Modelling the circular economy: designing a global baseline of economic activity and material flows

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Draft April 14, 2017 for the 2017 GTAP conference

Abstract

This paper aims at describing the process to design a business as usual baseline scenario, and deriving the environmental consequences in terms of energy, emissions and material use. It starts by describing current demographic trends and corresponding Baseline projections (notably for population growth/composition including ageing, and urbanisation). It then outlines economic trends and projections, including economic growth (GDP, consumption, sectoral composition) and its drivers, such as labour and capital. These trends are based on a gradual conditional convergence of income levels among countries. In its final section it explores two factors which directly link economic trends to environmental pressures: energy use (energy mix such as fossil fuels, renewables and nuclear) and land use (in particular agricultural land). The paper focuses on global projections for major world regions such as the group of OECD countries, emerging economies of Brazil, Russia, India, Indonesia, China and South Africa (the BRIICS) and the rest of the world.

Two original results are expected from this paper compared to the previous ones describing the baseline creation methodology. First, the methodological results consists in developing a procedure to represent the circular economy in a global multi-region CGE model and link material use to economic output. The second output is a material-explicit baseline that goes beyond the current economic projections in which at best energy is described.

From these results, the quantification of material use and flows in the projected baseline indicates the critical materials to monitor for supply security as well as greenhouse gas and outdoor air pollutant emissions. Material flows and the relative decoupling from economic activity can be calibrated to historical trends and information in the literature. This allows projections of resource efficiency, growth employment and trade.

The model extension and baseline developed in this paper constitute a solid starting point to assess the impact of public policies promoting the transition to a circular economy. The effects of these policies on growth, competitiveness, and employment constitute the cornerstone of the rhetoric advocating for them and can be tested in the developed framework.

1 Introduction

Recent decades have witnessed an unprecedented growth in demand for resources. Global material demand jumped from 14 G tonnes in 1950 to 60-70 G tonnes today and is projected to reach 100 G tonnes in 2030. This has been driven by the rapid industrialization of emerging economies and continued high levels of material consumption in developed countries. Since 1990, the global use of material resources has grown slightly slower than global GDP, leading to a relative decoupling of material use and economic activity at the global scale. Relative decoupling has occurred overall in the OECD area across all material groups and all regions, but there are only a handful of instances of absolute decoupling (OECD, 2013, *Material resources, Productivity and the Environment*). However, the annual per capita material consumption in OECD countries remains high, about 60% above the world average. By 2050, the world population is expected to increase from about 7 to more than 9 billion, and the per capita income of the world's population to roughly triple (OECD, 2012, *Environmental Outlook to 2050*). This will substantially increase demand for energy, food and natural resources, especially if global production and consumption patterns converge with those in OECD countries. The associated environmental impacts will likely also increase.

Therefore, managing material flows increasingly becomes a critical topic in most countries for economic development, climate change mitigation, energy and material security and efficiency. Under labels such as "circular economy", "resource efficiency" and "sustainable development", many governments have started to address the subject. For instance, China passed its Law for the Promotion of the Circular Economy in 2008 and has incorporated the concept into its Five-Year Plans (Mathews and Tan 2011). The European Commission has developed a Circular Economy Package to monitor waste and recycling as well as stimulate material recycling. In doing so, the objective is to "boost global competitiveness, foster sustainable economic growth and generate new jobs"[1]. Several European countries also show initiatives at the national level: among others, France, the UK, Belgium, the Netherlands and Finland.

The circular economy represents an alternative to the linear take-make-consume-dispose economic model that currently predominates. A linear economy assumes that resources are readily available and easy to dispose of without taking into account planetary boundaries. Conversely, a circular economy refers to an industrial economy that is intentionally restorative by relying on renewable energy, minimizing the use of toxic materials and eradicating waste by careful design. The circular economy covers the increase of material recycling rates for production, economic structures that are less material- (and energy) intensive, as well as the shift in consumption patterns towards less material consumption. This concept thus relates to other concepts such as Industrial Ecology, Biomimicry, Cradle-to-Cradle, the Blue Economy and Sustainable Materials Management (Andersen 2007, Greyson 2007, EMF 2012, OECD 2012, Circle-Economy[2]). The transition towards the circular economy is an important approach in addressing these challenges and the transformation that it requires is likely going to result in significant structural changes in the economy, leading to the decline of certain sectors and the rise of others, with a reallocation of capital and labour along the way. Relatively little analytical work that examines these structural changes and the effect on the economy as a whole has been carried out to date and none of these efforts have attempted to adjust and improve existing macroeconomic modelling tools.

Few studies have been published to quantify the potential economic effects of the transition to a circular economy. The few published studies either have a very strong focus on one material or a country (Kang et al. (2006) on Korea; Godzinzki (2015) on France; Hotta 2012 on Asia) or focus on a very aggregate material use representation (Cambridge Econometrics 2014; Schandl et al. 2016). CGE models were designed to represent the circularity of economic flows in the economy and thus are very

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[1] http://ec.europa.eu/environment/circular-economy/index_en.htm.

[2] Knowledge Map Circular Economy, available at:

http://www.circle-economy.com/news/knowledge-map-circular-economy/.

adapted tools to model material circularity in the economy. A sound methodology for representing material flows with a CGE is still to be developed. To gain better insight in material use projections and the impacts of policies to promote economic circularity, a model with the economic inputs and output linked to the economic structure is required.

This paper aims to fill that gap by developing a methodology to project material use along with the economic structure in the OECD CGE model ENV-Linkages, and present a detailed baseline socioeconomic projection accounting for material use and recycling. By using a well-established model with detailed descriptions of the projections for the coming decades of sectoral and regional economic activity, and bilateral trade flows, more robust future projections of material flows can be developed. This paper thus at **presenting detailed projections of sectoral economic activity and resource use for the world and specific major economies** in absence of new dedicated policies. The work in this activity would target the further development of OECD modelling by linking physical resource flows (fossil fuels, materials) to specific economic activities and – to the extent possible – integrating essential elements of a circular economy, such as reuse and recycling of waste products as secondary inputs into production, substituting for primary resource use. This will provide countries with internally consistent and globally connected scenarios for the degree of circularity of economies as they evolve over time, and the main sectors and materials where resource efficiency and circularity policies should be aimed.

A baseline projection describes a possible future development and is not a prediction of future developments. Rather, it provides an internally consistent set of trend developments of all economic and environmental variables of the model. The baseline projection is calibrated such that it reproduces expected future trends for several key economic and environmental variables that are derived from published sources, including the IEA, UN and OECD. The baseline assumes no new environmental policies, but implicitly includes other government policies that are included in the expected trends for the key variables. It thus provides a benchmark against which policy scenarios aimed at improving environmental quality for the issues under investigation can be assessed. One robust way to portray modelling results consists in expressing the impact of policy changes on the model variables in terms of changes relative to a baseline, rather than providing absolute numbers.

The structure of this document is as follows. Section 0 reviews the existing literature on circular economy and concludes that there are missing tool to assess this issue. Section 3 provides background information on the ENV-Linkages model and the "conditional convergence" methodology. Then, in Section 4 the socio-economic drivers of economic growth are described, and the resulting macroeconomic trend is presented, as well as the energy, environmental and material indicators. In particular, it describes additional drivers that influence the energy system over the model horizon, and the resulting projected baseline trends for material and energy use and GHG emissions. Section 6 concludes.

2 Review of existing literature

2.1 Modelling approaches: sector specific vs economy wide

There is a small body of analytical work that assesses the macroeconomic consequences of a transition towards a more circular economy, or towards more efficient resource use more generally. This literature is rapidly emerging; the majority of known studies have been undertaken during the last five years. Because many aspects of a circular economy transition are "out of sample", empirical approaches relying on historical experience have not been widely utilised, except for a limited body of work assessing the impact of waste management policies on sectoral employment. Rather, most modelling has used an ex-ante approach, of which there two main variants.

The first approach, termed accounting modelling, typically involves the development of bottom up scenarios regarding material use or technological progress, usually in a handful of sectors. This has usually been done on the basis of expert opinion, and is mostly presented in terms of increased future recycling, re-manufacture, repair, or re-use rates for specific products. The economic benefits, either in terms of cost savings achieved through reduced material use or in terms of job creation, are then estimated. Recent assessments of the macroeconomic impacts of a circular economy transition using the accounting approach have been undertaken by TNO (Bastein, 2013), Ellen McArthur Foundation (2013), Rabobank (Stegeman, 2015), and SITRA (Arponen, 2015).

The second approach involves the use of numeric Computable General Equilibrium (CGE) or macro-econometric (ME) models. These provide a valuable complement to accounting models, which are generally restricted to a handful of sectors and do not incorporate agent reallocation in response to changing prices. More generally, numeric CGE or ME models are often considered to be particularly well suited to assessing the economic effects of a more circular economy; a transition that will involve the entire economy, from primary production and manufacturing, to the services sector and waste management activities. Table 1 provides a summary of some of the major CGE and ME studies that have been undertaken to date.

Table 1.Summary CGE and macro-econometric modelling of the circular economy or resource efficiency

Modelling Group	Year	Model Name	Model Type	Geographic Focus	Material Circularity?
Miyata	1999	-	CGE	Japan	Y
GWS - SERI	2004	PANTA RHEI	ME	Europe	N
Okashima/Yamashita	2005	ODIN-WR	CGE	Japan	Y
NIES Japan	2005	AIM	CGE	Japan	Y
KEI Korea	2006	AIM-INCGE	CGE	Korea	Y
IAMC China	Ongoing	AIM-IPAC	CGE	China	?
NIER Sweden	2009	EMEC	CGE	Sweden	N
Wuppertal Institute	2012	PANTA RHEI	ME	Germany	?
Cambridge Econometrics	2014	E3ME	ME	EU	N
French Ministry of Environment	2015	Vulcain	CGE	France	Y
NERA	2015	NewERA	CGE	World	N
Ellen McArthur	2015	-	CGE	World	N
World Bank	2015	-	CGE	Turkey	N
CSIRO	2015	GIAM/GTEM	CGE	World	N
UNEP IRP	2016	GTEM	CGE	World	N
ERC South Africa	2016	SAGE	CGE	South Africa	N
SINCERE consortium	2016	ASTRA	ME	Germany	Y?
DYNAMIX consortium	2016	ICES	CGE	EU	N
		MEMO	DSGE		N
		MEWA	DSGE		N
SIMRESS consortium	2016	GINFORS	ME	Germany	N
POLFREE consortium	2016	GINFORS	ME	World	N
		EXIOMOD	CGE		N

2.2 CGE and macro-econometric approaches: some aspects of existing modelling

The CGE and ME studies presented in Table 1 can be categorised along a variety of dimensions. First, in terms of geographic coverage, there is a clear divide between models that focus on a single, usually national level, economy, and those that integrate multiple countries or regions. Many early assessments of the circular economy focused on waste management policy, and were undertaken in specific countries with well documented data on waste and secondary material flows (e.g., Japan, Korea, and Sweden). More recently, there has been increased emphasis on a multi-regional approach; modelling undertaken in the DYNAMIX and POLFREE projects, and by UNEP IRP and Cambridge Econometrics, all incorporate some form of trade linking.

