Technical Notes on use of PoleStar for the OECD Environmental Outlook

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Introduction

These Notes summarize the assumptions and sources used for developing the Reference scenario in PoleStar.

Fuel Demand

Fuel demand in the scenario is driven by output from the JOBS model. JOBS estimates economic transfers between different economic sectors within an I-O framework. These transfers include those between energy-producing and energy-consuming sectors, which are taken for the purposes of this analysis as proxies for the transfer of fuel. The fuel-producing sectors tracked in JOBS are natural gas, electricity, coal, crude oil and petroleum. 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.

The raw JOBS output requires manipulation for entry into PoleStar. The JOBS output used in the PoleStar analysis is expressed in nominal dollar terms. Because values are in nominal terms, trends in raw output do not correspond directly to physical flows. However, JOBS also estimates prices for goods paid for by different consuming sectors, allowing an estimate of transfers in real terms (after first correcting for changes in efficiency of resource use in consuming sectors). As a result, using JOBS it is possible to estimate trends in physical fuel consumption, as indices calculated relative to consumption levels in the baseyear.

The sectors for which energy demand is reported in PoleStar analysis are more aggregate than those in JOBS. The correspondence is given in the following table:

PoleStar Sector	JOBS Sector(s)
Households	Households
Agriculture	Rice, OthCrops, Livestock, Fisheries, Forestry
Services	Service, Water, TradeTran, Dwellings
Industrial Subsector • Light Industry • Chemical • Iron & Steel • Non-ferrous Metals • Wood Products • Paper & pulp • Transport Equip • Construction • Stone, Glass, Clay	Corresponding Industrial Subsectors • Meat, OthFood • Chemicals • I_S • NonFer • WoodProd • PPP • MotorVehi, OtherManu • Construc • Minerals

Energy use by energy transformation sectors is also estimated. Three energy transformation sectors are included: oil refining, electricity generation and district heat. Of these, two are treated in JOBS: oil refining and electricity generation. Furthermore, in JOBS, within electricity generation a subset of feedstock fuels is considered: petroleum, coal and natural gas. In PoleStar, other sources of electricity are included: nuclear power, hydroelectric and renewables. For the Reference scenario, trends in refining activity and use of petroleum, coal and natural gas are derived from JOBS output. Real output from the oil refining sector drives refinery production in PoleStar, while real transfers from the refining, coal production and natural gas distribution sectors to the electricity generation sectors are used to generate trends in use of these fuels for electricity production. Trends in electricity generation from nuclear, hydroelectric and renewable plants are based on separate analyses from IEA (IEA, 2000). Fuel shares for district heat production are held at base-year levels.

For the PoleStar analysis, trends in real supplies from energy sectors to other sectors were applied to base-year consumption estimates based on IEA energy statistics (IEA, 1999). The PoleStar current accounts are broadly consistent with those of IEA. However, a few important differences should be noted:

1. In PoleStar, stock changes are subsumed into overall production values.
2. Within electricity generation slightly different accounting approach is used than that of the IEA for renewable feedstock fuels. Geothermal, solar and other non-biomass renewables are combined into a single category, whose conversion efficiency is set to 100%. In contrast, IEA uses a 10% efficiency for geothermal.
3. In principle, in the baseyear, conversion efficiencies can be calculated from the data provided by IEA (1999). However, the IEA's published figures for industrial consumption of coal and oil include fuels used by auto-producers of electricity and district heat. The IEA convention of including this consumption as an energy demand produces high apparent efficiencies of thermal electric generation plants and district heat plants. In PoleStar, energy conversion efficiencies are set using assumptions drawn from Lazarus et al., 1993 and other sources, and total industrial oil and coal consumption are adjusted so that total fuel consumption by industry and energy conversion sectors matches the IEA total.
4. Energy consumption for transport is not treated separately in the PoleStar analysis. Within JOBS, fuel consumption for transport comprises part of the energy use of two JOBS sectors: Households and TradeTran. It is difficult to disentangle the contribution of transport to total fuel consumption in these sectors. For the PoleStar analysis, energy use in transport is added to that of the Household sector.

CO_2 Emissions

Carbon emissions are estimated from energy consumption data and emissions factors based on IPCC (1995b). Carbon dioxide emissions are estimated for fossil fuel combustion and feedstock use.

Carbon emission intensities are applied to fuel consumption in all of the PoleStar sectors: Households, Transport (included with Households for this analysis), Services, Industry (exclusive of Energy Conversion), Agriculture and Energy Conversion. Industrial process emissions are not included.

