Model simulations for OECD's Environmental Outlook: Methods and Results.

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1 . The opinions expressed in this paper are those of the author and do not necessarily reflect the views of the OECD.

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0. Executive Summary

1. This paper provides a description of the JOBS/PoleStar model system used in the preparation of OECD's Environmental Outlook, presents some main points of the Reference Scenario used, and elaborates on the estimated impacts of some simulated policy shocks.

2. The general equilibrium model "JOBS" was used to "drive" the "PoleStar" system of Stockholm Environment Institute in Boston, USA, where a number of environmental impacts were simulated. This paper focuses on the links made between the two models concerning energy use and emissions of CO_2 and SO_2, and concerning activity levels in several sectors and emissions of nitrogen to water and related biochemical oxygen demand.

3. The paper also describes estimated impacts of a number of policy shocks – undertaken across the OECD area – meant to limit environmental problems believed to be of particular importance. While the macroeconomic impacts of the shocks are found to be quite limited, the shocks are in general estimated to have considerable environmental benefits.

4. The simulations that address climate change (through the elimination of energy subsidies and the introduction of carbon-related taxes) show very modest "carbon leakage". That is, CO_2 emissions outside the OECD area hardly increase at all as a consequence of these policies, enacted with OECD. This result should be seen in context with an assumed high supply elasticity of *Coal*, which – *inter alia* – imply that global *Coal* prices only decrease marginally when the demand for *Coal* is reduced.

5. The estimated net changes in CO_2 emissions as a result of the policy changes are split into impacts on emissions in different sectors, and for CO_2 emissions from "heavy industries", a further decomposition is made. It was found that the major part of the emission reductions from most of these sectors were explained by a strong estimated decrease in the "carbon intensity" of energy use, while gross production was only marginally affected. In other words – according to these simulations – heavy industries respond to the introduction of carbon-related taxes primarily through changing the fuel mix of energy use, for example by switching from *Coal* to *Natural gas*, rather than by limiting energy use.

6. While the "carbon leakages" were found to be very modest, more significant "leakages" were found in the JOBS/Polestar framework concerning environmental impacts of the agriculture sector in shocks that address elimination of a agriculture subsidies – including a rudimentary approximation of "Market Price Support" removal. For example, while nitrogen loading from the agriculture sectors was estimated to decrease 7% compared to the Reference Scenario in 2020 in OECD, it was found to increase 4% outside OECD.

1. Introduction and background

7. In April 2001, OECD presented its first Environmental Outlook (See OECD [2001]), which *inter alia* included model-based projections of a number of pressures on the environment, and explored impacts on these pressures of a number of possible policies. The simulations were undertaken on OECD's general equilibrium model "JOBS", which was linked to the "PoleStar" system of Stockholm Environment Institute in Boston, USA.

8. This paper provides a description of the model system used, presents some main points of the Reference Scenario used, and elaborates on the estimated impacts of the simulated policy shocks.

2. The JOBS model - a global CGE model

2.1 Basic characteristics

9. JOBS is a neo-classical general equilibrium model that was initially constructed to assess the economic impacts of globalisation on individual regions of the world. JOBS is a version of the "LINKAGE" model, used in the OECD Linkages II project, which *inter alia* resulted in the publication "The World in 2020 - Towards a New Global Age"[2]. The LINKAGE model was in turn derived from the "GREEN" model, that has been used in a series of analyses of policies to combat climate change[3].

10. JOBS is designed for the analysis of dynamic scenarios, which are solved as a sequence of static equilibria. The periods are linked by exogenous population and labour supply growth, capital accumulation and productivity developments. A Reference Scenario was developed for the OECD's Environmental Outlook, and impacts of a number of policy shocks was compared to this. The simulations were based on data from Version 4.0 of the Global Trade Analysis Project (GTAP) database, developed by Purdue University[4], with 1995 as the base year. This database contains consistent data for 50 sectors and 45 regions. The JOBS model is implemented with GAMS software, and includes a flexible aggregation facility that may be set by the user up to the maximum dimensions of the GTAP data set. The simulations for the Environmental Outlook were undertaken for 12 regions (see Table 1) and 26 economic sectors, including 6 energy sectors. OECD (2001) provides further details on the regions and sectors used.

Table 1. Regions used in the JOBS model

	Region name		**Region name**
NFT	Canada, Mexico & USA	CHN	China
WEU	Western Europe	EAS	East Asia
CEU	Central & Eastern Europe	SOA	South Asia
JPK	Japan & Korea	MEA	Middle East
ANZ	Australia & New Zealand	LAT	Latin America
FSU	Former Soviet Union	ARW	Africa & Rest of the World

2 . See OECD (1997)

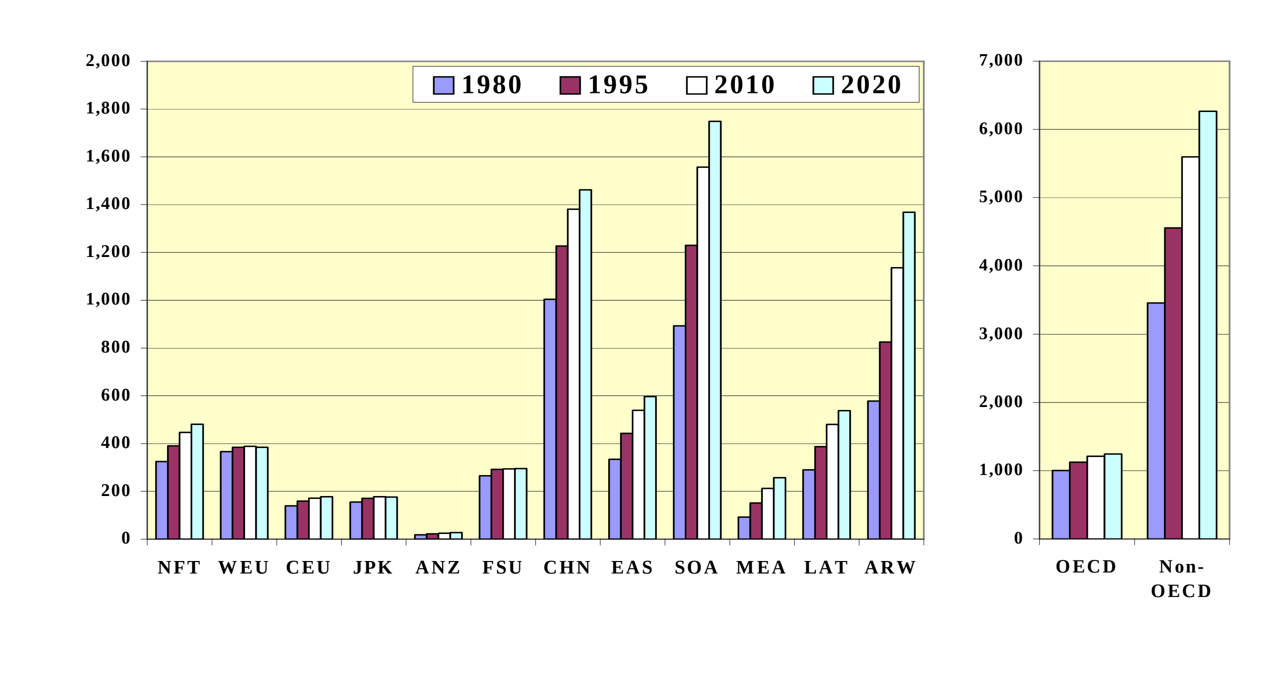
3 . See for instance Burniaux (2000).

4 . For further details, see http://www.agecon.purdue.edu/gtap. Version 5.0 of GTAP now includes an extension and update of the database compared to Version 4.0. This version was, however, not available at the time these simulations were made.

2.2 Population and labour force

11. The growth of total population and labour supply is exogenous in all the simulations, and the assumptions used are based on the medium fertility version of the 1998 UN population projection. Figure 1 illustrates the assumed developments in total population. Only a modest population increase is expected in the OECD area – 0.5% per year on average from 1995 to 2010, and 0.3% per year from 2010 to 2020. A more significant, but also here decreasing, growth is assumed in non-OECD regions. Between 1995 and 2010, total population outside OECD is assumed to increase 1.4% each year, while a growth rate of 1.1% annually is assumed between 2010 and 2020.

Figure 1. Total population in different regions, 1980 - 2020.



Source : United Nations' World Population Prospects 1950-2050 (The 1998 revision).

