# Annex 1: Dynamic General Equilibrium Model for Sustainable Transitions (GEMST-1)

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# 1 Introduction

This Annex presents a theoretical Dynamic Applied General Equilibrium (AGE) model that reflect the main dynamics of Energy Transition (ET), capturing main interactions and feedback loops across sectors through energy and input prices. One of the unique aspects of our model is the distinction between green and brown varieties for final sectors, which captures both transition risks and opportunities associated in different sectors. Moreover, this distinction allows for differentiating the transition mechanisms across sectors that are energy relevant. Furthermore, the model allows for differentiating energy transition drivers across sectors, which gives the flexibility to capture possible sectoral developments in the constructed scenarios. Unlike other CGE models, this model contributes to the literature by introducing sector-specific capital stocks which allows for differentiation of the cost of capital across sectors. Accordingly, the model can be used for several purposes like analyzing transition impacts of fiscal and monetary policy interventions, along with stress-testing the position of different stakeholders under different transition scenarios that help mitigating risks and exploiting emerging opportunities from the transition.

This annex is organized as follows: Section 2 present the model structure, its periodic equilibrium, along with model dynamics and the rule for sectoral allocation of new investments. In section 3, we outline the methodology for using the model in scenario analysis, along with model calibration for selected sectors.

# 2 The model

## 2.1 Consumers

We assume an economy with an infinite number of identical consumers who's behavior can be described by that of a representative consumer. The representative consumer gains utility from the consumption of electricity, $c_e$, and other final goods and services,$c_i$, with a total number $n$ of final goods and service, with $i \in \{1, ..., n\}$. Thus, utility reads:

$$U = u(c_e, c_i).$$

The utility function $u$ is assumed to have a CES form:

$$U = \left( \chi_e c_e^{\theta} + \sum_{i=1}^{n} \chi_i c_i^{\theta} \right)^{\frac{1}{\theta}}. \tag{1}$$

Here $\chi_e, \chi_i$ denote budget shares associated to the consumption of electricity and good $i$ respectively, having $0 < \chi_i, \chi_e < 1$ and $\sum_{i=1}^{n} \chi_i + \chi_e = 1$. We define $\theta = \frac{\sigma-1}{\sigma}$, where $\sigma$ represents the elasticity of substitution between different goods. $\theta$ is positive close to 0 to reflect low substitubility between final goods.

In every period of time, the representative consumer maximizes utility in (1) subject to the following budget constraint:

$$\begin{gathered} p_{EL}(1 + t_{cons}^{EL})c_{EL} + \textstyle\sum_{i=1}^{n} p_i(1 + t_i)c_i + Savings \leq \\ \omega L_0 + profits + resources\_income + capital\_income + tax\_revenues. \end{gathered} \tag{2}$$

The left hand side of this constraint consists of expenditures on goods and services along with savings, while the right hand side represents consumer's income from labor, firms' profit, the proceeds from capital and natural resources along with tax revenue in different sectors. Here, $p_{EL}$ and $p_i$ denote the producer prices for electricity and final good $i$ respectively. The price that is paid by consumers is equal to the producer price augmented by a possible ad-valorem tax $t_i$ (or a subsidy, depending on its sign), for final goods and services in sector $i$, and by $t_{cons}^{EL}$ for electricity. That is consumers pay $p_i(1 + t_i)$ and $p_{EL}(1 + t_{cons}^{EL})$ respectively. Moreover, $\omega$ denotes wages, and $L_0$ labor supply in the initial period. Firms in the economy are assumed to be owned by consumers. Accordingly, profits enter as an income in the budget constraint. Furthermore, consumers are assumed to own all capital and fossil fuel stocks. Consequently, the proceeds from selling/renting these stocks are channeled back to consumers. The government collects taxes and spends tax income on subsidies and consumption. We do not model the government explicitly, rather, the government is considered part of the representative household. Accordingly, we do not have to impose the government budget to balance, and all tax (subsidy) rates are exogenous and the tax and subsidy impacts on the total budget is assumed to be small. The first order conditions of the representative consumer's utility maximization problem yield the following demand functions:

$$c_i = \rho_i(\frac{P_{index}}{p_i(1+t_i)})^{\sigma}\frac{I^c}{P_{index}},$$

$$c_{EL} = \rho_{EL}(\frac{P_{index}}{p_{EL}(1+t_{EL}^{cons})})^{\sigma}\frac{I^c}{P_{index}},$$

defining $\rho = \chi^{\sigma}$. In these conditions, aggregate final price that represents Consumer Price Index (CPI), which reads:

$$P_{index} = \left(\sum_i \rho_i(p_i(1+t_i))^{1-\sigma} + \rho_{EL}(p_{EL}(1+t_{EL}^{cons}))^{1-\sigma}\right)^{\frac{1}{(1-\sigma)}}.$$

We denote the aggregate income on the right hand side of the consumer's budget constraint by $I$. National income available for consumption is calculated as the complement. Consumption consists of private and government consumption. Accordingly, $I^c = (1-s)I$, is allocated to consume final goods and services. On the other hand, savings are exogenous with $s$ saving rate, which in nominal terms yields $Savings = sI$. Savings are used to buy investment goods at an aggregate price of $P^{INV}$. Thus the volume of investments that can be invested on a national level reads:

$$INV = \frac{Savings}{P^{INV}}.$$

The production of investment goods consumes a bundle of final goods, with a CES specification. Hence, sectoral investment demand for final goods reads:

$$INV_i = \gamma_i^{INV} (\lambda_i^{INV})^{\sigma^{INV}-1} (\frac{p^{INV}}{p_i(1+t_i^{INV})})^{\sigma^{INV}} INV.$$

We normalize the aggregate price of investment goods, $p^{INV}$, to 1. That is, the numéraire for our economy is the price of investment. Consequently, changes in all prices are interpreted relative to this price. Moreover, this price is assumed fixed over time, which means that investment cost is constant along the horizon of our analysis and between scenarios, which allows us to identify nominal changes that does not link to the transition cost.

## 2.2 Production

We employ a nesting structure for our production. We describe in this section the functional forms and main assumptions for every nest.

