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AN OVERVIEW OF THE OECD ENV-LINKAGES MODEL

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ABSTRACT/RÉSUMÉ

An Overview of the OECD ENV-Linkages Model

This Working Paper presents a summary description of the OECD ENV-Linkages General Equilibrium model. This model has been developed by the Environment Directorate of the OECD Secretariat in order to assess the economic impact of abating Greenhouse Gases using several different economic instruments. The paper is divided into two parts. The first provides a brief description to the structure of the ENV-Linkages model and of its main equations. The second section describes the calibration method, first to fit the model on base year data, and second to dynamically produce a baseline emissions projection.

JEL classification: D58; Q32; Q43.

Keywords: Computable and other applied general equilibrium models; Exhaustible resources and economic development; Energy and the macroeconomy.

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Description synthétique du modèle ENV-Linkages de l'OCDE

Ce document de travail contient une description simplifiée du modèle d'Équilibre Général ENV-Linkages de l'OCDE. Ce modèle a été développé par la Direction de l'Environnement afin de quantifier les impacts économiques des réductions d'émissions de gaz à effet de serre en utilisant plusieurs instruments différents. Ce document contient deux sections. La première est une description simplifiée de la structure du modèle ENV-Linkages et de ses principales équations. La seconde section décrit la méthode de calibration utilisée, d'abord, pour ajuster le modèle aux données pour l'année initiale et, ensuite, pour produire une projection des émissions de référence.

Classification JEL : D58 ; Q32 ; Q43.

Mots-Clés : Modèles d'équilibre général appliqués et calculables ; ressources non renouvelables et développement économique ; énergie et macro-économie.

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AN OVERVIEW OF THE OECD ENV-LINKAGES MODEL

Jean-Marc Burniaux and Jean Chateau[1]

1. Introduction

1. The OECD ENV-Linkages General Equilibrium (GE) model is the successor to the OECD GREEN model for environmental studies, which was initially developed by the OECD Economics Department (Burniaux, *et al.* 1992) and is now hosted at the OECD Environment Directorate. GREEN was originally used for studying climate change mitigation policy and culminated in Burniaux (2000). It was developed into the Linkages model, and subsequently became the JOBS/Polestar modelling platform that was used to help underpin the OECD Environmental Outlook to 2020. A version of that model is also currently in use at the World Bank for research in global economic development issues. Previous work using the model includes development of a baseline to 2030 and a study of the consequence of structural change (including some environmental implications) associated with economic growth Much of the applied work with the model is reported in various chapters of the OECD *Environmental Outlook to 2030* (2008). Exploration of the model's properties and some sensitivity analysis is reported in OECD (2006). Most recently, the model has been used extensively in the context of a joint project between the OECD Economics Department and the OECD Environment Directorate on the economics of climate change mitigation (Burniaux *et al.,* 2008).

2. This Working Paper, which presents a summary description of the ENV-Linkages model rather than a full documentation, is structured as follows. Section 2 introduces the model and briefly reviews its key features, its recent developments and the climate policy instruments that can be simulated. Section 3 describes the structure of the model and discusses its main equations. Finally, Section 4 discusses the calibration method, first to fit the model on base year data, and second to dynamically produce a baseline emissions projection.

2. A brief overview of the ENV-Linkages model

Key features

3. The ENV-Linkages model is a recursive dynamic neo-classical general equilibrium model. It is a global economic model built primarily on a database of national economies. In its current form, the model represents the world economy in 12 countries/regions, each with 22 economic sectors (Tables 1 and 2). Each of the 12 regions is underpinned by an economic input-output table (usually sourced from national statistical agencies). The database has been built and maintained at Purdue University by the Global Trade

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Analysis Project (GTAP) consortium. A fuller description of the database can be found at Dimaranan (2006). Those tables identify all the inputs that go into an industry, and identify all the industries that buy specific products.

4. All production in ENV-Linkages is assumed to operate under cost minimisation with an assumption of perfect markets and constant return to scale technology. The production technology is specified as nested CES production functions in a branching hierarchy. The top node thus represents an output – using intermediate goods combined with value-added, on the one hand, and non-CO_2 greenhouse gases (GHGs) in sectors that emit these gases as joint-products (see below), on the other hand. This structure is replicated for each output, where the parameterisation of the CES functions may differ across sectors.

5. Total output for a sector is actually the sum of two different production streams: resulting from the distinction between production with an "old" capital vintage, and production with a "new" capital vintage. The substitution possibilities among factors are assumed to be higher with new capital than with old capital. In other words, technologies have putty/semi-putty specifications. This will imply longer adjustment of quantities to prices changes. Capital accumulation is modelled as in traditional Solow/Swan neo-classical growth model.

6. The valued-added bundle is specified as a CES combination of labour and a broad concept of capital. In the "crop" production sector, this capital is itself a CES combination of fertilizer and another bundle of capital-land-energy. The intention of this specification is to reflect the possibility of substitution between intensive and extensive agriculture. In the "livestock" sector, substitution possibilities are between bundles of land and feed, on the one hand, reflecting a similar choice between extensive and intensive livestock production, and of capital-energy-labour bundle, on the other hand. Production in other sectors is characterised by substitution between labour and a bundle of capital-energy (and possibly a sector-specific factor for primary resources).

7. Household consumption demand is the result of static maximization behaviour which is formally implemented as an "Extended Linear Expenditure System". A representative consumer in each region – who takes prices as given – optimally allocates disposal income among the full set of consumption commodities and savings. Saving is considered as a standard good and therefore does not rely on a forward-looking behaviour by the consumer.

8. The government in each region collects various kinds of taxes in order to finance a given sequence of government expenditures. Given also a sequence of public savings (or deficits) the government budget is balanced through the adjustment of the income tax on consumer income.

9. International trade is based on a set of regional bilateral flows. The model adopts the Armington[2] specification, assuming that domestic and imported products are not perfectly substitutable. Moreover, total imports are also imperfectly substitutable between regions of origin. Allocation of trade between partners then responds to relative prices at the equilibrium.

10. These core elements of ENV-Linkages are similar to those outlined in van der Mensbrugghe (2005) so a full model listing of equations will not be repeated here. The next section outlines some areas where improvements have been made.