12. The labour force in each region is assumed to constitute a fixed portion of the population in the age group 15-64 years. This means that – on balance – no major net changes are assumed to take place in factors such as the rate of unemployment, male and female labour force participation rates, etc.

2.3 GDP in the Reference Scenario

13. A specific development of total GDP is assumed for each region up until 2020 in the Reference Scenario, cf. Table 2 and Figure 2 below.[5] The assumptions are, as far as possible, the same as those used in the climate change policy analyses done by the OECD on the GREEN model, cf. Burniaux (2000). However, due to *inter alia* some differences in the regional groupings used in the GREEN and the JOBS models, the assumptions are not quite identical. In any case, it is underlined that the growth assumptions do not represent prognoses, merely a starting point for exploring possible impacts of changes in policy assumptions, etc.

5 . While the *total* GDP in each region is given exogenously, the *distribution* of this total production among the 26 sectors in each region of the model is determined endogenously, reflecting *inter alia* the relative producer prices and the relevant substitution elasticities.

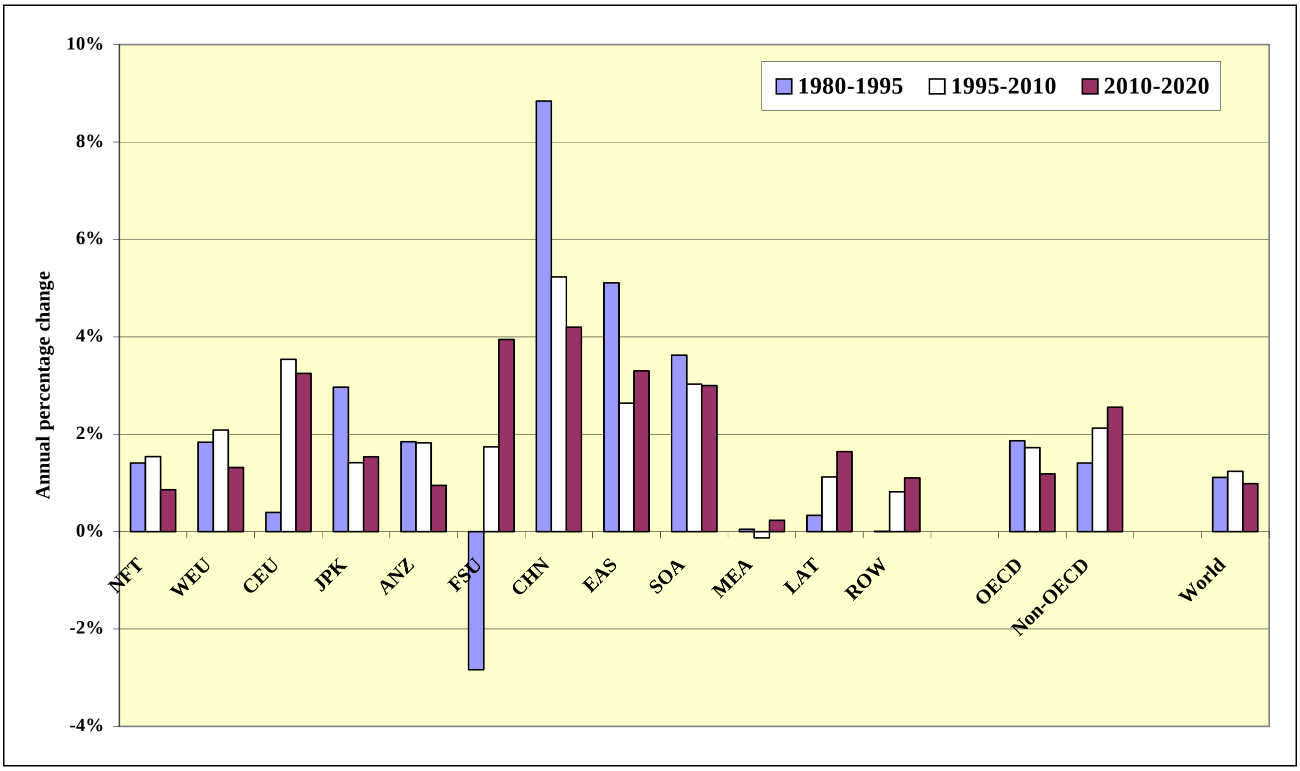
Table 2. Historic and assumed levels of real GDP in different regions, 1980 - 2020

1995 US$ billions. Market exchange rates.

	1980	1995	2000	2005	2010	2015	2020
NFT	4,960	7,347	8,476	9,590	10,588	11,463	12,410
WEU	5,861	8,071	9,087	10,331	11,129	11,813	12,539
CEU	370	449	536	668	817	975	1,163
JPK	2,980	5,084	5,277	5,942	6,528	6,998	7,539
ANZ	232	372	432	503	561	611	667
FSU	626	447	394	468	583	710	863
CHN	150	653	942	1,237	1,578	1,995	2,522
EAS	280	784	882	1,116	1,410	1,757	2,159
SOA	153	359	466	578	711	873	1,072
MEA	281	463	512	570	636	709	790
LAT	893	1,252	1,365	1,591	1,835	2,107	2,419
ROW	452	646	740	866	1,004	1,164	1,350
OECD	14,403	21,323	23,808	27,033	29,623	31,860	34,318
Non-OECD	2,834	4,604	5,302	6,426	7,757	9,315	11,175
World	17,237	25,927	29,109	33,459	37,380	41,175	45,493

Source : IMF (2000a) and IEA (2000) for 1980 numbers; GTAP database for 1995 numbers; and OECD for later years.

Figure 2. Historical and assumed changes in real GDP, 1980-2020



Source : IMF (2000a) and IEA (2000) for 1980 numbers; GTAP database for 1995 numbers; and OECD for later years.

14. Total GDP growth in OECD on average is assumed to decrease from 2.2% annually in the period 1995-2010 to 1.5% annually in the period 2010-2020. Outside OECD GDP growth is assumed to accelerate, from 3.5% annually in the period 1995-2010 to 3.7% annually in the decade up to 2020. As the OECD region is much larger in terms of GDP than the non-OECD region, the slowing of growth in the former dominates the latter concerning impacts on GDP at the World level.

15. While the GDP growth rates are exogenous in the Reference Scenario, capital productivity is endogenous. Furthermore, while the supply of labour is exogenous, the labour productivity parameter (which is uniform across sectors) is calibrated so as to ensure that the ratio of capital (in efficiency units) to labour (in efficiency units) is constant over the simulation period.[6]

16. Figure 3 describes the production structure used in JOBS. The inputs used to produce a given output have been divided into several distinct components, namely non-energy intermediate inputs, energy intermediate inputs, one category of labour, one type of capital, land (in agriculture sectors only) and a natural resource factor used in the *Forestry*, *Fisheries*, *Minerals*, *Coal*, *Crude oil* and *Natural gas* sectors. A nested set of CES functions is used to emulate the different degrees of substitution and complementarity between the various inputs. A brief description of substitution elasticities used is included in the figure.

17. At the top of Figure 3, an aggregate bundle of non-energy intermediate inputs is combined with a "Value added and energy" bundle, with a very low elasticity of substitution (0.05). Hence, these two bundles will always be used in almost fixed proportions. The aggregate non-energy intermediate bundle is decomposed into demand for individual intermediate goods, with no substitution possibility between the different goods. In many cases, this is a reasonable approximation, as the substitution possibilities in the "Real World" are often limited. However, in some cases, this technical assumption imposes unrealistic limitations on the substitutions that can take place when relative prices change, e.g. as a result of increases in taxes on certain products[7].

18. In the agriculture sectors JOBS does, however, allow additional substitution possibilities: In the *Rice* and *Other crops* sectors, it is possible to substitute between the use of *Chemicals* inputs and the "Capital, energy and land" bundle, and in the *Livestock* sector, one can substitute between the use of Land and the use of purchased feedstock. Hence, for example, a tax increase on *Chemicals* used in *Rice* production can lead to a substitution away from the use of such chemicals towards more use of capital, land or energy.

19. JOBS distinguishes between two vintages of capital -- Old and New (the latter being largely equal to each year's investment) -- with the substitution possibilities (e.g. across energy sources) being higher concerning new capital than for old. New capital is perfectly mobile between sectors, and its allocation ensures a uniform rate of return across sectors. The rate of return to old capital in expanding sectors is also equal to the economy-wide rate of return on new capital. Declining sectors are assumed to release capital, which is added to the stock of new capital in a given year. The rate of return on old capital in declining sectors will be lower than the return achieved in other sectors, and is determined by sector-specific supply and demand conditions.