The sectoral coverage of existing modelling also varies considerably. In particular, some models are based upon IO tables with a highly aggregated structure of primary production; there is often no distinction between energy and non-energy minerals, between forestry and fisheries, or between different types of biomass. At the other end of the spectrum, the EXIOBASE and GTAP IO tables make these distinctions, and (in the former case) also separate industrial and construction minerals from their metallic equivalents. Models which incorporate more sectorally detailed IO tables will be better able to assess the impact of circular economy enabling policies on the extraction rate of different virgin resources.

There is also a distinction in the extent to which different studies link economic flows (as represented in the SAM) with associated physical flows of resources and materials. The recent development of CGE models that are based upon environmentally extended multi-regional input output tables (e.g. EXIOMOD and GINFORS) allow for more accurate calculation of the potential material efficiency gains resulting from upstream policy. Similarly, several of the national level CGE assessments have been able to assess recycling policies by linking the economic model with a physical model of waste and secondary material flows. Recent examples of this latter approach include work by Godzinkski (2015) for France and by the Fraunhofer Institute (2016)[3] for Germany.

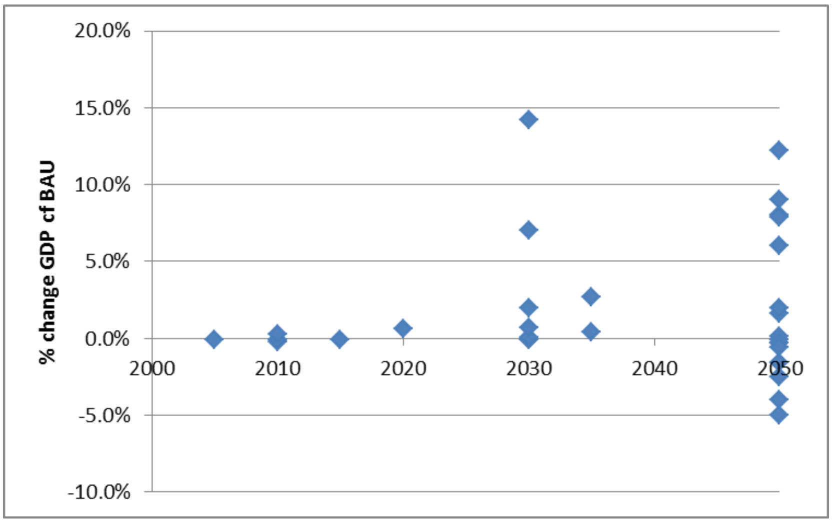
Finally, only a limited number of circular economy enabling policies have been implemented in a CGE or ME framework. Much of the existing modelling has tended to focus on improvements in resource or material productivity within a continued "linear" economy. This is reflected in the widespread use of two policies: resource or material taxes (but in a context without the possibility of secondary material substitution) and public R&D spending leading to material augmenting technological change). In terms of the latter, it is apparent from the current literature that the achievable rates and costs of efficiency gains resulting from technological change are not well constrained. There are also several studies that attempt to model material circularity; that is where secondary materials replace the use of their primary equivalents (those derived from virgin resources) in production. Three main policies are implemented in this context: material taxes, landfill taxes, and subsidies for secondary production. Again, it is clear from the literature that there is uncertainty regarding the substitutability of primary and secondary materials; several studies use an elasticity of substitution between 0 and 1 (Okushima, 2005; Distelkamp et al. 2010) while others use an elasticity of 2 or 3 (Godzinski, 2015).

2.3 Results of existing numeric modelling studies

Figure 1 shows the projected GDP impact of circular economy enabling policies according to existing CGE and ME modelling. There is considerable variation, but most existing work finds that these policies will improve material productivity without having a major impact on the value of aggregate output. There are a handful of studies that predict that circular economy enabling policy can also result in sizeable GDP increases (e.g., in excess of 5%). These results should probably be interpreted with caution; they are driven largely by assumptions around the achievable rate and likely cost of technological progress which, as explained earlier, is subject to considerable uncertainty.

[3] Fraunhofer ISI (2016), "Modeling the macroeconomic effects of material efficiency with an approach which integrates substance flow and economic modeling".

Figure 1. GDP impact of existing numeric modelling of circular economy enabling policies



One consistent finding from existing work is the emergence of winner and loser sectors. Almost all the studies predict decreased activity in upstream extractive sectors such as energy and non-energy mining. Other sectors may benefit from circular economy policies; manufacturing activity often increases due to the receipt of targeted innovation funding, service sectors expand as material taxes become binding, and secondary materials production grows due to landfill taxation and subsidies.

3 Methodology

The core tool used in this paper is the dynamic global multi-sector, multi-region model ENV-Linkages, which is linked to physical input-output tables for material flows.[4]

The process of calibration of the ENV-Linkages model is broken down into two stages (cf. Chateau et al., 2011). First, a number of parameters are calibrated, given some elasticity values, on base-year values of variables. Second, the baseline projection to 2060 is based on convergence assumptions, i.e. countries gradually catch up to their technology frontier, while the country-specific technology frontier in itself also evolves over time. Special emphasis is put on integrating some of the current theoretical and empirical knowledge on long-term economic growth, and making transparent assumptions about the drivers of GDP growth over the projection period. Macroeconomic and demographic trends are then combined with sector-specific projections, including detailed projections for energy and agriculture, to arrive at a full socioeconomic projection over time.

The baseline projection describes a possible future development and is not a prediction of future developments. Rather, it provides an internally consistent set of trend developments of all economic and environmental variables of the model. The baseline projection is calibrated such that it reproduces expected future trends for several key economic and environmental variables that are derived from published sources, including the IEA, UN and OECD. The baseline assumes no new policies for the environmental issues, but implicitly includes other government policies that are included in the expected trends for the key variables. It thus provides a benchmark against which policy scenarios aimed at transitioning to a circular economy can be assessed.

[4] A technical description of the OECD ENV-Linkages model, as well as other recent publications based on the model, can be found on www.oecd.org/environment/modelling.

The main issue to tackle here is to reconcile physical data of a widely varying range of materials in volume for total use, domestic extraction, trade imports and recycling. In addition, the baseline projection hinges on the structural evolution of the economy as projected by ENV-Linkages. This socioeconomic baseline is based on a detailed description of the macroeconomic drivers of growth, as well as the evolution of material use in production, consumption preferences for a given product and rarefaction of primary resources.

This paper builds on the baseline calibration approach described in Chateau et al. 2014, which differs from the standard approach that assumes that the economy is on a steady-state growth path, but is harmonised to short-term economic forecasts of OECD and IMF. The calibration method used in ENV-Linkages has the major advantage that it does not depend on a steady-state assumption, and is able to produce realistic patterns of the major variables over the model horizon. The current version of the model already contains projections of key physical quantities for energy and emissions of greenhouse gases and air pollutants, but will be extended for materials.

3.1 The OECD ENV-Linkages model

3.1.1 How does it work?

The OECD's ENV-Linkages general equilibrium (GE) model is an economic model that describes how economic activities are linked to each other across sectors and regions. It also links economic activity to environmental pressures, specifically to emissions of greenhouse gases (GHGs). The model projects these links between economic activities and emissions several decades into the future to shed light on the medium- and long-term impacts of environmental policies. The advantages of multi-sectoral, multi-regional dynamic GE models like ENV-Linkages are several, and include their global dimension, their overall consistency and the fact that they build on rigorous micro-economic foundations. These models are best suited for analysing the medium- and long-term implications of large policy shifts requiring significant reallocation across sectors and countries/regions, as well as the associated spill-over effects. In that sense, these models are the tools of choice for assessing a wide range of climate change policies.

ENV-Linkages is the successor to the OECD GREEN model, initially developed by the OECD's Economics Department (Burniaux, et al. 1992) and is now hosted by the OECD Environment Directorate. Much of the applied work carried out with the model has been reported in various chapters of the OECD Environmental Outlook to 2030 (OECD, 2008). An updated version of the model was used extensively in the joint project between the OECD Economics Department and the OECD Environment Directorate on the economics of climate change mitigation (OECD, 2009). Most recently, the model has been used to study the impacts of phasing out fossil fuels subsidies (IEA, OPEC, OECD, World Bank, 2010; Burniaux and Chateau, 2011); the impacts of border-tax adjustments (Burniaux et al., 2010); direct and indirect linking of carbon markets (Dellink et al., 2010a; and the costs and effectiveness of the Copenhagen pledges (Dellink et al., 2010b). A more detailed overview of the ENV-Linkages version 3, as used for the OECD Environmental Outlook to 2050 (OECD, 2012), is provided in Chateau et al. (2012).

ENV-Linkages is a global economic model built primarily on a database of national economies. In the version of the model used here, the world economy is divided in 25 countries/regions, each with 35 economic sectors (Table 1 and Table 2 respectively), including 5 different technologies to produce electricity.