2 See Armington (1969)

Recent improvements

11. Much of the model-development effort expended since van der Mensbrugghe (2005) has been to improve its usefulness. Given the varied needs of the OECD Environment Directorate, flexibility was deemed essential in building a general-purpose tool for environmental policy analysis. The objective of these changes was therefore to make ENV-Linkages as adaptable as possible to studying different policy issues within a relatively short time horizon. Some of the features include:

- General purpose routines that extract data from various source databases: GTAP database, United Nations Population Prospects, IMF, US-EPA for non-CO_2 greenhouse gases, IEA databases for energy demands and CO_2 emissions associated to fuel combustion, economic baseline drivers such as productivity, labour force participation, etc. This has made it possible to adapt to new versions of databases with little disruption and quick turnaround.

- Development and maintenance of database routines that allow a source file including 96 countries/regions to be maintained. The aggregation routines permit an easy shift between sectoral and regional aggregations of the model. The procedures automatically generate aggregated data that serve as preliminary projections of the baseline for a model simulation. A high degree of flexibility in the routines permits modification for different applications. Consistency across aggregations in model parameters and calibrations is largely automatic with only residual effort needed to make different aggregations largely equivalent from an economic perspective; *i.e.* that the sum of individual region responses to most policy are nearly equal to the whole of an aggregated region. Nonetheless, some simulation results would be aggregation dependent. For instance, "Armington trade-off" between goods of different /countries/regions would be affected by the retained aggregation.

- For the current purpose, the model has been aggregated into 22 sectors and 12 regions, as reported in Tables 1 and 2.

[Table 1. ENV-Linkages model sectors]

[Table 2. ENV-Linkages model regions]

- Flexibility has also been developed in changing the model's structure. Some elements of the model may be added or removed in order to focus on specific issues while keeping the model tractable. For example, it is easy to change between an economy that follows a quasi-balanced growth path (where the capital to output ratio is fixed) versus one where it does not. The structure of the energy demand can be modified easily too. In the model currently used, the energy bundle consists of several nests implying different degree of substitution between specific energy sources. International trade shares may be made to evolve over time rather than just respond to price changes – so globalisation can be factored in. Other areas have also been made to be more flexible. The importance of these changes is that the model can be re-specified on relatively short notice to study issues of interest for policy from alternative perspectives.

- Non-CO_2 greenhouse gases are a significant contributor to climate change. Approximately 30% of the human-induced greenhouse effect can be attributed to the non-CO_2 greenhouse gases (though most of this is from methane and nitrous oxide). Burniaux (2000) reported that abating non-CO_2 gases was cheaper in many cases than abating CO_2 from energy. This result has been upheld by other studies that have since been completed (Weyant and de la Chesnaye, 2006). The current version of the model incorporates several emission sources of non-CO2 gases (methane, nitrous oxide and industrial gases). These gases are introduced by considering an additional nest at the top of the production function including the emissions of these gases in a way similar to Hyman *et al.* (2002).

- The dynamic calibration of the model has been made more flexible. In the construction of a baseline scenario (*e.g.* the central projection made on the basis of a set of exogenous drivers and used as a benchmark for subsequent policy simulations) some trends may be exogenously determined, or left as part of the solution of the model simulation.

Climate policy instruments

12. For studying the impacts of climate change policy, three instruments have been developed:

– carbon dioxide taxes, global or sector-specific

– tradable emission permits (with flexibility between regions and sectors)

– regulatory policy (modelled as *quantity constraints*)

13. Taxes and tradable permits are applied on inputs of fossil-fuel producing sectors (refined petroleum, natural gas, coal). They are applied, as well, on final demands of fossil-based energy. This requires calculating emission coefficients that link base-year quantities of carbon dioxide emissions and base-year constant-dollar quantities. A carbon dioxide emissions database has been developed for GTAP (Lee, 2002) that uses data provided to GTAP by the International Energy Agency. The emission rates for non-CO_2 gases come from US-EPA (2006a). 27 sources of emissions over the 32 censed by US-EPA are implemented in the model.

14. Regulatory policy has also been introduced in the model through a mechanism imposing a shadow cost on the firm's inputs or capital. It has the effect of changing the marginal cost of particular inputs, or changing the quantity of capital used to produce a given output, but does use market instruments. The analysis requires assumptions to be made concerning the cost of the regulatory policy, but it breaks the link between policy instruments and revenue transfer that is inherent in tax policy and tradable permits.

15. Factor-income taxes as well as factor taxes and subsidies on factor supply have also been introduced as these instruments are distinguished in the GTAP version 6.2 database.

3. The structure of the model

16. This section outlines more formally the structure of the ENV-Linkages model. It provides a methodological overview of the model rather than an exhaustive listing of all equations in the model.

Consumption

17. Income generated by economic activity ultimately reflects demand for goods and services by final consumers. ENV-linkages represent consumers as being largely similar at a very aggregated level of consumption. As such, the model postulates a representative consumer who allocates disposable income according to preferences among consumer goods and saving. In this version of the model, consumers purchase goods and services as produced by firms (*i.e.* a *transition matrix* to map produced goods into consumer goods is not implemented). The consumption/saving decision is static instead of forward-looking: saving is treated as a "good" and its amount is determined simultaneously with the demands for the other goods, the price of saving being set arbitrarily equal to the average price of consumer goods. This means

that consumers are saving a constant proportion of their income and not adjusting that to reflect future events that may impact on income.

18. Formally, a representative consumer maximises well-being (utility) subject to resource constraints:

$$\begin{aligned} &Max \;\; U = \sum_k \mu_k \ln(C_k - \theta_k) + \mu_s \ln(\frac{S}{P_s}) \\ &\qquad Subject\;to \quad \sum_k P_k^c \; C_k + S = Y, \quad and \quad \sum_k \mu_k + \mu_s = 1 \end{aligned} \qquad [1]$$

where U represents utility, C is a vector of k consumer goods, P^c is the vector of consumer prices, S represents the value of saving, P_s the relevant price of saving, and Y is total income (completely allocated between consumption and savings). The parameter θ is the floor level of consumption – its main function is in making the utility function non-homothetic, which is consistent with considerable empirical evidence (*e.g.* Dowrick, *et al*. 2003). Since consumers are not represented with forward-looking behavior, some care needs to be exercised in studying policies that consumers may reasonably be expected to anticipate – either the policy itself or its consequences.

19. For each country, the consumer's objective function thus gives rise to household private consumptions [2] and saving [3]:

$$C_k = Pop \times \theta_k + \frac{\mu_k}{P_k^c} \times Y^*, \quad where \;\; Y^* = Y^c - Pop \times \sum_k P_k^c \times \theta_k \qquad [2]$$

$$S = Y^c - \sum_k P_k^c \times C_k \qquad [3]$$

where Pop represents population, Y^c represents household disposable income and $Y*$ is a *supernumerary* income (i.e. income above the subsistence level).

