ_{L_R} represents the share of Ricardian labour input over total labour. $L_{R,t}$ and $L_{NR,t}$ represent, in turn, CES bundles of different types of labour services with elasticities of substitution equal to $\sigma_{L_R} > 1$ and $\sigma_{L_{NR}} > 1$, respectively.

In modeling emissions and abatement we follow Nordhaus (2008), Heutel (2012) and Annicchiarico and Di Dio (2015), (2016). Emissions at firm level, $Z_{Y,t}$, are assumed to be a byproduct of output. However, this relationship is affected by the abatement effort U_t. In particular, we assume:

$$Z_{Y,t} = (1 - U_t)\varphi_Y Y_t^{\mu_Y}, \tag{12}$$

where $\mu_Y > 0$ is the elasticity between emissions and output and $\varphi_Y > 0$ is a technological parameter relating emissions to output.[6] A policy to mitigate intermediate-sector emissions is mapped onto the model through the reduction of $Z_{Y,t}$.

The cost of emission abatement along with the adjustment cost of this abatement is, in turn, a function of the firm's abatement effort and output:

$$\mathcal{C}_A = \phi_1 U_t^{\phi_2} Y_t + \frac{\gamma_{\mathcal{C}_A}}{2}\left(\frac{U_t}{U_{t-1}} - 1\right)^2 Y_t, \tag{13}$$

where $\phi_1 > 0$, $\phi_2 > 1$ and $\gamma_{\mathcal{C}_A} > 0$ are technological parameters of abatement cost.

Each firm faces a quadratic cost of adjusting nominal prices, measured in terms of aggregate production and given by

$$ADJ_{P,t} = \frac{\gamma_{P_Y}}{2}\left(\frac{P_t}{ind_t^P P_{t-1}} - 1\right)^2 Y_t, \tag{14}$$

where γ_{P_Y} is a measure of the degree of nominal price rigidity and

$$ind_t^P = \Pi_{t-1}^{\kappa_P}\bar{\Pi}^{1-\kappa_P}, \tag{15}$$

is a geometric average of past (gross) and long-run inflation, where the weight of past inflation is determined by the indexation parameter $\kappa_P \in [0, 1]$.

Moreover, hiring and firing unionized workers as well as changing the optimal level of electricity is costly, so that intermediate firms have to bear the following adjustment costs:

$$ADJ_{L_R,t} = \frac{\gamma_{L_R}}{2}\left(\frac{L_{R,t}}{L_{R,t-1}} - 1\right)^2 Y_t, \tag{16}$$

$$ADJ_{L_{NR},t} = \frac{\gamma_{L_{NR}}}{2}\left(\frac{L_{NR,t}}{L_{NR,t-1}} - 1\right)^2 Y_t, \tag{17}$$

$$ADJ_{EL,t} = \frac{\gamma_{EL}}{2}\left(\frac{EL_t}{EL_{t-1}} - 1\right)^2 Y_t, \tag{18}$$

where γ_{L_R}, $\gamma_{L_{NR}}$ and γ_{EL} are all positive parameters determining the size of these adjustment costs.

The problem for the representative intermediate-good producing firm is to choose the sequence $\{P_t, K_t, L_{R,t}, L_{NR,t}, U_t, EL_t\}_{t=0}^{\infty}$ in order to maximize the sum of expected discounted real profits subject to the demand from final good producers and exporters, given production and abatement technologies. See Appendix B for further details.

6. Notice that we assume production activity is itself source of pollution.

3.3 Electricity producers

The electricity sector is made up of a continuum of monopolistically competitive producers indexed by $i \in [0,1]$. In order to produce the amount of electricity demanded by the intermediate good producers, the typical firm i combines fossil fuels: coal (COA_t), natural gas (GAS_t) and crude oil (OIL_t), electricity generated from nuclear energy and electricity generated from renewable sources (RES). Furthermore, we assume that fossil fuels and electricity generated from nuclear energy are purchased from the importers, whereas the electricity generated from RES is supplied by domestic producers. In what follows we drop the i index to simplify notation.

Following Bartocci and Pisani (2013), the electricity production technology is modeled according to a system of nested CES functions. Total electricity is produced combining the electricity generated from conventional sources, EL_{CON}, (fossil fuels and nuclear energy) and the electricity generated from RES, $EL_{RES,t}$:

$$EL_t = \left[\rho_{EL_{CON}}^{\frac{1}{\theta}} EL_{CON,t}^{\frac{\theta-1}{\theta}} + (1-\rho_{EL_{CON}})^{\frac{1}{\theta}} EL_{RES,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{19}$$

where $\theta > 1$ is the elasticity of substitution between electricity generated from conventional sources and RES and $\rho_{EL_{CON}}$ represents the share of electricity generated from conventional sources over the total production of electricity.

The electricity generated from conventional sources is produced according to

$$EL_{CON,t} = \left[\rho_{EL_{FOS}}^{\frac{1}{\theta_{CON}}} EL_{FOS,t}^{\frac{\theta_{CON}-1}{\theta_{CON}}} + (1-\rho_{EL_{FOS}})^{\frac{1}{\theta_{CON}}} EL_{NUC,t}^{\frac{\theta_{CON}-1}{\theta_{CON}}} \right]^{\frac{\theta_{CON}}{\theta_{CON}-1}}, \tag{20}$$

where $\theta_{CON} > 1$ is the elasticity of substitution between electricity generated from fossil fuels and nuclear energy and $\rho_{EL_{FOS}}$ represents the share of electricity generated from fossil fuels used in the production of electricity generated from conventional sources.

The electricity generated from RES is produced according to

$$EL_{RES,t} = \left[\begin{array}{c} \rho_{EL_{SOL}}^{\frac{1}{\theta_{RES}}} EL_{SOL,t}^{\frac{\theta_{RES}-1}{\theta_{RES}}} + \rho_{EL_{WIN}}^{\frac{1}{\theta_{RES}}} EL_{WIN,t}^{\frac{\theta_{RES}-1}{\theta_{RES}}} + \rho_{EL_{BIO}}^{\frac{1}{\theta_{RES}}} EL_{BIO,t}^{\frac{\theta_{RES}-1}{\theta_{RES}}} \\ +(1-\rho_{EL_{SOL}} - \rho_{EL_{WIN}} - \rho_{EL_{BIO}})^{\frac{1}{\theta_{RES}}} EL_{HYD,t}^{\frac{\theta_{RES}-1}{\theta_{RES}}} \end{array} \right]^{\frac{\theta_{RES}}{\theta_{RES}-1}}, \tag{21}$$

where $\theta_{RES} > 1$ is the elasticity of substitution between the electricity generated from solar, wind, biomass and hydroelectric energy and $\rho_{EL_{SOL}}$, $\rho_{EL_{WIN}}$ and $\rho_{EL_{BIO}}$ represent the share of the electricity generated from solar, wind and biomass in the production of electricity from RES, respectively.

In turn, the electricity generated from fossil fuels is produced by combining the electricity generated from coal and crude oil, $EL_{COAOIL,t}$, with natural gas, GAS_t:

$$EL_{FOS,t} = \left[\rho_{EL_{COAOIL}}^{\frac{1}{\theta_{FOS}}} EL_{COAOIL,t}^{\frac{\theta_{FOS}-1}{\theta_{FOS}}} + (1-\rho_{EL_{COAOIL}})^{\frac{1}{\theta_{FOS}}} GAS_t^{\frac{\theta_{FOS}-1}{\theta_{FOS}}} \right]^{\frac{\theta_{FOS}}{\theta_{FOS}-1}}, \tag{22}$$

where $\theta_{FOS} > 1$ is the elasticity of substitution between the electricity generated from coal-and-crude oil and natural gas, while $\rho_{EL_{COAOIL}}$ represents the share of coal and crude oil in the total production of electricity generated from fossil fuels.

Finally, the electricity generated from coal and crude oil is produced combining coal, COA_t, with crude oil, OIL_t according to:

$$EL_{COAOIL,t} = \left[\rho_{COA}^{\frac{1}{\theta_{COAOIL}}} COA_t^{\frac{\theta_{COAOIL}-1}{\theta_{COAOIL}}} + (1-\rho_{COA})^{\frac{1}{\theta_{COAOIL}}} OIL_t^{\frac{\theta_{COAOIL}-1}{\theta_{COAOIL}}} \right]^{\frac{\theta_{COAOIL}}{\theta_{COAOIL}-1}}, \tag{23}$$

where $\theta_{COAOIL} > 1$ is the elasticity of substitution between coal and crude oil, while ρ_{COA} represents the share of coal over total production of electricity generated from coal and oil.

Furthermore, it is assumed that electricity from renewable sources is generated according to the following production function:

$$R\hat{E}S_t = A_{R\hat{E}S,t}\left(K_{R\hat{E}S,t}\right)^{\alpha_{R\hat{E}S}}\left(F_{R\hat{E}S}\right)^{1-\alpha_{R\hat{E}S}}, \tag{24}$$

where $R\hat{E}S_t = \{EL_{SOL,t}, EL_{WIN,t}, EL_{BIO,t}, EL_{NUC,t}, EL_{HYD,t}\}$, $K_{R\hat{E}S,t}$ is the capital employed in the production of RES and $F_{R\hat{E}S} = \{SOL, WIN, BIO, NUC, HYD\}$ denotes the endowment of natural resources.

Further, it is assumed that the production of electricity generated from fossil fuels contributes to carbon emissions according to

$$Z_{EL,t} = (1 - U_{EL,t})\varphi_{EL} EL_{FOS,t}^{\mu_{EL}}, \tag{25}$$

where $U_{EL,t}$ represents the abatement effort, $\mu_{EL} > 0$ is the elasticity between emissions and electricity generated from fossil fuels and $\varphi_{EL} > 0$ is a technological parameter. A policy to mitigate emissions from the electricity sector is mapped onto the model through the reduction of $Z_{EL,t}$.

The abatement cost faced by the generic firm i is

$$\mathcal{C}_{EL} = \frac{P_{EL,t}}{P_t}\phi_1^{EL} U_{EL,t}^{\phi_2^{EL}} EL_{FOS,t} + \frac{\gamma_{\mathcal{C}_{EL}}}{2}\frac{P_{EL,t}}{P_t}\left(\frac{U_{EL,t}}{U_{EL,t-1}} - 1\right)^2 EL_{FOS,t}, \tag{26}$$

where $\phi_1^{EL} > 0$, $\phi_2^{EL} > 1$ and $\gamma_{\mathcal{C}_{EL}} > 0$ are technological parameters of abatement cost. Along with the intermediate good producers, the electricity sector is also subject to the emission cap, therefore each firm has to purchase emission permits at the market price $P_{Z,t}$.

The problem for the electricity producers is to choose the following sequence:

$$P_{EL,t}, COA_t, GAS_t, OIL_t, EL_{NUC,t}, EL_{RES,t}, U_{EL,t}, K_{SOL,t}, K_{WIN,t}, K_{BIO,t}, K_{HYD,t} \tag{27}$$

in order to maximize the sum of expected discounted real profits subject subject to demand for its own variety, (19)-(23) and (24). See Appendix C for details.

3.4 Exporting firms

We assume that Italy is a "semi-small" economy in its export markets. There is a continuum of monopolistically competitive exporting firms transforming domestic intermediate goods into exportable goods using a linear technology. They demand goods from domestic intermediate good producers and sell them in foreign markets, assuming that they are able to price their product in the currency of the customer, $P^*_{X,t}(j)$. Furthermore, we assume that there are costs to adjusting prices, namely:

$$ADJ_{P^*_X,t} = \frac{\gamma_{P^*_X}}{2}\left(\frac{P^*_{X,t}(j)}{ind_t^{EXP} P^*_{X,t-1}(j)} - 1\right)^2 Y_t, \tag{28}$$

where $\gamma_{P^*_X} > 0$ and

$$ind_t^{EXP} = \left(\Pi^*_{t-1}\right)^{\kappa_{EXP}}\left(\bar{\Pi}^*\right)^{1-\kappa_{EXP}}, \tag{29}$$

is a geometric average of past (gross) and long-run inflation prevailing in the foreign market, where the weight of past inflation is determined by the indexation parameter $\kappa_{EXP} \in [0, 1]$.

The (exogenous) world demand of all domestically produced intermediate goods is of the type:

$$EXP_t = \alpha_{EXP} \left(\frac{P^*_{X,t}}{P^*_{C_Y,t}} \right)^{-\theta_{EXP}} WD_t, \tag{30}$$

where $\theta_{EXP} > 1$ is the elasticity of substitution between tradeable goods, WD_t is the global demand, α_{EXP} is the share of domestic intermediate goods in the global demand bundle and $P^*_{C,t}$ is the foreign consumption price index.

The world demand of the variety j is

$$EXP_t(j) = \left(\frac{P^*_{X,t}(j)}{P^*_{X,t}} \right)^{-\theta_{EXP}} EXP_t, \tag{31}$$

where $P^*_{X,t}$ is the ideal export price index, given by $P^*_{X,t} = \left[\int_0^1 P^*_{X,t}(j)^{1-\theta_{EXP}} dj \right]^{\frac{1}{1-\theta_{EXP}}}$.