Table 1: ENV-Linkages model regions

Macro region	Countries and regions	Comprising countries
OECD America	Canada	
	Mexico	
	United States	
OECD Europe	OECD EU 4 Larger countries	France, Germany, Italy, United Kingdom
	OECD EU 17 smaller countries	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden
	Other OECD	Israel, Switzerland, Norway, Turkey, Iceland, Liechtenstein
OECD Pacific	Australia & New Zealand	
	Japan	
	Korea	
Rest of Europe & Asia	China	
	Non-OECD EU	Cyprus, Latvia, Lithuania, Malta, Bulgaria, Croatia, Romania
	Russia	
	Caspian region	Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Georgia, Tajikistan, Turkmenistan, Uzbekistan
	Other Europe	Albania, Belarus, Ukraine, Moldova, Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Republic of Macedonia, Monaco, Montenegro, San Marino, Serbia
Latin America	Brazil	
	Chile	
	Other Latin America	Bermuda, Greenland, Saint Pierre and Miquelon, Argentina, Plurinational, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Falkland Islands (Malvinas), French Guiana, Guyana, South Georgia and the South Sandwich Islands, Suriname, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Belize, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, British Virgin Islands, Cayman Islands, Cuba, Dominica, Grenada, Haiti, Montserrat, Netherlands Antilles, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Turks and Caicos Islands, Virgin Islands (US), Antarctica, Bouvet Island, British Indian Ocean Territory, French Southern Territories
Middle East & North Africa	Middle East	Oman, Bahrain, Islamic Republic of Iran, Kuwait, Qatar, Saudi Arabia, United Arab, Iraq, Lebanon, Palestinian Territory (Occupied), Syrian Arab Republic (Syria), Yemen
	North Africa	Egypt, Morocco, Tunisia, Algeria, Libya, Western Sahara
South & South-East Asia	ASEAN 9 (excl. Indonesia)	Cambodia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Myanmar, Timor-Leste
	Indonesia	
	India	
	Other Asia	American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Futuna Islands, Mongolia, Taiwan, Democratic People's Republic of Korea, Special Administrative Region of China Macao, Bangladesh, Nepal, Pakistan, Sri Lanka, Afghanistan, Bhutan, Maldives
Sub-Saharan Africa	South Africa	
	Other Africa	Cameroon, Cote d'Ivoire, Ghana, Nigeria, Senegal, Benin, Burkina Faso, Guinea, Togo, Cape Verde, Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, Sierra Leone,Central African Republic, Chad, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Angola, Democratic Republic of the Congo, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, United Republic of Tanzania, Uganda, Zambia, Zimbabwe, Rwanda, Burundi, Comoros, Djibouti, Eritrea, Mayotte, Seychelles, Somalia, Sudan, Botswana, Namibia, Lesotho, Swaziland

Table 2: ENV-Linkages model sectors

Group	Sector
Agriculture and forestry	Paddy Rice
	Wheat and meslin
	Other Grains
	Vegetables and fruits
	Sugar cane and sugar beet
	Oil Seeds
	Fibres Plant
	Other Crops
	Livestock
	Forestry
	Fisheries
Energy extraction and mining	Coal
	Crude Oil
	Gas extraction and distribution
	Other mining
	Petroleum and coal products
Industries	Chemicals
	Non-metallic minerals
	Iron and Steel
	Paper and paper products
	Metals n.e.s.
	Fabricated metal products
	Electricity
	Food Products
	Other manufacturing
	Motor vehicles
	Electronic Equipment
	Textiles
Transport	Land Transport
	Air Transport
	Water Transport
Water	Water
Construction	Construction
Services	Other Services (private) and Dwellings
	Other Services (Government)

The core of the static equilibrium is formed by the set of Social Account Matrices (SAMs) that described how economic sectors are linked; these are based on the GTAP database (GTAP, 2011; version 9 is used for this baseline). Many key parameters are set on the basis of information drawn from various empirical studies and data sources (see Chateau *et al.*, 2010).

The ENV-Linkages model has a simple recursive-dynamic structure, where households base their decisions on static expectations concerning prices and quantities. Household consumption, demand and savings are implemented through an “Extended Linear Expenditure System”. Since consumers are not represented with forward-looking behaviour, some care needs to be exercised in studying policies that consumers may reasonably be expected to anticipate – either the policy itself or its consequences. In each period, investment net-of-economic depreciation is equal to the sum of government savings, consumer savings and net capital flows from abroad.

Production in the model is represented using a nested sequence of constant elasticity of substitution (CES) functions (see Figure 1 for a stylised representation of this structure). Four types of input factors are specified: labour, capital, energy and a sector-specific natural resource (e.g. land).

Production is assumed to operate under cost minimisation, perfect markets and constant returns to scale technology. The substitutability between inputs means that the intensity of using capital, energy, labour and land changes when their relative price changes: for example, as labour becomes more expensive, less of it is used relative to capital, energy and land. The possibilities to shift away from expensive inputs is however limited. Specific sectors, such as in agriculture or energy production, have an adjusted production function to reflect the specifics of that sector (e.g. fertiliser use is linked to land use for crop production).

World trade in ENV-Linkages is based on a set of regional bilateral flows. In each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. Allocation of trade between partners responds to changes in relative prices between regions. 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. Exchange rates between regions adjust to ensure that trade balances are not affected by the policies.

The government in each region collects various kinds of taxes in order to finance government expenditures. For simplicity it is assumed in the Baseline that these expenditures grow at the same rate as the real GDP. Assuming a given stream of public savings (or deficits), the government budget is balanced through the adjustment of a lumpsum transfer (tax) to the household.

Market goods equilibrium implies 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 between the demands (both final and intermediary) addressed to domestic producers and the import demand. The general equilibrium framework ensures that a unique set of relative prices emerges such that demand equals supply in all markets simultaneously (i.e. across all regions, commodities, and factors of production). All prices are expressed relatively to the *numéraire* of the price system that is chosen as the index of OECD manufacturing exports prices. Implementation of a policy in the model leads to a new equilibration process and thus a new set of equilibrium prices and quantities to compare with the original equilibrium.

The land-based sectors, including three agricultural sectors and forestry, provide direct links to indicators for climate change (e.g. emissions from deforestation), biodiversity (e.g. land under forest cover) and water. The recently improved land-use module of ENV-Linkages is calibrated to mimic land-use relations in the coupled IMAGELEITAP models described below. The underlying complexities of the land model in IMAGE, and its detailed links with the agricultural model LEITAP (see below), are approximated in ENV-Linkages in a stylised and aggregated manner where region- and sector-specific elasticities are used to represent the possibilities to change between different land uses, such as transforming grazing land into cropland.

The structure of **energy** inputs in production is of particular interest for analysing climate change and health impacts of local air pollution. In the model, energy is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and the other fossil fuels (crude oil, refined oil products and gas products). A higher degree of substitution is assumed among the other fuels than with electricity and coal.

CO_2 emissions from the combustion of energy in the model are directly linked to the use of different fuels in production. Other GHG emissions are linked to output. The following non-CO2 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 fertilisers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); iii) industrial gases (SF6, PFCs and HFCs) from chemicals industry (foams, adipic acid, solvents), aluminium, magnesium and semi-conductors production. These emissions are calibrated with historical data collected by the International Energy Agency (IEA, 2010a). For non-CO2 GHGs data the IEA relies on the EDGAR 4.1 database developed by PBL. For projections of future non-CO2 emissions and for allocation of different sources to activities by the different economic sectors the model uses information provided by the United States Environmental Protection Agency.

3.1.2 How is the model used to make projections?

ENV-Linkages uses a complex approach for its projections. Unlike models which assume that the economy is on a steady-state growth path, it is able to produce more realistic patterns of the major variables over the model horizon.

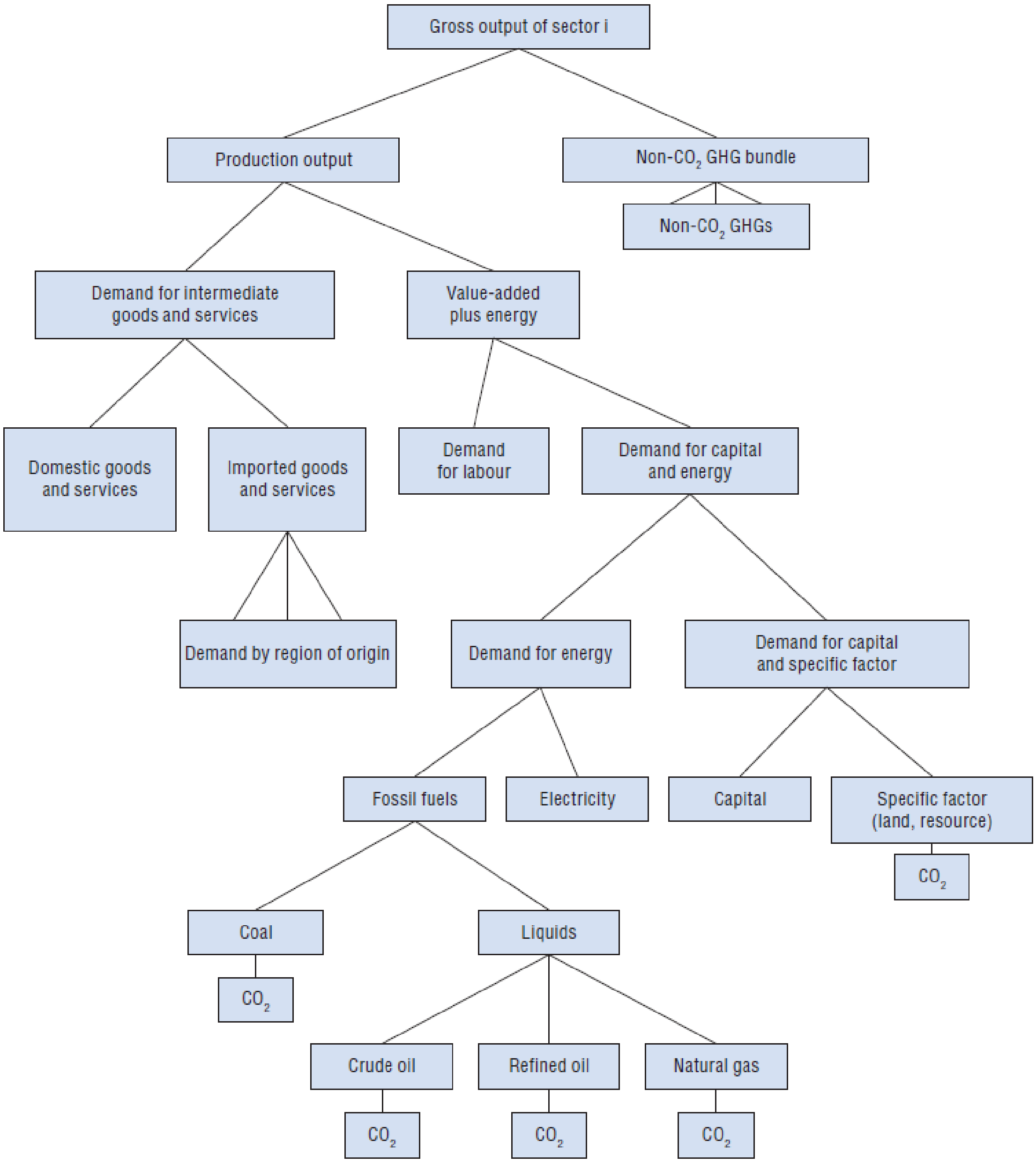
The process of calibrating the ENV-Linkages model is broken down into three stages (cf. Chateau et al., 2012):

i. A number of parameters are calibrated to represent the data for 2004 as an initial economic equilibrium. This process is referred to as the static calibration.
ii. The 2004 database is updated to 2007 by simulating the model dynamically to match historical trends over this period. Price levels are further adjusted such that all values in the model reflect 2010 real USD using purchasing power parities provided by the IMF.
iii. The Baseline projection for the model horizon 2008-2050 is based on conditional convergence assumptions about labour productivity and other socio-economic drivers (demographic trends, future trends in energy prices and energy efficiency improvements; see Duval and de la Maissonneuve, 2009). These convergence assumptions are used to identify the evolution of key economic and environmental variables.
iv. The Baseline projection is then obtained by running the model dynamically over the period 2007-2050, keeping these key variables exogenous but letting the model parameters adjust endogenously. Thus, the model parameters are calibrated using the structural relations of the model (production functions, household preferences, etc.) to mimic the evolution of the key variables over time. It should be emphasised that when the policy simulations are performed on this calibrated baseline, the model parameters are exogenously fixed, while the model variables are fully endogenous. For instance, while GDP is exogenous in the Baseline projection, it becomes fully endogenous in policy simulations.