SO_x Emissions

Data on sulphur emissions for the baseyear are based on Posch et al. (1996) and Kuylenstierna (1998). Sulphur emission intensities are applied to fuel consumption in all sectors. Additionally, industrial process emissions for Nonferrous Metals sector are included.

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 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 petroleum, all other fuels staying at the baseyear 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 baseyear value.

BOD and Nitrogen Loading

Households and Services

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 emissions are determined by the size of urban and rural populations and by regional GDP per capita, as described below.

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 representative values for developing countries are shown in Table 1. In this study, the United States value is used for OECD regions and the developing countries value is used for non-OECD regions.

Table 1. Typical loading rates for untreated domestic sewage

Region	BOD [BOD_5] (kg/capita/year) Sewered Population	BOD [BOD_5] (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]

*Chapra 1997
**WHO 1982
***Assumed unsewered population contributes 80% less BOD than sewered population in industrialized countries, compared to 65% in developing countries, because of higher standards in septic tanks.

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 (shown in Table 2).

Table 2. Average Percent of BOD Removed During Wastewater Treatment

Region	% BOD Removed
N Amer	81.3
W Europe	82.6
Mexico	77.8
Cent + E Europe	58.4

The relationship between treatment level and income (GDP per capita) assumed in the analysis 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.

Data for 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).

Livestock Production

Estimates for water pollution from livestock wastes, in the form of nitrogen (N) and biochemical oxygen demand (BOD), are calculated in PoleStar for the current accounts and the Reference scenario. Loading factors per unit of feed energy requirements are estimated for the baseyear using data on livestock populations and milk production from the FAOSTAT database, and the loading factors from WHO (1982). It is assumed that only livestock in feedlots contribute significantly to water pollutant loads. For the policy shock scenarios, relative trends for waste generation by livestock compared to Reference levels are estimated from relative trends in real transfers of feedgrain to the livestock sector in JOBS, which serves as a proxy for energy needs of lot-fed animals.

Estimated BOD emissions 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:

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

Fertilizer

Following the IPCC guidelines (IPCC/OECD/IEA, 1996), we assume 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% (IPCC/OECD/IEA, 1996).

Nitrogen in manufactured fertilizers is typically in the form of ammonium or nitrate salts. Since nitrate is already oxidized, it does not contribute to oxygen demand. For this analysis it is assumed that fertilizers do not contribute to oxygen demand (in contrast to the nitrogen contained in livestock wastes).

Industry

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

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

The data of Hettige et al. (1997) suggest that aggregate manufacturing intensities decline steadily from around 5.5 kg/million $/day at an annual income per capita level of $500 to around 4.0 kg/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).

Timber Production

Three categories of forest products are considered — fuelwood, paper and pulp and an aggregate category containing all other wood products. Requirements for fuelwood are driven by requirements for biomass developed in the energy analysis. Requirements for paper and pulp and for other wood products are driven by value added in the paper and pulp and the wood products sub-sectors in JOBS.

Wood products are designated as being either primary or secondary. Primary products are different kinds of roundwood, that is, felled trees from which the twigs, branches and leaves have been removed. Primary products (such as sawlogs, veneer logs, pulpwood, chips) are used to produce secondary wood products (such as sawnlogs, veneer, paper, pulp and plywood). Wood products are grouped into three categories: paper and pulp, fuelwood and all other wood products. The last category represents all remaining secondary wood products, such as sawnwood, plywood, veneer, etc. Baseyear data on production and trade are taken from the online FAOSTAT database (FAO, 2000).

The analysis proceeds as follows. First, requirements and production of secondary wood products are developed. Second, the production of secondary products is used to determine the requirements for primary roundwood products, by first converting secondary wood production to primary fibre input requirements, and then taking account of the supply of fibre from sources other than roundwood (e.g., non-wood fibre and recycled fibre). It is assumed that for each 1% increase in pulp production, there is a -0.2% decrease in the fraction of fibre that comes from roundwood. After first accounting for trade, regional production of roundwood is then determined. In the Reference Scenario, production is assumed to expand onto a mix of plantation and forest land. A fixed fraction of new plantation area is assumed to come from natural forest. Data on land-use conversion rates are scarce. For this study, we examined data for three aggregate tropical regions – Africa, Latin America and Asia – reported in FAO (1996b). Based on these figures, we assumed a fraction of 85% for all regions except the Middle East. For the Middle East, where natural forest area is scarce, the fraction is 10%

For most regions, it is assumed that importers of secondary wood products in the baseyear maintain their self-sufficiency ratio in the Reference Scenario, defined as the ratio of production to domestic requirements. Most regions that are exporters in the baseyear maintain their share of total exports in the scenario. However, Western Europe, an exporter in the baseyear, has no net exports in 2020, consistent with the results from JOBS.