The typical exporter j will set the price $P^*_{X,t}(j)$ so as to maximize the present discounted value of profits subject to (31). Under symmetry, the first order condition with respect to $P^*_{X,t}(j)$ in steady state is found to be

$$\frac{S_t P^*_{X,t}}{P_t} = \frac{\theta_{EXP}}{\theta_{EXP} - 1}. \tag{32}$$

3.5 Importing firms

There is a continuum of monopolistically competitive importers indexed by $m \in [0, 1]$. Each importer buys a single variety of $COA_t, GAS_t, OIL_t, EL_{NUC,t}$, $ROIL_t$ (refined oil), $BIOF_t$ (biofuel) and $IMPF_t$ and sells them in the domestic market. Assuming a linear technology, the problem of the typical importer m is

$$\max_{\{P_{\hat{N},t}(m)\}} E_0 \sum_{t=0}^{\infty} Q_{0,t} \left\{ \sum_{\hat{N}} \left[\left(\frac{P_{\hat{N},t}(m)}{P_t} \hat{N}_t(m) - \frac{S_t P^*_{\hat{N},t}(m)}{P_t} \hat{N}_t(m) \right) - ADJ_{P_{\hat{N},t}} \right] \right\}, \tag{33}$$

subject to the electricity producers' demand for each variety of COA_t, GAS_t, OIL_t and $EL_{NUC,t}$ (see equation (110)), the demand of $IMPF_t$ from the final good producers (see equations (95)) and the demand of $ROIL_t$ and $BIOF_t$ from households:

$$\hat{N}_t(m) = \left(\frac{P_{\hat{N},t}(m)}{P_{\hat{N},t}} \right)^{-\theta_{\hat{N}}} \hat{N}_t, \tag{34}$$

where

$$\hat{N}_t = \{COA_t, GAS_t, OIL_t, EL_{NUC,t}, ROIL_t, BIOF_t, IMPF_t\}, \tag{35}$$

and

$$ADJ_{P_{\hat{N},t}} = \frac{\gamma_{P_{\hat{N}}}}{2} \left(\frac{P_{\hat{N},t}(m)}{ind_t^{P_{\hat{N}}} P_{\hat{N},t-1}(m)} - 1 \right)^2 Y_t, \tag{36}$$

which represents the price adjustment cost function with $ind_t^{P_{\hat{N}}} = \Pi_{t-1}^{\kappa_{P_{\hat{N}}}} \bar{\Pi}^{1-\kappa_{P_{\hat{N}}}}$.

Under symmetry and in steady state, the first order condition with respect to the generic $P_{\hat{N},t}$ is:

$$\frac{P_{\hat{N},t}}{P_t} = \frac{\theta_{\hat{N}}}{\theta_{\hat{N}} - 1} \frac{S_t P^*_{\hat{N},t}}{P_t}. \tag{37}$$

3.6 Households

The population (constant and normalized to 1) is divided into two types of households: Ricardian and non-Ricardian. The population share of Ricardian and non-Ricardian households is s_R and $1-s_R$ respectively. In what follows, the indexes R and NR refer to Ricardian and Non-Ricardian variables.

3.6.1 Ricardian households

Ricardian households are characterized by the following lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(u(C_t^R - h_{C^R} \overline{C}_{t-1}^R) - \omega_{L_R} \int_0^1 \frac{L_{R,t}^H(h_{L_R})^{1+v_{L_R}}}{1+v_{L_R}} dh_{L_R} \right), \tag{38}$$

where C_t^R denotes consumption; $L_{R,t}^H(h_{L_R})$ denotes labour in the activity h_{L_R}; β is the discount factor; h_{C^R} is the habit persistence parameter; v_{L_R} is the inverse of the Frisch elasticity and ω_{L_R} is a scale parameter governing the disutility arising from labour.

We assume a logarithmic utility function for consumption:

$$u(C_t^R - h_{C^R} \overline{C}_{t-1}^R) = \log(C_t^R - h_{C^R} \overline{C}_{t-1}^R). \tag{39}$$

and the flow budget constraint is

$$\begin{aligned} P_{C,t}C_t^R + B_t^R + S_t B_t^{F,R} + P_{I,t} I_t^R + P_{I_{RES},t} I_{RES,t}^R = {} & \left(1 - \tau_t^{L_R} - \tau_{h,t}^{W_{L_R}}\right) P_t \int_0^1 W_{L_R,t}(h_{L_R}) L_{R,t}^H(h_{L_R}) dh_{L_R} \\ & + R_{t-1} B_{t-1}^R + (R_{t-1}^* + rpbrf_{t-1}) S_t B_{t-1}^{F,R} \\ & + \tau_t^K \delta_K P_{I,t} u_t^K K_t^R \\ & + (1-\tau_t^K) r_t^K P_{I,t} u_t^K K_t^R \\ & + \tau_t^{K_{RES}} \delta_{K_{RES}} P_{I_{RES},t} K_{RES,t}^R \\ & + (1-\tau_t^{K_{RES}}) r_t^{K_{RES}} P_{I_{RES},t} K_{RES,t}^R \\ & + tcrk_t P_{I,t} I_t^R + tcrk_{RES,t} P_{I_{RES},t} I_{RES,t}^R \\ & - P_t TAX_t^R + P_t Tr_t^R \\ & - P_{I,t} ADJ_{I^R,t} - P_{I_{RES},t} ADJ_{I_{RES,t}^R} \\ & - P_{I,t} ADJ_{u^K,t} - P_t \int_0^1 ADJ_{W_{L_R},t}(h_{L_R}) dh_{L_R} + V_t^R \end{aligned} \tag{40}$$

where $P_{C,t}$ is the consumption price index; I_t^R and $I_{RES,t}^R$ denote investment in intermediate goods and in the RES sector respectively; $P_{I,t}$ and $P_{I_{RES},t}$ are the prices of the two types of investment goods; $tcrk$, $tcrk_{RES}$, τ_t^K and $\tau_t^{K_{RES}}$ denote the tax rates (or subsidies) on investment and capital in both intermediate goods and the RES sector; δ_K and $\delta_{K_{RES}}$ are the depreciation rates of capital; B^R and $B^{F,R}$ are the amount of domestic and foreign bonds purchased by the Ricardian households; R_t and R_t^* are the nominal domestic and foreign interest rates; S_t denotes the nominal exchange rate; $W_{L_R,t}(h_{L_R})$ is the wage relative to the activity h_{L_R}; $\tau_t^{L_R}$ and $\tau_{h,t}^{W_{L_R}}$ are the social security and labour tax rates levied on households; TAX_t and Tr_t are lump-sum taxes and transfers; V_t^R denotes profits earned from the ownership of intermediate good producing firms, electricity producing firms, importing and exporting firms.

Following Schmitt-Grohé and Uribe (2003), the risk premium for foreign bonds is defined as

$$rpbrf_t = -\eta^F \left(e^{BR_t^F - \overline{BR}^F} - 1\right), \tag{41}$$

where η^F and $\overline{BR}^F$ are constant parameters. The capital laws of motion are

$$K_{t+1}^R = (1-\delta_K)\, K_t^R + I_t^R, \tag{42}$$

$$K_{RES,t+1}^R = (1-\delta_{K_{RES}}) K_{RES,t}^R + I_{RES,t}^R. \tag{43}$$

Adjustment costs are defined as follows:

$$ADJ_{I^R,t} = \frac{\gamma_I}{2}\left(\frac{I_t^R}{K_t^R} - \delta_K\right)^2 K_t^R,$$

$$ADJ_{I_{RES,t}^R} = \frac{\gamma_{I_{RES}}}{2}\left(\frac{I_{RES,t}^R}{K_{RES,t}^R} - \delta_{K_{RES}}\right)^2 K_{RES,t}^R,$$

$$ADJ_{u^K,t} = \left[\gamma_{u_1^K}\left(u_t^K - 1\right) + \frac{\gamma_{u_2^K}}{2}\left(u_t^K - 1\right)^2\right] K_t^R,$$

$$ADJ_{W_{L_R},t}(h_{L_R}) = \frac{\gamma_{W_{L_R}}}{2}\left(\frac{W_{L_R,t}(h_{L_R})}{ind_t^W W_{L_R,t-1}(h_{L_R})} - 1\right)^2 Y_t,$$

$$ADJ_{W_{L_{NR}},t}(h_{L_{NR}}) = \frac{\gamma_{W_{L_{NR}}}}{2}\left(\frac{W_{L_{NR},t}(h_{L_{NR}})}{ind_t^W W_{L_{NR},t-1}(h_{L_{NR}})} - 1\right)^2 Y_t,$$

where γ_I, $\gamma_{I_{RES}}$, $\gamma_{u_1^K}$, $\gamma_{u_2^K}$, $\gamma_{W_{L_R}}$, $\gamma_{W_{L_{NR}}}$ are all positive parameters determining the size of these adjustment costs and $ind_t^W = \Pi_{t-1}^{\kappa_W}\bar{\Pi}^{1-\kappa_W}$.

We assume that C_t^R is a consumption bundle aggregating final good consumption $C_{Y,t}^R$ and fuel consumption $C_{F,t}^R$ used to satisfy transportation needs:

$$C_t^R = \left[\alpha_{C_Y}{}^{\frac{1}{\theta_C}} C_{Y,t}^R{}^{\frac{\theta_C-1}{\theta_C}} + (1-\alpha_{C_Y})^{\frac{1}{\theta_C}} C_{F,t}^R{}^{\frac{\theta_C-1}{\theta_C}}\right]^{\frac{\theta_C}{\theta_C-1}}, \tag{44}$$

where $\theta_C > 1$ is the elasticity of substitution between goods and fuel consumption and α_{C_Y} is the share of goods consumption.

In turn, fuel consumption is a bundle that aggregates refined oil, $ROIL_t$ and biofuel, $BIOF_t$:

$$C_{F,t}^R = \left[\alpha_{ROIL}{}^{\frac{1}{\theta_{C_F}}} ROIL_t^R{}^{\frac{\theta_{C_F}-1}{\theta_{C_F}}} + (1-\alpha_{ROIL})^{\frac{1}{\theta_{C_F}}} BIOF_t^R{}^{\frac{\theta_{C_F}-1}{\theta_{C_F}}}\right]^{\frac{\theta_{C_F}}{\theta_{C_F}-1}}, \tag{45}$$

where $\theta_{C_F} > 1$ denotes the elasticity of substitution between consumption of refined oil and biofuel and α_{ROIL} is the share of refined oil.

Solving the cost minimization problem yields the demands for $C_{Y,t}^R$ and $C_{F,t}^R$ given by

$$C_{Y,t}^R = \alpha_{C_Y}\left[\frac{P_{C_Y,t}(1+\tau_t^C)}{P_{C,t}}\right]^{-\theta_C} C_t^R, \tag{46}$$

$$C_{F,t}^R = (1-\alpha_{C_Y})\left(\frac{P_{C_F,t}}{P_{C,t}}\right)^{-\theta_C} C_t^R, \tag{47}$$

where $P_{C_Y,t}$ and $P_{C_F,t}$ are the price indexes of goods and fuel consumption respectively, while τ_t^C is the tax rate on consumption. The overall consumption price index is defined as

$$P_{C,t} = \left\{ \alpha_{C_Y} [P_{C_Y,t}(1+\tau_t^C)]^{1-\theta_C} + (1-\alpha_{C_Y}) P_{C_F,t}{}^{1-\theta_C} \right\}^{\frac{1}{1-\theta_C}} . \tag{48}$$

The demands for $ROIL_t^R$ and $BIOF_t^R$ are simply:

$$ROIL_t^R = \alpha_{ROIL} \left[\frac{P_{ROIL,t}(1+\tau_t^{ROIL})}{P_{C_F,t}} \right]^{-\theta_{C_F}} C_{F,t}^R, \tag{49}$$

$$BIOF_t^R = (1-\alpha_{ROIL}) \left[\frac{P_{BIOF,t}(1+\tau_t^{BIOF})}{P_{C_F,t}} \right]^{-\theta_{C_F}} C_{F,t}^R, \tag{50}$$

where τ_t^{ROIL} and τ_t^{BIOF} are the tax rates on refined oil and biofuel, respectively, and the fuel consumption price index is defined as

$$P_{C_F,t} = \left\{ \alpha_{ROIL} [P_{ROIL,t}(1+\tau_t^{ROIL})]^{1-\theta_{C_F}} + (1-\alpha_{ROIL}) [P_{BIOF,t}(1+\tau_t^{BIOF})]^{1-\theta_{C_F}} \right\}^{\frac{1}{1-\theta_{C_F}}} , \tag{51}$$

where $P_{ROIL,t}$ and $P_{BIOF,t}$ are the (ideal) price indexes of $ROIL_t^R$ and $BIOF_t^R$, respectively. Finally, both $ROIL_t^R$ and $BIOF_t^R$ are bundles of differentiated imported varieties:

$$ROIL_t^R = \left[\int_0^1 ROIL_t^R(m)^{\frac{\theta_{ROIL}-1}{\theta_{ROIL}}} dm \right]^{\frac{\theta_{ROIL}}{\theta_{ROIL}-1}} , \tag{52}$$

$$BIOF_t^R = \left[\int_0^1 BIOF_t^R(m)^{\frac{\theta_{BIOF}-1}{\theta_{BIOF}}} dm \right]^{\frac{\theta_{BIOF}}{\theta_{BIOF}-1}} , \tag{53}$$

where $\theta_{ROIL} > 1$ and $\theta_{BIOF} > 1$ are the elasticities of substitution among the varieties of refined oil and biofuel, respectively. The corresponding demands for the generic variety m can be easily derived.