The Baseline has been adjusted to incorporate the effects of the economic crisis of 2008-2009 and medium-term projections made by the World Bank (2010), IMF (2010) and OECD (2010). Note that while the Baseline assumes no new policies for the environmental issues mentioned in this paper, it does include the energy policies listed in the reference (current policies) energy projections of the IEA (2009a&b; 2010b). It also assumes that the EU Emission Trading System (EU-ETS) is implemented between 2006 and 2012, with a permit price that would rise gradually from 5 to 25 constant USD by 2012 and is not extended thereafter.[5]

[5] Note that all policy simulations carried out assume continuation of the EU-ETS until 2020. This way, the costs of the policies are explicitly represented in the simulations.

Figure 1: Stylised structure of production in ENV-Linkages



3.2 Material Baseline

ENV-Linkages is primarily based on the GTAP economic database, with several extensions for specific model elements, such as energy data from IEA, agricultural data from IFPRI, and modules that have been developed in-house for e.g. damages from climate change and outdoor air pollution.

Given the relatively high level of aggregation of the GTAP database, the only relevant sector to separate in the model is Wood Products ("Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials"), but it remains to be seen whether this is a high priority.

Using external data, the Other Mining sector, in GTAP comprising the aggregate of "Mining of uranium and thorium ores", "Mining of metal ores", and "Other mining and quarrying", could be split between various metals (e.g. copper) and materials; similarly, recycling and waste management activities should be identified (see below). One more potential disaggregation is in livestock: ruminants and non-ruminants have very different biomass profiles.

The desired disaggregation of regions depends on the materials that are covered and whether the analysis will focus on resource rents for large exporters or more on materials use. Although not all materials come from mining, some preliminary insights can be gained by looking at the largest producers of Other Mining in 2011 in the GTAP9 database (see Table 3, in bold the regions that are separated in the ENV-Linkages 25-region aggregation). Of course, for specific materials the main source countries could be very different, so this is just a first indication.

Table 3: Largest producers of Other Mining in GTAP 9

	Country	Value		Country	Value
1	**CHN**	276972	11	**IND**	20875
2	AUS	117747	12	PER	20210
3	**BRA**	76779	13	XNF*	20083
4	**USA**	48718	14	**ZAF**	15410
5	**IDN**	33108	15	BEL	13481
6	**CHL**	32971	16	TUR	12212
7	HKG	28483	17	**JPN**	11728
8	**CAN**	27917	18	DEU	11184
9	**RUS**	24174	19	KAZ	11061
10	**MEX**	23468	20	FRA	10303

Note: XNF comprises Algeria, Libya and Western Sahara. The high value for Hong Kong is an artefact of the database construction.

3.3 Base year linking of economic and material flows

The material flow data (in kilotonnes) need to be linked to the economic data in ENV-Linkages (in USD). This can be done by mapping each material to the most relevant economic activity, using different fixed coefficients per subsector:

1) Biomass: input from all agricultural sectors, incl. fisheries and forestry, in all sectors (incl. between agricultural sectors);
2) Fossil fuels: input of coal, crude oil and gas sectors in all sectors;
3) Metal ores:
   a) Iron ore: Other Mining input in Iron & Steel;
   b) Non-ferrous metals: Other Mining input in Non-metallic minerals;
4) Minerals:
   a) First step: Other Mining input in all sectors except Iron & Steel and Non-metallic minerals;
   b) Second step: separate materials used in chemical and construction industries;
5) Domestic Materials Consumption equals sum of 1) through 4).

Water is usually not considered as a material, but we could add a water use indicator.

3.4 Dynamic calibration of the baseline

As a first approximation, a fixed link between economic flows and material flows can be assumed, i.e. the evolution of the economic flows represents all technological progress. The review of existing studies could provide insights into whether we should specify some autonomous efficiency improvements in resource use, beyond what is already there in the model through the specification of the economic flows.

Secondly, baseline provision of secondary materials, e.g. through the specification of recycling rates, need to be specified for all materials; these should resemble a continuation of current policies, but no new policies.

To highlight uncertainties related to dynamic projections of resource use, multiple baselines will have to be specified; these can perhaps build on the SSPs that are used in climate change modelling.

3.5 Modelling secondary materials use, waste and recycling

In GTAP, secondary materials are mostly the input of Other Manufacturing (which includes recycling) into manufacturing. Similarly, all waste handling activities are captured under Non-commercial services.

Godzinski (2015) describes an economic representation of waste and recycling in a CGE modelling context that could provide a useful starting point. In his approach, a new Waste & Recycling (WRC) sector is specified. External data is required to specify a production function for this new sector. The new sector WRC provides two outputs: (i) secondary materials, and (ii) disposed waste (potentially split in landfilling and incineration). The production function for materials users is then changed as follows: the input of the economic flow representing (virgin) material use gets a separate nest in the production function, with a CES function between virgin and secondary materials use; the substitution elasticity can be varied in the analysis. Current and externally projected recycling rates can be used to specify the base shares of virgin and secondary materials.

Further attention needs to be paid to how the flows of materials into the new WRC sector are specified and linked to the economic activities in the model.

Finally, one should also consider how to specify resource efficiency improvements. This requires probably some heroic assumptions, but might build on the information on energy efficiency from the IEA and on the EXIOMOD model of TNO, who specify a government policy cost for reducing material intensities due to command and control and information policies.

4 Results

4.1 Baseline: key trends

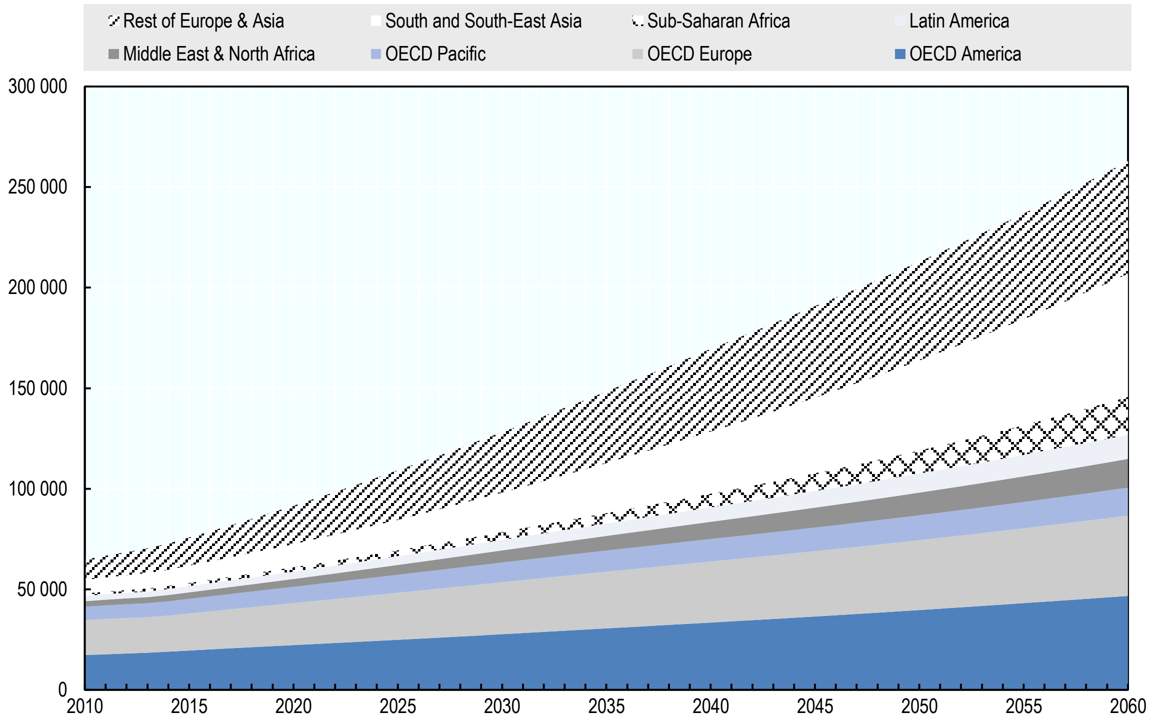
Based on the methodology presented in the Environmental Outlook to 2050 (OECD 2012), this section explores how global and regional economic growth, population, labour force participation, urbanisation, energy and land use could develop by 2050 if no new policies are introduced. The overall finding is that the Baseline scenario (i.e. business as usual) is not a viable pathway for future development, as it leads to substantial environmental pressure and considerable costs.

As shown in Figure 2, World gross domestic product (GDP) is projected to nearly quadruple over the coming four decades, in line with the past 40 years. By 2050, the OECD’s share of the global economy is projected to decline from 54% in 2010 to less than 32%, while the share of Brazil, Russia, India, Indonesia, China and South Africa (the BRIICS) is projected to grow to more than 40%. The US economy, which has been the largest in the world, as measured by GDP and expressed in purchasing power parity exchange rates (PPPs), is projected to be overtaken by China around 2012. India’s GDP is projected to surpass that of the United States before 2040. Today’s global “engines of growth” – China and India – could see their average GDP growth rates slow down to 2050, while remaining well above the average growth rate of the OECD region. The Baseline projects that Africa will experience high economic growth rates between 2030 and 2050, but will remain the poorest continent.

There are significant differences in demographic developments across regions and countries. By 2050, the world population is projected to grow by another 2.2 billion people, reaching almost 9.2 billion. Most of this growth will occur in South Asia, the Middle East and especially Africa. The population profiles of all regions are ageing, especially China and the OECD countries.

Figure 2: Projections for real gross domestic product: Baseline, 2010-2060

Billions of USD, 2010 PPP exchange rates



Source: OECD (2014) for OECD countries and ENV-Linkages model for non-OECD countries.

Populations are becoming increasingly urbanised. By 2050, 2.8 billion more people than today are projected to be living in urban areas, which will contain nearly 70% of the world's population. The rural population is projected to decrease by 0.6 billion. This urbanisation has pros and cons – while a concentrated population might make it generally easier to supply with modern energy and water infrastructure, levels of exposure to outdoor air pollution will be higher and could worsen environmental conditions in slums, with serious consequences for human health.