The fraction from roundwood for paper and pulp is given by the ratio of "pulp for paper" to the total of "pulp for paper", "recovered paper" and "other fibre" from FAOSTAT. For fuelwood, it is assumed that the fraction from roundwood is 0% for developing regions, and 50% otherwise, on the assumption that in developing regions fuelwood production is generally obtained by gathering branches and other excess material, rather than by felling trees.

Wood products are produced from either commercially exploitable forest or plantations. Data on the area of commercially exploitable forest and plantations are taken from FAO-commissioned Global Fibre Supply Study (FAO, 1998). The annual increase in biomass on exploitable forest and current plantations are taken from the same source. For an assessment of potential production, the reported value should be reduced, to take into account the amount of the increment that is left in the forest and uncertainties in the reported increment figures. For this analysis, increments are reduced by 25% to estimate the increase in roundwood area.

Agricultural Demand and Supply

Baseyear data on agricultural demand and supply are taken from the FAOSTAT database (FAO, 1996a). For this study, crop commodities are classified as Wheat and Coarse Grains, Rice and Other Crops. The livestock commodities are classified as Beef, etc., Other Meat, Milk and Fish. The "Beef, etc." category includes animals that are suitable for grazing, such as cattle, sheep and goats. The "Other Meat" category includes animals that are not grazed, such as pigs and poultry. Other Meat also includes eggs and animal by-products. The "Milk" category includes milk products.

Food Demand

Food demand in the analysis is expressed as per capita caloric intake multiplied by population. Total caloric intake is then split into consumption of crop and animal commodities. In the Reference scenario, dietary patterns adjust with rising incomes. Shifts in diet include greater food consumption in developing regions, with an increasing share of calories derived from animal products. In North America and Western Europe, where caloric intake per capita is currently high (Bender, 1997), it is expected that intake levels off, or declines, due to saturation effects and health concerns, e.g., with respect to high-fat diets. In the other regions, as their average incomes grow, diets tend towards the pattern typical of Europe today.

Livestock Production

In the scenario, patterns of trade in animal products are based on *self-sufficiency ratios* (SSRs) for the baseyear. The SSR is defined as the amount of food (in tonnes) available from domestic sources, divided by requirements. In general, SSRs change little over the course of the scenario, increasing for regions that were net exporters in the baseyear and staying at base-year levels for importers. North America, Australia+New Zealand and the Middle East depart from this pattern. In North America and Australia+New Zealand, exports increase significantly over the course of the scenario to meet part of the rapidly growing world demand. In the Middle East, the SSR decreases over the scenario, in response to increasing pressures placed by livestock on land resources.

To facilitate allocation of feeds to different kinds of livestock in the baseyear, for this analysis. livestock were separated into two groups. The first includes animals that can make use of grazing resources, such as beef and dairy cattle, sheep and goats. Feed requirements in the scenario are expressed as changes in feed energy requirements per tonne of meat or milk. Scenario values for OECD regions were based on historical changes in the OECD as a whole. Scenario assumptions for developing regions were based on scenarios developed by Bouwman (1997).

Crop Production

In the Reference scenario, assumptions are made for the demand and productivity of crop products. The main variables affecting productivity are the yields, cropping intensities and irrigated area. Changes in these variables are set in the scenario based on values assumed in Leach (1995) and in the *Bending the Curve* study (Raskin et al., 1998; Heaps et al., 1998). Given these assumptions, in the scenario limits on production are assumed to be determined principally by limits on rainfed crop area. Regional scenario assumptions for domestic production and trade are constrained by the assumption of continuity in trade patterns: i.e., SSRs are consistent with historical trends.

Crop Trade

Trade assumptions are developed in the scenario in several steps. First, the self-sufficiency ratios are assumed to be as in the baseyear in every region. Second, the amount of rainfed crop area is determined that would be required to meet this level of production. This area is then compared to the area of potential cropland (see below). For importing regions, if the required area is below the limit, then the self-sufficiency ratio remains as in the baseyear. Otherwise, it is lower than in the baseyear by the amount required to stay within the land constraints. Third, total net import requirements are determined. Finally, production in exporting regions is set so that global demand is met.

