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**Economic Implications
of the IEA Efficient World
Scenario**

**Jean Château,
Bertrand Magné,
Laura Cozzi**

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ENVIRONMENT DIRECTORATE

**OECD ENVIRONMENT WORKING PAPER No. 64 - ECONOMIC IMPLICATIONS OF THE IEA
EFFICIENT WORLD SCENARIO**

By Jean Chateau (1), Bertrand Magné(1) and Laura Cozzi(2)

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ABSTRACT

In its 2012 edition of the *World Energy Outlook*, the International Energy Agency (IEA) produced an *Efficient World Scenario* (IEA, 2012) to assess how implementing only economically viable energy efficiency measures would affect energy markets, investment and greenhouse emissions (GHG). The IEA analysis found that in order to halve global primary energy demand over 2010-2035, additional investments of USD 11.8 trillion in more efficient end-use technologies would be necessary. Using the OECD ENV-Linkages macro-economic model, this report simulates the economic and environmental impacts which the IEA *Efficient World Scenario* implies.

The core of this analysis draws upon the careful consideration of energy efficiency investments and the induced structural reallocation of primary production factors, across sectors and regions. This analysis also takes into account additional energy and environment policies from the *Efficient World Scenario* (EWS), such as fossil fuel subsidy reform in emerging countries, regional carbon prices, electricity regulations, etc. While the link between energy savings and necessary investments is calibrated, the OECD model simulates the whole panoply of possible economic impacts, such as changes in consumption behaviours, firms' technological choices and international trade flows.

Among the expected benefits, the EWS scenario brings about vast reductions in GHG emissions, primarily (but not solely) due to reduced energy consumption. According to model simulations, achieving the EWS Scenario would imply an increase in global GDP of 1.1% relative to the baseline, in 2035. The scenario would clearly benefit most countries, with the exception of certain energy exporters who would see the demand for their energy decline. In addition to a shift towards more capital-intensive and less energy-intensive technologies, there would also be a significant rise in the demand for domestically-produced services, transport equipment and construction, as these sectors are the main recipients of investments. Such effects will impact countries' relative competitiveness in supplying certain goods or services, and thus lead to changes in regional trade landscapes. Moreover, the EWS Scenario implies some employment reallocations, most notably between sectors in non-OECD economies. The bulk of these employment adjustments would be shifted away from energy intensive industries and towards the service and manufacturing sectors.

JEL Classification: D58, Q43, Q54, E2

Keywords: Computable general equilibrium, energy efficiency, climate change policies, macroeconomics

RÉSUMÉ

Dans son Edition 2012 du « World Energy Outlook », l'Agence Internationale de l'Énergie a élaboré un *Scénario pour un monde plus efficace* (IEA, 2012) visant à déterminer comment des mesures d'efficacité énergétiques viable affecteront les marchés de l'énergie, les investissements et les émissions de gaz à effet de serre (GES). L'analyse de l'IEA indique que pour diminuer de moitié la demande d'énergie primaire sur l'horizon 2010-2035, près de 11.8 trillions USD d'investissement supplémentaires dans les technologies plus efficace en énergie sont nécessaires. Utilisant le modèle ENV-Linkages de l'OCDE, ce rapport détaille les conséquences économiques et environnementales du *Scénario pour un monde plus efficace*.

Le cœur de l'analyse repose sur une étude approfondie et une prise en compte rigoureuse des investissements dédiés aux gains d'efficacité énergétiques, ainsi que les réallocations structurelles des facteurs de production et des autres intrants, qu'ils induisent, entre les secteurs et les pays. Cette analyse tient aussi compte de politiques énergétiques et environnementales supplémentaires, décrites dans le *Scénario pour un monde plus efficace (EWS)*, telles que les réformes des subventions aux énergies fossiles dans les pays en développement, la tarification du carbone dans certaines régions, des régulations dans le secteur électrique,... Ainsi, tandis que le lien entre les gains d'énergie et les investissements correspondants issus des calculs de l'IEA sont calibrés, le modèle de l'OCDE simule une panoplie d'impacts économiques, au travers des modifications dans les comportements de consommation, dans les choix technologiques des entreprises ou dans les flux de commerce international.