Production

20. Firms in all sectors minimise the cost of producing the goods and services that are demanded by consumers and other producers (domestic and foreign). Production is represented by constant returns to scale technology.

21. Figure 1 illustrates the typical nesting of the model's sectors (some sectors, like agriculture, have a different nesting).

[Figure 1. Structure of production in ENV-Linkages]

22. In Figure 1, each node represents a constant elasticity of substitution (CES) production function. This gives marginal costs and represents the different substitution (and complementarity) relations across the various inputs in each sector. Each sector uses intermediate inputs – including energy inputs - and primary factors (labour and capital). In some sectors, primary factors include natural resources, *e.g.* trees in forestry, land in agriculture, etc.

23. The top-level production nest considers final output as a composite commodity combining emissions of non-CO_2 gases and the production of the sector net of these emissions. In sectors that do not emit non-CO_2 gases, the corresponding emission rate is set equal to zero. For the purpose of calibration,

these non-CO_2 gases are valuated using an arbitrary very low carbon price. The following non-CO_2 emission sources are considered: *i)* methane from rice cultivation, livestock production (enteric fermentation and manure management), coal mining, crude oil extraction, natural gas and services (landfills); *ii)* nitrous oxide from crops (nitrogenous fertilizers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); *iii)* industrial gases (SF6, PFC's and HFC's) from chemicals industry (foams, adipic acid, solvents), aluminum, magnesium and semi-conductors production. The values of the substitution elasticities are calibrated such as to fit to marginal abatement curves available in the literature on alternative technology options, (see, for instance, US-EPA (2006b).

24. The second-level nest considers the gross output of sector (net of GHGs) as a combination of aggregate intermediate demands and a value-added bundle, including energy. For each good or service, output is produced by different production streams which are differentiated by capital vintage (old and new). Capital that is implemented contemporaneously is new – thus investment impacts on current-period capital; but then becomes old capital (added to the existing stock) in the subsequent period. Each production stream has an identical production structure, but with different technological parameters and substitution elasticities. Letting $X_{i,v}$ represents gross output of sector i (net of GHGs) using capital of vintage v, the equations representing production are derived from first order conditions E3-E5 of the firm's profit maximisation objective.

$$INT_i = \sum_v \alpha_{i,v}^{INT} \times A_{i,v}^{\sigma_{i,v}^p - 1} \times \left(\frac{VC_{i,v}}{P_i^{INT}} \right)^{\sigma_{i,v}^p} \times X_{i,v} \quad [4]$$

$$VA_{i,v} = \alpha_{i,v}^{VA} \times A_{i,v}^{\sigma_{i,v}^p - 1} \times \left(\frac{VC_{i,v}}{P_i^{VA}} \right)^{\sigma_{i,v}^p} \times X_{i,v} \quad [5]$$

$$VC_{i,v} = \frac{1}{A_i} \times \left[\alpha_{i,v}^{INT} \left(P_i^{INT} \right)^{1-\sigma_{i,v}^p} + \alpha_{i,v}^{VA} \left(P_i^{VA} \right)^{1-\sigma_{i,v}^p} \right]^{(1/(1-\sigma_{i,v}^p))} \quad [6]$$

where *INT* is the intermediate demand bundle (P^{INT} its price), *VA* represents value-added (P^{VA} its price), *VC* is unit variable cost of producing one unit of net of GHGs output (average costs include the cost of capital), *A* is a technical change term. In order to determine the industry-wide cost that includes both capital vintages, there is an averaging (weighted) of variable costs across the two vintages.

25. The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, old capital is assumed to be only partially mobile across sectors, reflecting differences in the marketability of capital goods across sectors. There is also homogeneity in the use of old and new capital.

26. In each period, the supply of primary factors (*e.g.* capital, labour, land and natural resources) is usually predetermined On the right hand side of the tree in Figure 1 value-added is shown as being composed of a labour input [7] along with a composite capital/energy bundle [8]:

$$L_i = \sum_v \alpha^L_{i,v} \times \lambda_i^{\sigma^V_{i,v}-1} \times \left(\frac{P^{VA}_{i,v}}{W_i}\right)^{\sigma^V_{i,v}} \times VA_{i,v} \qquad [7]$$

$$KE_{i,v} = \alpha^{KE}_{i,v} \times \left(\frac{P^{VA}_{i,v}}{P^{KE}_{i,v}}\right)^{\sigma^V_{i,v}} \times VA_{i,v} \qquad [8]$$

where L represents labour (W its price), λ is the technical progress associated with labour, and KE is the capital-energy bundle (P^{KE} its price). The price of the value-added bundle, for generation ν, is:

$$P^{VA}_{i,v} = \frac{1}{A_{i,v}} \times \left[\alpha^{KE}_{i,v}\left(P^{KE}_{i,v}\right)^{1-\sigma^V_{i,v}} + \alpha^L_{i,v}\left(\frac{W_i}{\lambda_i}\right)^{1-\sigma^V_{i,v}}\right]^{(1/(1-\sigma^V_{i,v}))} \qquad [9]$$

27. The value-added bundle (VA) is a sub-component of the top level node that produces sectoral net-of-GHGs output X_i. Similar sub-components also exist in formulating the capital and energy bundles. In fact, as shown in Figure 1, the capital is bundled with a sector-specific resource when one exists and energy is itself a bundle of different energy inputs.

28. The energy bundle is of particular interest for analysis of climate change issues. Energy, as reported in Figure 2, is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and a bundle of the "other fossil fuels". At the lowest nest, the composite "other fossil fuels" commodity consists of crude oil, refined oil products and natural gas. The value of the substitution elasticities are chosen as to imply a higher degree of substitution among the other fuels than with electricity and coal.

[Figure 2. Structure of energy demand in ENV-Linkages]

[Table 3. Parameter values]

29. Given the dual streams of production (from old and new capital), there is a higher degree of substitutability between energy sources when capital is new, but after one year it becomes a sunk cost and falls to a low level of substitutability among energy sources. Moreover, in the sectors that produce fossil fuels (with the exception of natural gas), there is no substitutability between energy inputs. The low level of substitutability of energy when old capital is present is consistent with empirical findings by Arnberg and Bjorner (2007) who look at plant level changes in energy intensity. However, since this model includes the possibility of changes in industry composition, the overall responsiveness to energy price changes will be higher than these researchers found at plant levels.

30. Once a sector's optimal combination of inputs is determined from relative prices, sectoral output (included GHGs) prices are calculated assuming competitive supply (zero-profit) conditions.