20. The model does not include an investment function that relates the overall level of investment to the expected rate of return. Indeed, there is no forward-looking behaviour incorporated in the model at all. Instead, the value of investment in each year and region is equal to the value of aggregate saving in the region. Aggregate saving, in turn, is derived from household behaviour.

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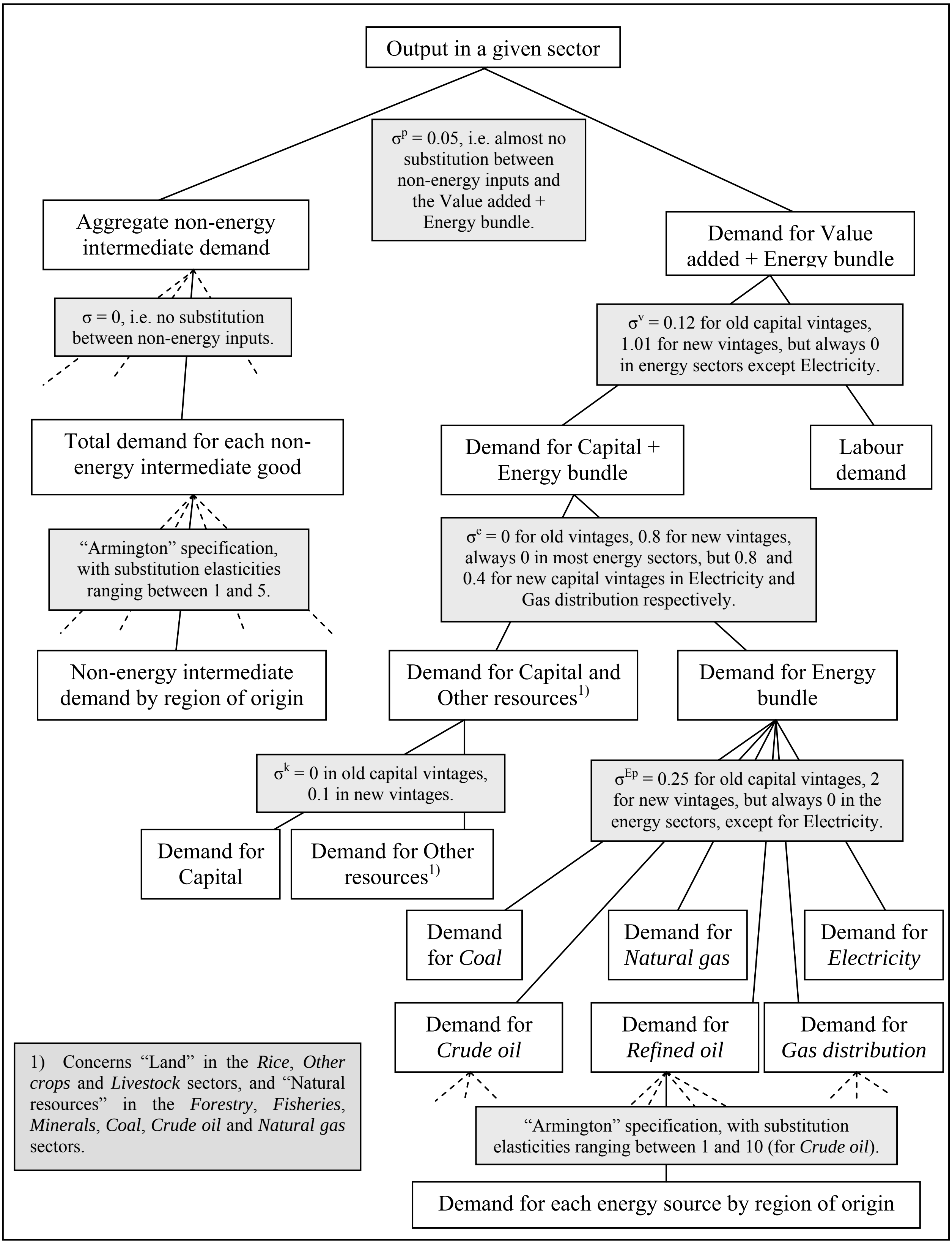
6 . In the policy shocks, the growth rates of capital and labour productivity calculated endogenously in the Reference Scenario are used as exogenous assumptions. In these simulations, real GDP and capital-labour ratios are endogenous.

7 . One could, e.g., expect an increase in the use of *Wood products* as input in the *Construction* sector, if the relative price of *Iron and steel*, or *Non-ferrous metals*, increased. In the current version of JOBS, such a substitution is not possible.

Figure 3. Nested structure of production in the JOBS model



21. Household consumption demand is modelled through the use of a "extended linear expenditure system"(ELES). This includes a demand for savings, which in turn is determined as the difference between household disposable income and current expenditures. The demand for each category of goods and services consists of two components: a population-adjusted subsistence minimum and a component reflecting *inter alia* the relative prices of the different categories.[8]

22. The volume of government expenditure is assumed to be a constant share of real GDP at market prices. Real government saving is exogenous, thus the government is assumed to have a target for the net fiscal position of the public budget. The direct tax rate on household income is endogenous, and the household tax schedule shifts over time to accommodate the given level of real government saving.

23. Domestically produced products and imported products of the same type are assumed to be imperfect substitutes, which *inter alia* implies that their prices may differ in a given market (Armington specification). The Armington elasticities are assumed to be equal between all regions, and between all end-users within each region, but they vary between sectors. One implication of the Armington specification is that each region faces a downward-sloping demand curve for its exports. The more their production is to increase, the lower their relative exports price needs to be. Hence, regions that expand their production more rapidly than other regions will tend to experience a term-of-trade loss.

2.4 Productivity and factor supply assumptions

24. Exogenous assumptions have been made in JOBS concerning overall agricultural productivity growth, the supply and productivity growth of land (used in the *Rice*, *Other crops* and *Livestock* sectors), the productivity of *Chemicals* inputs used in *Rice* and *Other crops* and of feedstock (i.e. used in *Livestock*). Table 3 details the assumptions used.

25. JOBS also includes a sector-specific natural resource factor used in the *Forestry*, *Fisheries*, *Minerals*, *Coal*, *Crude oil* and *Natural gas* sectors. It has been assumed that the supply curve for these factors remain unchanged over the simulation period in the *Forestry*, *Fisheries* and *Minerals* sectors, while they shift outward 0.5% per year in the *Coal*, *Crude oil* and *Natural gas* sectors.

26. It is further assumed that the supply-elasticity of the sector-specific factor is 0.25 in *Forestry* and *Fishery*, 0.5 in *Minerals*, 2 in *Crude oil* and *Natural gas* and 10 in the *Coal* sector, where supply in the time horizon of the Environmental Outlook is believed to be rather flexible[9].

27. Finally, JOBS includes assumptions concerning autonomous energy efficiency improvements (AEEI) – improvements in the efficiency in use of the 6 energy goods in all sectors of the economy which are assumed to take place independently of any response to changes in relative prices. In the Reference Scenario, these efficiency parameters are assumed to improve 0.75% per year in all sectors and regions.

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8 . Income elasticity estimates needed to calibrate the ELES system are taken from the GTAP database. A problem with an ELES demand system is that all income elasticities over time converge towards 1, meaning that the budget shares of each product category become constant. To alleviate this problem, the demand parameters are re-calibrated between each period, so that the income elasticities remain more or less constant over time.

9 . The supply elasticity says by what percentage the supply of that factor would change if the price changed 1%, for a given choice of supply-curve. The supply elasticities used are based, *inter alia*, on Burniaux and Martins (2000).

Table 3. Agriculture assumptions used in the JOBS model

Annual percentage changes. 1995 - 2020.

	Reference agricultural productivity	Land supply growth	Land productivity growth	Fertiliser productivity growth	Feedstock productivity growth
Canada, Mexico &United States	2.5	-0.1	1.5	0.5	0.5
Western Europe	2.0	-0.2	2.3	0.1	0.1
Central & Eastern Europe	1.0	-0.1	1.6	0.0	0.0
Japan & Korea	3.0	-0.2	0.6	1.0	1.0
Australia & New Zealand	2.5	-0.1	2.7	-0.1	-0.1
Former Soviet Union	1.7	-0.1	1.1	0.0	0.0
China	1.8	-0.5	2.0	0.0	0.0
East Asia	2.5	0.8	1.8	0.0	0.0
South Asia	1.8	0.2	1.5	0.0	0.0
Middle East	1.8	0.2	1.5	0.0	0.0
Latin America	2.5	0.6	2.3	0.0	0.0
Africa & Rest of the World	1.8	0.2	1.5	0.0	0.0

Source : Based on Martin and Mitra (1999), Alexandratos (1995) and OECD (1995).