Parmi les bénéfices escomptés, le scénario EWS implique de larges réductions des émissions de GES, résultant principalement des économies d'énergie, mais pas seulement. Selon les simulations du modèle, la mise en place de l'EWS impliquerait une hausse de 1.1% du PIB mondial, par rapport au scénario central, à l'horizon 2035. De façon robuste la majorité des pays bénéficierait de cet environnement à l'exception de certains pays producteurs d'énergie fossiles qui verraient se réduire leur balance commerciale. Au-delà du mouvement vers des technologies plus intensives en capital et moins énergivores, se constate une croissance significative des demandes de services, d'équipement de transports et de construction, et ce du fait que ces biens composent la majeure partie des biens d'investissement. L'ensemble de ces effets affecteront les compétitivités relatives des pays, d'un bien à l'autre et devraient de ce fait transformer le panorama des spécialisations de commerce régionales. Enfin le scénario EWS impliquerait des réallocations sectorielles de l'emploi entre les secteurs, principalement dans les économies émergentes. Ces ajustements se feraient en faveur de l'emploi dans les services et l'industrie et au détriment de l'emploi dans les secteurs producteurs d'énergie.

Classification JEL: D58, Q43, Q54, E2

Mots-clés: Équilibre Général Calculable, efficacité énergétique, politiques de changement climatique, macro-économie.

FOREWORD

This report, “Economic Implications of the IEA Efficient World Scenario” results from the collaboration between the OECD Environment Directorate and the International Energy Agency. It has been prepared by Jean Chateau and Bertrand Magné¹, Laura Cozzi². This study details and extends the analysis undertaken for chapter 10 of the IEA's World Energy Outlook 2012 and constitutes a piece of the OECD Environment Directorate project on “Competiveness and Clean Technology Investment.

This document provides a quantitative analysis of implementing an ambitious set of energy efficiency measures, with a focus on implications for the global economy and a more detailed analysis for specific sectors and regions.

The generous financial contribution from the Danish Energy Agency is gratefully acknowledged.

Two versions of this report were presented at meetings of the OECD Working Party on Climate, Investment and Development (WPCID), respectively in December 2012 and April 2013; this working paper has thus benefited from the comments received from delegates.

The report has also benefited from valuable comments on an earlier draft by Lars Brømsøe Termansen of the Danish Energy Agency, Helen Mountford, Shardul Agrawala, Anthony Cox and Rob Dellink of the OECD. Feedback on the presentation of preliminary results from several participants at the IEA “Roundtable on the Macroeconomic and Employment Impacts of Energy Efficiency” held in January 2013 and organised within the IEA project “Capturing the Multiple Benefits of Energy Efficiency” is also appreciated. We would also like to thank participants from the 2013 GTAP international conference held in Shanghai and the IEW international conference in Paris. Finally, the authors would like to thank Elizabeth Corbett and Marie-Jeanne Gaffard, who provided excellent editorial assistance.

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¹ OECD Environment Directorate.

² IEA.

EXECUTIVE SUMMARY

This study sheds light on the global and regional economic implications of an energy efficiency scenario prospect. This *Efficient World Scenario* (EWS) is described in the “World Energy Outlook 2012” report from International Energy Agency (IEA, 2012). Energy efficiency plans have prime importance in a full and ambitious policy package to tackle long term climate challenges effectively (OECD, 2012a, IEA, 2012). Energy efficiency alone contributes half of all emissions savings needed to achieve the IEA *450 Scenario* objective, relative to a *business-as-usual* scenario, thereby paving the way for a long term stabilisation of global average temperature increase to 2°C relative to pre-industrial levels.

The *Efficient World Scenario (EWS)*³ of the “World Energy Outlook (WEO)” was constructed to assess how implementing only economically-viable energy efficiency measures would affect energy markets, energy prices, energy-related investments and emissions. The IEA analysis found that halving global primary energy demand over 2010-2035, primarily in fossil fuel consumption, would require USD 11.8 trillion in additional investments in more efficient end-use technologies. But these dedicated investments would be more than offset by a USD 17.5 trillion reduction in energy fuel expenditures and a USD 5.9 trillion decrease in energy supply infrastructure investments. Energy demand-side savings, from both buildings and industries, would primarily take the form of lower electricity consumption.