Investment and Market goods equilibria

31. This version of the model does not include an investment schedule that relates investment to interest rates. In each period, investment net-of-economic depreciation is equal to the sum of government savings, consumer savings and net capital flows from abroad. Investment as well as government demand use final goods according with a CES specification. Then, the total demand of a good in the economy is

equal to the consumer final demand plus the intermediary demands from firms plus the intermediary demands by final good sectors, corresponding to government and investment expenditures.

32. Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated, according to the Armington principle, between the demands (both final and intermediary) addressed to domestic producers and the import demand(see below).

Foreign Trade

33. World trade in ENV-Linkages is based on a set of regional bilateral flows. The basic assumption is that imports originating from different regions are imperfect substitutes Therefore in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports - commonly referred to as the Armington specification - formally implies that each region faces a reduction in demand for its exports if domestic prices increase. The Armington specification is implemented using two CES nests. At the top nest, domestic agents choose the optimal combination of the domestic good and an aggregate import good[10]. At the second nest, agents optimally allocate demand for the aggregate import good [12] across the range of trading partners *r'*.

$$XMT_i = \beta_i^m \times \left(\frac{PA_i}{PMT_i} \right)^{\sigma_i^m} \times XA_i \qquad [10]$$

$$PMT_i = \left[\sum_r \beta_{i,r}^W PM_{i,r}^{\;1-\sigma_{i,r}^w} \right]^{(1/(1-\sigma_i^w))} \qquad [11]$$

where X*MT* is the bundle of imports of a particular good or service (*PMT* its price) and *XA* represents the aggregate demand for domestically produced and import goods (*PA* is its price).

$$WTF_{r',i} = \beta_{r',i}^w \times \left(\frac{PMT_i}{PM_{r',i}^M} \right)^{\sigma_i^w} \times XMT_i \qquad [12]$$

where $WTF_{r'}$ is import of a particular good or service from region *r'*. Its price, $PM_{r'}$, represents the domestic import price (*e.g.* domestic producer price of its partner r' adjusted for export tax or subsidy, transport margin, "iceberg" costs, and domestic tariffs).

Prices

34. ENV-Linkages is fully homogeneous in prices and only relative prices matter. All prices are expressed relatively to the *numéraire* of the price system that is arbitrarily chosen as the index of OECD manufacturing exports prices. From the point of view of the model specification, this has an impact on the evaluation of international investment flows. They are evaluated with respect to the price of the *numéraire* good. Therefore, one way to interpret the foreign investment flows is as the quantity of foreign saving which will buy the average bundle of OECD manufacturing exports.

35. The domestic producer price of the good j in the model is defined as a composite index of the average variable cost [6] and the costs of the non-CO2 GHGs bundle, plus production taxes. The aggregate market prices of a good i (PA) is calculated as a composite index of domestic producer prices and import

prices. Then the prices of final or intermediary demands are market prices (PA) plus agent-specific *ad-valorem* taxes.

Government and long-term closure

36. Government collects income taxes, indirect taxes on intermediate and final consumption as well as possible carbon taxes, production taxes, tariffs, and export taxes/subsidies. Aggregate government expenditures are linked to real GDP. Since predicting corrective government policy is not an easy task, the real government deficit is exogenous. The closure of the model implies that some fiscal instrument is endogenous – in order to meet government budget constraint. The fiscal closure rule in ENV-Linkages is that the income tax rate adjusts to offset changes that may arise in government expenditures, or as a result of other taxes. For example, a reduction or elimination of tariff rates is compensated by an increase in household direct taxation, *ceteris paribus.* Alternative closure rules can be easily implemented.

37. Each region runs a current-account surplus (or deficit), which is fixed (in terms of the model *numéraire*). Closure on the international side of each economy is achieved by having, as a counterpart of these imbalances, a net outflow (or inflow) of capital, which is subtracted from (added to) the domestic flow of saving. These net capital flows are exogenous. In each period, the model equates investment to saving (which is equal to the sum of saving by households, the net budget position of the government and foreign capital flows). Hence, given exogenous sequences for government and foreign savings, this implies that investment is ultimately driven by household savings.

Dynamic Features

38. The ENV-Linkages model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations concerning prices and quantities. Dynamics in the model originate from two endogenous sources: *i)* accumulation of productive capital and *ii)* the putty/semi-putty specification of technology, as well as, from exogenous drivers like population growth or productivity changes.

Capital accumulation and sectoral allocation of capital

39. At an aggregate level, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus investment. Differences in sectoral rates of return determine the allocation of investment across sectors. The model features two vintages of capital, but investment adds only to new capital. Sectors with higher investment, therefore, are more able to adapt to changes than are sectors with low levels of investment. Indeed, declining sectors whose old capital is less productive begin to sell capital to other firms (which they can use after incurring some adjustment costs). [3]

The putty/semi-putty specification

40. The substitution possibilities among production factors are assumed to be higher with the *new* than with the *old* capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (*e.g.* tariff removal), the demands for production factors adjust gradually to the long-run equilibrium because the substitution effects are delayed over time. The adjustment path depends on the

[3] Formally, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy.

values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

4. Calibration of the ENV-Linkages model

41. The process of calibration of the ENV-Linkages model is broken down into three stages. First, a number of parameters are calibrated, given some elasticity values, on base-year (2001) values of variables. This process is referred to as the static calibration. Second, the 2001 database is updated to 2005 by simulating the model dynamically over the period 2001-2005 and static calibration is performed again with price re-normalisation in order to express all variables in 2005 real $US. Third, the baseline projection is obtained by defining a set of exogenous socio-economic drivers (demographic trends, labour productivity, future trends in energy prices and energy efficiency gains) and running the model dynamically again over the period 2005-2050.[4]

Static calibration of the model

42. Many key parameters are set on the basis of information drawn from various empirical studies and data sources (elasticities of substitution, income elasticities of demand, supply elasticities of natural resources, etc). Table 3 reports some key elasticities used in the current version of the model. Use of these parameters was illustrated in Figures 1 and 2, as well as by the equations in Section 3. Income elasticities of household demand as well as Armington elasticities are taken from the GTAP 6.2 database.