3. The PoleStar framework

28. The PoleStar framework was developed by Stockholm Environment Institute in Boston, USA, to describe developments for a number of environmental parameters. The framework has previously been used in a number of scenario analyses, for instance in the publication “Bending the Curve: Toward Global Sustainability” (Raskin et al., 1998). A number of modifications were made to the framework for the Environmental Outlook, so the results from the JOBS could be used as drivers for the environmental impacts simulated in PoleStar. This section provides an overview of the assumptions used concerning the environmental pressures discussed in this paper. A fuller description of the PoleStar system, as implemented in the Environmental Outlook, is given in OECD (2001).

3.1 Fuel demand

29. JOBS estimates economic transactions valued in constant prices between different economic sectors. These transactions include those between energy-producing and energy-consuming sectors, which are taken as proxies for the volume of fuels used. The fuel-producing sectors tracked in JOBS are *Coal*, *Crude oil*, *Natural gas*, *Refined oil* and *Electricity*. Within PoleStar, trends in household biomass consumption and district heat are also estimated. Biomass consumption is estimated based on a cross-sectional analysis, using IEA energy data, of per capita biomass consumption against income. District heat consumption per capita is held at base year levels in all regions.

30. Energy use by the energy sectors is also estimated. Three energy transformation sectors are included in PoleStar: oil refining, electricity generation and district heat. Of these, two are treated in JOBS: *Refined oil* and *Electricity* generation. Furthermore, within electricity generation a subset of feedstock fuels is considered: *Refined oil*, *Coal* and *Natural gas*. For the Reference Scenario, trends in refining activity and use of *Refined oil*, *Coal* and *Natural gas* are derived from JOBS. Real output from the *Refined oil* sector drives refinery production in PoleStar, while real inputs from the *Refined oil*, *Coal* extraction and *Gas*

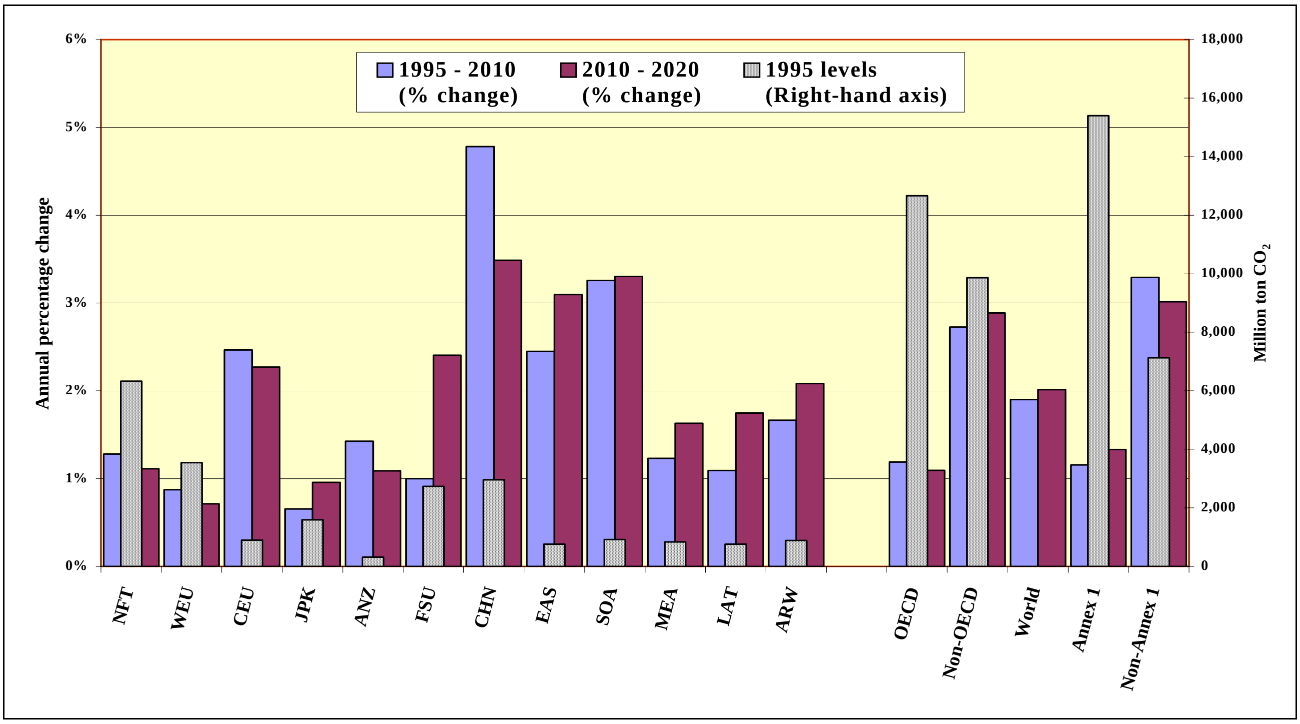
distribution sectors to the *Electricity* generation sector are used to generate trends in use of these fuels for electricity generation. Inputs of nuclear, hydroelectric and renewables into electricity generation in PoleStar are based on separate analyses from IEA (IEA 2000). Fuel shares for district heat production in PoleStar are held at base year levels. Trends in real supplies from energy sectors to other sectors were applied to base year consumption estimates based on IEA energy statistics (IEA, 1999).

3.2 CO_2 emissions

31. Energy-related carbon emissions are estimated from energy consumption data and emissions factors based on IPCC (1995). Carbon dioxide emissions are estimated for fossil fuel combustion and feedstock use. Carbon emission intensities are applied to fuel consumption in all sectors. Industrial process emissions are not included.

32. Figure 4 illustrates the estimated development of CO_2 emissions in the Reference Scenario in various regions. The projections are within the range of results from other modelling exercises, cf. OECD (2001) for further discussion. Emissions are estimated to increase in all regions. However, while CO_2 emissions are estimated to grow 36% between 1995 and 2020 in Annex 1 countries as a group, the growth over this period is estimated to be almost 120% outside Annex 1.

Figure 4. Energy-related CO_2 emissions in the Reference Scenario
Levels in 1995 and annual percentage changes.



Source: OECD -- JOBS and PoleStar.

3.3 SO_x emissions

33. Data on sulphur emissions for the base year are based *inter alia* on Posch et al. (1996). Sulphur emission intensities are applied to fuel consumption in all sectors. Additionally, industrial process emissions for *Non-ferrous metals* sector are included.

34. In the industrial sector, a gradual reduction of sulphur emission factors for fuel combustion and process emissions is assumed in most regions over the course of the Reference Scenario, reflecting the fact that these can be affected by end-of-pipe cleaning technologies and fuel switching. In all regions emission coefficients converge linearly to a value of 0.65 for *Coal*, 0 for *Crude oil* (used as a feedstock in the *Chemical* sector) and 0.0005 for *Refined oil*, all other fuels staying at the base year value. The values would converge completely in 2050; otherwise they change linearly with time. Some regions start out with emission coefficients below these target values. In that case, the emission coefficient remains at the base year value.

3.4 BOD and Nitrogen Loading

3.4.1 Households and Services

35. Sources of domestic pollution include pollution from both the household and service sectors. For this analysis, pollutant generation is represented by biochemical oxygen demand (BOD). Estimates of BOD are constructed separately for urban and rural areas. Loadings are estimated by multiplying population by an emission factor, and then taking treatment into account. Separate emission factors are used for sewered and unsewered waste. A fraction of sewered urban wastes is assumed to be treated to some degree, while in rural areas it is assumed that the population is not connected to central sewer systems, and no waste is treated. BOD loadings are determined by the size of urban and rural populations and by regional GDP per capita, as described below.

36. Data on BOD loading factors (kg BOD/person) are scarce, but they are known to vary regionally and by sewered and unsewered population. Values for the United States and for representative developing countries are shown Table 4. In the Environmental Outlook, the United States value is used for all OECD regions and the developing countries value is used for non-OECD regions.