Under the Baseline scenario, world energy demand in 2050 is projected to be about 80% higher than today. The 2050 global (commercial) energy mix is not projected to differ significantly from today's, with fossil fuels still providing about 85%, renewable sources (including biofuels, but not traditional biomass) providing just above 10%, and the remainder provided by nuclear. Of fossil fuels, it is uncertain whether coal or gas will be the main source of increased energy supply.

Globally, the area of agricultural land is projected to expand in the next decade to match the increase in food demand from a growing population, intensifying competition for land. Agricultural land is expected to peak before 2030 and decline thereafter, as population growth slows down and yield improvements continue. Deforestation rates are already declining, and this trend is projected to continue, especially after 2030 when demand for more agricultural land eases.

This section describes the main socio-economic drivers of environmental change that underlie the key environmental concerns of this paper: economic growth, demographic changes, labour force participation, urbanisation, energy and material content. All these drivers have been modelled under the business-as-usual Baseline scenario to see how they might develop by 2050 if no new policies are put in place. This section starts by describing current demographic trends and the Baseline projections (notably population growth/composition and urbanisation). It then outlines economic trends and projections. These trends are based upon a gradual convergence of income levels among countries. Then, its final sections explore two factors which directly link economic trends to environmental pressures: energy use and material content.

The Baseline projection presented here implies severe environmental pressures. As will be discussed, these pressures pose important risks and expected costs that could erode the natural capital base upon which economic growth is built. For this reason, the Baseline cannot be considered to be a viable pathway for future development. Although the nature of these impacts is beset with uncertainty, the implications of not taking action to address the environmental pressures, and failing to account for the environmental consequences of economic activities, are potentially very large. OECD (2008a) provides an overview of the cost of inaction on key environmental challenges, including climate change, water pollution and environment-related health issues. Essential insights from that overview include the following: i) "defining and measuring the cost of inaction is complex", especially for intangible environmental impacts; and ii) "despite the measurement difficulties, existing literature suggests very strongly that the costs of policy inaction in selected environmental areas can be considerable".

4.2 Demographic developments

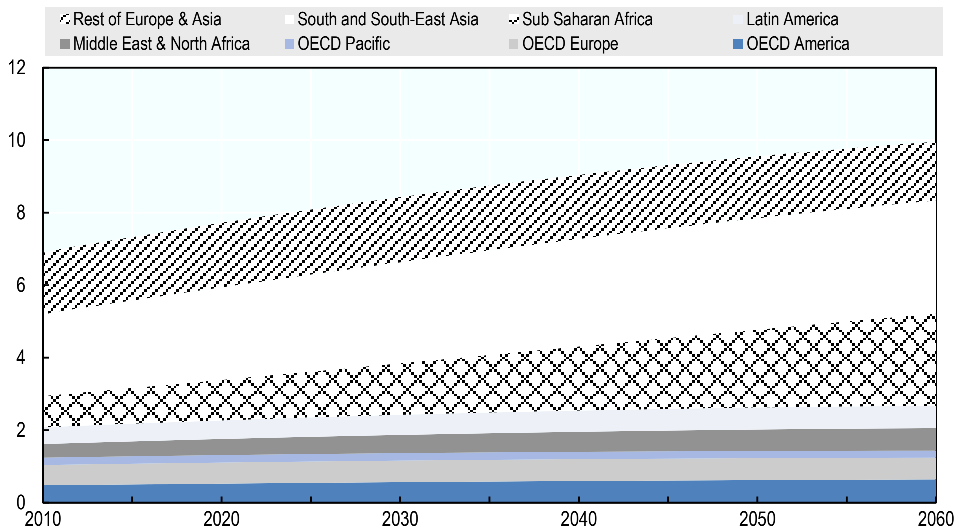
Population dynamics are key drivers of local and global environmental change. Growing populations lead to increases in the consumption of natural resources and in land use, posing additional environmental pressures. Changes in wealth and age structure also modify lifestyle, consumption habits and diet, all of which can have consequences for the environment. The proportion of elderly versus young people in a population also affects the labour market, which is one of the main drivers of economic growth – along with technological progress, human capital improvements and physical capital accumulation. This section outlines how some of these factors are projected to develop to 2050 under the Baseline scenario.

4.2.1 Population growth and composition

The world's population has increased from less than 4 billion in 1970 to 7 billion today (Figure 3). By 2050, the United Nations projects global population to be almost 9.2 billion – an additional 2.2 billion people.

Figure 3: World population by major regions, 1970-2060

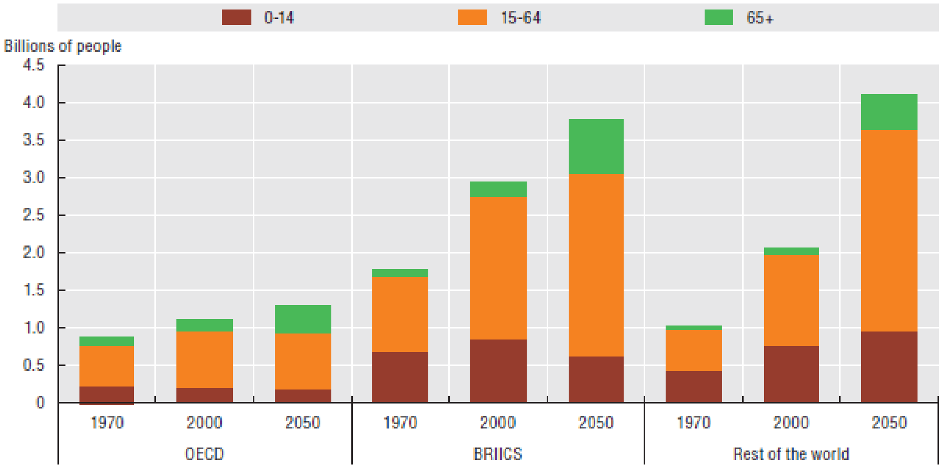
Billion people



Source: UN (2013) as used in the ENV-Linkages model.

There are significant regional and country differences in the projected demographic developments to 2050. Population growth rates are assumed to be low in the OECD countries (0.2% per year between 2010 and 2050, on average), with population even falling in Japan, Korea and some European countries. However, in countries like the United States and Canada, immigration is projected to continue to increase population levels. For the "BRIICS" countries (Brazil, Russia, India, Indonesia, China and South Africa), population is projected to grow at 0.4% per year on average, although growth rates are likely to be higher in India, while Russia's growth looks to be negative. Most of the population growth (on average +1.3% per year) in the coming decades is projected to take place in the non-BRIICS or developing countries ("Rest of the World" or RoW group). Within this group, growth rates are projected to be higher in Africa and South Asia than in Latin America.

Figure 4 illustrates how the population in OECD countries has aged since 1970: the share of children in the total population has steadily declined, while the share of elderly people has increased. Recent trends in fertility rates and life expectancy suggest that similar patterns are appearing in Russia and China. According to the UN (2009) projections, population ageing will only become prominent in the RoW group after 2030. Ageing implies changes in lifestyle and consumption patterns, and diminishes the labour force (see below, Figure 7). Ageing also has implications for health care and other services. In general, these trends lead to a more than proportional increase in the demand for such services (see also the section on the sectoral structure of the economy below).



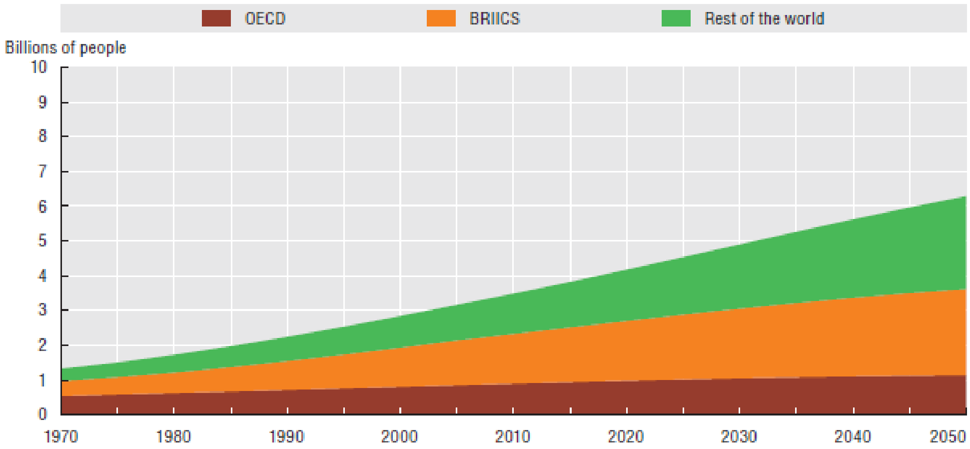
Source: Based on UN (2009), *World Population Prospects: The 2008 Revision*, UN, New York.
StatLink http://dx.doi.org/10.1787/888932570107

Figure 4: World population by age class, 1970-2050

4.2.2 Urbanisation

The world's population is becoming increasingly urbanised (Figure 5). In 1970, 1.3 billion people, or 36% of the world population, lived in urban areas. By 2009 that share had reached 50%. This trend is expected to continue in the coming decades, reaching nearly 70% in 2050 (UN, 2010). The increase in absolute numbers to 2050 is 2.8 billion, which implies that the total world population growth between 2010 and 2050 (more than 2.2 billion people) would be completely absorbed by urban areas. Rural population is projected to decrease by 0.6 billion people over the same period. This growth in urban population is expected to be unevenly distributed around the world. The share of urban population in OECD countries is projected to be about 86% of total population by 2050. In Sub-Saharan Africa, one of the least urbanised regions, urban dwellers accounted for about 37% of total population in 2010 – however, their share is projected to reach 60% by 2050.

Figure 5: Urban population by region, 1970-2050



Source: Based on UN (2010), *World Urbanization Prospects: The 2009 Revision*, UN, New York.