43. However, the information available on the values of these parameters is insufficient for the model simulation to be able to reproduce base-year data values. Given the modelling choices made with regard to the representation of both behaviours and structural technical relationships, some model parameters must be calculated to fit to the data for the initial year (expressed in 2001 $US) of the version 6 of the GTAP database. As a general rule, the parameters used to do this are those whose impact on the outcomes in terms of variation rates remains limited (scale parameters) or parameters for which there are no empirical studies (CES share coefficients). [5]

[Table 3. Key parameter values]

Dynamic calibration of the model

44. Ideally, an informed choice of prospective trends in exogenous variables would produce a set of acceptable scenarios. However, it is difficult to cover all these trends comprehensively. Furthermore, this would make comparisons of different alternative scenarios practically unmanageable. Therefore, the approach followed here considers only one single set of exogenous drivers while recognising that alternative sets may potentially generate somewhat different simulation results [6]. The baseline projection allows calculating the values of a number of parameter over time (such as energy efficiency gains, for

4 The baseline simulation also contains the assumption that the EU Emission Trading System is implemented over the period 2006-2012, assuming a permits price that will rise gradually from 5 to 25 constant $US in 2012 and for the years after.

5 During this calibration stage, all before-tax prices are normalised to unity, which makes it possible, inter alia, to ensure by means of dual cost functions that the sum of CES production function coefficients is equal to one.

6 For instance, differences in projected energy prices in the baseline scenario may affect the economic costs of policy scenarios, although by a marginal extent. For more on sensitivity analysis to baseline scenario, see OECD (2006).

instance), in order to reproduce the evolution of the exogenous drivers. In any variants or policy simulations, these parameter values are kept constant while all other variables in the model are fully endogenous.[7]

45. The list of exogenous drivers specified in the baseline projection is the following:

- Demographic projections and employment trends,
- Aggregate average and sectoral labour productivity growth, controlled by calibration of technical progress coefficients embodied in labour,
- Autonomous efficiency gains for capital, land and specific natural resources,
- Autonomous efficiency gains of fertilizers in crops sectors and of the food bundle in livestock rearing,
- Supply of land and natural resources (excepted for fossil fuels sectors),
- International trade margins,
- Shares of public expenditure in real GDP,
- Public savings and flows of international savings,
- Energy demands (projected by using elasticities of demands to GDP), for all kind of fuels demands excepted crude oil, controlled by calibration of the Autonomous Energy Efficiency Improvements (named AEEIs) in energy use, by sector and type of fuel,
- International prices of fossil fuels, controlled by calibration of the potential supply of fossil fuels resources,
- Investment to GDP ratios, controlled by calibration of the marginal propensity to save of the households,
- Non-CO_2 GHGs emissions, controlled by calibration of autonomous efficiency gains in non-CO_2 GHGs emissions, by sector and type of GHGs emissions

Data used for dynamic calibration

Socio-economic variables such as population, apparent labour productivity or investment to GDP ratios are discussed in Duval and De la Maisonneuve (2009).

46. AEEIs in energy uses have been dynamically calibrated on the basis of elasticities of each kind of energy demand to GDP for 2005-2030 as projected in the IEA's *World Economic Outlook* (2006). These elasticities are assumed to evolve after 2030 in line with their projected trends over the period 2025-2030.

7 For instance, in the baseline scenario, the technical progress embodied in labour is calibrated to reproduce given GDP trends. In contrast, in any policy variants, GDP is fully endogenous given this technical progress calculated in the baseline scenario.

47. The non-CO_2 greenhouse gases need to be calibrated in the base year database. For this purpose, the price of these emissions is arbitrary set equal to 0.5 USD per ton of CO_2 equivalent in the upper bundle of the gross output. Emissions by source reported in US EPA (2006b) are associated to the sectors of ENV-linkages, and for sake of consistency GHGs levels in 2005 are adjusted to match IEA data. It was not possible to associate all emission sources to an economic activity described in the model.[8] For the period 2005-2020, the non-CO_2 emissions are calibrated on forecasts made by the US EPA by adjusting an autonomous efficiency parameter in the emissions bundle of the production function. After 2020 the trend over the period 2015-2020 is extended, except for agriculture sources of non-CO_2 GHGs emissions where the trend assumed is taken from the OECD Environmental Outlook (2008).

48. The evolution of the international import prices of fossil fuels are also controlled for in the baseline scenario. During the period 2005-2008, the model reproduces the historical evolutions and short run projections made by the IEA for its *World Energy Outlook 2008* report. Over the medium term (2007 to 2030) the crude oil potential reserves in the “oil producing countries” (see Table 2. for the composition of this region) are calibrated to reproduce the exogenous trajectory of the international crude oil price assumed by IEA (2008). After 2030, the price is assumed to increase by 1% in real terms each year, the calibrated oil reserves of the oil producing region will then gradually decline, reflecting some exhaustion of existing reserves.

49. In line with IEA projections, the evolution of the international price of natural gas closely follows that of the crude oil price. This is controlled for by adjusting natural gases resources in all producing regions. After 2030, the link between international oil and natural gas prices is projected to be looser, in line with the assumption of a more elastic supply of natural gas in the longer term. The historical surge of the international coal price up to 2008 is introduced by controlling the supply of coal-producing regions. After 2008, the coal price is fully determined by the model mechanisms and remain almost constant in real terms, reflecting the presumption of an elastic coal supply at the world level.

50. From 2001-2005, current account balances as well as government savings are calibrated to match IMF historical data. After 2005, government deficits (or surplus) as well as current accounts deficits (or surplus) are assumed to gradually vanished (at an arbitrary 2.5% rate of reduction per year). However, the Chinese surplus and US deficit are assumed to disappear less rapidly (only after 2020).

Dynamic calibration of household preferences

51. In addition, the parameters relative to household demands (see equations 1-3) need to be recalibrated dynamically in the baseline simulation. The household preferences in ENV-Linkages include a minimum subsistence level of demand for each good that makes the utility function non-homothetic. However, when using the model over a rather long projection horizon, household income increase quite substantially and, if the minimum subsistence demands are not adjusted, income elasticity of demand for all goods converge towards unity. This problem is offset by adjusting the subsistence parameters in the baseline scenario for each period in order to reproduce the desired set of income elasticities.

52. Moreover in the baseline simulation, income elasticities of demand are evolving over time assuming, a conditional convergence of household preferences (*e.g.* income elasticities of demand for non-energy goods) of the non-OECD countries to the OECD standard, based on relative income per capita.

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8. Non-CO_2 emissions from forest and savannas’ burning are not introduced. They correspond to less than 5% of the non-CO_2 emissions reported by the US EPA.

Dynamic adjustment of world trade and output structures

53. In a model like ENV-Linkages that uses so-called Armington specifications to represent international trade flows, countries face downward sloping demand for their exports. Therefore, a fast-growing country would typically experience a decline in its relative factor prices, implying a depreciation of its real exchange rate, *ceteris paribus* (abstracting from the offsetting Balassa-Samuelson effect). This appears inconsistent with past history, which shows that imports from fast-growing countries have typically increased through the creation of new products rather than through price reductions (see in particular Krugman, 1989). In order to capture this historical feature in a simplified manner, the baseline projection further assumes a gradual exogenous increase in the share of non-OECD countries in the overall imports of OECD countries.