The OECD has contributed to the IEA analysis by deriving macroeconomic and sectoral implications from the EWS with the OECD ENV-Linkages macro-economic model. Some of these findings, including notably a boost in overall economic activity, were published in Chapter 10 of the “WEO 2012” and serve as a basis for this report. The report aims at providing more detailed information on the impacts of enhanced energy efficiency measures on countries’ GDPs, greenhouse gas emissions, household consumption, sectoral and regional changes in production, and trade specialisation patterns. The analysis presented in this paper results from coupling two complex modelling frameworks: the IEA’s bottom-up energy model and the OECD’s top-down general equilibrium model, using the latest information available.

Among expected benefits, the EWS brings about large reductions in GHG emissions, primarily but not solely as a result of energy savings. The scenario entails an 18% drop in energy-related CO₂ emissions in 2035 due to reduced fossil fuel consumption worldwide relative to the reference scenario used in this report, the IEA New Policies Scenario (NPS).⁴ In 2035, non-CO₂ GHG gases emissions are also 3.5% lower. The bulk of this reduction pertains to methane emissions. The net cumulative methane emission abatement is 6.2 GtCO₂eq over 2010-2035, equivalent to the amount of methane emitted globally by energy and agriculture sectors in 2010. In other words, within the next 25 years or so, the behavioural changes induced by the policies in the EWS would help save about one year of current methane emissions, in addition to the direct CO₂ abatement realised.

³ The EWS sees the adoption of more efficient equipment and processes in industry, improvements in building shells, windows, insulation, lighting and appliances, the use of more efficient vehicles and aeroplanes, and improvements in efficiency in power generation and grids. A summary of key policies by sector in the EWS is provided in Table 11.1, p. 329 of the IEA(2012) WEO report.

⁴ Equivalently, the CO₂ emissions reduction in 2035 is 31% lower than business-as-usual level given by the IEA Current Policies Scenario (IEA, 2012). Non-CO₂ GHG emissions are 6% lower when compared to business-as-usual.

While energy efficiency measures are necessarily costly, at least during their implementation phase, they are ultimately intended to reduce energy use. The resulting savings in energy expenditures could increase levels of disposable income and/or encourage additional spending elsewhere in the economy. The use of a general equilibrium model is needed to give quantitative insights into the net macroeconomic impacts resulting from these two adverse effects of the EWS measures. According to the OECD model simulations, this study indicates that achieving the EWS targets would result in a cumulative boost to the global economy of almost USD 20 trillion over the projection period, and in a global 2035 GDP of 1.1% higher than in the alternative IEA *New Policies Scenario*.

Increased economic activity reflects a gradual reorientation of the global economy towards more efficient economic structures, encouraging production and consumption of less energy-intensive goods and services. By 2020, an additional USD 400 billion of value is created globally and rises more than four-fold to reach USD 1,700 billion in 2035, according to the EWS. This scenario directly translates to increased household demand (+1.2% in 2035) for more energy-efficient goods and services. Overall changes in household consumption accounts for USD 280 billion in 2020 and over USD 1 200 billion in 2035. The remainder of additional value (USD 500 billion, in 2035) is consumed by productive sectors or used by governments in the form of goods and services. Electricity and energy fuel consumption are particularly affected in this scenario. Conversely, services and transport services play a key role, particularly in countries with the most stringent fuel economy standards.

The deployment of energy efficiency measures materializes incrementally in all sectors. The analysis depicts contrasting outcomes across countries. The EWS would clearly benefit most countries, with the exception of certain energy exporters who would see demand for their energy exports decline. In 2035, the United States economy is 1.3% larger in the EWS than in the NPS scenario, and economic growth is driven mainly by services. The European Union's GDP is 0.7% higher in 2035. The European Union sees a notable increase in domestic production and consumption of more energy-efficient road vehicles under this scenario, in addition to a stronger services demand. In many non-OECD countries, enhanced industrial activity, driven by energy efficiency investments, plays a large role in fostering economic growth. In addition to the shift towards consumption of domestically-produced services, there is a significant push in the consumption of manufacturing and construction goods. In 2035, China's GDP is USD 600 billion higher — a 1.4% increase. India and Indonesia receive the largest relative GDP boost in the Efficient World Scenario, with their economies larger by 3.9% for India and 2.4% for Indonesia, in 2035. Least developed African countries also benefit from additional investments in energy efficiency and increase their activity levels by 2% within the next 20 years. By contrast, Russia experiences a significant reduction in fossil fuel export revenues, which is only partially compensated by increased domestic activity, led by extra activity in the construction sector. In 2035, Russia's GDP is 2.9% lower than in the NPS.