### 2.2.1 Final goods and services

Every final sector $i$ has two main sub-sectors, we distinguish between a brown, $b$, and green, $g$, varieties, with $j \in \{b, g\}$, differentiated by whether the sub-sector uses brown or green technology. Which are defined based on several criteria outlined in section (3.1.1). A representative firm in sector $i$ chooses the combination of green and brown that maximizes its profits:

$$\pi_i = p_i Y_i - \sum_j p_{ij}(1 + t_{ij}) Y_{ij},$$

subject to its technology constraint:

$$Y_i \leq G(Y_{ij}).$$

In what follows a subscript on the variables or parameters denotes the (sub)sector, while a superscript denotes the designated input. Consequently, the notation $ij$ denotes a variety in final sector $i$ and a sub-sector $j$. For example, the final sector could be Agriculture and the sub-sector could reflect green or brown Agriculture. Accordingly, $\pi_i$, denotes profits from sector $i$, and $p_{ij}(1+t_{ij})$ represents the price that is paid by the firm for a variety from sub-sector $j$, which is equal to the producer price $p_{ij}$, augmented by a possible variety-specific tax (or a subsidy, depending on its sign) on this good $t_{ij}$.

The function $G$ takes a CES form between the green and brown varieties, of the type:

$$G(Y_{ij}) = \left(\sum_j \nu_{ij}(\lambda_{ij}Y_{ij})^{\eta_i}\right)^{\frac{1}{\eta_i}}.$$

Here, $\sigma_i = \frac{\eta_i - 1}{\eta_i}$, where $\eta_i$ represents the elasticity of substitution between green and brown varieties in sector $i$, which is sector-specific. Whenever $\eta_i > 1$ the two varieties are assumed substitutes. The firm's profit maximization problem in sector $i$ yields variety demand, $Y_{ij}$, and aggregate producer price for final good $i$, $p_i$, which read respectively:

$$Y_{ij} = \gamma_{ij}(\lambda_{ij})^{\sigma_i - 1}\left(\frac{p_i}{p_{ij}(1+t_{ij})}\right)^{\sigma_i} Y_i,$$

$$p_i = \left(\sum_j \gamma_{ij}\left(\frac{p_{ij}(1+t_{ij})}{\lambda_{ij}}\right)^{1-\sigma_i}\right)^{\frac{1}{(1-\sigma_i)}}.$$

In these last equations, $\gamma_{ij} = \nu_{ij}^{\sigma_i}$ represents the shares of brown and green varieties for final production of good $i$. While $\lambda_{ij}$ reflects the production productivity with respect of green and brown varieties in sector $i$. The interpretation of these parameters will be the same for subsequent nests with CES specifications.

### Variety production

As mentioned in previous section, in each sector a variety can be produced by a green, $g$, or brown, $b$, technology. Each variety can be produced using four main inputs, namely: labor, capital, energy and an aggregator for all other inputs. The representative firm in each sub-sector $ij$ chooses the optimal factor mix that maximizes its profit:

$$\pi_{ij} = p_{ij}Y_{ij} - p^E_{ij}(1+t^E_{ij})E_{ij} - r_{ij}(1+t^k_{ij})K_{ij} - \omega L_{ij} - p^s(1+t^s_{ij})S_{ij},$$

subject to its technology constraint:

$$Y_{ij} \leq H(L_{ij}, E_{ij}, K_{ij}, S_{ij}).$$

Here, $E_{ij}$, $L_{ij}$, $S_{ij}$ and $K_{ij}$ represent respectively the demand for energy, labor, other inputs, and capital by sub-sector $ij$. Also, $p^E_{ij}(1+t^E_{ij})$ represents the price that is paid by the representative firm in sub-sector $ij$ for energy, which is sector-specific and equals to the producer price for the energy firm in that sub-sector $p^E_{ij}$, augmented by a possible production tax (or a subsidy) $t^E_{ij}$. The price paid for capital input (marginal productivity of capital (MPK)) of type $j$ is $r_{ij}$ which is also augmented by a tax (subsidy) $t^k_{ij}$, on capital. Similarly for the demand of other inputs, $S_{ij}$,which is exogenous and represents the sum of intermediate inputs, and its price $p^s(1+t^s_{ij})$. Noting that both labor and other inputs are fully mobile across sectors, and thus have an economy wide unique price. The function $H$ is assumed to takes a Cobb-Douglas form of the form:

$$H(L_{ij}, E_{ij}, K_{ij}, S_{ij}) = (L_{ij})^{1-\phi_{ij}}(E_{ij})^{\alpha_{ij}}(K_{ij})^{\epsilon_{ij}}(S_{ij})^{\tau_{ij}}.$$

Here, $\alpha_{ij}$,and $\epsilon_{ij}$, $\tau_{ij}$are elasticity of output with respect to energy, capital and other intermediates in sector $ij$. We assume a constant returns to scale production function, thus, $0 < \alpha_{ij}, \epsilon_{ij}, \tau_{ij} < 1$ , and we define $\phi_{ij} = \alpha_{ij} + \tau_{ij} + \epsilon_{ij} \leq 1$ .

The Cobb-Douglas setup for brown and green sub-sectors means that the substitution between production factors is assumed constant and equal to 1. The firm's profit maximization problem in sector $i$ yields three first order conditions stating that the marginal rate of technical substitution is equal to the ratio of input prices of these factors. These conditions along with the production function yield factor demands in sector $i$ as a function of relative factor prices. Under perfect competition, the profit maximization problem yields that variety prices are then equal to the marginal unit cost.

### Energy nest

In its turn, the energy nest is assumed to be composed of fossil fuel bundle, $F_{ij}$, and electricity bundle, $EL_{ij}$. The energy firm could be thought of as a sub-sector-specific distributor/intermediary of energy. The profit of the such representative energy firm reads:

$$\pi_{ij}^{E} = p_{ij}^{E} E_{ij} - p_{ij}^{F}(1-t_{ij}^{F})F_{ij} - p^{EL}(1-t_{ij}^{EL})EL_{ij},$$

where $EL_{ij}$ and $F_{ij}$ represent respectively the demand for electricity, and for the fossil fuel bundle by sub-sector $ij$. The price paid for electricity and fossil fuel is$p^{EL}(1-t_{ij}^{EL})$ and $p_{ij}^{F}(1-t_{ij}^{F})$, respectively are also augmented by a tax (subsidy), on these inputs. The production function in the energy nests is also assumed to have a CES form. The first order conditions yield fossil fuel and electricity demand by the intermediate energy nest, which read respectively:

$$FF_{ij} = \gamma_{ij}^{F}(\lambda_{ij}^{F})^{\sigma_{ij}^{E}-1}(\frac{p_{ij}^{E}}{p_{ij}^{FF}(1+t_{ij}^{FF})})^{\sigma_{ij}^{E}} E_{ij},$$

$$EL_{ij} = \gamma_{ij}^{EL}(\lambda_{ij}^{EL})^{\sigma_{ij}^{E}-1}(\frac{p_{ij}^{E}}{p^{EL}(1+t_{ij}^{EL})})^{\sigma_{ij}^{EL}} E_{ij}.$$