A fiscal intervention on the supply side of the labour market aiming at stimulating employment and preserving fiscal revenues is implemented by a tax shift from labour (by reducing $\tau_t^{L_R}$) to refined oil consumption taxes (by increasing τ_t^{ROIL}). Similarly, a fiscal intervention aiming at enhancing the use of renewable resources reduces $\tau^{K_{RES}}$ and simultaneously increases τ_t^{ROIL}. The change in the tax rates will depend on the relative size of the tax bases, so as to ensure that the fiscal reform is ex-ante budget neutral.

3.6.2 Non-Ricardian households

The representative non-Ricardian consumer chooses the optimal allocation between consumption and leisure and consumes her net income (i.e. hand-to-mouth consumer). The utility function is

$$U_t^{NR} = u(C_t^{NR} - h_{C^{NR}} \overline{C}_{t-1}^{NR}) - \omega_{L_{NR}} \int_0^1 \frac{L_{NR,t}^H(h_{L_{NR}})^{1+\upsilon_{L_{NR}}}}{1+\upsilon_{L_{NR}}} dh_{L_{NR}}, \tag{54}$$

while the flow budget constraint is

$$\begin{aligned} \frac{P_{C,t}}{P_t} C_t^{NR} = & \left(1 - \tau_t^{L_{NR}} - \tau_{h,t}^{W_{L_{NR}}}\right) \int_0^1 W_{L_{NR},t}(h_{L_{NR}}) L_{NR,t}^H(h_{L_{NR}}) dh_{L_{NR}} - TAX_t^{NR} \\ & + Tr^{NR} - \int_0^1 ADJ_{W_{L_{NR},t}}(h_{L_{NR}}) dh_{L_{NR}} \end{aligned} \tag{55}$$

where

$$u(C_t^{NR} - h_{C^{NR}}\overline{C}_{t-1}^{NR}) = \log\left(C_t^{NR} - h_{C^{NR}}\overline{C}_{t-1}^{NR}\right),$$

and

$$ADJ_{W_{L_{NR},t}}(h_{L_{NR}})dh_{L_{NR}} = \frac{\gamma_{W_{L_{NR}}}}{2}\left(\frac{W_{L_{NR},t}(h_{L_{NR}})}{ind_t^W W_{L_{NR},t-1}(h_{L_{NR}})} - 1\right)^2 Y_t.$$

In a symmetric way with respect to the case of Ricardian households, we assume that C_t^{NR} is a consumption bundle aggregating good-consumption $C_{Y,t}^{NR}$ and fuel consumption $C_{F,t}^{NR}$:

$$C_t^{NR} = \left[\alpha_{C_Y}{}^{\frac{1}{\theta_C}} C_{Y,t}^{NR}{}^{\frac{\theta_C-1}{\theta_C}} + (1-\alpha_{C_Y})^{\frac{1}{\theta_C}} C_{F,t}^{NR}{}^{\frac{\theta_C-1}{\theta_C}}\right]^{\frac{\theta_C}{\theta_C-1}}, \tag{56}$$

where

$$C_{F,t}^{NR} = \left[\alpha_{ROIL}{}^{\frac{1}{\theta_{C_F}}} ROIL_t^{NR}{}^{\frac{\theta_{C_F}-1}{\theta_{C_F}}} + (1-\alpha_{ROIL})^{\frac{1}{\theta_{C_F}}} BIOF_t^{NR}{}^{\frac{\theta_{C_F}-1}{\theta_{C_F}}}\right]^{\frac{\theta_{C_F}}{\theta_{C_F}-1}}. \tag{57}$$

Solving all the cost minimization problems one can easily obtain demand conditions which are of the same form of those obtained for Ricardian consumers.

3.7 Aggregation and equilibrium conditions

Given the above assumptions, aggregation implies:

$$s_R K_t^R = K_t, \tag{58}$$
$$s_R K_{RES,t}^R = K_{RES,t}, \tag{59}$$
$$s_R I_t^R = I_t, \tag{60}$$
$$s_R I_{RES,t}^R = I_{RES,t}, \tag{61}$$

and

$$K_{RES,t} = K_{WIN,t}^{RES} + K_{HYD,t}^{RES} + K_{BIO,t}^{RES} + K_{SOL,t}^{RES}, \tag{62}$$

with

$$K_{RES,t+1} = (1-\delta_{K_{RES}})K_{RES,t} + I_{RES,t}, \tag{63}$$

Aggregate consumption is obtained as the average consumption of ricardian and non-ricardian:

$$C_t = s_R C_t^R + (1-s_R)C_t^{NR}, \tag{64}$$

and so also for the aggregate final-good consumption:

$$C_{Y,t} = s_R C_{Y,t}^R + (1-s_R)C_{Y,t}^{NR}, \tag{65}$$

and for the aggregate fuel consumption:

$$C_{F,t} = s_R C_{F,t}^R + (1-s_R)C_{F,t}^{NR}. \tag{66}$$

Furthermore, aggregate consumption of refined oil and biofuel are

$$ROIL_t = s_R ROIL_t^R + (1-s_R)ROIL_t^{NR}, \tag{67}$$
$$BIOF_t = s_R BIOF_t^R + (1-s_R)BIOF_t^{NR}, \tag{68}$$

where it is further assumed that the consumption of $ROIL_t$ generates emissions according to the following relationship:

$$Z_{ROIL,t} = \varphi_{ROIL} ROIL_t^{\mu_{ROIL}}, \tag{69}$$

where $\mu_{ROIL} > 0$ is the elasticity between emissions and refined oil consumption and $\varphi_{ROIL} > 0$ is a technological parameter. Total emissions are defined as:

$$Z_t^{TOT} = Z_{Y,t} + Z_{EL,t} + Z_{ROIL,t}. \tag{70}$$

The stock of emissions M_t evolves as follows:

$$M_t = (1 - \delta_M) M_{t-1} + Z_{Y,t} + Z_{EL,t} + Z_{ROIL,t} + Z_t^{RoW}, \tag{71}$$

where δ_M is the fraction of pollution which naturally decays in each time period and Z_t^{RoW} denotes emissions from the rest of the world.

Equilibrium in the labour market requires that the quantity of each category of labour employed must be equal to the supply, hence:

$$L_{R,t} = s_R L_{R,t}^H, \tag{72}$$

$$L_{NR,t} = (1 - s_R) L_{NR,t}^H. \tag{73}$$

We assume that all the investment goods used to build capital in the RES sector are imported, so that total imports can be defined as

$$\begin{aligned} IMPT_t = {} & \frac{S_t P_{IMPF,t}^*}{P_t} IMPF_t + \frac{S_t P_{OIL,t}^*}{P_t} OIL_t + \frac{S_t P_{COA,t}^*}{P_t} COA_t + \frac{S_t P_{GAS,t}^*}{P_t} GAS_t + \frac{S_t P_{EL_{NUC},t}^*}{P_t} EL_{NUC,t} \\ & + \frac{S_t P_{ROIL,t}^*}{P_t} ROIL_t + \frac{S_t P_{BIOF,t}^*}{P_t} BIOF_t + \frac{S_t P_{I_{RES},t}^*}{P_t}, \end{aligned} \tag{74}$$

where the asterisks denote foreign prices.

In equilibrium the following price conditions must hold:

$$P_{E,t} = P_{C_Y,t} = P_{I,t} \equiv \left[(1 - \alpha_{IMP}) (P_t)^{1-\sigma_{IMP}} + \alpha_{IMP} (P_{IMPF,t})^{1-\sigma_{IMP}} \right]^{\frac{1}{1-\sigma_{IMP}}}, \tag{75}$$

and

$$P_{I_{RES},t} = S_t P_{I_{RES},t}^*. \tag{76}$$

The aggregate stock of domestic and foreign bonds are

$$B_t = s_R B_t^R, \tag{77}$$

$$B_t^F = s_R B_t^{FR}, \tag{78}$$

and the net foreign assets position expressed in real terms is

$$BR_t^F = \frac{\left(R_{t-1}^* + rpbrf_{t-1} \right)}{\Pi_t} \frac{S_t}{S_{t-1}} BR_{t-1}^F + \frac{S_t P_{X,t}^*}{P_t} EXP_t - IMPT_t. \tag{79}$$

Finally, the economy resource constraint reads as

$$
\begin{aligned}
Y_t = {} & \frac{P_{C_Y,t}}{P_t}(C_{Y,t} + I_t + G_t) + \frac{S_t P^*_{X,t}}{P_t} EXP_t - IMPT_t \\
& + \mathcal{C}_A + \frac{P_{EL}}{P}\mathcal{C}_{EL} \\
& + ADJ_{P,t} + ADJ_{L_R,t} + ADJ_{L_{NR},t} + ADJ_{EL,t} \\
& + ADJ_{P_{EL},t} + ADJ_{COA,t} + ADJ_{OIL,t} + ADJ_{GAS,t} + ADJ_{EL_{NUC},t} \\
& + ADJ_{P_{COA},t} + ADJ_{P_{GAS},t} + ADJ_{P_{OIL},t} \\
& + ADJ_{P_{EL_{NUC}},t} + ADJ_{P_{ROIL},t} + ADJ_{P_{BIOF},t} + ADJ_{P_{IMPF},t} \\
& + \frac{P_{I,t}}{P_t} ADJ_{I^R,t} + \frac{P_{I_{RES},t}}{P_t} ADJ_{I^R_{RES},t} + \frac{P_{I,t}}{P_t} ADJ_{u^K,t} \\
& + ADJ_{W_{L_R},t} + ADJ_{W_{L_{NR}},t} + ADJ_{P^*_X,t}.
\end{aligned}
\tag{80}
$$

3.8 The government and the monetary authority

The flow budget constraint of the government in real terms is

$$
BR_t = \frac{BR_{t-1}}{\Pi_t} + DR_t, \tag{81}
$$

where BR_t is the public debt and DR_t denotes the secondary deficit defined as

$$
\begin{aligned}
DR_t = {} & \frac{(R_{t-1} - 1)}{\Pi_t} BR_{t-1} + \frac{P_{E,t}}{P_t} G_t + Tr_t + SUB_t - TAX_t - LTAX_t - CTAX_t - KTAX_t \\
& - EXCTOT_t - \frac{P_{Z,t}}{P_t}(Z_{Y,t} + Z_{EL,t}),
\end{aligned}
\tag{82}
$$

where Tr_t, SUB_t, $LTAX_t$, $CTAX_t$, $KTAX_t$ and $EXCTOT_t$ represent aggregate transfers, subsidies, labour taxes, consumption taxes, taxes and subsidies on capital and excises, respectively:

$$
Tr_t = s_R Tr^R_t + (1 - s_R) Tr^{NR}_t, \tag{83}
$$

$$
LTAX_t = s_R L_{R,t} W_{L_R,t} \left(\tau^{L_R}_t + \tau^{W_{L_R}}_{h,t} + \tau^{W_{L_R}}_{f,t}\right) + (1 - s_R) L_{NR,t} W_{L_{NR},t} \left(\tau^{L_{NR}}_t + \tau^{W_{L_{NR}}}_{h,t} + \tau^{W_{L_{NR}}}_{f,t}\right), \tag{84}
$$

$$
CTAX_t = \frac{P_{C_Y,t}}{P_t} \tau^C_t C_t, \tag{85}
$$

$$
\begin{aligned}
KTAX_t = {} & \tau^K_t \left(r^K_t - \delta_K\right) \frac{P_{I,t}}{P_t} u^K_t K_t - tcrk_t \frac{P_{I,t}}{P_t} I_t + \tau^{K_{RES}}_t \left(r^K_t - \delta_{K_{RES}}\right) \frac{P_{I_{RES},t}}{P_t} K_{RES,t} \\
& - tcrk_{RES,t} \frac{P_{I_{RES},t}}{P_t} I_{RES,t},
\end{aligned}
\tag{86}
$$

$$
SUB_t = sub^{L_R}_t L_{R,t} W_{L_{R,t},t} + sub^{L_{NR}}_t L_{NR,t} W_{L_{NR,t},t}, \tag{87}
$$

$$EXCTOT_t = \tau_t^{ROIL}\frac{P_{ROIL,t}}{P_t}ROIL_t + \tau_t^{BIOF}\frac{P_{BIOF,t}}{P_t}BIOF_t. \tag{88}$$

The lump-sum component of taxation is set endogenously according to the following "passive rule" as meant by Leeper (1991)

$$TAX_t = \overline{TAX} + T_B(BR_t - \overline{BR}) + T_D(DR_t - \overline{DR}) + T_Y\left(Y_t - \overline{Y}\right), \tag{89}$$

where the bar over a variable denotes steady state value, T_B, T_D and T_Y are sensitivity parameters and the distribution of the fiscal burden between Ricardian and Non-Ricardian households is set according to

$$TAX_t^R = s_R TAX_t, \tag{90}$$

$$TAX_t^{NR} = (1 - s_R)TAX_t. \tag{91}$$

Finally, $\frac{P_{Z,t}}{P_t}(Z_{Y,t} + Z_{EL,t})$ represents revenues from the sale of emission permits. Since $Z_{Y,t}$ and $Z_{EL,t}$ are set exogenously, the price of emission permits $\frac{P_{Z,t}}{P_t}$ is endogenously determined.