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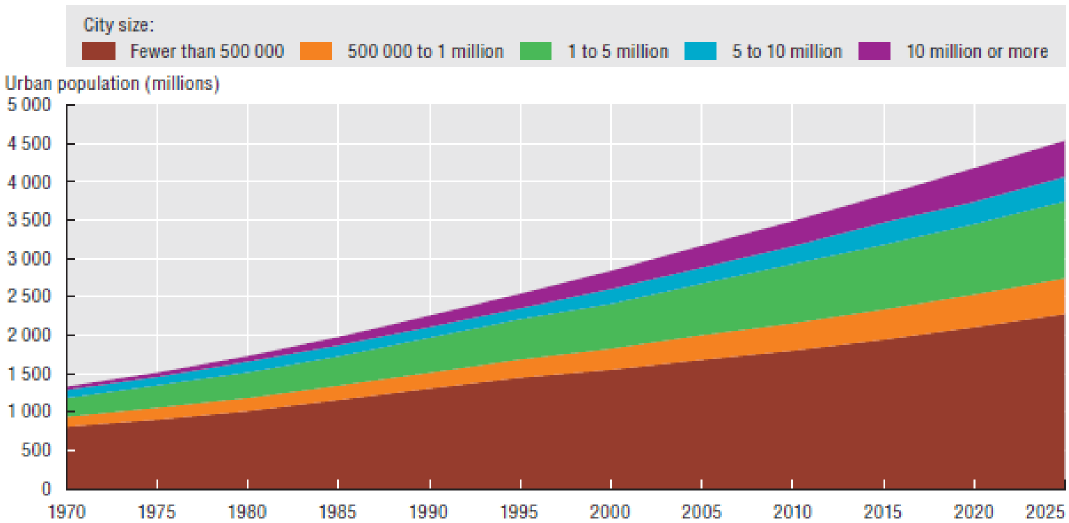
Small urban centres of less than 0.5 million inhabitants are projected to grow more rapidly than other urban areas (Figure 6). This would be a change from the observed trend in recent decades, when large mega-cities grew at the fastest rates (UN Habitat, 2006).

Figure 6: World urban population by city size, 1970-2025



Source: UN (2010), *World Urbanization Prospects: The 2009 Revision*, UN, New York.

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Urbanisation has both positive and negative environmental consequences. On the positive side, up to a certain level, the concentration of activities in urban areas can allow for economies of scale and easier interactions, meaning that urbanisation can lead to higher economic growth. Higher concentrations of people generally make it easier to provide access to modern and efficient infrastructure for the delivery of energy and water services. On the negative side, a greater concentration of economic activities can also cause higher levels of outdoor air pollution (Chapter 6, OECD 2012). Urbanisation also requires adapted transportation policies to avoid major complications in the transport system, and negative environmental implications can result from traffic congestion. Furthermore, one in every three city dwellers worldwide – about one billion people – lives in a slum (UN Habitat, 2003 and 2006). Urban slums – with substandard housing and inadequate water, sanitation and waste management services – have negative consequences for human health and the environment. This could become magnified with further urbanisation unless more ambitious urban development and environmental management policies are put in place. This is especially so as the number of people living in slums could well grow, despite the projected increase in average GDP levels.

4.3 Economic growth

Economic growth and rising per capita income, if based on the increased use of natural resources, may exacerbate pressures on the environment. But other sources of growth, such as technological progress (innovation) or improvements in education and human skills, can decouple environmental pressures from economic growth. This section discusses the degree to which the global economy will grow over the next four decades, the drivers of this growth and the implications.

4.3.1 How and where will the global economy grow to 2050?

Table 4: Economic growth over selected periods by region

Average annual percentage GDP growth rates

		2010-20	2020-40	2040-60
OECD America				
	Canada	2.2	2.0	1.9
	Chile	4.7	2.4	1.4
	Mexico	3.6	3.4	2.5
	USA	2.4	1.9	1.5
OECD Europe				
	EU large 4	1.5	1.6	1.3
	Other OECD EU	1.9	2.0	1.3
	Other OECD	3.6	2.6	1.7
OECD Pacific				
	Aus. & NewZ.	3.2	2.6	2.1
	Japan	0.9	1.0	1.1
	Korea	4.0	2.3	0.6
OECD		2.2	1.9	1.5

		2010-20	2020-40	2040-60
Rest of Europe and Asia				
	China	7.6	4.2	1.6
	Non-OECD EU	2.2	2.5	1.7
	Russia	3.6	2.1	0.9
	Caspian region	6.3	4.8	2.6
	Other Europe	2.4	3.3	2.0
Latin America				
	Brazil	3.3	3.0	1.8
	Other Lat.Am.	3.6	3.7	3.1
Middle East & North Africa				
	Middle East	3.4	3.7	2.3
	North Africa	3.9	4.9	3.2
South and South-East Asia				
	ASEAN 9	4.8	4.2	3.1
	Indonesia	6.1	4.6	3.3
	India	6.6	5.8	3.6
	Other Asia	4.2	4.2	3.7
Sub-Saharan Africa				
	South Africa	4.9	4.2	1.9
	Other Africa	5.9	6.5	6.0
World		3.5	3.1	2.2

Source: OECD (2014) for OECD countries and ENV-Linkages model for non-OECD countries.

The global economy, measured by real gross domestic product (GDP), has roughly tripled in the past four decades.[6] In the coming decades, world economic growth is likely to continue these historical trends, but the distribution of this growth across countries is projected to differ significantly (Table 4).

[6] While GDP is an adequate measure of economic activity, it is not a good indicator of welfare (Stiglitz et al., 2009).

Until the end of the 20th century, OECD countries accounted for the lion's share of global economic activity and per capita GDP levels were much higher than in the other regions. More recently, per capita GDP has increased rapidly in the BRIICS region, with an average growth rate of 5.4% between 1990 and 2008; more than three times the rate of the OECD region. The fast growth in the BRIICS has gradually shifted the relative regional weights in the global economy. By 2050, the share of global economic activity attributable to the BRIICS is projected to rise to more than 40%. By 2050, the OECD's share of the global economy is projected to decline from 54% in 2010 to less than 32%.[7] The US economy, which has been the largest in the world as measured by GDP and expressed in purchasing power parity exchange rates (PPPs), is projected to be overtaken by China around 2012. India's GDP is projected to surpass that of the United States before 2040. In nominal terms, however, GDP levels remain highest in the United States (Chateau et al., 2011).

Table 5: Annual average real GDP growth rates: Baseline, 2010-2050

Based on constant 2010 USD

	2010-2020	2020-2030	2030-2050	2010-2050
	%			
Canada	2.5	2.3	2.1	2.2
Japan and Korea	2.1	1.6	1.0	1.4
Oceania	2.8	2.4	2.2	2.4
Russia	3.0	2.8	2.2	2.6
US	2.2	2.3	2.1	2.2
EU27 and EFTA	2.1	2.0	1.7	1.9
Rest of Europe	4.7	5.0	3.6	4.2
Brazil	3.7	4.0	3.2	3.5
China	7.2	4.2	3.0	4.3
Indonesia	5.0	4.5	4.2	4.5
India	7.3	6.2	4.8	5.7
Middle East and North Africa	4.1	4.6	4.1	4.2
Mexico	4.5	3.6	2.9	3.5
South Africa	4.2	3.8	3.3	3.6
Rest of the world	4.4	4.5	4.5	4.5
OECD	**2.3**	**2.2**	**1.9**	**2.0**
BRIICS	**6.4**	**4.5**	**3.5**	**4.5**
World	**4.1**	**3.6**	**3.1**	**3.5**

Note: See Table 1.3 in Chapter 1 for a description of the ENV-Linkages model country groupings used in this *Outlook*.
Source: OECD Environmental Outlook Baseline; output from ENV-Linkages.
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The 2008 financial crisis led to a global economic recession in 2009 and uncertain prospects for the coming years. A modest recovery in OECD countries, combined with near double-digit growth in some of the major emerging economies – especially China and India – pulled the global economy back to a growth rate of just below 5% in 2010. However, the Baseline projections do not account for future shocks like these; they present the long-term trend rather than short-term forecasts. Short-term projections for growth remain highly uncertain.

The world real GDP (measured in constant 2010 USD) is projected to grow on average by about 3.5% per year from 2010 to 2050 (Table 5). This implies that world GDP would be multiplied almost fourfold over the period. This is similar to the past (1970-2008) average world GDP growth rate (expressed in 1990 USD), of close to 3.6% (Madison, 2010).

7 Estimates of regional shares in global GDP depend crucially on the use of exchange rates. Here GDP aggregates are valued using constant 2010 purchasing power parity (PPP) exchange rates as presented in IMF (2010). As in recent years the US dollar has depreciated against most currencies, using older exchange rates would imply higher shares of both the US and the OECD aggregate. See Chateau et al. (2011) for a further discussion.

China and India have been important engines of global economic growth in recent years, but their growth rates are projected to slow down in the coming decades as their underlying drivers of growth (including capital supply and human capital improvements from better education) converge towards those of OECD countries. The expected slowdown is also due to underlying demographic changes – for example, ageing is a prominent factor in China. While the projected absolute size of the Chinese economy is still largest, its growth rate is projected to be surpassed by those of other Asian countries, such as India and Indonesia (Table 5).

The highest growth rate (of around 6% annually) between 2030 and 2050 is projected for Sub-Saharan Africa (part of the Rest of the World region), although in absolute terms it will remain the poorest continent at the end of the projection period. OECD economies are projected to grow at a much slower pace through to 2050, with most of them growing at around 2% per year on average.

In recent decades, per capita income levels have increased on average in almost all regions of the world. This increase has not been evenly spread across the different regions, with per capita GDP levels increasing twice as fast in the BRIICS (3.4% annually between 1970 and 2009) as in the other regions (1.9% in the OECD and 1.6% in the rest of the world, respectively). By 2050, however, US per capita GDP is still projected to rank first, almost double that of China. Household per capita consumption shows similar differences across regions and countries (Table 6).

Table 6: Annual per capita GDP and household consumption: Baseline 2010-2050

Thousands constant 2010 USD/person

	GDP per capita			Consumption per capita		
	2010	2020	2050	2010	2020	2050
Canada	36.9	43.0	68.2	22.1	25.4	39.9
Japan and Korea	31.9	39.8	67.3	18.0	23.0	41.8
Oceania	27.8	32.5	50.0	17.9	20.5	31.6
Russia	15.2	21.1	49.6	9.9	15.3	35.9
US	45.7	52.3	85.3	32.3	37.1	56.6
EU27 and EFTA	30.2	36.4	63.5	18.0	21.9	39.6
Rest of Europe	10.7	16.4	53.5	7.1	10.1	31.0
Brazil	11.6	15.6	41.7	7.2	9.5	23.7
China	9.4	17.9	48.8	3.4	7.0	27.1
Indonesia	5.1	7.6	23.6	3.5	5.1	13.0
India	3.9	7.0	27.5	2.3	3.8	13.8
Middle East and North Africa	11.1	14.2	37.5	7.1	9.6	23.7
Mexico	13.2	18.9	44.3	9.5	13.1	25.8
South Africa	10.4	15.0	38.4	7.1	10.1	25.0
Rest of the world	3.9	5.0	13.3	2.6	3.4	8.3
OECD	**33.1**	**39.7**	**68.5**	**21.2**	**25.5**	**43.5**
BRIICS	**7.5**	**12.9**	**37.3**	**3.6**	**6.2**	**20.5**
World	**11.1**	**15.0**	**33.2**	**6.6**	**8.7**	**19.7**

Note: Valued using constant 2010 purchasing power parity (PPP) exchange rates.
Source: *OECD Environmental Outlook Baseline*; output from ENV-Linkages.
StatLink http://dx.doi.org/10.1787/888932571893

4.3.2 What drives economic growth?

Economic growth, or more precisely growth of GDP, is driven by i) increasing the value added of production through the increased use of capital, labour and natural resources (including land); ii) increasing the productivity of these primary production factors; and iii) reallocating production factors to those activities that yield the highest value added. Labour input (employment) is in turn driven by demographic developments, which combine population, age structure, labour market participation and unemployment scenarios.