The energy producer price for sub-sector, $ij$, writes:

$$p_{ij}^{E} = \left(\gamma_{ij}^{F}(\frac{p_{ij}^{FF}(1+t_{ij}^{FF})}{\lambda_{ij}^{F}})^{1-\sigma_{ij}^{E}} + \gamma_{ij}^{EL}(\frac{p^{EL}(1+t_{ij}^{EL})}{\lambda_{ij}^{EL}})^{1-\sigma_{ij}^{E}}\right)^{\frac{1}{(1-\sigma_{ij}^{E})}}.$$

### Fossil fuel bundle

Similarly to the energy nest, the fossil fuel bundle is a composite of coal, $X$, natural gas, $Z$, and oil, $O$. Profits of the representative active fossil fuel firms in the fossil fuels nest read:

$$\pi_{ij}^{FF} = p_{ij}^{FF} FF_{ij} - p^X(1+t_{ij}^X)X_{ij} - p^Z(1+t_{ij}^Z)Z_{ij} - p^O(1+t_{ij}^O)O_{ij},$$

The production function for the fossil fuel bundle is also assumed to take a CES form. Accordingly, the demand for coal, $X_{ij}$, natural gas, $Z_{ij}$, and oil, $O_{ij}$ read:

$$X_{ij} = \gamma_{ij}^X (\lambda_{ij}^X)^{\sigma_{ij}^{FF}-1} (\frac{p_{ij}^{FF}}{p^X(1+t_{ij}^X)})^{\sigma_{ij}^{FF}} FF_{ij},$$

$$Z_{ij} = \gamma_{ij}^Z (\lambda_{ij}^Z)^{\sigma_{ij}^{FF}-1} (\frac{p_{ij}^{FF}}{p^Z(1+t_{ij}^Z)})^{\sigma_{ij}^{FF}} FF_{ij},$$

$$O_{ij} = \gamma_{ij}^O (\lambda_{ij}^O)^{\sigma_{ij}^{FF}-1} (\frac{p_{ij}^{FF}}{p^O(1+t_{ij}^O)})^{\sigma_{ij}^{FF}} FF_{ij}.$$

Consequently, the price for the fossil fuel bundle in sector $ij$ reads:

$$p_{ij}^{FF} = \left( \gamma_{ij}^X (\frac{p^X(1+t_{ij}^X)}{\lambda_{ij}^X})^{1-\sigma_{ij}^{FF}} + \gamma_{ij}^Z (\frac{p^Z(1+t_{ij}^Z)}{\lambda_{ij}^Z})^{1-\sigma_{ij}^{FF}} + \gamma_{ij}^O (\frac{p^O(1+t_{ij}^O)}{\lambda_{ij}^O})^{1-\sigma_{ij}^{FF}} \right)^{\frac{1}{(1-\sigma_{ij}^{FF})}} .$$

We note here that the differences in energy prices between sub-sectors are mainly due to taxation and substitution opportunities between energy sources.

### 2.2.2 Electricity

The electricity sector plays a vital role in our model. From the demand side, electricity enters as an input for production of goods and services and as final consumption good by consumers. From the supply side, we assume that electricity can be produced in two ways: either through renewables or conventional fossil fuel power plants. More precisely, electricity can be generated using four renewable resources, $r$ , namely: wind, $w$, solar, $s$, hydro power, $h$, along with 'Other' renewable sources, $or$. That is, $r \in \{w, s, h, or\}$. Alternatively, electricity can be generated through a conventional fossil, $f$, non renewable resources, namely: coal, $x$, gas, $z$, and oil, $o$. that is, $f \in \{x, z, o\}$. The representative electricity distributing firm chooses the electricity mix between renewable and conventional fossil based power that maximize its profits:

$$\pi_{EL} = p^{EL} Y_{EL} - \sum_{r \in \{s,w,h,or\}} p_{ELr}(1 + t_{ELr}) Y_{ELr} - \sum_{f \in \{x,z,o\}} p_{ELf}(1 + t_{ELf}) Y_{ELf},$$

subject to its technology constraint:

$$Y_{EL} \leq G(Y_{ELr}, Y_{ELf}).$$

Subscript $r$ and $f$ denotes the source from which the electricity has been generated. Here $Y_{ELr}$ and $Y_{ELf}$ represent respectively the supply of renewable power and conventional fossil based power. Moreover, $p_{ELr}(1 + t_{ELr})$ represents the price that is paid by the electricity firm for renewable power of the type $r$, which is equal to the producer price in the renewable power market $p_{ELr}$, augmented by a possible tax (or a subsidy) on renewable power $t_{ELr}$ . Similarly, the producer price for conventional fossil based power input of the type $f$, denoted $p_{ELf}$, is also augmented a tax (subsidy) $t_{ELf}$.

The function $G$ takes a CES form between the seven types of power sources, which read:

$$G(Y_{ELr}, Y_{ELf}) = \left( \sum_{r \in \{s,w,h,or\}} \nu_{ELr}(Y_{ELr})^{\eta_{EL}} + \sum_{f \in \{x,z,o\}} \nu_{ELf}(Y_{ELf})^{\eta_{EL}} \right)^{\frac{1}{\eta_{EL}}}.$$

We define here $\sigma_{EL} = \frac{\eta_{EL}-1}{\eta_{EL}}$, where $\eta_{EL}$ represents the elasticity of substitution between different power sources. Whenever $\eta_{EL} > 1$, the inputs are substitutes. The firm's profit maximization problem in the electricity sector yields the following demand from different electricity sources:

$$Y_{ELr} = \gamma_{ELr}(\lambda_{ELr})^{\sigma_{EL}-1}\left(\frac{p^{EL}}{p_{ELr}(1 + t_{ELr})}\right)^{\sigma_{EL}} Y_{EL},$$

$$Y_{ELf} = \gamma_{ELf}(\lambda_{ELf})^{\sigma_{EL}-1}(\frac{p^{EL}}{p_{ELf}(1+t_{ELf})})^{\sigma_{EL}}Y_{EL},$$

with an aggregate economy wide electricity price of:

$$p^{EL} = \left(\sum_{r\in\{s,w,h,or\}} \gamma_{ELr}(\frac{p_{ELr}(1+t_{ELr})}{\lambda_{ELr}})^{1-\sigma_{EL}} + \sum_{f\in\{x,z,o\}} \gamma_{ELf}(\frac{p_{ELf}(1+t_{ELf})}{\lambda_{ELf}})^{1-\sigma_{EL}}\right)^{\frac{1}{(1-\sigma_{EL})}}.$$

Both $\gamma_{ELr} = (\nu_{ELr})^{\sigma_{EL}}$ and $\gamma_{ELf} = (\nu_{ELf})^{\sigma_{EL}}$ represent respectively the shares of the renewable power of the type $r$ and that of the conventional fossil power of the type $f$ in the electricity mix.