The monetary authority sets the short-term nominal interest rate in accordance with a Taylor-type rule:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\iota_r}\left[\left(\frac{\Pi_t}{\overline{\Pi}}\right)^{\iota_\pi}\left(\frac{Y_t}{\overline{Y}}\right)^{\iota_y}\left(\frac{S_t}{\overline{S}}\right)^{\iota_S}\right]^{1-\iota_r}\varepsilon_t^{MP}, \tag{92}$$

where ι_r, ι_π, ι_y, and ι_S, are policy parameters and ε_t^{MP} represents a monetary policy shock.

4 Parametrization and model solution

The model is calibrated for Italy using quarterly data. Table 1 describes the main economic ratios. The consumption-GDP and the investment-GDP ratios are set, respectively, to 61.3% and 17.5%, so that the implied steady state levels of public expenditure and imports are equal to 20% and 36%, respectively. The annual public debt-GDP ratio is set equal to 130% of GDP and the trade balance is zero in steady state. The discount factor β is set equal to 0.99, implying a steady state value of the real interest rate of 1%. The depreciation rates of capital (δ_K and $\delta_{K_{RES}}$) are set equal to 0.025, so that the steady state rental rate of capital is 4%.

Turning to the household side, the inverse of the Frisch elasticities (ν_{L_R} and $\nu_{L_{NR}}$) are set equal to 1. According to the estimates by Annicchiarico et al. (2015), the share of Ricardian and Non-Ricardian households (s_R, $1 - s_R$) are set to 0.7 and 0.3 respectively and the habit parameters (h_{C^R}, $h_{C^{NR}}$) are set to 0.9 for Ricardian households and 0.2 for Non-Ricardian households. The fraction of time spent working is set equal to 0.3 for both. This parametrization yields the implied values for the scale parameters related to the disutility of labour: $\omega_{L_R} = 9.9$ and $\omega_{L_{NR}} = 11$.

For electricity generation we use data in the 2014 AEEGSI annual report (see AEEGSI 2014). Table 2 shows the gross production of electricity generated by fossil fuel sources and RES together with their respective shares in total electricity production in 2013. We draw on these data to set the share of each electricity generation source and calibrate the weights of the nested CES electricity production functions accordingly. Specifically, each weight represents the share of a source relative to the electricity bundle it belongs to.

In Italy, the most relevant source of electricity generation is natural gas which accounts for 38% of total electricity production. Among the other fossil-fuel sources, coal accounts for 16% and oil for

7.5%. On the RES side, electricity generated from solar, wind and biomass represents respectively 7.8%, 5.2% and 4.9% of total electricity produced whereas the largest contribution comes from hydroelectric energy which amounts to 18.5%.[7] As a whole, the share of fossil-fuel sources and RES are 62% and 38%, respectively.

Table 3 lists the parameter values of the CES functions related to electricity generation and intermediate good production. It is worth underlining that the model described above encompasses all conventional sources used to generate electricity, including nuclear energy despite the fact that the latter is not used in the Italian electricity sector. Therefore, the model presents a flexible framework, within which the Italian economy represents a specific case. However, in this analysis the electricity generated from nuclear energy is set to zero.

We set the elasticity of substitution between electricity generated from conventional sources and RES, θ, equal to 0.6. The elasticity of substitution between electricity generated from coal and oil and natural gas, θ_{FOS}, is set at 0.9 and that between coal and oil, θ_{COAOIL}, at 0.3. The previous values are set according to Bartocci and Pisani (2013) and denote a low substitutability among alternative sources.[8] On the contrary, the electricity generated from RES, θ_{RES}, is characterized by a higher degree of substitutability among its components, so that we set the elasticity equal to 2, in line with Bartocci and Pisani (2013) and Bosetti et al. (2009).

For what concerns the production function of intermediate goods, we set the elasticity of substitution between value added and electricity, θ_Y, equal to 0.8. Following Bartocci and Pisani (2013) we set the elasticity of substitution between capital and labour, θ_{VA}, at 0.9 and the factor shares of value added and capital (ρ_{VA} and $\rho_{K_{VA}}$) at 0.96 and 0.53 respectively. The elasticity between Ricardian and non-Ricardian labour inputs σ_L is set equal to 1.4. The elasticities of substitution among varieties of domestically-produced intermediate goods and electricity (θ_{Y_H} and θ_{EL}) are set equal to 2.65 as well as the rest of the elasticities included in the model in order to define the degree of substitution among varieties.

The model includes several rigidities in the form of adjustment costs. According to the estimates by Annicchiarico et al. (2015) and Ratto et al. (2009) the parameters measuring the degree of price and wage rigidity (γ_{P_Y}, $\gamma_{W_{L_R}}$ and $\gamma_{W_{L_{NR}}}$) are set equal to 20, 15 and 15, respectively. The parameters related to the adjustment cost on investment in capital and labour of the intermediate goods sector, (γ_I, γ_{L_R} and $\gamma_{L_{NR}}$), are set equal to 75.9, 71 and 71, respectively. The remaining parameters related to the degree of price and quantity rigidity are all set equal to 6.

There are three emission functions in the model according to the source of pollution, namely output, electricity generated from fossil fuels and gasoline consumption for transportation. Each function has two parameters determining its shape: the emission intensity parameter, φ_X, and the elasticity μ_X, where $X = \{Y, EL_{FOS}, ROIL\}$. We estimate the elasticities computing the respective percentage variations between 2005-2013 in order to take into account the relevant period in which environmental regulations were implemented.

We compute the elasticity between output and emissions using ISTAT data for industrial production and emissions from the industrial sector. For the level of emissions generated by electricity from fossil fuel production we use TERNA data on thermoelectric electricity whereas ISTAT data are used for the relative level of emissions. For the elasticity between gasoline consumption and emissions, we use ISTAT data for emissions derived from transportation.[9] The data on household consumption of

7. Notice that geothermic energy appears in Table 2 but is not included in the model so that the sum of the electricity shares in the model is slightly lower than 100.

8. Strictly speaking, this parametrization entails a degree of complementarity among inputs used in the electricity generation.

9. Data from ISTAT and TERNA on emissions and electricity are available, respectively, at http://dati.istat.it and

gasoline are reported by the Italian Ministry of Economic Development[10]. We obtain the following values for the relative elasticities: $\mu_Y = 1.2$, $\mu_{EL_{FOS}} = 1.5$ and $\mu_{ROIL} = 0.6$.

Finally, the scale parameters of the abatement cost function for intermediate good firms and electricity producers (ϕ_1 and ϕ_1^{EL}) are set both to 0.025, while the parameters governing the convexity of the functions (ϕ_2 and ϕ_2^{EL}) are set both to 1.278. For these parameters we have drawn on previous studies estimating the parameters for the European Union (see Cline 2011)

Using this parametrization, the non-linear version of GEEM is solved in a TROLL platform which uses a Newton-type algorithm to solve non-linear deterministic models. To conduct our simulation exercise, we examine the deterministic response of the economy to unexpected permanent changes in the exogenous variables occurring at the beginning of our simulation time horizon. However, the analysis of the effects of permanent shocks requires solving a two-point boundary-problem, specifying the initial conditions for the predetermined variables and the terminal conditions for the forward looking variables. The more rigorous approach to solve this problem would make it necessary to derive the new steady state of the model and use the theoretical equilibrium values as terminal conditions. However, when dealing with a large scale model this solution strategy can be taxing. Alternatively, one may opt to reformulate the problem so that the terminal conditions are invariant to policy changes, as proposed by Roeger and in't Veld (1999). In this paper we have opted for this latter strategy.

5 Scenarios

We consider several policy scenarios for the Italian economy by using both an array of traditional policy shocks, commonly examined in DGE models for the evaluation of generic structural reforms, and other shocks designed to specifically evaluate the impact of climate-energy policies. It is worth noting that we will not deal with specific reform provisions that have been implemented or that the Italian government is about to implement. Indeed, our scenarios are intended to be only illustrative and have been constructed for the purpose of conducting a policy experiment. Accordingly, the simulation hypotheses concerning the credibility, the design and the size of the shocks are to some extent arbitrary. The simulations are carried out under the assumption that reforms are fully credible and the underlying policy measures are gradually introduced. The gradual introduction of policy change allows us to analyze the effects of a slower implementation, motivated either by possible institutional delays or due to the need to form consensus for policy changes. As common practice in applied economic modeling, all policy changes are assumed to be permanent. Households and firms have perfect foresight, therefore any possible source of uncertainty about the underlying path of policy changes is ruled out. As a result, forward looking agents adjust their behaviour accordingly, anticipating the long-run effects of the reforms. Of course, other assumptions are equally possible, such as providing economic agents with some information about the current or forthcoming policy change, namely, emission reduction may be announced some time before its implementation. This alternative hypothesis leads to a different adjustment of agents' behaviour which tends to reduce short-term adjustment costs. In fact, announcing policy changes ahead of time would induce firms to adjust prices and output more gradually, starting just before the reform comes into effect. Households, anticipating the future policy change would change their consumption decisions much less rapidly in the short term.

http://terna.it/it-it/sistemaelettrico/statisticheeprvisioni.aspx

10. Ministero dello Sviluppo Economico - Dipartimento per l'Energia - DGSAIE. http://www.sviluppoeconomico.gov.it/index.php/it/cittadino-e-consumatori/prezzi/mercati-dei-carburanti

Our analysis covers five wide areas: (i) emission reduction policies *(Scenario 1)*, *(Scenario 2)* ; (ii) fiscal policies and taxation, involving the recycling of permit revenues and public spending shifts, *(Scenario 3)*, *(Scenario 4)*, *(Scenario 5)*; (iii) liberalization measures *(Scenario 6)*, *(Scenario 7)*; (iv) policies aimed at improving economic efficiency *(Scenario 8)*, *(Scenario 9)*; (v) energy-price shocks *(Scenario 10)*. See Table 4 where all scenarios are summarized.

The first policy area includes policy interventions aimed at decarbonising the economy. The first scenario *(Scenario 1)* considers an emission reduction of 10 per cent involving both the manufacturing and electricity sectors implemented in a gradual way over a period of fifteen years. This shock is implemented by reducing the $Z_{Y,t}$ and $Z_{EL,t}$ in equations (12) and (25), respectively. In *Scenario 2* we assume that the revenues generated by the auctioning of permits to the electricity and intermediate good sectors (0.7 per cent of output on average) linked to emission reduction (by 10 per cent as in Scenario 1) are earmarked for reducing labour taxes (variables $\tau_t^{L_R}$ and $\tau_t^{L_{NR}}$ in equations (40) and (55)) over a period of fifteen years. In both scenarios the emissions generated from the consumption of $ROIL_t$ is not subject to any cap and it is thus free to adjust.

The second policy area includes fiscal shifts from labour or RES taxation to refined oil consumption taxes. Also, a public spending increase is implemented to capture the effects of demand-driven shocks. In particular, in *Scenario 3* we implement a budget-neutral tax shift from labour to refined oil consumption taxes (fuel excise taxes). This policy shift is thus designed by reducing labour tax rates (variables $\tau_t^{L_R}$ and $\tau_t^{L_{NR}}$ in equations (40) and (55)) in order to reduce taxation on labour income by 1 percent of output in the baseline simulation. At the same time, an increase in the refined oil consumption tax rate (variable τ_t^{ROIL}) is introduced in such a way to generate an ex-ante increase in fiscal revenues by 1 percent of nominal output in the baseline simulation. In *Scenario 4* we consider a budget-neutral tax shift from taxes on renewables to fuel excise taxes equivalent to 0.1 percent of baseline output. Finally, *Scenario 5* considers a public spending increase of 1 percent of baseline output. All the scenarios in this area are implemented in a gradual way over a period of five years, while the overall emissions of the economy are kept fixed.

The third policy area includes reform packages focusing on promoting market competition. In particular, *Scenario 6* considers the effects of a price markup reduction in the intermediate sector of 1 per cent, while in *Scenario 7* we document the effects stemming from a reduction in the electricity sector price markup of 10 per cent. These shocks are introduced into the model by increasing, respectively, θ_{Y_H} and θ_{EL}, that is, the elasticity of substitution between varieties in the intermediate good and in the electricity sectors. Both these shocks are implemented in a gradual way over a period of five years, while the overall emissions are kept at the cap level.

The fourth policy area includes some policy actions aimed at improving the business environment and enhancing economic efficiency. Put it differently, the policy reforms in this area aim at ameliorating the functioning of institutions, easing bureaucracy and reducing the administrative burden. The latter are expected to improve productivity, similarly to policies aimed at improving the efficiency of infrastructure. In particular, *Scenario 8* reports the effects of an exogenous 1 per cent productivity improvement in the intermediate good sector, while in *Scenario 9* we consider the effects related to a positive technological shock of 10 per cent, only in the renewables sector. These shocks are obtained in GEEM by varying, respectively, the exogenous factor A_t in the production function (see equation (7)) and the factor $A_{R\hat{E}S,t}$ in the electricity sector (see equation (24)). These simulations are implemented in a gradual way over a period of five years. Also in this case we assume an overall cap on total emissions.

Finally, *Scenario 10* documents the impact on economic activity of a permanent decrease in oil, gas and refined oil prices by 20 percent. This shock is designed to evaluate the dynamic response of the system to exogenous supply-side shocks. As in the previous scenarios, this simulation has been implemented in a gradual way over a period of five years and under the assumption of a cap on all emissions.