Table 4. Typical loading rates for untreated domestic sewage

Region	BOD [BOD5] (kg/capita/year) Sewered population	BOD [BOD5] (kg/capita/year) Unsewered population
United States*	54.9 [45.5]	11.0 [9.1]
Developing countries**	23.7 [19.7]	8.3 [6.9]

Source: * Chapra (1997) and ** WHO (1982)

37. The average BOD removed with each degree of treatment (primary, secondary, tertiary) was applied to average wastewater treatment levels in four of the regions in this analysis, to obtain the average percent of BOD removed by region. The relationship between treatment level and income (GDP per capita, measured in Purchasing Power Parities) assumed is as follows: below an income level of around $2400, it is assumed that only primary treatment is used, in which 25% BOD is removed. Above an income of $7,700, treatment levels are assumed to remain at 80%, close to the current average values in the regions shown in the figure.

38. Estimates of the percentage of the urban population connected to sewerage and the percentage of sewered wastewater that is treated are based on data from the Global Urban Observatory (UNCHS, 1998). The percentage of the urban population connected to sewerage and the percentage of wastewater treated increase with income, based on average city-level data from the Global Urban Observatory (UNCHS, 1998).

3.4.2 Livestock Production

39. Water pollution from livestock wastes, in the form of nitrogen and biochemical oxygen demand, is also calculated in PoleStar. Loading factors per unit of feed energy requirements are estimated for the base year using data on livestock populations and milk production from the FAOSTAT database of FAO, and the loading factors from WHO (1982). It is assumed that only livestock in feedlots contribute significantly to water pollutant loads. For the policy shocks, relative trends for waste generation by livestock compared to Reference Scenario levels are estimated from relative trends in real input of Other crops to the Livestock sector in JOBS, which serves as a proxy for energy needs of lot-fed animals.

40. Estimated BOD loadings are the sum of BOD that is associated with the wastes directly, as well as oxygen consumed in the oxidation of nitrogen (NBOD). The loading for NBOD is calculated from the nitrogen loading using the relationship:

$$\text{NBOD} = 4.57 \times \text{N}$$

3.4.3 Fertilisers

41. Following the IPCC guidelines (IPCC/OECD/IEA, 1996), it is assumed that 30% of the nitrogen applied is lost to leaching and runoff. Note that this value can vary over a broad range, from as little as 10% to as much as 80%. Nitrogen in manufactured fertilisers is typically in the form of ammonium or nitrate salts. Since nitrate is already oxidised, it does not contribute to oxygen demand. For this analysis it is assumed that fertilisers do not contribute to oxygen demand (in contrast to the nitrogen contained in livestock wastes). Changes in inputs of *Chemicals* into the *Rice* and *Other crops* sectors are used as proxies for changes in fertiliser use.

3.4.4 Industry

42. Estimation of biochemical oxygen demand contributed by manufacturing is based on a study by the World Bank's Development Research Group (Hettige et al., 1997), which examined data from 12 developing and industrialised countries. Consistent with the approach of Hettige et al., pollution generation is expressed as the product of an activity level — value added for the industrial sector — and an intensity. An abatement factor is applied to the total generation to estimate the final load:

$$\text{Total Industrial BOD} = \text{Industrial Value Added} \times \text{BOD Intensity} \times \left(1 - \frac{\%\ \text{Abatement}}{100}\right)$$

43. The data of Hettige et al. suggest that aggregate manufacturing pollution intensities decline steadily from around 5.5 kg BOD/million \$/day at an annual income per capita level of \$500 to around 4.0 kg BOD/million \$/day at an income level of \$5,000 and remain relatively steady, showing only a slight increase, for incomes above that level. For this study it is assumed that aggregate BOD intensities are 5.5 kg/million \$/day for GDP/capita below \$500, 4.0 kg/million \$/day for GDP/capita above \$5,000 and decline steadily for GDP/capita between \$500 and \$5,000. Abatement levels are also assumed to vary with income, following the tabulated values reported in Hettige et al. (1997).

4. Policy simulations

44. A large number of "policy shocks" were undertaken for the preparation of the Environmental Outlook, with impacts of the shocks commented in chapters dealing with various sectors or issues. Generally the shocks – a few of which are discussed in this paper – focused on elimination of subsidies to the sectors in question, and/or on the introduction of taxes on products stemming from the various sectors.

4.1 Removal of agricultural subsidies

45. Impacts of removal of subsidies to agriculture were estimated in several simulations. In addition to looking at the impacts of removing subsidies as defined and quantified in Version 4.0 of the GTAP database, an attempt was made to approximate impacts of eliminating "Market Price Support" in the agriculture sector. Market Price Support concerns measures that "artificially" elevate prices of the agriculture products, hence representing a – substantial – net transfer from consumers to farmers. Based on OECD (1999), average Market Price Support to agriculture in the 5 OECD regions was estimated to be as described in Table 5:

Table 5. Estimated agriculture Market Price Support in OECD regions. 1997.

	Estimated "Market Price Support" in % of total value of production in agriculture	Consumer subsidy rates estimated to cause a revenue loss similar to the extra revenue raised through the applied producer taxes
NFT	7.4	6.3
WEU	20.9	10.0
CEU	19.3	17.5
JPK	58.8	27.5
ANZ	3.5	6.0

Source: OECD (1999) and JOBS simulations.

46. In the shocks, *producer taxes* equal to the support rates of Table 5 were phased-in over a 5-year period in the three agriculture sectors *Rice*, *Other crops* and *Livestock*.[10] Over the same period, *consumer subsidies* of approximately the same amount were introduced for the sectors *Meat* and *Other food*. Hence, the elimination of the Market Price Support was meant not to impact on public finances. Obviously, this approximation of Market Price Support removal is rather rudimentary and incomplete. This should be kept in mind when interpreting the results.

47. Table 6 shows impacts on household demand, total demand and gross production in agriculture-related sectors, for the OECD as a whole, for the non-OECD area and for the World at large, of three different simulations, all of which were implemented as from 1996:

- One simulation where all "ordinary" agriculture subsidies of the GTAP database were removed in the OECD regions;
- One simulation where this is combined with the described approximation of Market Price Support elimination in OECD regions; and
- One simulation where, in addition to the above, an ad valorem tax on *Chemicals* used as input in *Rice* and *Other crops* is introduced and increased 2 percentage points each year in OECD regions.

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10. Hence – due to lack of data – the shocks do not reflect differences in Market Price Support levels between the different sub-sectors within agriculture (Rice, Other crops and Livestock).

48. Table 6 shows significant differences in impacts of an "ordinary" subsidy removal and the simulation where an attempt was made to illustrate elimination of Market Price Support. For instance, while in the first case small *decreases* in total demand and total production of Other food in the OECD area were estimated, significant *increases* were found when Market Price Support was also taken away. In the case of Meat demand and production, the differences between the two cases were smaller.

49. Adding also a tax on *Chemicals* use in *Rice* and *Other crops* in OECD regions did – not surprisingly – tend to lower production from these sectors somewhat, but the impact on production levels was not dramatic (about 2% additional reduction in the case of Other crops).

Table 6. Economic impacts of agriculture policy shocks

Levels in Reference Scenario and percentage changes caused by the shocks. 2020.