**Renewable power**

As mentioned above, renewable power is assumed to be generated through a solar, wind, hydro, or 'other' renewable sources. Accordingly, a renewable power of type $r \in \{s, w, h, or\}$ is produced by three factors of production, namely a stock of renewable productive capital $K_{ELr}$, labor $L_{ELr}$, and other inputs, $S_{ELr}$. Thus, the renewable power producing firm of type $r$ maximizes its profits:

$$\pi_{ELr} = p_{ELr}Y_{ELr} - r_{ELr}(1+t^k_{ELr})K_{ELr} - \omega L_{ELr} - p^s(1+t^s_{ELr})S_{ELr},$$

subject to its technology constraint:

$$Y_{ELr} \leq G(K_{ELr}, L_{ELr}, S_{ELr}),$$

Here, $r_{ELr}(1+t^k_{ELr})$ represents the price/rent that is paid by the renewable power firm for renewable capital of type $r \in \{s, w, h, or\}$, which is equal to the producer price (marginal productivity of capital) in the renewables market $r_{ELr}$, augmented by a possible tax (or a subsidy) on renewables $t^k_{ELr}$. Function $G$ is assumed to take a CES form between labor, other inputs and the renewable capital stock. The demand for these inputs read:

$$L_{ELr} = \gamma^l_{ELr}(\lambda^l_{ELr})^{\sigma_{ELr}-1}(\frac{p_{ELr}}{\omega})^{\sigma_{ELr}}Y_{ELr},$$

$$K_{ELr} = \gamma^k_{ELr}(\lambda^k_{ELr})^{\sigma_{ELr}-1}(\frac{p_{ELr}}{r_{ELr}(1+t^k_{ELr})})^{\sigma_{ELr}}Y_{ELr},$$

$$S_{ELr} = \gamma^s_{ELr}(\lambda^s_{ELr})^{\sigma_{ELr}-1}(\frac{p_{ELr}}{p^s(1+t^k_{ELr})})^{\sigma_{ELr}}Y_{ELr},$$

with an aggregate economy wide electricity price of:

$$p_{ELr} = \left(\gamma^l_{ELr}(\frac{\omega}{\lambda^L_{ELr}})^{1-\sigma_{ELr}} + \gamma^k_{ELr}(\frac{r_{ELr}(1+t^k_{ELr})}{\lambda^k_{ELr}})^{1-\sigma_{ELr}} + \gamma^s_{ELr}(\frac{p^s(1+t^s_{ELr})}{\lambda^s_{ELr}})^{1-\sigma_{ELr}}\right)^{\frac{1}{(1-\sigma_{ELr})}}.$$

Here $\sigma_{ELr} = \frac{\eta_{ELr}-1}{\eta_{ELr}}$, where $\eta_{ELr}$ represents the elasticity of substitution between different power sources. Whenever $\eta_{ELr} > 1$, the inputs are substitutes. While $\gamma^k_{ELr} = (\nu^k_{ELr})^{\sigma_{ELr}}$, $\gamma^l_{ELr} = (\nu^l_{ELr})^{\sigma_{ELr}}$, $\gamma^s_{ELr} = (\nu^s_{ELr})^{\sigma_{ELr}}$represent respectively the shares of the capital, labor and other inputs in the production of the renewable power of the type $r$ .

**Conventional fossil power**

We assume that the conventional fossil based power is generated by either coal, gas or oil plants. A conventional fossil power of type $f \in \{x, z, o\}$ is produced using four factors of production, namely a stock of productive capital, labor, other inputs, and a designated fossil fuel input. The conventional fossil based power producing firm of type $f$ maximizes:

$$\pi_{ELf} = p_{ELf}Y_{ELf} - r_{ELf}(1+t^k_{ELf})K_{ELf} - \omega L_{ELf} - p^s(1+t^s_{ELf})S_{ELf} - p^f(1+t^f_{ELf})F_{ELf}, \quad (3)$$

subject to its technology constraint, which is assumed to take a Cobb-Douglas form:

$$Y_{ELf} \leq G(K_{ELf}, L_{ELf}, S_{ELf}, F_{ELf}).$$

Here $K_{ELf}$, $L_{ELf}$, $S_{ELf}$, and $F_{ELf}$ represent respectively the demand for capital, labor, other inputs, and for the corresponding fossil fuel source by the conventional fossil power sector of the type $f \in \{x, z, o\}$. Furthermore, $p^f(1 + t^f_{ELf})$ represents the price that is paid by the conventional power firm for fossil fuel source $f$, which is equal to the economy wide producer price $p^f$, augmented by a possible carbon tax on that fossil fuel source $t^f_{ELf}$. The same thing applies to the price of other inputs.

Function $G$ is assumed to take a CES form between labor, other inputs, fossil fuel of a corresponding type, and the conventional fossil fuel capital stock. The demand for these inputs read:

$$L_{ELf} = \gamma^l_{ELf}(\lambda^l_{ELf})^{\sigma_{ELf}-1}(\frac{p_{ELf}}{\omega})^{\sigma_{ELf}} Y_{ELf},$$

$$S_{ELf} = \gamma^s_{ELf}(\lambda^s_{ELf})^{\sigma_{ELf}-1}(\frac{p_{ELf}}{p^s(1 + t^k_{ELf})})^{\sigma_{ELf}} Y_{ELf},$$

$$F_{ELf} = \gamma^s_{ELf}(\lambda^s_{ELf})^{\sigma_{ELf}-1}(\frac{p_{ELf}}{p^f(1 + t^f_{ELf})})^{\sigma_{ELf}} Y_{ELf},$$

$$K_{ELf} = \gamma^k_{ELf}(\lambda^k_{ELf})^{\sigma_{ELf}-1}(\frac{p_{ELf}}{r_{ELf}(1 + t^k_{ELf})})^{\sigma_{ELf}} Y_{ELf},$$

with an aggregate economy wide electricity price of:

$$p_{ELf} = \begin{pmatrix} \gamma^l_{ELf}(\frac{\omega}{\lambda^L_{ELf}})^{1-\sigma_{ELf}} + \gamma^k_{ELf}(\frac{r_{ELf}(1+t^k_{ELf})}{\lambda^k_{ELf}})^{1-\sigma_{ELf}} + \\ \gamma^f_{ELf}(\frac{p^f(1+t^f_{ELf})}{\lambda^f_{ELf}})^{1-\sigma_{ELf}} + \gamma^s_{ELf}(\frac{p^s(1+t^s_{ELf})}{\lambda^s_{ELf}})^{1-\sigma_{ELf}} \end{pmatrix}^{\frac{1}{(1-\sigma_{ELf})}}.$$