6 Results

In this Section we report the results of our simulations by showing the effects on the main macroeconomic variables. The impact of policy changes are evaluated for the first 2 years following implementation as well as over the medium-long run. Analysis is based on annual values. In the first policy area we study the effects of mitigation policies, while in all another areas experiments are conducted under the assumption that the overall emission cap (Z_t^{TOT}) is kept constant. We will see that this assumption allows us to isolate the effects of individual policy interventions and shocks, and observe the consequent re-allocation effects in the distribution of emissions between sectors.

6.1 Emission reduction policies

We start our analysis by considering the effects of measures aimed at directly reducing emissions. All these scenarios, in fact, envisage a gradual reduction of emissions by 10 per cent. Table 5 displays the economy's response to a 10 per cent 15-year-gradual decrease in emissions within the manufacturing and the electricity sectors. In this scenario output, consumption, investment and labour decrease persistently over the short as well as the medium-long term. The negative effects on the economic activity tend to accrue in the medium term (15 years), while in the long run these effects are mitigated. Since emission abatement is a costly activity, the steady reduction in emissions pushes manufacturing firms to cut back on production to sustain lower abatement costs, limiting their emissions according to the diminishing cap. As a result of the lower level of output, less resources are available for consumption and investment, so that such mitigation policy entails a crowding-out effect on the main components of demand. At the same time, reduced economic activity along with higher abatement costs will induce electricity producers to cut down their production, including RES and dirty sources of energy. Indeed, investments in RES also decrease as now electricity producers will find it more convenient to abate rather than change production structures towards RES technologies. It follows that climate mitigation policies are costly, especially in the short-medium run. In the long run, when the technological shift from dirty to clean inputs is fully underway, output decreases by -0.59 per cent, while consumption and investments still remain below their baseline values by around 0.5 and 0.4 per cent respectively.

Table 6 shows the impact of emission mitigation policy along with a mechanism of recycling the revenues generated by auction in order to reduce labour income taxes. In this case the tax reduction has a number of positive effects on economic activity by reducing distortions on employment decisions. By diminishing the allocative inefficiency of direct taxation, this measure provides incentives to increase labour supply, therefore gross wages and so unit labour costs decrease, while the negative effect on output is significantly mitigated relative to the previous scenario. The higher cost borne by firms due to the major abatement effort imposed by the mitigation policy is mitigated by the beneficial effects stemming from a more efficient labour market. In these circumstances, firms tend initially to substitute labour with capital in production given adjustment costs on labour; then, they tend to adjust labour upwards, making capital more productive. Overall, we observe that in the long run with this combination of policies the trade-off between environmental quality and economic activity is fully overcome. Actually, after 20 years we observe a positive impact on GDP, consumption and investment.

6.2 Fiscal policies and taxation

In this set of scenarios we consider interventions in the area of fiscal policy and taxation. All the experiments are conducted under the assumption that the total emission cap is kept constant over time. In particular, the first two scenarios envisage tax shifts towards refined oil (designed to be ex ante budget neutral), while the third one refers to an expansion of public sector consumption. We start with *Scenario 3*, where we assume a shift in the tax burden from labour income to fuel excise taxes. Table 7 reports the results for this scenario. In this case we observe that shifting the burden of taxation from labour to consumption reduces inefficiencies and distortions in the labour market, giving rise to an increase in output by 0.43 per cent after 5 years and and by 0.84 after 15 years, and in labour by 0.67 per cent after 5 years and by 1.11 per cent after 15 years. In the model the positive effect on labour and output of the tax shift is hampered by the presence of the total emission cap on total emissions which shifts firms' resources from production to abatement activities. The increase in labour triggers a correspondent increase in investment until the optimal capital-labour ratio is re-established. The beneficial effect of the tax shift is also recorded on aggregate consumption, while, as expected, a small dip in refined oil consumption is observed after 5 years from the onset of the simulation. In the first two years we observe, instead, a slight increase in the consumption of refined oil since in the short-run the (positive) income effect derived from lower taxes on labour income overcomes the (negative) substitution effect induced by the higher taxation on refined oil. In contrast, biofuel consumption rises persistently, so as to partially compensate the reduction in oil consumption. Also, it worth noting that non-Ricardian households will significantly benefit from the reduction in labour taxation as their income is highly sensitive to changes in labour taxation. As a result, the benefits accruing to Ricardian households are lower than those to non-Ricardian households.

In *Scenario 4* the tax shift is designed so as to encourage investments in renewable resources. See Table 8 for results. Indeed, investments in renewables increase already in the short run by around 10 per cent from the baseline up to 15 per cent after 30 years, contributing to output expansion. As a consequence, the demand for electricity increases, while the production structure moves towards clean inputs, with a decrease in the use of fossil fuel. Hence, emissions in the electricity sector decline sharply since its production is now more reliant on clean sources. Furthermore, the price of electricity steadily declines as the marginal cost of renewable resources is lower than that of fossil fuels.[11] However, positive effects on output in the medium run tend to be reinforced in the long run. Instead, consumption and investment display a negligible effect also in the long run.

Table 9 shows the effects of a 1 per cent increase in public spending according to *Scenario 5*. An increase in public spending entails a permanent fall in private consumption and a rise in labour supply due to the negative wealth effect.[12] The higher level of hours worked along with a major use of capital accounts for most of the observed increase in long-run output. Ricardian households, which are assumed to be 0.7 per cent of the workforce according to the model parametrization, anticipate future increases in taxes and, therefore, find it optimal to reduce their consumption in line with the declining value of future flows of disposable income. Lower consumption, in turn, implies a lower marginal rate of substitution between leisure and consumption, affecting the wage equation, so that the model predicts more hours worked and lower real wages. However, non-Ricardian households experience a drop in wages as a result of decreasing labour income and so consumption. Finally, the higher demand for electricity, due to a higher output level, is fulfilled with more renewables, inducing

11. This is consistent with the empirical evidence on the impact of RES utilisation on the wholesale electricity market. See, e.g., Clo et al., (2015) and Gelabert et al. (2011).

12. In this model, in fact, public spending is introduced as a pure waste.

a steady production shift from dirty to clean sources. This is a direct effect from the emission cap, which is binding at all times. As a consequence, more investment in RES capital is now required in the electricity sector. Also, the higher output generates more emissions in the intermediate good sector and less in the electricity sector as a result of the shift from fossil fuels to RES, while those from the transportation decline as a result of consumption reduction and in order to comply with the constant emission cap.

6.3 Liberalization

In this section we consider the effects of policies promoting competition in the manufacturing (i.e. the intermediate goods sector) and electricity sector. These scenarios refer to reform packages promoting market competition and favoring business which are mapped onto the model through a reduction of the price markup in sectors involved. Again, all policy experiments are conducted under the assumption of a fixed cap. *Scenario 6* displays the potential macroeconomic impact of a markup reduction in the intermediate good sector. See Table 10. As is usual in DGE models, this shock produces an expansionary effect on output, consumption and investment, induced by the enhanced competition among firms. In the medium term, liquidity constrained households, consuming their current income, will fully benefit from the price decrease and the resulting increase in their purchasing power, and as a result of this, their consumption will increase by more than that of Ricardian households. Also investments and labour will increase due to the induced higher demand of capital and labour. Intuitively, the lack of competition in the good market is a source of rents in favour of producers. From this point of view, it is then clear that pro-competitive reforms in the good market, by reducing the markup charged by firms, by diminishing these rents, tend to reduce distortions in the economy. Also, we note that the positive effect on the electricity price is basically the reflection of the higher demand for electricity induced by the expanded production in the intermediate sector.

Scenario 7 reports the effects of a markup reduction only in the electricity sector. The response of the economy in this case is shown in Table 11. As expected, by virtue of greater competition, electricity production rises and its price falls. The increased supply of electricity pushes intermediate good producers to use more intensively electricity and to substitute it for labour. In doing so, the lower demand for labour will induce a correspondent drop in wages and the resulting contraction of consumption. In addition, the compliance with the emission cap will induce the intermediate firms to reduce output to sustain lower abatement costs. Given the constant cap on the overall emissions, the burden of emission reduction is borne by the intermediate good sector where emissions are shown to reduce, while the electricity firms supply more electricity at cheaper prices through more conventional inputs and renewables.

6.4 Policies to improve economic efficiency

We now analyze the effects of policy interventions aimed at creating a more friendly business environment and at improving efficiency. *Scenario 8* displays the economic effects of an exogenous improvement in productivity of the firms operating in the intermediate good sector. See Table 12. As expected, this shock gives rise to positive effects on output, consumption and investment, and to a negative effect on labour. To be sure, in the labor market we observe higher wages as the improved productivity induces an additional demand of labour from intermediate firms so that wage setters are able to ask for higher remunerations. Nonetheless, labour shows a permanent decline, since more productive agents substitute working hours with leisure, namely the income effect prevails over the substitution effect. Consumption and investment dynamics strongly depend on the interplay between substitution and income effects. On the one hand consumers are prone to reduce saving and investment as more output can be obtained with the same level of capital; on the other hand, the higher return on capital might push consumers to save more. Turning to the distribution of emissions, we notice a reduction in the emissions from the intermediate and the electricity sectors, while emissions from refined oil consumption increase. Being more productive, in fact, firms in the manufacturing sector will reduce the use of electricity and be able to employ more resources for the abatement. At the same time, households, given their improved economic conditions will demand more refined oil.

Scenario 9 presents the economic effects of a positive productivity shock in the RES sector. The impact on output, consumption and investments is positive but negligible, whereas RES investments decrease as a result of higher level of productivity in this sector. As expected, the electricity sector will produce more by making use of less fossil fuel and, therefore, generating less emissions. See Table 13.

6.5 Energy-price shock

We conclude our analysis by studying the effects of energy price shocks. In particular, *Scenario 10* envisages a permanent drop in both oil, gas and refined oil prices. The total level of emissions is kept constant, as in the previous exercises. All results are shown in Table 14. As expected, beneficial effects on economic activity, namely on output, consumption, investment and electricity production are immediately observed. This shock positively affects the economy on both the supply and the demand side. On the supply side, although substitution possibilities are limited in the short run, a decrease in the price of oil and gas inputs reduces production costs in the electricity sector, so providing the intermediate goods sector with cheaper electricity. Nonetheless, the oil and gas price reduction induces a more intensive use of these sources in the energy mix along with a higher level of RES. The more intense use of RES allows electricity firms to reach an energy mix suitable to comply with the emission cap so that more electricity is now supplied at lower prices. Furthermore, in the short-medium run intermediate firms will find it convenient to substitute labour with electricity to fully benefit from the reduced electricity price. In the long run, labour inches up until the optimal combination of productive inputs capital-labour-electricity ratio is re-established. On the demand side, a decrease in oil prices leads to a gain in real income of households, so positively affecting consumer choices. In addition, higher expected profits make investment activity more profitable, so inducing intermediate firms to increase their capital endowments. Turning to emissions, we note that those from the electricity sector and those from consumption of refined oil increase, while emissions from the intermediate sector decrease to comply with the emission cap in the model. This entails that the burden of emission reduction is fully borne by the intermediate good sector while the electricity sector meets its emission target making use of more renewables.

7 Conclusions

In this paper we have presented GEEM, a new dynamic general equilibrium model for the Italian economy primarily designed for the study of climate and energy policies. The structure of the model is general, however, and can thus be used for the analysis of fiscal policy changes and tax reforms along with the macroeconomic implications of greater competition in product and labour markets, as well as in the energy sector. From this perspective, GEEM can serve as a comprehensive tool for studying the macroeconomic implications of actual and hypothetical reform scenarios operating in different domains under alternative climate policy regimes. Environmental policies, in particular climate actions, are likely to produce pervasive effects on the economy, significantly interacting with other policies. The environmental constraint, represented by climate policies, along with the additional costs of abatement and the possibility of shifting from one energy source to another, is shown to shape the response of the economy to policy changes in different areas of intervention.

To understand the functioning of GEEM and show its potential as a simulation tool, we have presented the results of policy interventions aimed at (i) reducing the level of emissions, (ii) diminishing distortions in the labour market, (iii) reducing the use of polluting energy sources in favour of cleaner sources, (iv) fostering competition in the product and in the energy markets and (v) increasing productivity in the economy. We have also studied the effects of an energy price shock.

Our results show the strong impact of mitigation policies on the level and the composition of economic activity, the importance of recycling revenues from environmental policy as a means to reconcile different policy objectives and the significant reallocation of emission permits across sectors stemming from expansionary policy, tax shifts aimed at increasing the use of clean energy sources and liberalization policies.

Overall GEEM seems well suited for policy analysis. The development of models is, however, a long term and continuous process. The version of the model presented in this paper represents a first step, to be refined and extended in the future along several dimensions. First, the parametrization of the model is based on calibration. A smaller version will be estimated by using Bayesian techniques. Second, the model represents an economy in isolation, taking as given the behaviour of the rest of the world. As a consequence, the policy scenarios analyzed in this paper do not consider the implications of a multi-country implementation of environmental policies. Instead, owing to the beggar-thy-neighbour nature of some of the policies considered in this paper, it would be relevant to investigate this issue in the context of a multi-country model, accounting for possible spillover effects across countries and the adoption of coordinated climate actions. Finally, the present version of GEEM abstracts from endogenous technological change which can be an important factor driving the impact of climate policies and the adoption of cleaner technologies along with the use of renewable energy sources. We leave these points for future research.