54. In addition, the increase in global competition is accompanied by growth in the use of services in production, in line with the argument advanced in OECD (2005). This is simulated by adjusting dynamically the input-output structure such as to increase the weight of services (in the broad sense of the term) in the composition of the bundle of intermediate goods, for non-agricultural and non-fossil fuels sectors.

Software and model solution

55. ENV-Linkages is written in the General Algebraic Modeling System (GAMS) modelling language. GAMS is particularly useful for numerical modelling of linear, nonlinear and mixed integer optimization systems. The software has a number of solvers that can be used for a particular problem and, in many cases, switching between solvers is straightforward. In the past this has proved useful since problems that don't solve with one solution algorithm may solve with another.

56. For economic problems, GAMS can be particularly useful since it allows problems to be written as mixed complementarity – which specifies inequalities that the solution must meet. This facilitates the solutions to problems involving budgets constraints or homogeneous products being produced by multiple sectors.

Future Model developments

57. A number of developments will be introduced into the ENV-Linkages model to enhance its applicability to climate policy analysis.

Carbon capture and storage

58. Carbon dioxide capture and storage (CCS) is a process for reducing emissions by first extracting CO_2 from flue gas streams (generally from electricity production), fuel processing and other industrial processes, including cement production. Once captured and compressed, the CO_2 is transported by pipeline or tanker to a storage site: generally for injection into suitable geological formation, but sometimes also into deep waters. Numerous studies (*e.g.* IEA, 2004) have looked at the feasibility of CCS and generally concluded that at prices near USD 50 per tonne of CO_2, CCS is feasible for both natural gas and coal combustion. There is an energy penalty that must be paid, and the capital cost is substantial, but there did not appear to be any technical obstacles to implementation. Based on the results of various studies, CCS will be implemented in ENV-Linkages. It will result in lower emissions of CO_2 from various sources following substantial investments in capital additions – when CO_2 prices reach threshold levels. It will also cause less energy to be produced for a given quantity of natural gas or coal since some of the energy is used in compression and pumping of the CO_2. Retrofitting will also occur, but at a slow and expensive rate.

Land-use change emissions

59. A potentially important source of GHG emissions that is not going to be implemented at this stage is that associated with land-use change. Achard, *et al*. (2004) reported a large potential for this source, but data are currently very poor and scientific understanding is incomplete. Once the data quality and completeness improve, steps will be taken to incorporate it into the model.

Electricity sector disaggregation

60. The ENV-Linkages version used in this study incorporates electricity generation as a single sector with no explicitly distinction between electricity from nuclear, hydro, fossil-fuels, or renewables of various types. Given the importance of electricity in emissions of CO_2, it is useful to separate electricity production into its aggregate fuel sources. This feature will be incorporated for the next stage of this project.

Concluding remarks

61. ENV-Linkages is an economic model that continues to evolve for use in environmental policy. It has a rigorous foundation in general equilibrium economics and captures core aspects of the world economy. It thus facilitates exploration and quantification of policy responses to a wide range of government initiatives. For policies such as carbon dioxide taxes, the model is very strong in representing the full array of general equilibrium repercussions that the tax would cause.

62. Some of the model's limitations in representing economic phenomenon such as endogenous capital mobility and forward-looking behaviour complicate the types of policies that the model can adequately address. For example, future policy action announced today would not affect today's behaviour of firms and consumers in the model. This would lead to overstating the cost of the policy upon actual implementation. On the other hand, insofar as the policy announcement is not fully credible, the model's response to the policy may be more appropriate. This example illustrates the need to present the model's results along with clear discussion of the context in which policy is assumed to operate.

TABLES AND FIGURES

Table 1. ENV-Linkages model sectors

No	Env-linkages (2008)	GTAP Codes	GTAP SECTORS Label	Description
1	Rice	pdr	Paddy rice	Paddy Rice: rice, husked and unhusked
2	Other crops	wht	Wheat	Wheat: wheat and meslin
		gro	Cereal grains nec	Other Grains: maize (corn), barley, rye, oats, other cereals
		v_f	Vegetables. fruit. nuts	Veg & Fruit: vegetables, fruitvegetables, fruit and nuts, potatoes, cassava, truffles,…
		osd	Oil seeds	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra
		c_b	Sugar cane. sugar beet	Cane & Beet: sugar cane and sugar beet
		pfb	Plant-based fibers	Plant Fibres: cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
		ocr	Crops nec	Other Crops: live plants; cut flowers ; flower buds & seeds ; fruit & vegetable seeds, beverage and spice crops, unmanufactured tobacco
3	Livestock	ctl	Cattle.sheep.goats.horses	Cattle: cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof
		oap	Animal products nec	Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails,…
		rmk	Raw milk	Raw milk
		wol	Wool. silk-worm cocoons	Wool: wool, silk, and other raw animal materials used in textile
4	Forestry	frs	Forestry	Forestry: forestry, logging and related service activities
5	Fisheries	fsh	Fishing	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
6	Coal	coa	Coal	Coal: mining and agglomeration of hard coal, lignite and peat
7	Crude Oil	oil	Oil	Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
8	Gas extraction and distrib.	gas	Gas	Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
		gdt	Gas manufacture. distribution	Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply
9	Electricity	ely	Electricity	Electricity: production, collection and distribution
10	Petroleum & coal products	p_c	Petroleum. coal products	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
11	Food Products	cmt	Meat: cattle.sheep.goats.horse	Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal
		omt	Meat products nec	Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal
		vol	Vegetable oils and fats	Vegetable Oils: crude and refined oils of soya-bean, maize, olive, sesame, ground-nut, olive, sunflower & cotton seeds, safflower, rape,…
		mil	Dairy products	Milk: dairy products
		pcr	Processed rice	Processed Rice: rice, semi- or wholly milled
		sgr	Sugar	Sugar
		ofd	Food products nec	Other Food: prepared and preserved fish or vegetables, fruit & vegetable juices, prepared and preserved fruit and nuts, all cereal flours, …
		b_t	Beverages and tobacco produ	Beverages and Tobacco products
12	Manuf. of mineral prod.	omn	Minerals nec	Other Mining: mining of metal ores, uranium, gems. other mining and quarrying
13	Non-ferrous metals	nfm	Metals nec	Non-Ferrous Metals: production and casting of copper, aluminum, zinc, lead, gold, and silver
14	Iron & steel	i_s	Ferrous metals	Iron & Steel: basic production and casting
15	Chemicals	crp	Chemical.rubber.plastic prods	Chemical Rubber Products: basic chemicals, other chemical products, rubber and plastics products
16	Fabricated Metal Products	fmp	Metal products	Fabricated Metal Products: Sheet metal products, but not machinery and equipment