		Rice			OthCrops			Livestock			Meat			OthFood		
		Household demand	Total demand	Gross production	Household demand	Total demand	Gross production	Household demand	Total demand	Gross production	Household demand	Total demand	Gross production	Household demand	Total demand	Gross production
OECD	Reference Scenario *(Million 1995 US$)*	*312*	*89,097*	*88,733*	*306,164*	*777,757*	*708,932*	*75,094*	*620,313*	*631,651*	*392,754*	*623,255*	*609,948*	*1,695,618*	*2,697,491*	*2,645,187*
	Ordinary subsidy elimination	-2.5%	-0.5%	-0.7%	-2.5%	-1.5%	-4.2%	-4.6%	-1.7%	-2.3%	-1.6%	-1.2%	-1.5%	-0.7%	-0.6%	-0.7%
	Above + maket price support elimination	-8.5%	5.1%	4.8%	-10.1%	-3.3%	-11.9%	-14.9%	-2.4%	-3.3%	-0.3%	-0.3%	-1.6%	5.5%	3.7%	3.4%
	Above + tax on agriculture chemicals	-10.0%	4.8%	4.4%	-11.3%	-3.9%	-13.8%	-15.0%	-2.5%	-3.4%	-0.4%	-0.4%	-1.7%	5.2%	3.5%	3.2%
non-OECD	Reference Scenario *(Million 1995 US$)*	*132,916*	*283,611*	*283,631*	*624,637*	*1,243,180*	*1,245,255*	*371,146*	*740,826*	*731,171*	*188,599*	*275,139*	*272,845*	*971,592*	*1,429,043*	*1,429,708*
	Ordinary subsidy elimination	-0.1%	0.0%	0.1%	-0.2%	0.0%	1.8%	-0.3%	0.0%	0.4%	-0.1%	-0.1%	0.3%	-0.1%	0.0%	0.1%
	Above + maket price support elimination	-0.2%	0.3%	0.4%	-0.3%	0.2%	4.9%	-0.5%	0.3%	1.2%	0.0%	0.2%	2.0%	0.0%	0.2%	0.8%
	Above + tax on agriculture chemicals	-0.3%	0.3%	0.4%	-0.4%	0.2%	5.8%	-0.5%	0.3%	1.2%	0.0%	0.1%	2.0%	0.0%	0.2%	0.8%
World	Reference Scenario *(Million 1995 US$)*	*133,228*	*372,708*	*372,364*	*930,801*	*2,020,936*	*1,954,187*	*446,241*	*1,361,140*	*1,362,822*	*581,353*	*898,394*	*882,793*	*2,667,210*	*4,126,534*	*4,074,895*
	Ordinary subsidy elimination	-0.1%	-0.1%	-0.1%	-1.0%	-0.6%	-0.4%	-1.0%	-0.8%	-0.8%	-1.1%	-0.9%	-0.9%	-0.5%	-0.4%	-0.4%
	Above + maket price support elimination	-0.3%	1.5%	1.5%	-3.5%	-1.1%	-1.2%	-2.9%	-0.9%	-0.9%	-0.2%	-0.1%	-0.5%	3.5%	2.5%	2.5%
	Above + tax on agriculture chemicals	-0.3%	1.4%	1.4%	-4.0%	-1.4%	-1.3%	-3.0%	-1.0%	-0.9%	-0.3%	-0.2%	-0.5%	3.3%	2.4%	2.4%

Source: OECD -- JOBS.

50. One should not put much emphasis on the estimated increase in demand for, and production of, *Rice* in OECD regions in the simulation where Market Price Support was eliminated. The result is largely driven by developments in Japan & Korea, where the (almost) non-existence of *Rice* imports in the base year caused particular modelling problems, which constrain *Rice* imports also in the policy shocks.[11] The consumer subsidies increase demand for *Other food*, causing a need for increased inputs of *Rice*, which – with the modelling approach used – are almost exclusively produced domestically.

51. In most OECD regions (with Australia & New Zealand as the exception) real GDP decreased slightly when Market Price Support was removed as described above. The largest decreases were found in Japan & Korea (-0.4% in 2020, when measured at factor prices, compared to the Reference Scenario) and Central & Eastern Europe (-0.2%). These estimated impacts should, obviously, be seen in the context of the rudimentary – and incomplete – approximation to the Market Price Support elimination that was used.

52. The simulated policies were found to have considerable impacts on certain environmental pressures. Removing all subsidies in OECD regions – including Market Price Support – caused an estimated drop in agricultural irrigation water use in OECD of 10% in 2020 compared to the Reference Scenario, while a 3.5% *increase* was found outside OECD. Significant differences were found between regions within OECD, spanning from a 25% decrease in irrigation water use in Western Europe to a 7.5% *increase* in Australia & New Zealand. Nitrogen loading from the agriculture sectors was estimated to decrease 7% in OECD (with impacts ranging from an 18% decrease in Central & Eastern Europe to a 5% increase in Australia & New Zealand), but *increase* 4% outside OECD. BOD loadings from *Livestock* decreased 2.5% on average in OECD, but were found to increase almost 4% outside OECD. Impacts of agriculture methane emissions were limited (they decreased about 1% in OECD in 2020, compared to the

11. An attempt was made to alleviate the problem by inserting a (very low) Rice import to the region in the base year – accompanied by very high tariff rates – but, even if a considerable percentage increase (130%) in Rice imports was obtained, in dollar terms imports remained negligible.

Reference Scenario) – and should in any case be seen in context of the debatable impacts of the shocks on *Rice* production. The tax on *Chemicals* was estimated to cause a 21% reduction in agricultural nitrogen loading in OECD on average, while emissions outside OECD were hardly affected. The largest impact on nitrogen loading within OECD (-38%) was found in Australia & New Zealand.

4.2 Removal of energy subsidies and introduction of carbon-related taxes

53. Another set of policy shocks concerned the energy sector. First, all subsidies to the energy sectors, as defined and quantified in GTAP, were eliminated (with effect from 1996). In a second simulation, additionally, a carbon-related *ad valorem* tax was levied on all *Coal*, *Crude oil* and *Natural gas* use in OECD regions. The taxes increased 2 / 1.6 / 1.2 percentage points respectively each year from 1996. They were "carbon-related" in the sense that the *yearly percentage point increases* in the tax rates were differentiated according to the carbon content of an energy unit of each fuel. However, these were *ad valorem* taxes, and no correction was made for the fact that the price per kg carbon contained in each fuel in the "Real World" differed considerably in the base year. In particular, the price per ton of carbon contained in *Coal* was much lower than the price per ton of carbon contained in *Crude oil*.[12] There were also differences between regions in prices per kg of carbon in each fuel, which are not reflected in the taxes used here. Prices in the base year for each fuel in each region (like other prices in the model) are generally set equal to 1 in JOBS, with corrections made for any taxes or subsidies, applicable for households or for one or more of the production sectors[13]. For this reason, the taxes introduced in these shocks are *not proper carbon-differentiated taxes*.

54. Both simulations gave very small impacts on real GDP, but a tiny decrease was – not surprisingly – found when the carbon-related taxes were introduced (-0.1% compared to the Reference Scenario in 2020 for OECD as a whole).

55. Impacts on total demand for energy products in OECD regions were considerable – especially when the carbon-related taxes were introduced, see Table 7. As could be expected, the impacts were particularly significant on demand for *Coal*. The 4% decrease in demand for *Coal* in OECD in the case where "only" existing subsidies had been eliminated stems almost exclusively from Western Europe – the only example of really significant energy subsidies in OECD regions included in GTAP.

56. Figure 5 illustrates the estimated impacts of the two energy policy shocks on total CO_2 emissions in 2020. In the case with subsidy elimination plus carbon-related taxes, for OECD as a whole, emissions were estimated to be 25% lower than in the Reference Scenario, where emissions in 2020 were 33% higher than in 1995. The largest emission reductions in this case were found in Australia & New Zealand (-32%), while the smallest reductions in the OECD regions in this case were found in Japan & Korea (-22%).

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12 . According to Capros et al. (2000), the average boarder price in the EU was 104.1, 83.7 and 65.9 €$_{97}$ per ton oil equivalent for crude oil, natural gas and coal respectively in 1995. One ton of oil equivalents of the three fuels contain about 0.83, 0.58 and 1 ton of carbon, respectively. The carbon content also varies somewhat within each fuel category. It is, for example, 10-15% higher in lignite than in coking coal. Hence, the implicit price per ton of carbon in imports into EU in 1995 was 126 €$_{97}$ per ton of carbon in *Crude oil*, 146 €$_{97}$ per ton of carbon in *Natural gas* and 66 €$_{97}$ per ton of carbon in *Coal*. However, these implicit carbon prices do not take into account that whereas almost all the energy in *Coal* stems from carbon, hydrogen also contributes significantly to the energy content in *Natural gas* and – to a lesser extent – in *Crude oil*.

13 . This means that the price of e.g. *Coal* differed between coal-using sectors, if taxes or subsidies differed between sectors. Hence, for example, in NFT the price of *Coal* used in the *Minerals* sector (which *inter alia* includes cement production) was 1.0762 in 1995, while the price of *Coal* used in *Electricity* generation was 1.0864. In Western Europe, the price of *Coal* in these two sectors was 1.0000 and 1.0001 respectively.