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Appendix A

At the optimum the demand for the domestic variety is given by

$$Y_{H,t}(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta_{Y_H}} Y_{H,t}. \tag{93}$$

As we will see, pro-competitive policy interventions in the product market will be introduced into the model by increasing θ_{Y_F}. Perfect competition and free entry drive the final good-producing firms' profits to zero, so that from the zero-profit condition we obtain:

$$P_t = \left[\int_0^1 P_t(j)^{1-\theta_{Y_H}} dj\right]^{\frac{1}{1-\theta_{Y_H}}}. \tag{94}$$

which defines the aggregate price index of our economy.

Similarly, the demand for each foreign variety is given by

$$IMPF_t(m) = \left(\frac{P_{IMPF,t}(m)}{P_{IMPF,t}}\right)^{-\theta_{IMPF}} IMPF_t. \tag{95}$$

Perfect competition and free entry drive the final good-producing firms' profits to zero, so that from the zero-profit condition we obtain:

$$P_{IMPF,t} = \left[\int_0^1 P_{IMPF,t}(m)^{1-\theta_{IMPF}} dm\right]^{\frac{1}{1-\theta_{IMPF}}}. \tag{96}$$

Appendix B

The problem for the representative intermediate-good producing firm is to choose the sequence $\{P_t, K_t, L_{R,t}, L_{NR,t}, U_t, EL_t\}_{t=0}^{\infty}$ in order to maximize the sum of expected discounted real profits subject to the demand from final good producers and exporters, given production and abatement technologies.

Under symmetry the optimal steady-state conditions for this problem boil down to the following equations:

$$Y - \theta_{Y_F}(1-MC)Y + \left[\frac{P_Z}{P}(1-U)\mu_Y\varphi_Y\theta_{Y_F}Y^{\mu_Y} - (1-\theta_{Y_F})\phi_1 U^{\phi_2} Y\right] = 0, \tag{97}$$

$$-\frac{P_I}{P}r^K u^K + MC[A(d(M))]^{\frac{\theta_Y-1}{\theta_Y}}\left(\frac{\rho_{VA}Y}{VA}\right)^{\frac{1}{\theta_Y}}\left(\frac{\rho_{K_{VA}}VA}{u^K K}\right)^{\frac{1}{\theta_{VA}}} u^K = 0, \tag{98}$$

$$\phi_1\phi_2 U^{\phi_2-1}Y = \frac{P_{Z,t}}{P_t}\varphi_Y Y^{\mu_Y}, \tag{99}$$

$$W_{L_R}(1 - sub^{L_R} + \tau_f^{W_{L_R}}) = MC[A(d(M))]^{\frac{\theta_Y-1}{\theta_Y}}\left(\frac{\rho_{VA}Y}{VA}\right)^{\frac{1}{\theta_Y}}\left[\frac{(1-\rho_{K_{VA}})VA}{L}\right]^{\frac{1}{\theta_{VA}}}\left(\frac{\rho_{L_R}L}{L_R}\right)^{\frac{1}{\sigma_L}} ef_{L_R}^{\frac{\sigma_L-1}{\sigma_L}}, \tag{100}$$

$$W_{L_NR}(1 - sub^{L_{NR}} + \tau_f^{W_{L_{NR}}}) = MC[A(d(M))]^{\frac{\theta_Y - 1}{\theta_Y}} \left(\frac{\rho_{VA} Y}{VA}\right)^{\frac{1}{\theta_Y}} \left[\frac{(1-\rho_{K_{VA}})VA}{L}\right]^{\frac{1}{\theta_{VA}}} \left(\frac{\rho_{L_{NR}} L}{L_{NR}}\right)^{\frac{1}{\sigma_L}} ef_{L_NR}^{\frac{\sigma_L - 1}{\sigma_L}}, \tag{101}$$

$$\frac{P_{EL}}{P} = MC[A(d(M))]^{\frac{\theta_Y - 1}{\theta_Y}}, \tag{102}$$

where MC is the marginal cost for producing one unit of output; r^K is the rental rate of capital; $P_{Z,t}$ is the price of emission permits; P_I is the price of investment; sub^{L_R} and $sub^{L_{NR}}$ denote, respectively, government subsidies to firms for Ricardian and non-Ricardian workers; $\tau_f^{W_{L_R}}$ and $\tau_f^{W_{L_{NR}}}$ denote social security contribution tax rates borne by firms for Ricardian and non-Ricardian workers; P_{EL} is the price of electricity.

Appendix C

The representative firm chooses the sequence

$$\{P_{EL,t}, COA_t, GAS_t, OIL_t, EL_{NUC,t}, EL_{RES,t}, U_{EL,t}, K_{SOL,t}, K_{WIN,t}, K_{BIO,t}, K_{HYD,t}\}_{t=0}^{\infty}, \tag{103}$$

in order to maximize the sum of expected discounted real profits:

$$E_0 \sum_{t=0}^{\infty} Q_{0,t} \left\{ \begin{array}{c} \frac{P_{EL,t}}{P_t} EL_t - ADJ_{P_{EL},t} - \mathcal{C}_{EL} - \frac{P_{Z,t}}{P_t} Z_{EL,t} - \sum_N \left[\frac{P_{N,t}}{P_t} N_t + ADJ_{N,t}\right] \\ -\frac{P_{I^{RES},t}}{P_t} r_t^{K^{RES}} (K_{WIN,t} + K_{HYD,t} + K_{BIO,t} + K_{SOL,t}) \end{array} \right\} \tag{104}$$

subject to demand for its own variety, (19)-(23) and (24), where $Q_{0,t}$ is the stochastic discount factor, $N_t = \{COA_t, GAS_t, OIL_t, EL_{NUC,t}\}$, $r_t^{K^{RES}}$ is the rental rate of capital and

$$ADJ_{P_{EL},t} = \frac{\gamma_{P_{EL}}}{2} \left(\frac{P_{EL,t}}{ind_t^{P_{EL}} P_{EL,t-1}} - 1\right)^2 Y_t,$$

$$ADJ_{N,t} = \frac{\gamma_N}{2} \left(\frac{N_t}{N_{t-1}} - 1\right)^2 Y_t,$$

represent the adjustment costs, with $ind_t^{P_{EL}} = \Pi_{t-1}^{\kappa_{P_{EL}}} \bar{\Pi}^{1-\kappa_{P_{EL}}}$.

Under symmetry the optimal steady-state conditions for this problem are the following:

$$\frac{P_{EL}}{P} = \frac{\theta_{EL}}{\theta_{EL} - 1} MC_{EL,t}, \tag{105}$$

$$\begin{aligned} \frac{P_N}{P} = & \left(\frac{\rho_{EL_{COAOIL}} EL_{FOS}}{EL_{COAOIL}}\right)^{\frac{1}{\theta_{FOS}}} \left(\frac{\rho_{EL_N} EL_{COAOIL}}{N}\right)^{\frac{1}{\theta_{COAOIL}}} \\ & \times \left[MC_{EL} \left(\frac{\rho_{EL_{CON}} EL}{EL_{CON}}\right)^{\frac{1}{\theta}} \left(\frac{\rho_{EL_{FOS}} EL_{CON}}{EL_{FOS}}\right)^{\frac{1}{\theta_{CON}}} - \frac{P_Z}{P}(1 - U_{EL,t}) \varphi_{EL} \mu_{EL} EL_{FOS}^{\mu_{EL} - 1} \right], \end{aligned} \tag{106}$$

$$\frac{P_{I_{RES},t}}{P_t} r^{K^{RES}} = \alpha_{\hat{RES}} MC_{EL,t} \frac{EL_{\hat{RES}}}{K_{\hat{RES}}} \left[\frac{(1-\rho_{EL_{CON}})EL}{EL_{RES}}\right]^{\frac{1}{\theta}} \left(\frac{\rho_{EL_{\hat{RES}}} EL_{RES}}{EL_{\hat{RES}}}\right)^{\frac{1}{\theta_{RES}}}, \tag{107}$$

$$\phi_1^{EL}\phi_2^{EL}U_{EL}^{\phi_2^{EL}-1} = \frac{P_Z}{P_{EL}}\varphi_{EL}EL_{FOS}^{\mu_{EL}-1}. \tag{108}$$

Furthermore, we assume that $N_t = \{COA_t, GAS_t, OIL_t, EL_{NUC,t}\}$ is a bundle of different varieties indexed by $m \in [0,1]$:

$$N_t \equiv \left[\int_0^1 N_t(m)^{\frac{\theta_N-1}{\theta_N}} dm\right]^{\frac{\theta_N}{\theta_N-1}}, \tag{109}$$

where $\theta_N > 1$ is the elasticity of substitution among the varieties of N_t.

Given $N_t = \{COA_t, GAS_t, OIL_t, EL_{NUC,t}\}$, each electricity producer demands the variety m according to:

$$N_t(m) = \left(\frac{P_{N,t}(m)}{P_{N,t}}\right)^{-\theta_N} N_t, \tag{110}$$

where

$$P_{N,t} = \left[\int_0^1 P_{N,t}(m)^{1-\theta_N} di\right]^{\frac{1}{1-\theta_N}}, \tag{111}$$

are the corresponding price indexes.

Tables

Table 1: Economic Ratios

Consumption (% GDP)	61.3
Investment (% GDP)	17.5
Import (% GDP)	36
Public expenditure (% GDP)	20

Table 2: Electricity gross production by source (GWh)

Source	Production	% of total production
Natural Gas	109,990	38.21
Coal	45,812	15.92
Oil	21,738	7.55
Hydro	53,240	18.5
Solar	22,400	7.78
Wind	15,000	5.21
Biomass	14,000	4.86
Geothermic	5,650	1.96

Source: AEEGSI 2014 annual report

Table 3: CES parameters calibration

Parameter	Calibration	Description
Electricity generation		
θ	0.6	Elasticity of substitution between conventional sources and RES
θ_{FOS}	0.9	Elasticity of substitution between coal-and-oil and gas
θ_{COAOIL}	0.3	Elasticity of substitution between coal and oil
θ_{RES}	2	Elasticity of substitution among RES
θ_{Y_H}	2.65	Elasticity of substitution among varieties of domestically-produced intermediate goods
$\rho_{EL_{CON}}$	0.63	Factor share of conventional sources
ρ_{COA}	0.68	Factor share of coal
ρ_{COAOIL}	0.38	Factor share of coal-and-oil
$\rho_{EL_{SOL}}$	0.21	Factor share of solar
$\rho_{EL_{WIN}}$	0.14	Factor share of wind
$\rho_{EL_{BIO}}$	0.13	Factor share of biomass
Intermediate goods production		
θ_Y	0.8	Elasticity of substitution between value added and electricity
θ_{VA}	0.9	Elasticity of substitution between capital and labour
θ_{EL}	2.65	Elasticity of substitution among varieties of electricity
σ_L	1.4	Elasticity of substitution between Ricardian and Non-Ricardian labour
ρ_{VA}	0.96	Factor share of value added
$\rho_{K_{VA}}$	0.53	Factor share of capital

Table 4: Simulated Scenarios

Classification	Scenario	Description
Emission reduction policies	1	Emission reduction in intermediate-good and electricity sectors (10%), phased in over 15 years
	2	1 + carbon market revenues earmarked for reducing labour taxes (0.7% of GDP), phased in over 15 years
Fiscal policies and Taxation	3	Tax shift from labour to refined oil consumption taxes (1% of GDP)
	4	Tax shift from RES to refined oil consumption taxes (0.1% of GDP), phased in over 5 years
	5	Public spending increase (1% of GDP), phased in over 5 years
Liberalization measures	6	Decrease in intermediate-good sector price markup (1%), phased in over 5 years
	7	Decrease in electricity sector price markup (10%), phased in over 5 years
Economic efficiency policies	8	Productivity improvement in the intermediate-goods sector (1%), phased in over 5 years
	9	Productivity improvement in RES sector (10%), phased in over 5 years
Energy-price shocks	10	Decrease in oil and gas prices (20%), phased in over 5 years