The decrease in the energy-to-capital ratio in sectors conducting energy-efficient investments alters countries' relative competitiveness in supplying certain goods and services, thus leading to changes in regional specialisation in production. For example, the policies in the EWS particularly encourage the production of Transport Equipment and Transport Services in Japan and the European Union, whilst iron and steel and other energy intensive industries are stimulated notably in China and India. Trade plays a significant role in these overall economic adjustments. Global trade, including energy and non-energy goods, increases by 0.2%. The most traded products remain services and manufactured products, increasing their trade volumes by about +2% in 2035. The demand for energy-efficient transport equipment is particularly stimulated by the policy; with net change in overall traded volume reaching +3%.

The Efficient World Scenario induces some employment reallocation, especially between sectors within non-OECD economies. The bulk of these employment adjustments are shifted away from energy production, energy transformation and other energy intensive industries, to benefit the services sector and the manufacturing industry. The services sector in India alone captures a third of global reshuffled employment.

Finally, the reform of fossil fuel consumption subsidies in emerging and developing economies, as assumed by the IEA in the design of the EWS, plays a non-trivial role, both in reducing global fossil fuel consumption and restoring more efficient allocation of resources throughout the entire economy. If the pace of fossil fuel subsidy reform in the scenario is slower than under the EWS, however, this would lead to a global increase in total primary energy consumption of 0.7 % in 2020 and 1.4% in 2035. Global GDP benefits, relative to the central IEA New Policies Scenario, decrease from 1.1% under the Efficient World Scenario to 0.9% in 2035. This slower implementation of fossil fuel subsidy reform partially hinders the Efficient World Scenario objective of reducing overall energy consumption. Therefore an ambitious and multilateral reform of fossil fuel consumption subsidies is needed to complement specific energy-efficiency measures in any comprehensive policy package aiming to decrease reliance on fossil fuels and promote effective climate change mitigation at lowest cost.

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ECONOMIC IMPLICATIONS OF THE IEA EFFICIENT WORLD SCENARIO

1. Introduction

Energy efficiency curbs energy demand growth, reduces energy imports and mitigates emissions from energy-related CO₂, other greenhouse gas emission as well as local air pollutants. Energy efficiency is a vital element of a full and ambitious policy package to tackle long term climate challenges effectively (OECD, 2012). Indeed, energy efficiency alone contributes more than half of all emissions savings needed to achieve the IEA 450 Scenario objective, relative to the IEA central New Policies Scenario, thereby paving the way for a long term stabilisation of global average temperature increase to 2°C relative to pre-industrial levels (IEA, 2012).

In its 2012 edition of the World Energy Outlook, the International Energy Agency (IEA) constructed the Efficient World Scenario (IEA, 2012) to assess how implementing only economically viable energy efficiency measures would affect energy markets, energy prices, investment and emissions. The IEA analysis found that halving global primary energy demand over 2010-2035 would require USD 11.8 trillion additional investments in more-efficient end-use technologies. These dedicated investments would be more than offset by a USD 17.5 trillion reduction in energy fuel expenditures and USD 5.9 trillion lower investments in energy supply infrastructure. The OECD contributed to IEA analysis by deriving some preliminary economic implications from the Efficient World Scenario with the OECD ENV-Linkages macro-economic model. Some of these findings, including notably a boost in overall economic activity, were published in Chapter 10 of the World Energy Outlook (2012) and serve as a basis for this report. The report aims at providing complementary, more detailed material on GDP, household consumption, sectoral and regional changes in production and trade patterns. The report also presents additional benefits of enhanced energy efficiency measures in terms of non-CO₂ emission abatement.

The analysis draws upon careful consideration of dedicated energy efficiency investments, a core element of the Efficient World Scenario, causing structural reallocation of primary factors in production (i.e. capital, labour, primary energy and, where applicable, natural resources) across sectors and regions. Targeted additional investments, enforced by regulation, act as policy incentives across all economic agents (i.e. productive sectors and households). The link between energy savings and corresponding investment requirements derived by the IEA allows for the impact assessment of economic agents' behaviour, consumption choices and trade patterns of goods and services. The scenario also includes the progressive reform of fossil fuel consumption subsidies in emerging and developing countries.