In general, regions that are importers in the baseyear remain importers in the scenario, and the same is true for exporters. The main exceptions are Central and Eastern Europe and the FSU, as they recover from a recent drop in production and as yields in the FSU, which today are well below those of Western Europe and North America, increase.

Potentially Cultivable Land

Estimates of potential productivity of rainfed land for 91 developing countries were prepared by the FAO and the International Institute for Applied Systems Analysis in Vienna (Alexandratos, 1995; Fischer, 1993). The extent of potentially cultivable land and its distribution in different land-use categories was calculated based on these estimates and aggregated to 5 regions: Sub-Saharan Africa, Middle East, Latin America, China and South and Southeast Asia (Fischer, 1993). For this study, where applicable, estimated areas of potential cropland in each PoleStar region was developed by assuming the same distribution of potential cropland under different land uses as in comparable regions from Fischer (1993). For other regions, potential cropland was assumed to be uniformly distributed under forest and grazing land.

Cropland is assumed to be lost to degradation at a rate comparable to historical rates. Cropland loss rates are based on regional aggregate rates estimated by Heaps et al. (1998) using the global soil degradation map prepared for the GLASOD study (Oldeman et al., 1991; GRID/UNEP, 1991).

Agricultural Inputs

Agricultural Withdrawals

Data for 1995 on withdrawals and available supply are taken from the OECD environmental compendium for OECD countries (OECD, 1999), and from Shiklomanov (1999) for other countries. For the Reference scenario, agricultural yield assumptions determine trends in agricultural water use, as described below.

For this analysis, all agricultural withdrawals are assigned to irrigation. In the Reference scenario, irrigation intensities increase with yields. Based on empirical yield-response curves (Hexem and Heady, 1978), it is assumed that for each 1% increase in yields, irrigation intensities increase by 0.25% . As a result, water intensities increase gradually over the course of the scenario as yields increase, but at a slower rate than the increase in yields.

Fertilizer

In the Reference scenario, the amount of nitrogen fertilizer applied per hectare (the intensity) is calculated in terms of yields, so that the trends in fertilizer use are consistent with the yield assumptions, based on crop production data from FAOSTAT and fertilizer application data from FAO's Land and Water Division (FAO, 1999). In the scenarios, application rates increase with yields, using log-linear regression curves estimated from cross-sectional data.

Land Use Changes

The principal source for data on land for this analysis is the FAOSTAT database (FAO, 1996a), supplemented by information from other sources. The FAOSTAT database provides figures for crop area, permanent pasture, forest, Protected areas, and protected forest areas, are based on data from the World Conservation Monitoring Centre (WCMC, 1998a,b). The area of barren land is calculated from the Global Land Cover Characteristics database version 1.2 (USGS/UNL/JRC, 1999).

In the OECD regions, built environment in the scenario increases at a fixed rate based on historical trends in the United States, consistent with the similar economic growth in those regions. In the U.S., between 1982 and 1992 developed land per capita increased at a rate of about 0.6% per year on average. It is assumed that built environment per capita increases in all OECD regions at half this rate, 0.3% per year, throughout the scenario. Built environment per capita in Africa, Mexico and Central + South America converges towards the OECD average with increasing income, while China, South Asia, East Asia, the Middle East, Central and Eastern Europe, FSU, ROE and ROW all converge towards the more compact value for Western Europe. The shares of forest area, barren land and "other" land in the total area converted to built environment are based on the non-cultivable land area available under each of these land types in the baseyear. It is assumed that all non-cultivable land under forest and "other" land is equally suitable for conversion to the built environment. Data on conversion rates of barren land to built land are not available. It is assumed in the scenario that much of the barren land would be essentially unusable for the built environment, due to the expense of delivering water in arid areas. Specifically, it is assumed that 10% of barren land in each region is suitable for conversion to the built environment.

In the Reference scenario, cropland in the developing regions expands into pasture land and unprotected forest areas in proportion to the amount of potentially cultivable land under those uses, after losses of potential cropland to degradation and conversion have been taken into account. In every region grazing land expands into unprotected forest and "other" land in proportion to the area of non-cultivable land under these uses. Forest plantations expand largely onto natural forest, with the remainder expanding onto “other” land. Deforestation rates are estimated by taking all conversions of forest land to other uses and subtracting from the total area.