No	Env-linkages (2008)	GTAP	GTAP SECTORS	Description
17	Paper & Paper Products	ppp	Paper products. publishing	Paper & Paper Products: includes publishing, printing and reproduction of recorded media
18	Non-Metallic Minerals	nmm	Mineral products nec	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
19	Other Manufacturing	tex	Textiles	Textiles: textiles and man-made fibres
		wap	Wearing apparel	Wearing Apparel: Clothing, dressing and dyeing of fur
		lea	Leather products	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear
		otn	Transport equipment nec	Other Transport Equipment: Manufacture of other transport equipment
		ele	Electronic equipment	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
		ome	Machinery and equipment nec	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
		omf	Manufactures nec	Other Manufacturing: includes recycling
		mvh	Motor vehicles and parts	Motor Vehicles: cars, lorries, trailers and semi-trailers
		lum	Wood products	Lumber: wood and products of wood and cork, except furniture; articles of straw and plaiting materials
20	transport services	otp	Transport nec	Other Transport: road, rail ; pipelines, auxiliary transport activities; travel agencies
		wtp	Sea transport	Water transport
		atp	Air transport	Air transport
21	Services	trd	Trade	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal goods,…
		wtr	Water	Water: collection, purification and distribution
				retail sale of automotive fuel
		cmn	Communication	Communications: post and telecommunications
		ofi	Financial services nec	Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding (see next)
		isr	Insurance	Insurance: includes pension funding, except compulsory social security
		obs	Business services nec	Other Business Services: real estate, renting and business activities
		ros	Recreation and other services	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons
		osg	PubAdmin/Defence/Health/Ed	Other Services (Government): public administration and defense; compulsory social security, education, health and social work, sewage, refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
22	Construction & Dwellings	cns	Construction	Construction: building houses factories offices and roads
		dwe	Dwellings	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)