Here $\sigma_{ELf} = \frac{\eta_{ELf}-1}{\eta_{ELf}}$, where $\eta_{ELf}$ represents the elasticity of substitution between different power sources. Whenever $\eta_{ELf} > 1$, the inputs are substitutes. While $\gamma^k_{ELf} = (\nu^k_{ELf})^{\sigma_{ELf}}$,

$\gamma^l_{ELf} = (\nu^l_{ELf})^{\sigma_{ELf}}$, $\gamma^s_{ELf} = (\nu^s_{ELf})^{\sigma_{ELf}}$ represent respectively the shares of the capital, labor and other inputs in the production of the renewable power of the type $f$.

## 2.3 Initial static equilibrium

Market clearing condition states that quantities supplied in every market should equal to the quantity demanded. Market clearing condition for final goods and services requires that quantity demanded for consumption ($c_i$) and to produce investment goods ($INV_i$) is equal to quantity supplied by each sector ($Y_i$). Thus, we have $n$ conditions for final sectors, which read:

$$c_i + INV_i = Y_i, \quad i \in \{1, 2, ..., n\} \ . \tag{4}$$

The supply of labor force in the initial period of the model is exogenously given ($L_0$). Labor is demanded by firms in the power ($L_{ELr}$ and $L_{ELf}$) and final goods sub-sectors ($L_{ij}$). Thus, market clearing condition for the labor market reads:

$$\sum_{j\in\{b,g\}} \sum_{i=1}^{n} L_{ij} + \sum_{r\in\{s,w,h,or\}} L_{ELr} + \sum_{f\in\{o,c,g\}} L_{ELf} \leq L_0. \tag{5}$$

Similar condition can be derived for 'other' inputs $S$, that reads:

$$\sum_{j\in\{b,g\}} \sum_{i=1}^{n} S_{ij} + \sum_{r\in\{s,w,h,or\}} S_{ELr} + \sum_{f\in\{x,z,o\}} S_{ELf} \leq S_0. \tag{6}$$

Fossil fuel of type $f \in \{x, z, o\}$ is used to produce electricity , along with other final goods and services in sub-sector $ij$ , while the supply is exogenously give. Market clearing conditions for coal, gas and oil read:

$$X_{ELx} + \sum_{j\in\{b,g\}} \sum_{i=1}^{n} X_{ij} \leq X_0, \tag{7}$$

$$Z_{ELz} + \sum_{j\in\{b,g\}} \sum_{i=1}^{n} Z_{ij} \leq Z_0, \tag{8}$$

$$O_{ELo} + \sum_{j\in\{b,g\}} \sum_{i=1}^{n} O_{ij} \leq O_0. \tag{9}$$

Electricity produced ($Y_{EL}$) is used for final consumption ($c_{EL}$) and for production in sub-sector $ij$ ($EL_{ij}$). Market clearing for the electricity sector reads:

$$c_{EL} + \sum_{j\in\{b,g\}} \sum_{i=1}^{n} EL_{ij} = Y_{EL}. \tag{10}$$

Regarding capital stocks used to produce different goods and services, under the assumption of heterogeneous capital stocks across sectors. In this case market clearing conditions for capital stocks read:

$$K_{ij} \leq K_{ij,0}, \quad j \in \{b, g\}, \quad i \in \{1, 2, ...n\}. \tag{11}$$

for brown and green capital, and read:

$$K_{ELf} \leq K_{ELf,0}, \quad f \in \{x, z, o\}. \tag{12}$$

for coal, gas and oil respectively. Similarly, for renewables we have:

$$K_{ELr} \leq K_{ELr,0}, \quad r \in \{s, w, h, or\}. \tag{13}$$

Different factor demands for producing electricity and final goods and services can be expressed as functions of wages and prices of fossil fuel, capital, along with final produced quantities. Assuming full employment of the stocks of all factors, conditions (4) – (13) yield $(13 + 2n)$ conditions which determine produced quantities for electricity and final goods $(Y_{EL}, Y_i)$, along with producer prices for fossil fuel, marginal productivity of capital in all sectors, along with wages $(p^x, p^z, p^o, p^s, r_{ELr}, r_{ELf}, r_{ij}, \omega)$.

Periodic equilibria are determined by the same conditions after taking changes in supply and demand of different factors into account.

## 2.4 Sectoral allocation of new investments

As we have a sector-specific capital stock, the model reports in every period endogenously sector specific marginal productivity of capital (MPK). The dynamics of the model are assumed to take place by allocating available investment goods in every period across final sub-sector $ij$, renewable power, $r$, or conventional power, $f$. We use subscript $m$ to denote these sectors. In every period, we compute sectoral incentives to invest in sector $m$, $SII_m$ as the the difference between the endogenous sector-specific MPK and the exogenous sector-specific cost of capital, which read:

$$SII_m = MPK_m - P^{INV}((\iota + MI_m) + \delta_m).$$

Here, $\delta_m$ denotes exogenous sector-specific depreciation rate. Sector-specific monetary/supervisory exogenous intervention, $MI_m$, would affect the cost of capital through differentiating the exogenous interest rate, $\iota$, faced by all sectors in the economy.

In every period, new investments are allocated among different sectors taking into account their sectoral incentives to invest. We assume a weighted average allocation of available new investments in every period, where sectors with the highest $SII_m$ would get the highest share of allocated investments. Market shares between green and brown varieties in every final sector, $\gamma_{ij}$, are endogenous and proportional to the invested capital in these sub-sectors. New investments will change the supply of sectoral capital stocks and market shares between green and brown varieties, which along with other changes in demand and supplies of other primary factors, will induce a new $MPK_m$ and a new $SII_m$ in the subsequent period. The latter will result in new allocation of investments in the subsequent period. In the long run, one converges towards an equilibrium where MPK equals the cost of capital in all sectors.

Accordingly, monetary or supervisory policies, can influence the investment process by influencing the interest operating firms have to pay on borrowed capital through $MI_m$. This can be done, by a reduction in the cost of capital for targeted sectors, which in turn affects the sectoral incentive to invest and the allocation of new investments. We note here that the level of the interest rate does not matter for monetary policy effects because as we have a maximizing profits for different firms in the model, we keep investing in capital goods up to the point where the sectoral incentive to invest is zero. Accordingly, if capital cost goes down by 20 bps due to policy intervention, the effects are the same regardless of the initial level of interest rate.