This exercise required a model recalibration to match IEA regional representation (now covering 25 countries and regions) and to reproduce more accurately IEA energy trends at sectoral level. This analysis also necessitated methodological innovations to link the energy-oriented (bottom-up) IEA World Energy Model, and the OECD's top-down ENV-Linkages model which describes disaggregated sectoral and regional economic activities within a global context. All results are presented as deviations from the central IEA New Policies Scenario, which here serves as the reference scenario. The updated results highlighted in this report may therefore show slight discrepancies compared to preliminary numbers published in the World Energy Outlook and obtained with a more aggregated framework. However, their qualitative direction and the magnitude of deviations relative to the New Policies Scenarios remain to a large extent unchanged.

After a short description of underlying policies and climate change implications of IEA scenarios, section 2 contains a comprehensive overview of energy trends and specific energy-efficiency investments in the Efficient World Scenario. Section 3 develops the economic implications of the Efficient World Scenario. Subsection 3.1 briefly introduces the ENV-Linkages model and discusses methodological issues. Subsection 3.2 depicts the fundamental policy channels for productive sectors in several subsections. Global trends on GDP, household consumption, sectoral and regional changes in production patterns are highlighted in subsection 3.3. Section 3.4 pinpoints the policy impact on global GHG emissions. The global presentation is followed in subsection 3.5 by country profiles decomposing the sectoral contribution to domestic GDP, detailing changes in household consumption behaviour and highlighting altered trade patterns. Section 3.6 includes a sensitivity analysis on additional impacts of a slowed reform of fossil fuel consumption subsidies, as stipulated by the Efficient World Scenario, and aims to disentangle the joint policy effects on fossil fuel energy consumption and economic growth. Section 4 offers some final remarks. The Annex contains technical details on the ENV-Linkages model and on its calibration procedure to factor in Efficient World Scenario's energy components.

2. IEA scenarios in the World Energy Outlook 2012

2.1 IEA recurrent scenarios: Current Policies, New Policies and 450 Scenarios

In its World Energy Outlook publication, the IEA provides yearly updates of three recurrent scenarios — the Current Policies Scenario, the New Policies Scenarios and the 450 Scenarios — to depict the possible evolution of energy markets through to 2035 (IEA, 2012). The scenarios are differentiated primarily by their underlying assumptions about government policies. This report draws heavily upon these scenarios, description of which is provided in Box 1 below.

The New Policies Scenario is the central IEA scenario. It also serves as the reference scenario in this analysis to ensure consistency and complementarity with the IEA publication. Details on Efficient World Scenario policy components are provided in sub-section 2.3.

Box 1. The IEA recurrent scenarios

The **Current Policies Scenario (CPS)** is based on the perpetuation, without change, of government policies and measures enacted by mid-2012.

Examples of policies and measures included in **CPS**: State-level renewable portfolio standards in the United States, including energy efficiency as a means of compliance; European Union-level target to reduce GHG emissions by 20% in 2020, relative to 1990, EU Emission Trading Scheme or 20% targeted share in energy demand based on renewable sources by 2020; Cap-and-trade scheme in South Korea from 2015. 12th Five-Year Plan in China, including 17% cut in CO₂ intensity (i.e. CO₂ per unit of energy consumed) by 2015 and 16% reduction in energy intensity (i.e. energy consumed per unit of GDP) by 2015 compared with 2010.

- ✓ Fossil fuel consumption subsidies are progressively phased out in countries that already have policies to do so.

The **New Policies Scenario (NPS)** – the IEA central scenario – takes into account broad policy commitments and plans that have already been implemented to address energy-related challenges as well as those that have been announced, even where the specific measures to implement these commitments have yet to be introduced. It assumes only cautious implementation of current commitments and plans.

Examples of *additional* policies and measures included in **NPS**: Partial implementation of the EU-level target to reduce primary energy consumption by 20% in 2020; 30% reduction in GHG emissions compared with business-as-usual by 2020 in South Korea; In China, 40% reduction in CO₂ intensity compared with 2005 by 2020.

- ✓ Fossil fuel consumption subsidies are phased out in all net-importing regions by 2020 (at the latest) and in net-exporting regions where specific policies have already been announced.

The **450 Scenario** sets out an energy pathway that is consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to 2°C compared with pre-industrial levels. This 450 scenario is broadly in line with the 450 Accelerated Action scenario published in the OECD Environmental Outlook to 2050 (OECD, 2012a).