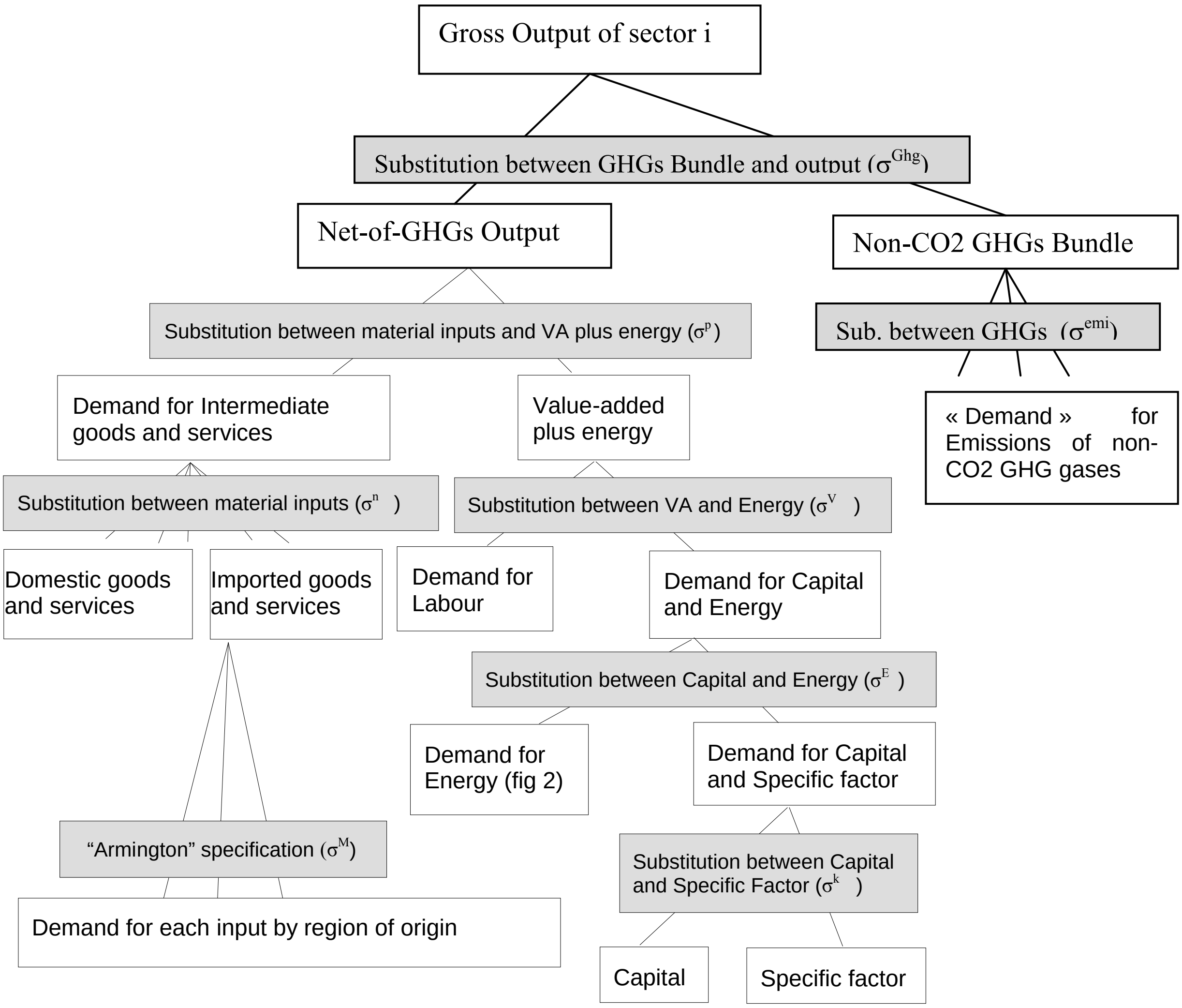
Table 2. ENV-Linkages model regions

ENV-Linkages regions	GTAP countries/regions
1) Australia, New Zealand	Australia, New Zealand
2) Japan	Japan
3) Canada	Canada
4) United States	United States
5) European Union and EFTA	Austria, Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, Netherlands, Portugal, Sweden, France, Germany, United Kingdom, Italy, Spain, Switzerland, Rest of EFTA, Czech Republic, Slovakia, Hungary, Poland, Romania, Bulgaria, Cyprus, Malta, Slovenia, Estonia, Latvia, Lithuania
6) Brazil	Brazil
7) China	China, Hong Kong
8) India	India
9) Russia	Russian Federation
10) Oil producing countries	Indonesia, Venezuela, Rest of Middle East, Islamic Republic of Iran, Rest of North Africa, Nigeria
11) Rest of Annex 1 countries	Croatia, Rest of Former Soviet Union
12) Rest of the world	Korea, Taiwan, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of East Asia, Rest of Southeast Asia, Cambodia, Rest of Oceania, Bangladesh, Sri Lanka, Rest of South Asia, Pakistan, Mexico, Rest of North America, Central America, Rest of Free Trade Area of Americas, Rest of the Caribbean, Colombia, Peru, Bolivia, Ecuador, Argentina, Chile, Uruguay, Rest of South America, Paraguay, Turkey, Rest of Europe, Albania, Morocco, Tunisia, Egypt, Botswana, Rest of South African Customs Union, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Rest of Southern African Development Community, Mauritius, Madagascar, Uganda, Rest of Sub-Saharan Africa, Senegal, South Africa.

Table 3. Key parameter values

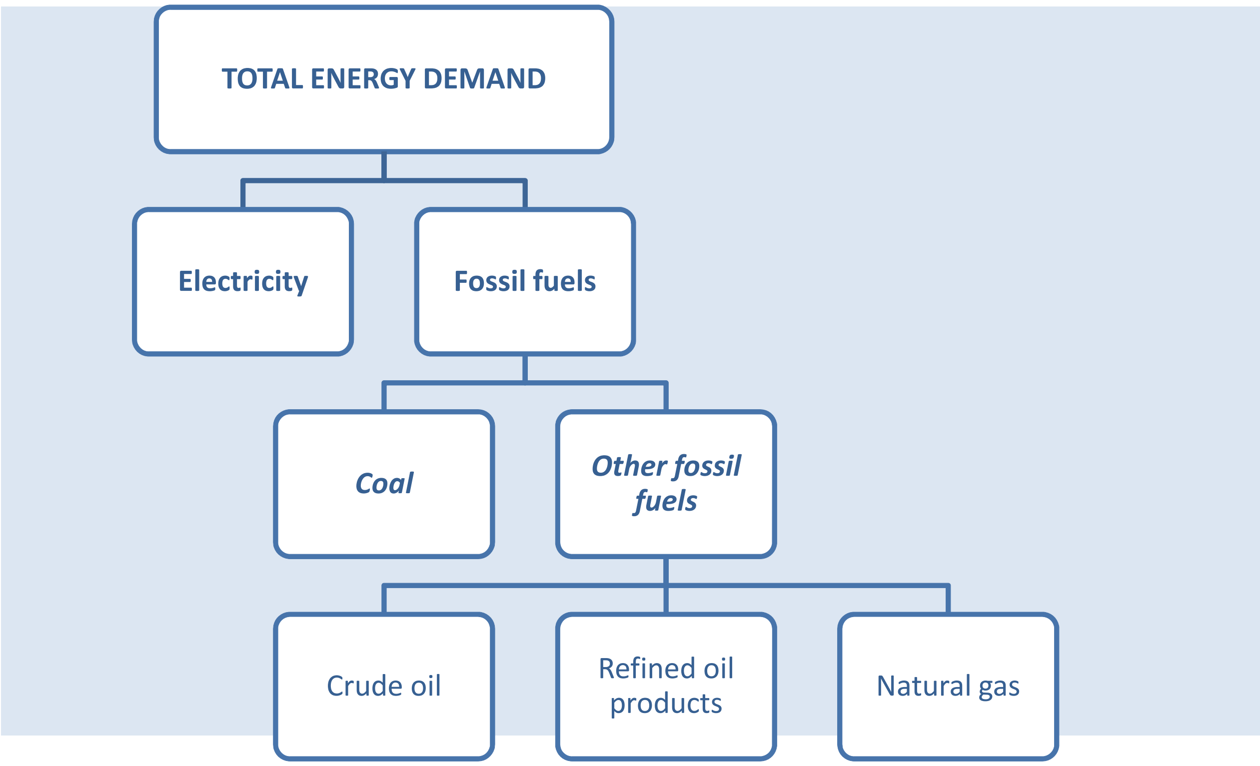
Substitution between GHGs bundle and Net-of-GHGs Output	σ^{Ghg}	Substitution is from 0.03-0.05 for Agr. Sectors to 0.15-0.3 in some industrial emissions
Substitution between material inputs and VA plus energy	σ^{p}	Substitution between material inputs and VA plus energy is 0, except for new capital in manufacturing where it is 0.1.
Substitution between material inputs	σ^{n}	Substitution between material inputs is 0 for non services and non manufacturing sector and 0.1 for other sectors.
Substitution between VA and Energy	σ^{V}	0.05 for old capital vintages and 0.4 for new vintages in agriculture, forestry and fishing and fossil fuels sectors and varying form 0.2-0.27 (1.8-2.1 in other sectors)
Substitution between inputs investment and government exp.	σ^{f}	0.8
Substitution between Capital and Energy	σ^{E}	0 for old capital vintages, 0.2-0.8 for new vintages, but always 0 in coal and crude oil.
Substitution between Capital and Specific Factor	σ^{k}	Substitution between Capital and Specific Factor is 0
Elasticity between Electricity & Non-electricity energy inputs	σ^{ELY}	0.062 for old capital and 0.5 for new in electricity sector. 0.12 and 1 in other sector except fossil fuel where equals to 0 and chemicals where 0.08 and 0.4.
Elasticity between Coal & Non-Coal bundle	σ^{Coa}	0.03 for old capital and 0.25 for new in electricity sector. 0.12 and 1 in other sector except fossil fuel where equals to 0.
Elasticity between enery inputs in Non-Coal bundle	σ^{Ep}	0.25 for old capital vintages, 2 for new vintages, but always 0 in the energy sectors, except for Electricity
Armington elasticity, domestic versus imports	σ^{X}	Varies from 0.9 to 5depending on sectors, identical across regions. GTAP data is used
Armington elasticity, import sources	σ^{W}	Same as σ^{X}
Armington elasticity, intermediate goods imports	σ^{M}	Same as σ^{X}
Armington elasticity, energy imports	σ^{EI}	Same as σ^{X}

Figure 1. Structure of production in ENV-Linkages



Note: see Table 3 for parameter values

Figure 2. Structure of energy demand in ENV-Linkages



Note: See Table 1 for parameter value.
Source: OECD.

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