## 2.5 Capital dynamics

For every sector $m$, aggregate capital stocks follow the following law of motion:

$$K_{m,t+1} = INV_{m,t} + (1 - \delta_m)K_{m,t}.$$

This rule means that the sectoral stock of capital in the next period is the sum of new investments and the net of depreciation capital stock in the current period. Sectors with no or low new investments (lower than what is needed to cover for depreciated capital) tend to decrease and diminish over time. The main assumption in the model is that capital invested across sectors is irreversible, meaning that once capital is invested, it cannot be transformed to another shape or reallocated to another sector. This capital immobility hypothesis is needed to reproduce the gradual adjustment of capital stocks. Moreover, this putty-clay assumption entails an out of steady state asymmetry in the rate of return to capital (MPK) across sectors. Accordingly, the associated loss to the the sectoral allocation of investment that incentivizes investors to reallocate their savings can be interpreted as an adjustment cost for the economy.

# 3 Calibration and baseline

Our interest lies in quantifying the effects of central banks' green intervention on the transition process towards a low carbon economy, taking into account the possible energy related feedback loops across sectors and between transition scenarios. The model developed in this study is non-linear, we resort therefore to numerical methods to solve it. Accordingly, we present in this section the chosen final sectors and our criteria to define green sub-sectors. We also outline the calibration procedure for different model's parameters, along with the basic definitions for key variables of interest.

## 3.1 Final sectors

The focus of this study is on emission intensive sectors as these sectors are the ones that have the most effect on emission reductions and achieving a meaningful transition to a low carbon economy. Accordingly, we identify six final sectors, namely: Real-estate, Agriculture and Forestry, Manufacturing, Transportation, Utility and Construction, while the rest of the sectors are aggregated in the 'Other' sector. The aggregation of economic activities across these sectors is detailed in table (1) of Appendix A of this Annex, where we base this aggregation on GTAP10 database [Aguiar et al., 2019]. Later on we use this database for our calibration exercise.

### 3.1.1 Green sub-sectors

The distinction between green and brown sub-sectors is based on their different energy resources as production factor, which can further be translated to CO2 emissions. Moreover, this distinctions are based on the sector-specific mean in order to capture different transition mechanism (electrification and efficiency improvements) across different sectors. We assume that green sectors are more energy efficient and cleaner (emission efficient) than their brown alternative. More precisely, we assume that green sub-sectors differ from brown ones in the following aspects:

- Elasticity of substitution between energy sources, where green sub-sectors are assumed to have higher elasticity of substitution in the energy nest, $\sigma_{ij}^{E}$. This implies that the green sub-sector is defined as the sector that can switch between electricity and different fossil fuels easier. That includes switching from green to brown energy sources. Following Chateau et al. (2014), we set this elasticity to 0.125 for Real estate, Agriculture and Transportation brown sectors, and 0.2 for Manufacturing, Utility and Construction and Other brown sectors. For green final sectors, $\sigma_{ig}^{E}$ is set close to 1 and assumed 0.95 [Chateau et al., 2014].

- Efficiency in energy use: this is reflected by productivity of energy sources. Green sub-sectors are assumed to be more productive in energy sources than brown ones. In order to calibrate this difference, we use total energy and feed-stock savings potentials reported in table 1 of [IEA, 2007] for the Manufacturing sector, which estimates a global improvement potential for the share of industrial energy use to range between 18% and 26%, while estimates for global improvement potential for CO2 emissions rage is 19-32%. For Agriculture and forestry sector we use 34% energy efficiency improvement [Apazhev et al., 2019]. For Utilities and Construction we assume an improvement of 10%, Transportation 25% [Smokers and Kampman, 2006], and for Real estate and the Other sector 23% .

- Electrification: is captured by the share of electricity in the energy bundle $\gamma_{ij}^{E}$. These shares are calibrated using the GTAP10 database for brown sectors. For green sectors, we assume that electrification will take place in road and rail transportation and accordingly the share of fossil fuel bundle in the energy nest of the Transportation sector is set to be 25% relative to the same share in the brown Transportation sector. In the Manufacturing sector, we assume that the green sub-sector is 30% higher in its dependency of electricity compared to the brown sub-sector. Real-estate and Utilities and Construction green sub-sectors are assumed to be 25% less dependent on fossil fuel in the energy bundle compared their brown alternative, while in the Agriculture and Forestry sector, the green sub-sector is assumed to be 20% more dependent on electricity in its energy bundle. Finally, the green Other sector is assumed to be 5% less dependent on fossil fuel in its energy bundle compared to the brown alternative.

The aforementioned definition of green sub-sectors capture the different transition mechanisms across sectors, where some sectors move completely to a clear green substitute, while transition in other sectors takes place through efficiency improvements. We note that the used estimates to define green sub-sectors are approximations at best as we have a challenge to define it precisely since the modeled sectors are highly aggregated. Future research should consider more granular sectors which allows for higher precision in defining the green sub-sectors.

## 3.2 Calibration

In this section we elaborate on the calibration of the parameters in chosen sectors. More precisely, we calibrate the elasticities of substitution, elasticity of output with respect to different production factors, consumption budget shares, shares of brown and green varieties in each final sectors, and the shares of each production factor in the modeled production nests.

To calibrate output elasticities and input shares in production nests, we use input-output tables by GTAP10 database [Aguiar et al., 2019]. The reason to choose GTAP10 is because it provides the required granularity with regard to energy sources. Our model is one region economy with different energy sources and since energy prices are determined by international markets, we calibrate the model for a world economy. Therefore, we aggregate the database for 1 region and 10 sectors aggregation level. The aggregation scheme of GTAP10 can be found in Appendix B of this Annex. For final sectors, as we have a Cobb-Douglas specification, the elasticity of output with respect to a certain factor equals the ratio of cost expenditures on that factor over the output value in the initial period. As conventional in such calibration exercise, using input-output database for CGE models, we assume the units in every production nest to be selected in a way that reflects input prices of 1 in the benchmark initial period, which implies the same unit of the investment good in period zero. Accordingly, elasticities of output and input shares in different nests can be calculated from the GTAP firm's cost structure. We use the obtained elasticities and shares as our benchmark calibration for brown final sectors. For green final sectors, these parameters are adjusted as explained above to reflect our definition of green varieties. The share of green in different sectors is calibrated to reflect their market share in the corresponding sectors (between 1% and 2% in period 0).