Table 5: Scenario 1 - Electricity and Intermediate emissions -10%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	-0.13	-0.30	-0.68	-1.08	-1.83	-0.94	-0.59
Consumption C_t	-0.14	-0.30	-0.55	-0.65	-0.64	-0.54	-0.50
Consumption - Ricardian C_t^R	-0.13	-0.27	-0.49	-0.61	-0.69	-0.71	-0.67
Consumption - Non Ricardian C_t^{NR}	-0.42	-0.99	-1.84	-1.61	0.70	3.51	3.54
Consumption - Final Good $C_{Y,t}$	-0.14	-0.30	-0.55	-0.65	-0.64	-0.54	-0.49
Consumption - Fuel $C_{F,t}$	-0.14	-0.30	-0.55	-0.65	-0.64	-0.55	-0.51
Consumption - Roil $ROIL_t$	-0.14	-0.30	-0.55	-0.65	-0.63	-0.55	-0.51
Consumption - Biofuel $BIOF_t$	-0.14	-0.30	-0.55	-0.65	-0.64	-0.55	-0.51
Investments I_t	-0.15	-0.18	-0.24	-0.33	-0.41	-0.38	-0.40
RES Investments $I_{RES,t}$	-0.99	-1.07	-1.21	-1.39	-1.30	-0.79	-0.78
Labour L_t	-0.04	-0.12	-0.32	-0.67	-1.11	-0.87	-0.63
Real wages W_t	-0.27	-0.63	-1.31	-1.87	-1.83	-0.92	-0.41
CPI $P_{C_{Y,t}}$	0.04	0.07	0.09	0.03	-0.16	-0.05	0.01
GDP Deflator P_t	0.01	0.00	0.00	0.00	-0.02	0.00	0.00
Emissions - Total Z_t^{TOT}	-0.37	-0.97	-2.73	-5.63	-8.53	-8.74	-8.74
Emissions - Intermediate $Z_{Y,t}$	-0.41	-1.06	-2.97	-6.17	-9.59	-9.66	-9.74
Emissions - Electricity $Z_{EL,t}$	-0.43	-1.13	-3.32	-6.97	-10.11	-10.77	-10.57
Emissions - Roil $Z_{ROIL,t}$	-0.08	-0.18	-0.33	-0.39	-0.38	-0.33	-0.31
Electricity - Total EL_t	-0.09	-0.24	-0.66	-1.20	-1.58	-1.39	-1.09
Electricity - Fossil $EL_{FOS,t}$	-0.11	-0.29	-0.79	-1.43	-1.87	-1.62	-1.22
Electricity - RES $EL_{RES,t}$	-0.06	-0.15	-0.42	-0.77	-1.04	-0.97	-0.86
Electricity Price $P_{EL,t}$	-0.08	-0.20	-0.41	-0.45	-0.53	0.24	0.60

All the variables are expressed in percentage deviations from steady state values

Table 6: Scenario 2 - Electricity and intermediate emissions -10% - Recycling Labour 0.7% GDP

	Years						
	1	2	5	10	15	20	30
GDP Y_t	-0.10	-0.22	-0.43	-0.49	-1.02	-0.13	0.20
Consumption C_t	-0.05	-0.11	-0.20	-0.32	-0.27	0.21	0.10
Consumption - Ricardian C_t^R	-0.05	-0.10	-0.18	-0.22	-0.26	-0.29	-0.25
Consumption - Non Ricardian C_t^{NR}	-0.16	-0.23	-0.63	-2.74	-0.53	12.23	8.50
Consumption - Final Good $C_{Y,t}$	-0.05	-0.11	-0.21	-0.32	-0.27	0.22	0.11
Consumption - Fuel $C_{F,t}$	-0.05	-0.10	-0.20	-0.32	-0.27	0.20	0.09
Consumption - Roil $ROIL_t$	-0.05	-0.10	-0.20	-0.32	-0.27	0.20	0.09
Consumption - Biofuel $BIOF_t$	-0.05	-0.10	-0.20	-0.32	-0.27	0.20	0.09
Investments I_t	0.57	0.54	0.46	0.37	0.30	0.29	0.24
RES Investments $I_{RES,t}$	-0.87	-0.92	-0.98	-1.04	-0.84	-0.35	-0.32
Labour L_t	-0.01	-0.03	0.00	0.17	-0.03	0.05	0.33
Real wages W_t	-0.23	-0.53	-1.36	-2.77	-2.76	-0.55	-0.73
CPI $P_{C_{Y,t}}$	0.02	0.02	0.02	0.08	-0.04	-0.10	0.01
GDP Deflator P_t	0.01	0.00	0.00	0.00	-0.01	0.00	0.00
Emissions - Total Z_t^{TOT}	-0.37	-0.95	-2.70	-5.61	-8.50	-8.68	-8.69
Emissions - Intermediate $Z_{Y,t}$	-0.40	-1.04	-2.92	-6.07	-9.49	-9.62	-9.74
Emissions - Electricity $Z_{EL,t}$	-0.45	-1.18	-3.44	-7.19	-10.33	-10.85	-10.58
Emissions - Roil $Z_{ROIL,t}$	-0.03	-0.06	-0.12	-0.19	-0.16	0.12	0.05
Electricity - Total EL_t	-0.09	-0.23	-0.60	-1.05	-1.31	-1.04	-0.68
Electricity - Fossil $EL_{FOS,t}$	-0.11	-0.28	-0.74	-1.28	-1.60	-1.26	-0.80
Electricity - RES $EL_{RES,t}$	-0.05	-0.13	-0.35	-0.61	-0.78	-0.63	-0.45
Electricity Price $P_{EL,t}$	-0.12	-0.24	-0.43	-0.46	-0.47	0.39	0.62

All the variables are expressed in percentage deviations from steady state values

Table 7: Scenario 3 - Tax shift from labour to ROIL 1% GDP

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.05	0.13	0.43	0.75	0.84	0.81	0.80
Consumption C_t	0.22	0.45	0.55	0.31	0.33	0.55	0.48
Consumption - Ricardian C_t^R	0.20	0.38	0.34	0.16	0.17	0.16	0.16
Consumption - Non Ricardian C_t^{NR}	0.88	2.26	5.63	3.76	4.13	9.75	8.14
Consumption - Final Good $C_{Y,t}$	0.26	0.54	0.80	0.57	0.59	0.81	0.74
Consumption - Fuel $C_{F,t}$	0.16	0.30	0.12	-0.16	-0.13	0.09	0.02
Consumption - Roil $ROIL_t$	0.14	0.24	-0.05	-0.34	-0.31	-0.10	-0.16
Consumption - Biofuel $BIOF_t$	0.26	0.54	0.80	0.58	0.61	0.82	0.76
Investments I_t	0.18	0.18	0.19	0.25	0.29	0.31	0.35
RES Investments $I_{RES,t}$	0.13	0.16	0.25	0.38	0.48	0.52	0.56
Labour L_t	0.08	0.22	0.67	1.11	1.11	0.95	0.91
Real wages W_t	-0.01	-0.14	-0.88	-1.23	-0.78	0.03	-0.30
CPI $P_{C_{Y,t}}$	-0.07	-0.14	-0.11	0.09	0.10	-0.02	0.01
GDP Deflator P_t	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.01	0.03	0.15	0.26	0.23	0.14	0.09
Emissions - Electricity $Z_{EL,t}$	-0.05	-0.13	-0.33	-0.47	-0.42	-0.29	-0.15
Emissions - Roil $Z_{ROIL,t}$	0.08	0.14	-0.03	-0.21	-0.19	-0.06	-0.10
Electricity - Total EL_t	0.00	0.00	0.03	0.12	0.24	0.34	0.45
Electricity - Fossil $EL_{FOS,t}$	0.00	0.00	0.01	0.09	0.21	0.32	0.44
Electricity - RES $EL_{RES,t}$	0.01	0.02	0.07	0.17	0.28	0.37	0.48
Electricity Price $P_{EL,t}$	0.02	0.06	0.11	0.10	0.15	0.20	0.09

All the variables are expressed in percentage deviations from steady state values

Table 8: Scenario 4 - Tax shift from RES taxes to ROIL +0.1% GDP

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.02	0.04	0.10	0.10	0.09	0.09	0.10
Consumption C_t	0.01	0.02	0.01	0.00	-0.01	-0.03	-0.01
Consumption - Ricardian C_t^R	0.01	0.02	0.01	-0.01	-0.01	0.00	0.00
Consumption - Non Ricardian C_t^{NR}	-0.01	0.03	0.13	0.25	0.00	-0.58	-0.12
Consumption - Final Good $C_{Y,t}$	0.01	0.03	0.04	0.02	0.01	0.00	0.02
Consumption - Fuel $C_{F,t}$	0.01	0.01	-0.03	-0.05	-0.05	-0.07	-0.05
Consumption - Roil $ROIL_t$	0.00	0.00	-0.05	-0.07	-0.07	-0.09	-0.07
Consumption - Biofuel $BIOF_t$	0.01	0.03	0.04	0.03	0.02	0.00	0.03
Investments I_t	0.08	0.08	0.08	0.07	0.07	0.06	0.06
RES Investments $I_{RES,t}$	10.44	11.60	13.58	14.20	14.52	14.75	15.03
Labour L_t	0.00	0.01	0.02	0.01	0.00	0.01	-0.01
Real wages W_t	0.03	0.07	0.16	0.20	0.12	0.03	0.12
CPI $P_{C_{Y,t}}$	-0.02	-0.02	-0.01	0.00	0.00	0.01	0.00
GDP Deflator P_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.03	0.07	0.15	0.16	0.13	0.10	0.07
Emissions - Electricity $Z_{EL,t}$	-0.06	-0.15	-0.33	-0.34	-0.26	-0.19	-0.13
Emissions - Roil $Z_{ROIL,t}$	0.00	0.00	-0.03	-0.04	-0.04	-0.05	-0.04
Electricity - Total EL_t	0.20	0.53	1.50	2.82	3.75	4.40	5.20
Electricity - Fossil $EL_{FOS,t}$	-0.03	-0.07	-0.12	0.01	0.24	0.48	0.88
Electricity - RES $EL_{RES,t}$	0.63	1.65	4.60	8.33	10.74	12.29	13.97
Electricity Price $P_{EL,t}$	-0.37	-0.93	-2.40	-3.94	-4.89	-5.55	-6.29

All the variables are expressed in percentage deviations from steady state values

Table 9: Scenario 5 - Public spending increase +1% GDP

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.06	0.13	0.31	0.47	0.55	0.61	0.68
Consumption C_t	-0.19	-0.39	-0.66	-0.77	-0.78	-0.78	-0.78
Consumption - Ricardian C_t^R	-0.18	-0.39	-0.69	-0.81	-0.81	-0.79	-0.77
Consumption - Non Ricardian C_t^{NR}	-0.39	-0.34	-0.18	-0.11	-0.12	-0.38	-0.95
Consumption - Final Good $C_{Y,t}$	-0.19	-0.39	-0.66	-0.78	-0.79	-0.79	-0.79
Consumption - Fuel $C_{F,t}$	-0.18	-0.38	-0.64	-0.75	-0.76	-0.76	-0.75
Consumption - Roil $ROIL_t$	-0.18	-0.38	-0.64	-0.75	-0.76	-0.76	-0.75
Consumption - Biofuel $BIOF_t$	-0.18	-0.37	-0.65	-0.75	-0.76	-0.76	-0.75
Investments I_t	1.51	1.50	1.43	1.36	1.30	1.24	1.13
RES Investments $I_{RES,t}$	0.20	0.25	0.34	0.41	0.47	0.52	0.60
Labour L_t	0.05	0.12	0.27	0.44	0.53	0.59	0.70
Real wages W_t	-0.19	-0.31	-0.32	-0.20	-0.13	-0.10	-0.11
CPI $P_{C_{Y,t}}$	0.06	0.06	-0.06	-0.02	-0.01	0.00	0.00
GDP Deflator P_t	0.01	0.01	-0.01	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.04	0.08	0.14	0.16	0.15	0.13	0.09
Emissions - Electricity $Z_{EL,t}$	-0.03	-0.06	-0.13	-0.15	-0.11	-0.07	0.01
Emissions - Roil $Z_{ROIL,t}$	-0.11	-0.23	-0.39	-0.45	-0.46	-0.46	-0.45
Electricity - Total EL_t	0.01	0.02	0.07	0.18	0.28	0.36	0.49
Electricity - Fossil $EL_{FOS,t}$	0.00	0.01	0.06	0.16	0.26	0.35	0.48
Electricity - RES $EL_{RES,t}$	0.01	0.03	0.10	0.22	0.31	0.38	0.50
Electricity Price $P_{EL,t}$	-0.08	-0.07	0.12	0.20	0.19	0.15	0.06

All the variables are expressed in percentage deviations from steady state values

Table 10: Scenario 6 - Markup reduction in the intermediate good sector -1%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.03	0.09	0.23	0.37	0.43	0.45	0.46
Consumption C_t	0.01	0.04	0.11	0.18	0.20	0.20	0.21
Consumption - Ricardian C_t^R	0.02	0.05	0.09	0.10	0.11	0.11	0.11
Consumption - Non Ricardian C_t^{NR}	-0.12	0.01	0.74	1.94	2.26	2.37	2.64
Consumption - Final Good $C_{Y,t}$	0.01	0.04	0.11	0.18	0.20	0.20	0.21
Consumption - Fuel $C_{F,t}$	0.02	0.05	0.11	0.18	0.20	0.20	0.21
Consumption - Roil $ROIL_t$	0.02	0.05	0.11	0.18	0.20	0.20	0.21
Consumption - Biofuel $BIOF_t$	0.02	0.05	0.12	0.18	0.20	0.20	0.21
Investments I_t	0.78	0.79	0.81	0.83	0.84	0.85	0.87
RES Investments $I_{RES,t}$	0.39	0.45	0.56	0.64	0.71	0.75	0.82
Labour L_t	0.01	0.02	0.06	0.10	0.11	0.11	0.09
Real wages W_t	0.05	0.14	0.44	0.83	0.97	1.02	1.08
CPI $P_{C_{Y,t}}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GDP Deflator P_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.00	0.01	0.01	-0.03	-0.07	-0.11	-0.17
Emissions - Electricity $Z_{EL,t}$	-0.01	-0.03	-0.04	0.01	0.11	0.20	0.32
Emissions - Roil $Z_{ROIL,t}$	0.01	0.03	0.07	0.11	0.12	0.12	0.13
Electricity - Total EL_t	0.02	0.05	0.16	0.33	0.46	0.56	0.70
Electricity - Fossil $EL_{FOS,t}$	0.02	0.05	0.15	0.31	0.45	0.55	0.68
Electricity - RES $EL_{RES,t}$	0.02	0.06	0.18	0.35	0.48	0.58	0.72
Electricity Price $P_{EL,t}$	-0.01	0.04	0.21	0.34	0.34	0.29	0.19