The Baseline projects that between 2010 and 2030, GDP growth is largely driven by the increased use of physical capital (such as buildings, machines and infrastructure), which boosts economic activity especially in the emerging economies.[8] As physical capital and energy use mostly go together in production processes, this type of growth implies substantial increases in energy demand in the near future (see the section on energy below).

In the longer run, the baseline projections foresee a slow transition towards more balanced growth in all major economies, with growth partially converging across economies and physical capital accumulation and human capital contributing more equally to GDP growth. Countries that are further behind in terms of education (which contributes to human capital) and physical capital levels are projected to experience higher growth rates during the catch-up phase, as explained in Box 1. Such projections are uncertain and depend on several assumptions, especially about the institutional capacity for development. The catch-up effect results in a growing contribution by human capital to long-term GDP growth, partly limiting increases in environmental pressure (decoupling environment from economic growth). However, to achieve these increases in human capital development, it will be essential that education and training policies build workers' knowledge and skills.

Box 1: The conditional convergence methodology:

Assumptions for model-based projections

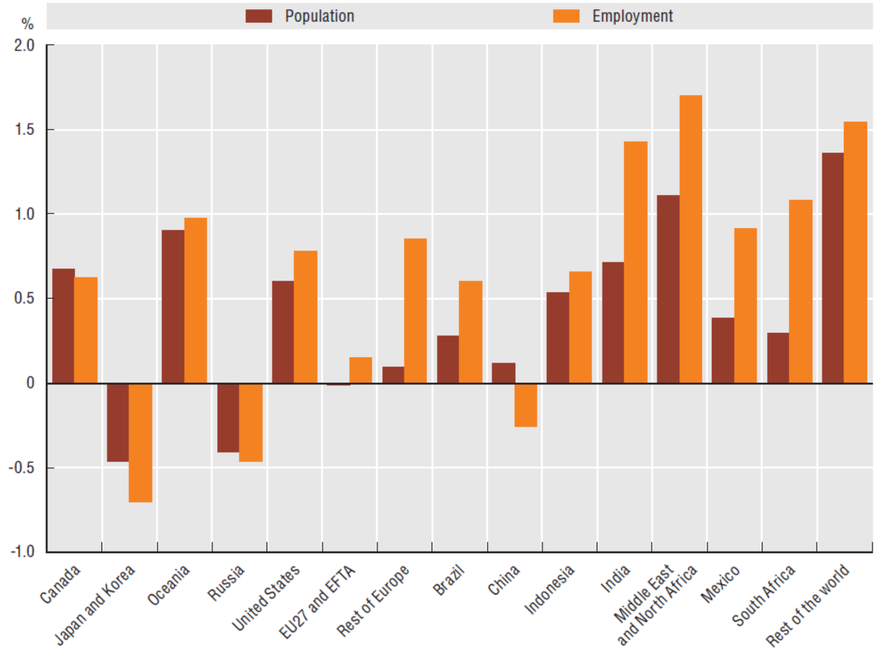
Baseline economic scenarios underlying global environmental economic projections – such as those developed for the Intergovernmental Panel on Climate Change (IPCC, 2007) – typically assume that globally, income levels will gradually converge towards those of most developed economies. This baseline projection takes a similar approach, though placing special emphasis on the drivers of GDP growth over the projection period rather than projecting convergence only on income levels (Duval and de la Maisonneuve, 2010). Based on this, long-term projections are made for five main drivers of per capita economic growth: i) total factor productivity; ii) human capital (which drives labour productivity); iii) capital-to-output ratios; iv) population, age structure, participation and unemployment scenarios (which together drive employment levels); and v) natural resource availability. Gradual convergence of regions towards the best performing

While the labour force is ultimately constrained by population, differences between growth rates in population and employment can nevertheless persist over many years, reflecting changes in demographics, labour force participation trends and unemployment projections. The average annual growth rate of population is compared to that of employment in Figure 7. Continued ageing of the population is projected in many OECD countries, and also in China and some other emerging economies. This is related to lower labour participation rates. However, the much younger population profiles in many developing countries, especially in Africa and Asia, imply that the share of working-age people will increase over time, thereby boosting labour supply. This also holds for India, although this trend is combined with an increased share of elderly people.

International trade also affects economic growth, and is projected to continue to outpace GDP growth. But the existing current account imbalances seem untenable over the long run as they put pressure on exchange rates. Therefore, this baseline projects a gradual reduction of current account balances over time. For most regions, the current account is projected to balance by 2050, but larger imbalances for China and the United States will require longer to fully fade.

[8] Although short-term cycles in economic activity are not considered in the projections presented in **Error! Reference source not found.**, developments for 2010-2015 are based on short-term projections by IMF (2010), the World Bank (2010) and the OECD.

Figure 7: Average annual population and employment growth rates, 2010-2050



Sources: Population: UN (United Nations) (2009), *World Population Prospects: The 2008 Revision*, UN, New York. Employment: *OECD Environmental Outlook Baseline*, output from ENV-Linkages.

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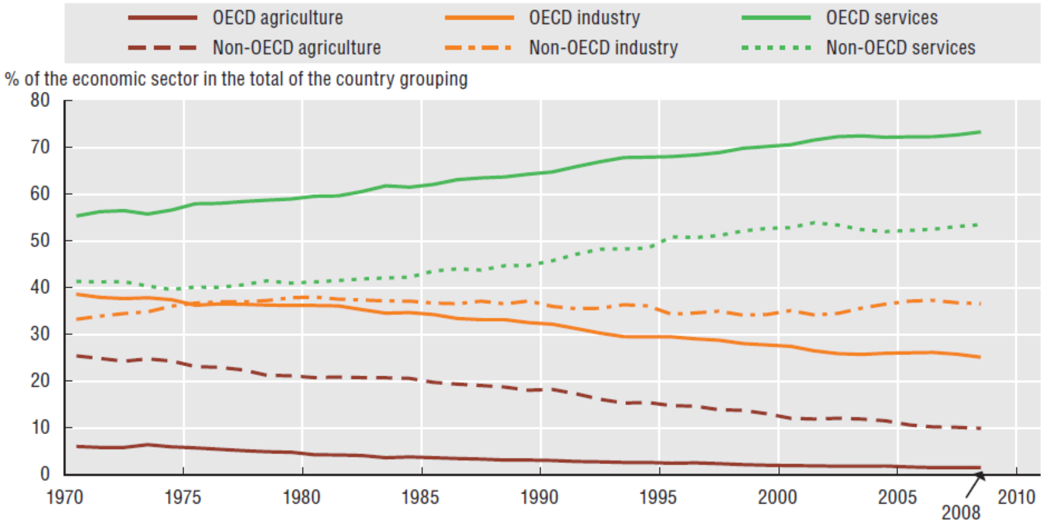
4.3.3 How will the structure of the economy change?

The sectoral composition of the different regions has shifted over time, with the service sector contributing a growing share (Figure 8). This increasing share of services in value terms results from an increase in their production cost relative to other goods, but also reflects a structural shift towards a more services-oriented economy. This structural change is in part driven by the evolution of household consumption patterns. Demand for services, including health care services, increases as the average person gets older and wealthier. It is also to some extent driven by growing use of research and development (R&D) and services in industrial production. There have obviously been significant shifts within these large sectoral groupings. The types of services provided nowadays are quite distinct from those 40 years ago, for instance through the emergence of information and communications as a sector.

Figure 8: Global trends in the proportion of value added by sector, 1970-2008



Note: The aggregate category of "industry" encompasses all manufacturing sectors.

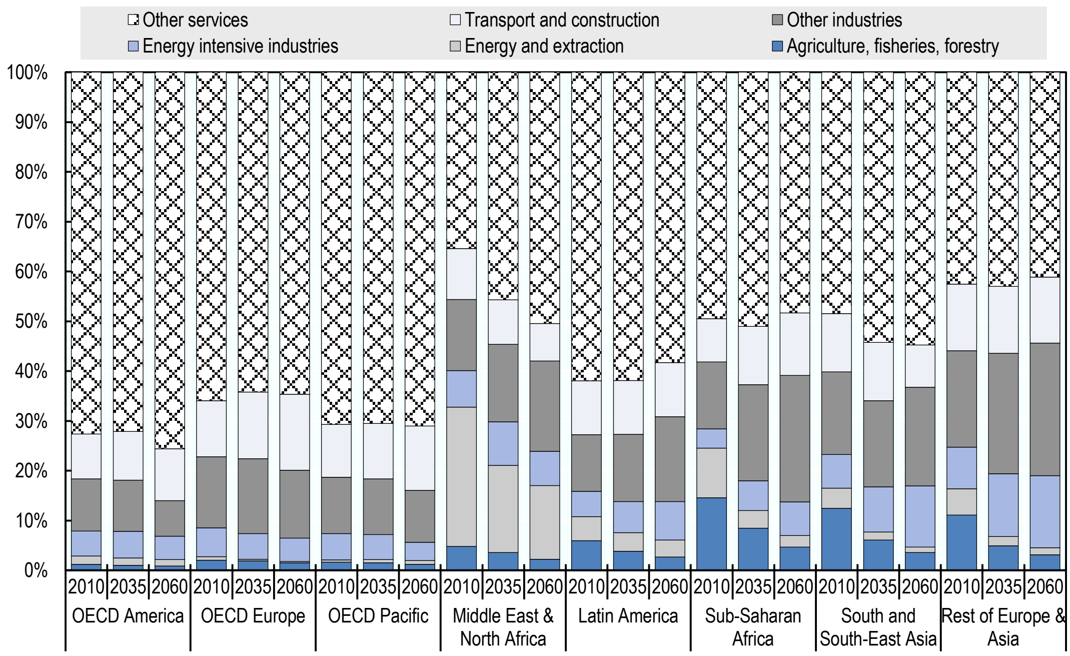
Source: OECD calculations based on World Bank (2010), *World Development Indicators*, World Bank, Washington, DC, *http://data.worldbank.org/data-catalog/world-development-indicators*.