Municipal Wastes

In the baseyear, waste generation rates in OECD regions, are based on data given in OECD (1997; 1999). In the remaining regions, waste generation rates in rural and urban areas are based on the default regional generation rates given in Doorn and Barlaz (1995). In the scenario, high-income OECD generation rates are, in accordance with developments over the last decade, assumed to increase at a slightly lower rate than GDP, while other regions converge toward the average rate in high-income OECD regions as incomes increase.

For the OECD regions, the waste processing fractions were calculated using data from OECD (1997; 1999). For other regions the processing fractions are based on the regional aggregate figures in the Global Urban Indicators Database (UNCHS, 1998), which provides city-level data and regional averages. Processing fractions are applied to the total population in high-income OECD and transitional regions, but to the urban population alone in developing regions. In the Reference Scenario, recycling trends in North America to 2020 are based on anticipated trends in the U.S. to 2020 (Tellus Institute, 1998). Trends in Western Europe are based on anticipated trends in the EU. Recycling rates in other regions, which are very low compared to North American and European levels, rise gradually over the course of the scenario, by 10 percentage points between 1995 and 2020. Landfill fractions decline by the same amount.

Methane emission factors in the Reference Scenario are decomposed into a product of three factors: the degradable organic carbon content (DOC), the fraction of the DOC that is dissimilated to gas, and fraction of the gas emitted that is methane, following the methodology adopted for SEI's Greenhouse Gas Scenario System (SEI, 1993). The degradable organic content converges gradually in all regions toward the baseyear value for North America. This convergence reflects the increasing importance of paper, which has a high degradable organic content, in the waste streams of all regions.

Methane recovery in North America, Western Europe and Japan & Korea is close to 10% in 1995. In the scenario, methane recovery in these regions increase to 60% by 2020, based on anticipated developments in the U.S. (Tellus Institute, 1998). Methane recovery in the Australia & New Zealand region is negligible in the baseyear, and is assumed to reach 40% by 2020. Recovery rates in all other regions is assumed to reach 20% by 2020, based on the assumptions in Tellus Institute (1998).

Domestic and Industrial Water Use

Data for 1995 on water withdrawals and available supply of water are taken from the OECD environmental compendium for OECD countries (OECD, 1999), and from Shiklomanov (1999) for other countries. These sources provide water withdrawal data for agricultural, domestic and industrial uses. Industrial withdrawals include both manufacturing withdrawals and withdrawals for cooling thermal power plants. Separate data on manufacturing and energy withdrawals are available in OECD (1999), but not in Shiklomanov (1999).

Domestic Water Use

Domestic water use includes water withdrawals for the household and service sectors. The measure of activity for domestic withdrawals is regional population. In the Reference Scenario, in North America and Australia+New Zealand, domestic water intensities are assumed to decrease by 20% between 1995 and 2050. In Western Europe and Japan+Korea, where current domestic intensities are much less than those in North America and Australia+New Zealand, domestic water intensities are assumed to remain at baseyear levels. In non-OECD regions, intensities converge toward average OECD patterns.

Industrial Water Use

In the scenario analysis, industrial water use is disaggregated into withdrawals for cooling thermal power plants and for manufacturing. Water withdrawals for manufacturing are further disaggregated by subsector. The measure of activity for manufacturing withdrawals is subsectoral value added, with the water intensity defined as withdrawals per unit value added. For thermal cooling, electricity output from thermal power plants is the measure of activity.

For OECD regions, OECD data on thermal electric cooling were used to allocate total industrial withdrawals to manufacturing and energy in OECD regions (OECD, 1999). Data on withdrawals by manufacturing subsector are scarce. For this study, United States data on industrial water withdrawals in 1983 (Gleick, 1993) was used to assign relative intensities to individual manufacturing subsectors, using subsectoral value added data for 1983 from UNIDO (1997). The same relative intensities are used for all regions. To allocate total industrial withdrawals to manufacturing and energy in non-OECD regions, the manufacturing and energy intensities for the North American region were scaled by the same factor to recover the total industrial withdrawals for the region.

For the Reference Scenario, trends in water intensity are based on trends in the United States, where disaggregated time-series data are available (Gleick, 1993). Assuming a slowing of the historical trend, intensities in OECD regions are assumed to drop by 10% between 1995 and 2025, and by 20% between 1995 and 2050 in all sectors. Manufacturing intensities in the non-OECD regions are assumed to converge toward the average for the OECD regions as incomes rise.

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