All the variables are expressed in percentage deviations from steady state values

Table 11: Scenario 7 - Markup reduction in the electricity sector -10%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	-0.02	-0.04	-0.11	-0.17	-0.16	-0.13	-0.08
Consumption C_t	-0.02	-0.05	-0.09	-0.10	-0.09	-0.08	-0.07
Consumption - Ricardian C_t^R	-0.02	-0.04	-0.08	-0.10	-0.10	-0.11	-0.11
Consumption - Non Ricardian C_t^{NR}	-0.13	-0.26	-0.43	-0.12	0.33	0.62	0.98
Consumption - Final Good $C_{Y,t}$	-0.03	-0.05	-0.09	-0.10	-0.09	-0.08	-0.06
Consumption - Fuel $C_{F,t}$	-0.02	-0.05	-0.09	-0.10	-0.09	-0.08	-0.07
Consumption - Roil $ROIL_t$	-0.02	-0.05	-0.09	-0.10	-0.09	-0.08	-0.07
Consumption - Biofuel $BIOF_t$	-0.02	-0.05	-0.09	-0.10	-0.09	-0.08	-0.07
Investments I_t	0.01	0.01	-0.01	-0.02	-0.03	-0.04	-0.04
RES Investments $I_{RES,t}$	2.01	2.25	2.79	3.32	3.68	3.94	4.30
Labour L_t	-0.01	-0.02	-0.07	-0.14	-0.17	-0.18	-0.19
Real wages W_t	-0.05	-0.12	-0.23	-0.26	-0.18	-0.11	0.00
CPI $P_{C_{Y,t}}$	0.01	0.01	0.01	0.00	-0.01	-0.01	0.00
GDP Deflator P_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	-0.06	-0.15	-0.42	-0.76	-0.98	-1.11	-1.21
Emissions - Electricity $Z_{EL,t}$	0.13	0.34	0.95	1.73	2.20	2.48	2.71
Emissions - Roil $Z_{ROIL,t}$	-0.01	-0.03	-0.06	-0.06	-0.05	-0.05	-0.04
Electricity - Total EL_t	0.13	0.33	0.95	1.85	2.54	3.06	3.76
Electricity - Fossil $EL_{FOS,t}$	0.13	0.34	0.98	1.88	2.57	3.08	3.76
Electricity - RES $EL_{RES,t}$	0.12	0.32	0.91	1.78	2.48	3.02	3.75
Electricity Price $P_{EL,t}$	-0.28	-0.71	-1.88	-3.06	-3.74	-4.20	-4.81

All the variables are expressed in percentage deviations from steady state values

Table 12: Scenario 8 - Intermediate-good sector TFP shock +1%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.07	0.19	0.55	0.83	0.92	0.96	0.98
Consumption C_t	0.13	0.30	0.57	0.75	0.79	0.80	0.81
Consumption - Ricardian C_t^R	0.15	0.32	0.59	0.70	0.72	0.72	0.73
Consumption - Non Ricardian C_t^{NR}	-0.18	-0.30	0.04	1.95	2.47	2.54	2.79
Consumption - Final Good $C_{Y,t}$	0.13	0.30	0.57	0.76	0.79	0.80	0.81
Consumption - Fuel $C_{F,t}$	0.13	0.30	0.56	0.74	0.78	0.79	0.80
Consumption - Roil $ROIL_t$	0.13	0.30	0.56	0.74	0.78	0.79	0.80
Consumption - Biofuel $BIOF_t$	0.13	0.30	0.57	0.74	0.78	0.79	0.80
Investments I_t	0.27	0.28	0.30	0.33	0.35	0.36	0.39
RES Investments $I_{RES,t}$	-0.07	-0.07	0.03	0.23	0.27	0.30	0.34
Labour L_t	-0.06	-0.15	-0.35	-0.40	-0.39	-0.38	-0.39
Real wages W_t	0.12	0.25	0.48	0.97	1.19	1.25	1.32
CPI $P_{C_{Y,t}}$	-0.02	-0.04	0.02	0.00	0.00	0.00	0.00
GDP Deflator P_t	-0.01	-0.01	0.01	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.02	0.07	0.21	0.25	0.22	0.19	0.14
Emissions - Electricity $Z_{EL,t}$	-0.09	-0.24	-0.62	-0.76	-0.72	-0.65	-0.54
Emissions - Roil $Z_{ROIL,t}$	0.08	0.18	0.34	0.44	0.47	0.47	0.48
Electricity - Total EL_t	-0.02	-0.04	-0.09	-0.01	0.08	0.16	0.25
Electricity - Fossil $EL_{FOS,t}$	-0.02	-0.06	-0.13	-0.05	0.05	0.13	0.24
Electricity - RES $EL_{RES,t}$	0.00	-0.01	-0.02	0.06	0.14	0.20	0.28
Electricity Price $P_{EL,t}$	-0.04	-0.10	-0.25	0.00	0.13	0.15	0.11

All the variables are expressed in percentage deviations from steady state values

Table 13: Scenario 9 - RES sector TFP shock 10%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.05	0.11	0.39	0.10	0.06	0.06	0.07
Consumption C_t	0.04	0.08	0.13	0.12	0.12	0.12	0.12
Consumption - Ricardian C_t^R	0.03	0.07	0.13	0.14	0.13	0.13	0.12
Consumption - Non Ricardian C_t^{NR}	0.16	0.35	0.29	-0.39	-0.31	-0.10	0.05
Consumption - Final Good $C_{Y,t}$	0.04	0.08	0.14	0.12	0.12	0.12	0.12
Consumption - Fuel $C_{F,t}$	0.04	0.08	0.13	0.12	0.11	0.11	0.11
Consumption - Roil $ROIL_t$	0.04	0.08	0.13	0.12	0.11	0.11	0.11
Consumption - Biofuel $BIOF_t$	0.04	0.08	0.13	0.12	0.11	0.11	0.11
Investments I_t	0.11	0.11	0.12	0.10	0.10	0.10	0.10
RES Investments $I_{RES,t}$	-3.56	-3.82	-4.59	-2.74	-2.91	-2.96	-3.01
Labour L_t	0.02	0.05	0.14	0.05	0.00	-0.01	-0.02
Real wages W_t	0.08	0.19	0.31	0.10	0.02	0.05	0.09
CPI $P_{C_{Y,t}}$	0.00	0.00	0.04	0.00	-0.01	-0.01	0.00
GDP Deflator P_t	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	0.07	0.17	0.55	0.15	0.04	0.00	-0.02
Emissions - Electricity $Z_{EL,t}$	-0.16	-0.40	-1.26	-0.37	-0.12	-0.02	0.01
Emissions - Roil $Z_{ROIL,t}$	0.02	0.05	0.08	0.07	0.07	0.07	0.06
Electricity - Total EL_t	0.29	0.76	2.00	2.60	2.67	2.69	2.72
Electricity - Fossil $EL_{FOS,t}$	-0.11	-0.26	-0.80	-0.09	0.21	0.38	0.56
Electricity - RES $EL_{RES,t}$	1.03	2.68	7.51	7.85	7.46	7.18	6.88
Electricity Price $P_{EL,t}$	-0.63	-1.57	-4.70	-3.43	-3.27	-3.25	-3.22

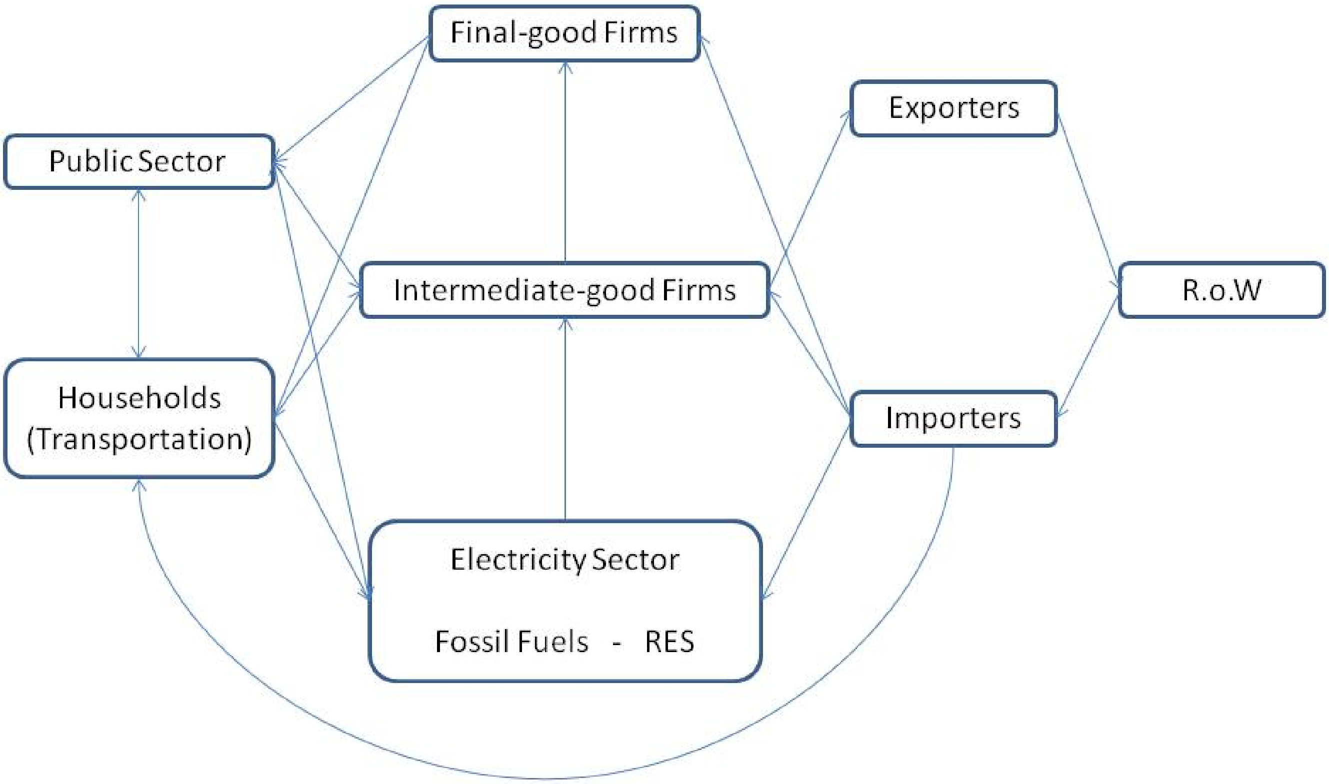
All the variables are expressed in percentage deviations from steady state values

Table 14: Scenario 10 - Shock on OIL and GAS price -20%

	Years						
	1	2	5	10	15	20	30
GDP Y_t	0.05	0.11	0.27	0.85	1.29	1.53	1.72
Consumption C_t	0.41	1.23	4.22	6.86	7.24	7.28	7.29
Consumption - Ricardian C_t^R	0.42	1.21	4.08	6.64	6.94	6.93	6.89
Consumption - Non Ricardian C_t^{NR}	0.25	1.70	7.69	12.21	14.57	15.73	17.00
Consumption - Final Good $C_{Y,t}$	0.19	0.65	2.59	4.92	5.31	5.36	5.38
Consumption - Fuel $C_{F,t}$	0.82	2.30	7.36	10.64	11.01	11.02	11.00
Consumption - Roil $ROIL_t$	0.97	2.72	8.65	12.23	12.60	12.61	12.60
Consumption - Biofuel $BIOF_t$	0.21	0.68	2.64	4.96	5.31	5.32	5.31
Investments I_t	3.42	3.41	3.32	3.30	3.33	3.36	3.41
RES Investments $I_{RES,t}$	0.98	1.17	1.69	2.49	3.03	3.46	4.14
Labour L_t	-0.06	-0.13	-0.26	-0.08	0.10	0.18	0.21
Real wages W_t	-0.05	-0.09	-0.43	-0.20	0.49	0.91	1.29
CPI $P_{C_{Y,t}}$	0.13	0.26	0.52	-0.13	-0.14	-0.08	-0.02
GDP Deflator P_t	0.10	0.03	-0.07	0.00	0.00	0.00	0.00
Emissions - Total Z_t^{TOT}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Emissions - Intermediate $Z_{Y,t}$	-0.15	-0.43	-1.31	-2.10	-2.54	-2.84	-3.08
Emissions - Electricity $Z_{EL,t}$	0.07	0.17	0.46	1.22	2.10	2.76	3.28
Emissions - Roil $Z_{ROIL,t}$	0.58	1.62	5.11	7.17	7.38	7.39	7.38
Electricity - Total EL_t	0.18	0.48	1.47	3.28	5.02	6.47	8.54
Electricity - Fossil $EL_{FOS,t}$	0.25	0.66	2.00	4.47	6.83	8.80	11.57
Electricity - RES $EL_{RES,t}$	0.06	0.16	0.50	1.17	1.82	2.40	3.35
Electricity Price $P_{EL,t}$	-0.28	-0.46	-0.78	-1.91	-3.07	-4.16	-5.84

All the variables are expressed in percentage deviations from steady state values

Figure 1: Simplified flow chart of the model



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