Table 7. Impacts on total demand for energy products

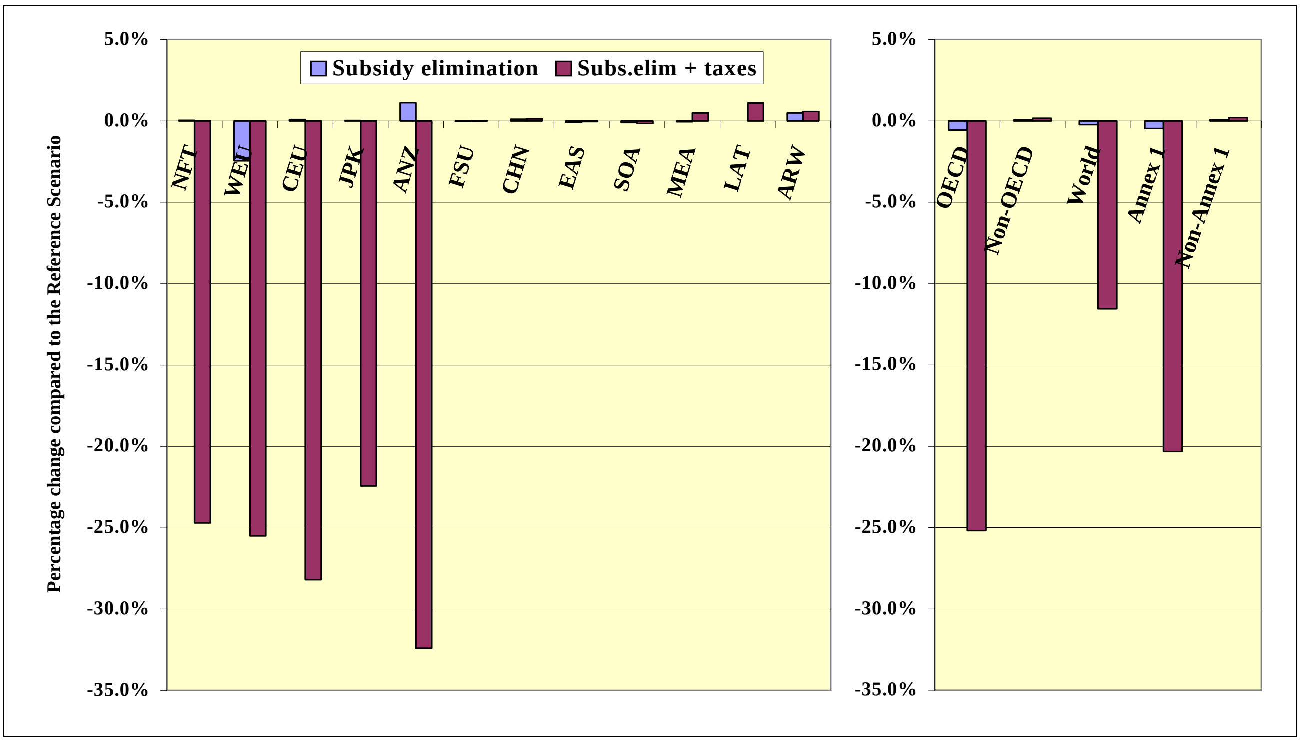
Levels in the Reference Scenario and percentage changes in the policy shocks. 2020.

		Coal	CrudeOil	NaturGas	RefOil	GasDistr	Elect
OECD	Reference Scenario (Million 1995 US$)	*115,165*	*367,945*	*182,391*	*835,807*	*508,325*	*953,392*
	Subsidy elimination	-4.0%	0.0%	0.0%	-0.1%	0.0%	-0.4%
	Above + carbon-related taxes	-31.6%	-18.1%	-16.7%	-14.5%	-5.3%	0.1%
non-OECD	Reference Scenario (Million 1995 US$)	*141,077*	*319,162*	*114,667*	*610,113*	*116,938*	*713,059*
	Subsidy elimination	0.2%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%
	Above + carbon-related taxes	0.1%	2.1%	0.5%	0.2%	-0.1%	-0.1%
World	Reference Scenario (Million 1995 US$)	*256,241*	*687,107*	*297,058*	*1,445,920*	*625,263*	*1,666,451*
	Subsidy elimination	-1.7%	-0.1%	0.0%	-0.1%	0.0%	-0.3%
	Above + carbon-related taxes	-14.2%	-8.7%	-10.1%	-8.3%	-4.3%	0.0%

Source: OECD -- JOBS.

Figure 5. Impacts of energy policy simulations on total CO_2 emissions

Percentage changes compared to the Reference Scenario. 2020.



Source: OECD -- JOBS and PoleStar.

57. The case with only elimination of all energy subsidies in OECD regions was found to have rather limited impact on CO_2 emissions – as expected from the results shown in Table 7. A 2.4% reduction in CO_2 emissions in 2020 was estimated for Western Europe, while a 1.1% *increase* in such emissions was found for Australia & New Zealand – in part explained by a 2% increase in *Coal* production in that region.

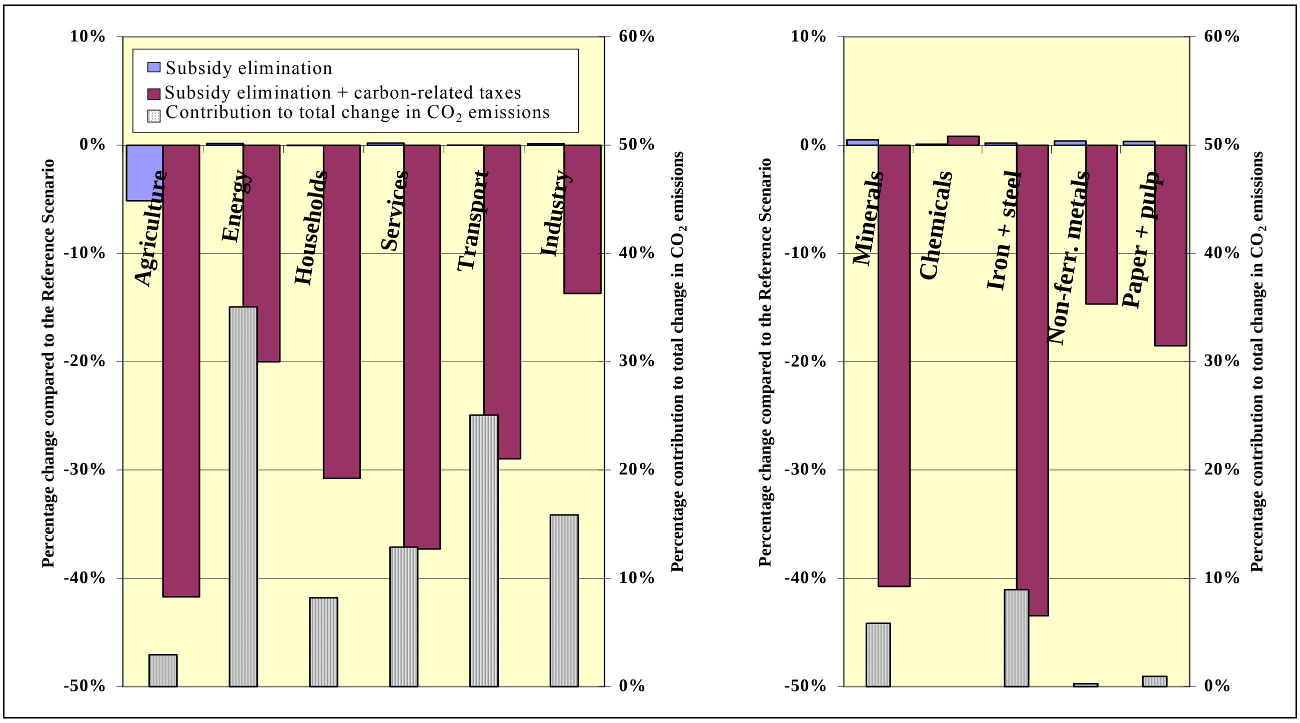
58. It is further clear from Figure 5 that the JOBS/PoleStar system indicates very low "carbon leakages": There is almost no increase in CO_2 emissions outside OECD when policies are altered within OECD. This is – in part – related to the assumed high supply elasticity for *Coal*, described in Section 2.4.

59. In Figure 6 impacts of the same policy shocks on sectoral CO_2 emissions in 2020 in – as an example – Japan & Korea are illustrated. The left part of the Figure shows impacts in fairly aggregate sectors used in PoleStar, while the right part of the Figure highlights impacts in some industrial sub-

sectors.[14] The largest *percentage* impacts in the aggregate sectors are estimated for the Agriculture sector.[15] This is especially the case for the simulation that "only" included an elimination of all energy subsidies. However, the largest *absolute* contribution to the total change in CO_2 emissions (in the case with both subsidy elimination and carbon-related taxes) is estimated to come from the Energy sector, where emissions at the outset also were largest. Among the industrial sub-sectors, the largest percentage and absolute emission reductions were found in the Iron & steel industry, while for the *Chemicals* industry, an almost negligible *increase* in CO_2 emissions was estimated. This increase is analysed further below.