GTAP's cost structure for consumption can be used to get the budget shares associated with the consumption of electricity and other final goods. The calibrated benchmark budget shares can be found in table (3) of Appendix B. With regard to the supply of initial capital stocks and fossil fuel, we use the corresponding value of these factors in GTAP. For the initial supply of the 'Other' inputs, we sum the value across all factors that are not explicitly present in our chosen sectors. We normalize the reported supply under GTAP10 of labor, capital, fossil fuel and Other inputs to 1000. Sectoral capital stocks are divided between green and brown sectors based on the assumed benchmark market shares of each in Appendix B.

With regard to the electricity mix in the benchmark period, we use the data provided by the International Energy Agency (IEA) for electricity mix of 2017 for the world economy[IEA, 2021]. We use the electricity mix in order to allocate the capital used in the power sector (capital supply) across different electricity sources considered in our model in the initial period. For elasticity of electricity production with respect to different production factors according to different power sources, we look at the cost composition of different power generation technologies. We use investment costs to reflect capital input, while the share of fixed cost is used to determine the cost mix of the 'Other' inputs, and finally variable cost is used to determine other operating costs like labor and fuel for conventional power plants [Hirth and Steckel, 2016]. For the hydro power, we take 0.06 as an operating and maintenance cost while the rest is considered as a capital cost ([et al., 2013], [Ray, 2019]).

With regard to elasticity of substitution of final consumption between different final commodities $\sigma$, should be set low (0.01) because the evidence suggests the products these sectors produce are not close substitutes in consumption (REFS). On the other hand, the elasticity of substitution between green and brown varieties is assumed high by definition and set to 4 for all sectors. We thus assume that consumers do not have very strong preferences over how products are produced. Similarly, for different electricity sources the elasticity is quite high, equals to 5, as the electricity output is the homogeneous once generated [Chateau et al., 2014]. The CES between factors in the production of renewable and conventional power, $\sigma_{ELr}$ and $\sigma_{ELf}$ respectively, are assumed positive and substantially lower than 1, thus set at 0.35.

Emission intensity of fossil fuel use per sector is calibrated using the GTAP database as well. Emission intensity is defined as the amount of CO2 emission emitted per unit of fossil fuel used in production of the corresponding sector. Due to the aggregation of emission data for the electricity sector, emission intensity of energy source is assumed the same for all conventional power plants. That is, emission intensity of using coal is the same between coal, oil or gas power plants.

The benchmark calibration is summarized in Appendix B.

#### 3.2.1 Macro drivers

All scenarios share the same growth rates of population, labor force, and productivity. We assume that productivity (energy efficiency gains) grows only in green sectors at a growth rate of 1% per year [OECD, 2020]. Population is assumed to grow at 0.85% on average, real domestic product at 3% in the period 2021-2040, and capital is assumed to depreciate on average at 2.5% rate for all sectors under all scenarios [IEA, 2020].

In this model, the paths of investments in final sectors between green and brown subsectors are endogenous and depend on the allocation of investments in every period. In contrast, in order to allow for comparability with other studies and to make sure that our scenarios reflect the expected transition in the power sector, we adopt the IEA's transition scenarios to guide the transition in the power sector. Accordingly, the evolvement of the electricity mix is assumed exogenous and given by IEA's developed scenarios [IEA, 2021]. IEA identifies three main scenarios: the Stated Policies Scenario (STEPS), the Announced Pledges Scenario (APS), and the Net Zero Emissions (NZE). For scenarios with an ambitious climate policy, we use the paths assumed under SDS. For business as usual scenarios, we assume the electricity mix to evolve under CPS. On the other hand, fossil fuel supply is assumed constant over time and across scenarios, and set to the levels in the benchmark period, which means that the entire shift in fossil fuel demand is fully reflected in the change of energy prices.

### 3.2.2 Carbon prices

Estimates of carbon prices needed to achieve a 2 degree goal varies a lot across studies and across periods depending on the model used and the underlying assumptions and uncertainty. Guivarch and Rogelj (2017) report that these estimates range between 15 - 360 USD for the short run (2030) and between 45-1000 USD in 2050. Estimates under the IEA's scenarios range between USD 15-65 in 2030, USD 20-75 in 2040 and USD 30-90 in 2050 under (STEPS) scenario. Under the Net Zero Emissions (NZE) scenario carbon prices range between USD 90-130 in 2030, USD 160-205 in 2040 and 200-250 in 2050. Stiglitz et al. (2017) reported a global carbon price between USD 40-80 per ton of CO2 emitted by 2020 and USD 50-100 by 2030 would be needed to limit the increase in global warming to 2°C. On the other hand, the IMF estimated a present global average carbon price to be USD 2 per ton of CO2 emitted [IMF, 2021].

For our purpose, as we use IEA's scenarios for the evolution of electricity mix over time, climate tax is implicit for the power sectors and its levels corresponds to those assumed under IEA's scenarios. Moreover, we use the average carbon prices under IEA's scenarios (STEPS and NZE scenarios) for final sectors. Accordingly, we assume a carbon tax that reaches USD

40 in 2030, USD 50 in 2040 and 60 in 2050 for our benchmark scenario. Moreover, we assume a carbon prices that start at 50 USD and reach USD 110 in 2030, USD 180 in 2040 and USD 225 by 2050 under our Ambitious Climate Action (ACA) scenario. For the initial period, we assume a low level for carbon price of USD 5 /tCO2e following the current global carbon price.

### 3.2.3 Effect on emissions

As fossil fuel supply in our model is assumed exogenous, so do emissions. However, in order to determine the effect of certain policy on emissions, we can infer the ex-ante first order emission impacts from the endogenous changes in fossil fuel prices by using price elasticities of supply for different fossil fuel sources. Accordingly, we estimate how fossil fuel supply would react to the change in their prices, which, using the emission intensity of different fossil fuels, determines the prospected first order change in emissions.

There are many studies that reported estimates for price elasticity of supply in the literature for different fossil fuel sources. For the US, Dahl (2009) report, under simple models, a long run own price elasticity of 0.41 for natural gas. For coal, they reported a short run elasticity of 0.61 and a long run elasticity of 1.31. In an earlier survey, Dahl and Duggan (1998) investigated price elasticity of supply for oil and natural gas exploration. The long run price elasticity of supply for oil ranged between 0.48 and 2.85, with an average of 1.64. For natural gas, the estimates ranged between 0.52 and 1.06. Ponce and Neumann (2014) estimated own price elasticity of natural gas to be 0.76 for the United States. For this study, we use emission long run average elasticities of 1.64, 1.06 and 0.76 for oil, gas and coal respectively, to calculate potential first order supply changes following endogenous price changes.