StatLink http://dx.doi.org/10.1787/888932570221

The Baseline projects that this structural shift towards a more services-oriented economy will level off in OECD countries by 2050. As indicated in Figure 9, sector shares in real terms (i.e. relative price effects are excluded) are more or less stable over time. According to the assumption of economic convergence, the service sectors in developing countries are projected to contribute a growing share to the global economy, while the share of the agricultural sector diminishes. These trends fit with the global shift towards more labour-driven economic growth. The declining share of agriculture does not imply that absolute levels of food production will decrease, but merely that it grows less quickly than other sectors in the economy. To feed a growing population, global food production needs to continue to grow, thereby leading to increases in demand for agricultural land.

Figure 9: Share of sectors in real GDP by region: Baseline, 2010-2050

Percentage of GDP, 2010, 2035 and 2060



Source: ENV-Linkages model.

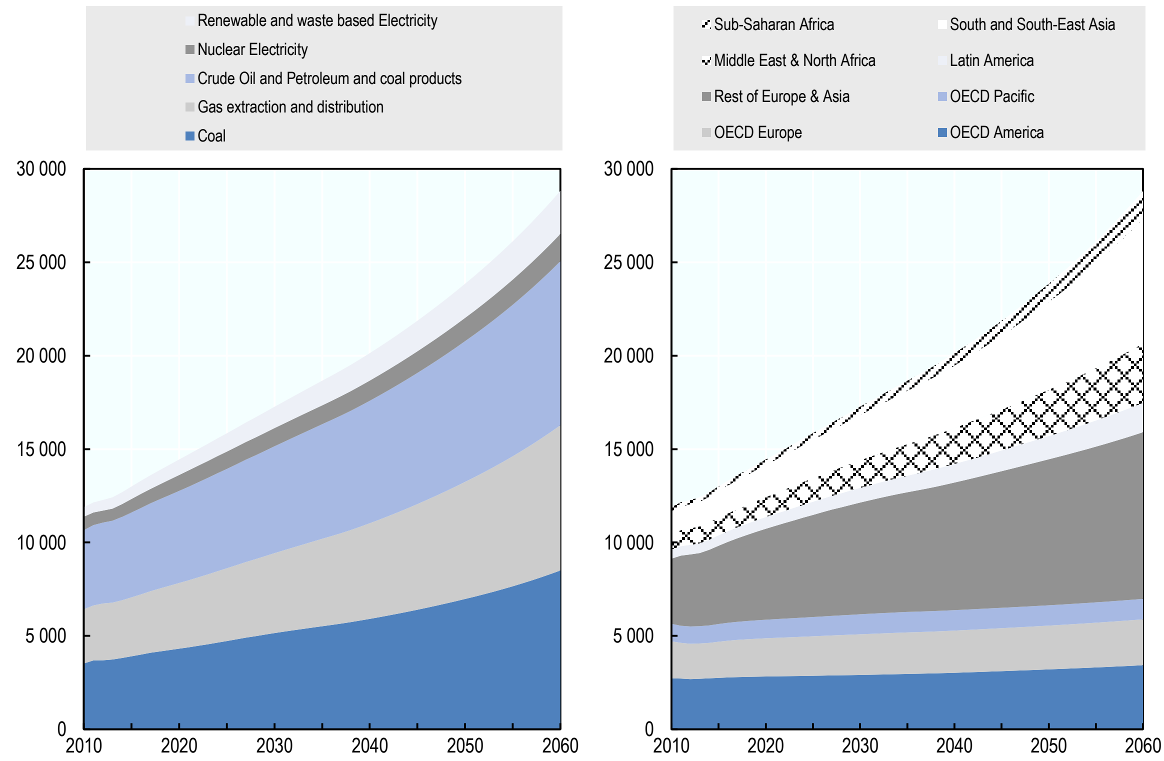
4.4 Baseline projection: energy

Energy use is essentially driven by economic activity and technological developments, including energy efficiency improvements. Energy consumption patterns differ widely across the world. In OECD countries the average person consumes 3 tons of oil equivalent of energy (toe) a year, while in low-income regions, such as most of Africa and parts of Asia and Latin America, the figure is well below 1 toe (IEA, 2011). In 2009, about 1.4 billion people in low-income regions still had no access to electricity, and nearly 2.7 billion people mainly relied on traditional biomass (IEA, 2010).

As GDP is projected to almost quadruple by 2050, total commercial energy use is also projected to grow strongly over the next four decades, reaching about 900 Exajoule (EJ)[9] in 2050 – around an 80% increase over global energy consumption in 2010 (Box 2).[10] Continuous improvements in energy efficiency will reduce overall energy intensity (i.e. the ratio between energy use and GDP) to about 40% lower than current levels in 2050. Climate change (especially CO2 emissions) and health impacts from local air pollution are strongly linked to trends in energy use and production. Figure 10 shows how the Baseline projection on total primary energy use relates to historical trends and the range found in the literature, as reviewed in van Vuuren et al. (2011).

Figure 10: Global primary energy use: Baseline, 1980-2050

Million tonnes of oil equivalent



Source: ENV-Linkages model based on IEA (2014).

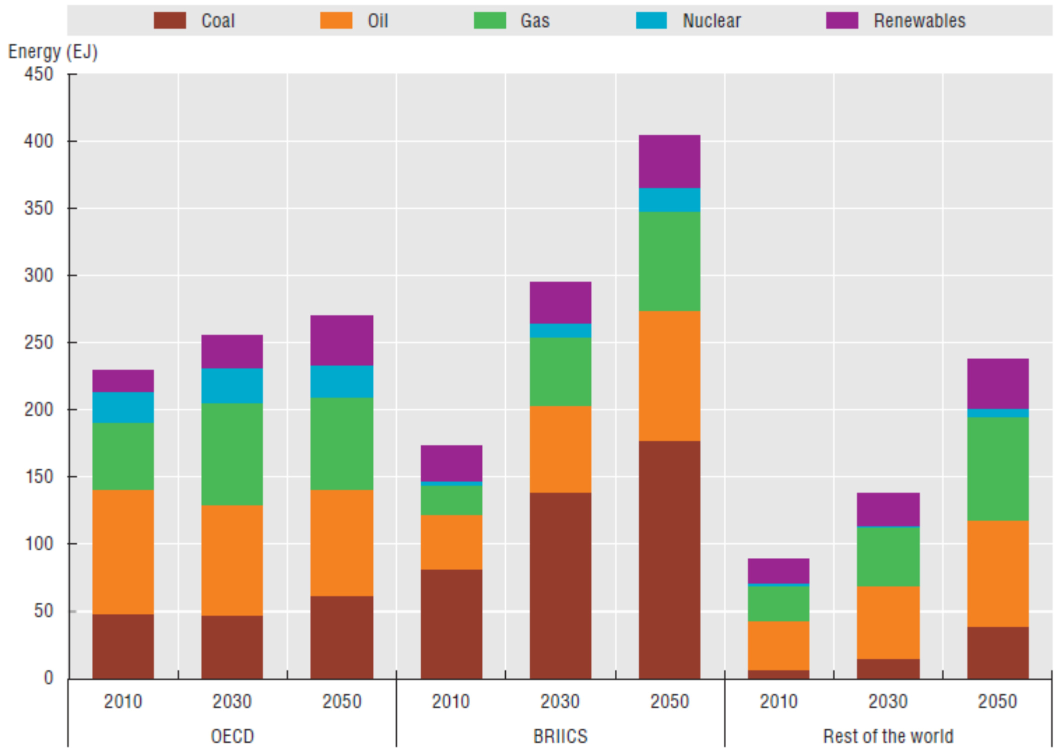
Figure 11 shows how the Baseline projects the different energy sources to change regionally by 2050. Despite the fact that most energy is currently consumed in industrialised countries, emerging and developing countries play a dominant role in energy production worldwide. In 2008, China supplied

[9] 1 Exajoule equals 1 billion Gigajoule, which is roughly equivalent to 23.9 million toe.

[10] There is no widely accepted method for accounting for primary energy use from different energy sources. This graph uses the methodology proposed by the IEA, which assumes a 33% efficiency for nuclear power and 100% for renewable power. Alternative methods may lead to slightly different contributions of nuclear power and renewables to the energy mix.

more than 40% of global coal production and the Middle East and Russia together accounted for almost 40% of oil production and about 35% of natural gas production (IEA, 2011). Consumption growth in the Baseline projection is mainly driven by increasing demand in the BRIICS and some other developing countries. Oil production in Europe, and to a lesser extent in North America,[11] decreases in the Baseline because of the progressive depletion of oil reserves.

Figure 11: Commercial energy production by fuel: Baseline, 2010-2050



Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932570278

The increase in energy consumption in the Baseline scenario is consistent with similar projections by the International Energy Agency (IEA).[12] Assuming no change in current policies, fossil fuels retain a large market share in the Baseline, as their average prices remain lower than those of alternative fuels in most countries. Annual average growth rates of consumption are projected to be in the order of 0.5% for oil and 1.8% for coal and natural gas. For oil and natural gas, depletion and resulting price increases around the middle of the 21st century are projected to lead to stabilisation or even a peak in production, which is concentrated in only a few resource-rich regions. For coal, however, resource scarcity is not projected to limit production, or even lead to price increases, in the foreseeable future. With strong economic growth in coal-rich regions, it is likely that the share of coal in the energy mix will further increase. At the same time, non-fossil energy production, including commercial biomass and other renewables, will increase steadily.

[11] The decrease in North America occurs in the United States and Mexico. In contrast, Canada is projected to increase oil production, especially from non-conventional sources such as shale oil.

[12] Energy consumption patterns have been calibrated to match those of the IEA projections.

Box 2: Uncertainties in energy projections

There are some key uncertainties surrounding energy projections embedded in the Baseline scenario: i) The development of the energy intensity of the global economy has historically varied between 1%-2%. The assumptions made about this factor will have a major impact on projections of future emissions. The Baseline projects an average annual reduction in energy intensity of 1.3%, which is similar to IEA projections (IEA, 2010).

ii) A major driver of the energy mix is the relative price of different fuels. Given the complex nature of international fuel markets, and the large uncertainties surrounding resources, technology development and fuel prices in the future, this poses a major source of uncertainty in the Baseline projection of this paper.

4.5 Baseline projection: material content

Two main results are expected from this paper. First, the methodological results consists in developing a procedure to represent the circular economy in a global multi-region CGE model and link material use to economic output. The second output is a material-explicit baseline that goes beyond the current economic projections in which at best energy is described.

From these results, the quantification of material use and flows in the projected baseline indicates the critical materials to monitor for supply security as well as greenhouse gas and outdoor air pollutant emissions. Material flows and the relative decoupling from economic activity can be calibrated to historical trends and information in the literature. This allows projections of resource efficiency, growth employment and trade.

5 Conclusion

The model extension and baseline developed in this paper constitute a solid starting point to assess the impact of public policies promoting the transition to a circular economy. The effects of these policies on growth, competitiveness, and employment constitute the cornerstone of the rhetoric advocating for them and can be tested in the developed framework.

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