Figure 6. Impacts of energy simulations on sectoral CO_2 emissions in Japan & Korea

Changes compared to Reference Scenario and contributions to total CO_2 emission change. 2020.



Source : OECD -- JOBS and PoleStar.

60. In Table 8, the impacts on CO_2 emissions in industrial (compared to the Reference Scenario) sub-sectors of the shock that includes both subsidy elimination and carbon-related taxes are decomposed into

- A part caused by changes in gross production;
- A part caused by changes in the "energy intensity" of production; and
- A part caused by changes in the "carbon intensity" of energy use.

61. Table 8 shows that most of the changes in CO_2 emissions when energy subsidies are eliminated and carbon-related taxes are introduced generally can be explained by changes in the "carbon-intensity" of the fuel use. In most industrial sectors, the carbon intensity is estimated to decrease significantly in this shock – due to substitution away from carbon-intensive fuels – but in the *Chemicals* sector, the picture is more mixed. A fairly strong increase in the carbon intensity for the *Chemicals* sector in Japan & Korea explains the small estimated net *increase* in CO_2 emissions from the sector, cf. Figure 6.

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14. The PoleStar industrial sub-sectors Construction, Light Industry, Transport equipment and Wood products show no changes in CO_2 emissions, and have not been included in the graph.

15. In PoleStar there is no distinction between the sub-sectors *Rice*, *Other Crops* and *Livestock* used in JOBS.

Table 8. Decomposition of impacts on industrial CO_2 emissions

Percentage changes compared to the Reference Scenario. 2020.

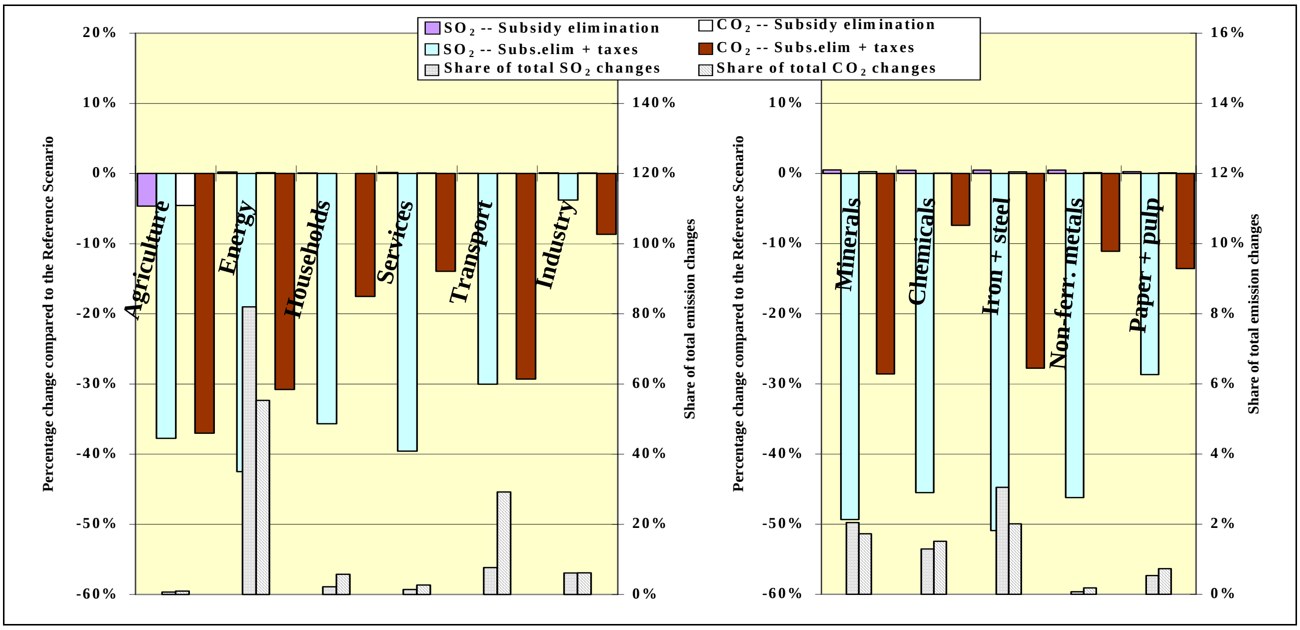
	Change in gross production					Change in $ energy input per unit of gross production					Change in CO_2 emissions per $ energy input				
	Minerals	Chemicals	Iron&steel	NonFer	Pulp&paper	Minerals	Chemicals	Iron&steel	NonFer	Pulp&paper	Minerals	Chemicals	Iron&steel	NonFer	Pulp&paper
NFT	-1.3%	-1.2%	-0.7%	-0.4%	-0.2%	-4.6%	-8.0%	-7.5%	-4.2%	-5.8%	-24.1%	1.9%	-21.4%	-6.8%	-8.1%
WEU	-2.1%	-0.2%	-0.1%	-0.2%	-0.1%	-5.0%	-5.7%	-7.0%	-3.8%	-4.4%	-16.7%	-3.2%	-34.1%	-14.3%	-9.4%
CEU	-2.5%	-3.2%	-6.4%	-2.2%	-0.3%	-5.8%	-5.9%	-6.4%	-4.0%	-5.2%	-16.9%	-0.6%	-24.2%	-15.6%	-23.4%
JPK	-1.2%	-1.3%	-1.1%	-1.1%	-0.3%	-2.0%	-4.7%	-3.5%	-1.1%	-1.8%	-38.5%	7.3%	-40.7%	-12.5%	-16.5%
ANZ	-0.9%	0.3%	0.1%	-3.1%	0.3%	-11.1%	-8.3%	-9.0%	-6.9%	-6.6%	-13.3%	0.0%	-39.2%	-15.2%	-19.0%
FSU	0.1%	0.7%	2.3%	1.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	-0.2%	-0.1%	0.1%
CHN	0.0%	0.4%	0.3%	0.1%	0.0%	-0.1%	0.1%	0.1%	0.0%	0.0%	0.2%	0.1%	0.1%	0.2%	0.2%
EAS	0.1%	0.5%	0.7%	0.5%	-0.3%	0.0%	0.0%	0.0%	0.1%	-0.1%	-1.4%	-0.3%	-0.6%	-0.6%	-0.3%
SOA	-0.2%	0.0%	0.4%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	-0.1%	-0.3%	0.2%	-0.3%
MEA	2.1%	2.0%	4.4%	3.4%	0.6%	0.4%	0.1%	0.2%	0.1%	0.1%	-0.9%	-0.4%	-0.7%	-0.4%	0.0%
LAT	-0.5%	0.1%	0.4%	-0.1%	-0.2%	-0.2%	-0.1%	-0.3%	-0.1%	0.0%	-0.8%	0.1%	-0.4%	-0.4%	-0.6%
ARW	0.3%	0.2%	1.8%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%	0.5%	-0.1%

Source: OECD -- JOBS and PoleStar.

62. The JOBS/PoleStar model system also estimates impacts of the policy shocks on SO_2 emissions. As an example, Figure 7 illustrates the estimated impacts on both sectoral CO_2 and SO_2 emissions in the NAFTA region of the shock that includes both an elimination of all energy subsidies and the introduction of carbon-related taxes. In the *Reference Scenario*, 51% and 38% of SO_2 emissions in 2020 took place in the Industry and Energy sectors respectively, while the similar percentages concerning CO_2 emissions were 21% and 41%, with 23% of CO_2 emissions stemming from the Transport sector. While the *total* percentage reductions in SO_2 and CO_2 emissions in the region caused by the shock are almost exactly the same (about 25%), the changes in sectors and sub-sectors differ somewhat. The percentage reductions in SO_2 emissions in the energy sector, the household sector and the service sector are found to be significantly larger than the respective percentage reductions in CO_2 emissions, while the opposite is the case for the Industry sector. Hence, Industry's share of total SO_2 and CO_2 emissions increased to 53% and 21% respectively, when all energy subsidies were eliminated and carbon-related taxes were introduced.

Figure 7. Impacts on sectoral CO_2 and SO_2 emissions in North America

Changes compared to the Reference Scenario and shares of total changes. 2020.



Source : OECD -- JOBS and PoleStar.

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