Global emission intensities and shares of emissions from different fossil fuel source are calculated from the data provided in[IEA, 2021] in 2018. Accordingly, we find that 44.11% of global emissions are associated to coal, 34.43% to oil, and 21.46% are associated to gas under CPS scenario.

Results are presented in the main text.

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# Appendix A

Table 1: Aggregation scheme corresponding to GTAP 10 database.

| No. | Code | Code (GTAP10) | Description |
|---|---|---|---|
| 1 | Electricity | ely | Electricity. |
| 2 | Coal | coa | Coal. |
| 3 | Oil | oil p_c | Oil; Petroleum, coal products. |
| 4 | Gas | gas gdt | Gas; Gas manufacture, distribution. |
| 5 | Real-estate | afs rsa dwe | Accommodation, Food and servic; Real estate activities; Dwellings. |
| 6 | Agriculture and Forestry | pdr wht gro v_f osd c_b pfb ocr ctl oap rmk wol frs fsh cmt omt vol mil pcr sgr ofd b_t | Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibers; Crops nec; Bovine cattle, sheep and goats; Animal products nec; Raw milk; Wool, silk-worm cocoons; Forestry; Fishing; Bovine meat products; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products. |
| 7 | Manufacture | tex wap lea lum ppp chm bph rpp nmm i_s nfm fmp ele eeq ome mvh otn omf | Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Chemical products; Basic pharmaceutical products; Rubber and plastic products; Mineral products nec; Ferrous metals; Metals nec; Metal products; Computer, electronic and optic; Electrical equipment; Machinery and equipment nec; Motor vehicles and parts; Transport equipment nec; Manufactures nec. |
| 8 | Utility and Construction | wtr cns | Water; Construction. |
| 9 | Transport | otp wtp atp whs | Transport nec; Water transport; Air transport; Warehousing and support activi. |
| 10 | Other sectors | oxt trd cmn ofi ins obs ros osg edu hht | Minerals nec; Trade; Communication; Financial services nec; Insurance; Business services nec; Recreational and other service; Public Administration and defe; Education; Human health and social work a. |

# Appendix B: Benchmark calibration

Since final sectors represent distinct goods for consumption, we set the elasticity of substitution between final goods $\sigma$ to 0.01. Benchmark electricity mix ([IEA, 2019]).

Table 3: Benchmark consumption budget shares

| Parameter\Sector | Real-estate | Manufacturing | Transportation | Agriculture | Utilities & Cons. | Electricity | Other |
|---|---|---|---|---|---|---|---|
| Budget share ($\rho_i$,$\rho_{EL}$) | 17.76% | 11.97% | 3.64% | 17.76% | 1.13% | 1.59% | 51.93% |

Table 4: Benchmark parameters for final production

| Parameter\Sector | Other | Real-Estate | Agriculture | Manufacturing | Transportation | Utilities & Cons. |
|---|---|---|---|---|---|---|
| $\sigma_i$ | 4 | 4 | 4 | 4 | 4 | 4 |
| $\gamma_{ib}$ | 98% | 98% | 98% | 98% | 98% | 98% |
| $\alpha_{ij}$ | 0.0136 | 0.0122 | 0.0266 | 0.0505 | 0.2369 | 0.0116 |
| $\epsilon_{ij}$ | 0.2144 | 0.5149 | 0.1296 | 0.1183 | 0.1760 | 0.1409 |
| $\tau_{ij}$ | 0.3920 | 0.3217 | 0.6427 | 0.6839 | 0.3918 | 0.5889 |
| $\sigma_{ib}^E$ | 0.2 | 0.125 | 0.125 | 0.2 | 0.125 | 0.2 |
| $\gamma_{ib}^F$ | 0.2566 | 0.2359 | 0.5044 | 0.5352 | 0.9459 | 0.3753 |
| $\sigma_{ib}^F$ | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |
| $\gamma_{ib}^X$ | 0.0408 | 0.0192 | 0.0371 | 0.0768 | 0.0006 | 0.0365 |
| $\gamma_{ib}^Z$ | 0.2451 | 0.3362 | 0.1359 | 0.1756 | 0.0169 | 0.1036 |
| $\lambda_{ib}^F, \lambda_{ib}^{EL}, \lambda_{ib}^X, \lambda_{ib}^Z, \lambda_{ib}^O$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $\sigma_{ig}^E$ | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| $\gamma_{ig}^F$ | 0.2437 | 0.1769 | 0.4035 | 0.3746 | 0.2364 | 0.2814 |
| $\sigma_{ig}^F$ | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 | 0.51 |
| $\gamma_{ig}^X$ | 0.0408 | 0.0192 | 0.0371 | 0.0768 | 0.0006 | 0.0365 |
| $\gamma_{ig}^Z$ | 0.2451 | 0.3362 | 0.1359 | 0.1756 | 0.0169 | 0.1036 |
| $\lambda_{ig}^F, \lambda_{ig}^{EL}$ | 1.23 | 1.23 | 1.34 | 1.28 | 1.25 | 1.1 |
| $\lambda_{ig}^X, \lambda_{ig}^Z, \lambda_{ig}^O$ | 1 | 1 | 1 | 1 | 1 | 1 |

Table 5: Benchmark parameters for electricity mix and power sectors

| Parameter\Sector | Wind | Solar | Hydro | Other | Coal | Gas | Oil |
|---|---|---|---|---|---|---|---|
| $\sigma_{EL}$ | 5 | | | | | | |
| $\gamma_{ELr}, \gamma_{ELf}$ | 5.38% | 2.89% | 16.06% | 12.88% | 36.91% | 22.84% | 3.03% |
| $\lambda_{ELr}, \lambda_{ELf}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\sigma_{ELr}$ | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| $\gamma^k_{ELr}, \gamma^k_{ELf}$ | 0.808 | 0.91 | 0.8776 | 0.8776 | 0.6642 | 0.25 | 0.868 |
| $\gamma^s_{ELr}, \gamma^s_{ELf}$ | 0.157 | 0.018 | 0.0833 | 0.0833 | 0.0229 | 0.0408 | 0.013 |
| $\gamma^l_{ELr}, \gamma^l_{ELf}$ | 0.035 | 0.072 | 0.0391 | 0.0391 | 0.0329 | 0.0182 | 0.036 |
| $\gamma^f_{ELf}$ | - | - | - | - | 0.28 | 0.691 | 0.083 |
| $\lambda^k_{ELr}, \lambda^k_{ELf}, \lambda^s_{ELr}, \lambda^s_{ELf}$ $\lambda^l_{ELr}, \lambda^l_{ELf}, \lambda^f_{ELr}, \lambda^f_{ELf}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 |