Examples of *additional* policies and measures included in **450 Scenario** : Finance for domestic measures; staggered introduction of CO₂ prices in all OECD countries; In Japan, 25% reduction in GHG emissions compared with 1990 by 2020; In Russia, 25% reduction in GHG emissions by 2020, compared with 1990.

- ✓ Fossil fuel consumption subsidies are phased out by net-importers by 2020 and by net exporters by 2035.

This box content is reproduced from Annex B of World Energy Outlook 2012 (IEA, 2012, p. 629). Detailed policies and measures by sector and by country implemented in each scenario can be found in this publication.

2.2 Design of the Efficient World Scenario

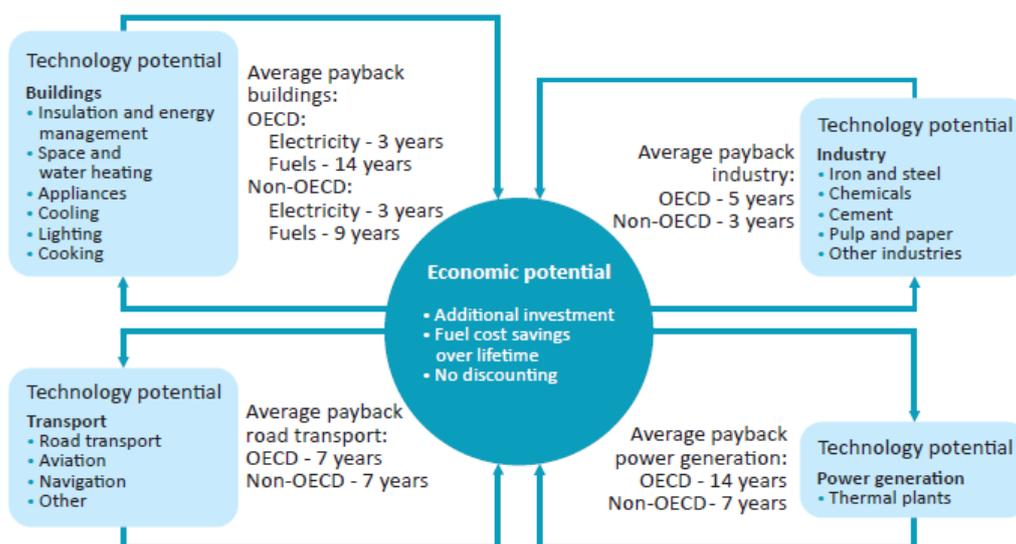
Energy efficiency curbs energy demand growth, reduces energy imports and mitigates pollution, and should be considered just as important to the future energy balance as unconstrained energy supply. An Efficient World Scenario (EWS) was constructed in the World Energy Outlook 2012 (IEA, 2012) to assess the implications on energy markets, energy prices, investment and emissions of implementing only energy efficiency measures that are economically viable. Measures were applied at a very detailed technical level and the indicator chosen to assess economic viability was the acceptable payback period for each class of investment for the technologies in the power, industry, transport, and building sectors⁵. Figure 2 illustrates the methodology for assessing the technical and economic potential.

⁵ Sectoral definitions differ between the IEA World Energy Model and the OECD ENV-Linkages model. The ENV-Linkages model used to derive the economic implications of the Efficient World Scenario features a more disaggregated representation of economic activity by sector.

The payback test was applied after having identified the long term technical potential, and key technologies and measures to improve energy efficiency by sector, in the period through to 2035. This process involved analysis of a huge amount of data and information from literature review, consultation, and interviews with professionals. Further information on the steps to estimate the technical potential can be found in the World Energy Outlook (IEA, 2012).

The criterion for determining the acceptable payback period was the amount of time an investor might be reasonably willing to wait to recover the cost of an energy efficiency investment (or the additional cost, where appropriate). Here, acceptable payback periods are calculated as averages over the Outlook period and take into account both regional and sector-specific considerations.

Figure 1. Efficient World Scenario methodology



Source: World Energy Outlook 2012 (IEA, 2012)

The scenario makes no bold assumptions about technical breakthroughs, but instead shows the extent of benefits that could be achieved if known best technologies and practices to improve energy efficiency were systematically adopted.

Further, the Efficient World Scenario is compared with the New Policies Scenario to interpret its energy and environmental implications in the next section. The key distinction between the New Policies Scenario and the Efficient World Scenario concerns extra investments dedicated to more energy efficient goods and services. Policies in areas other than energy efficiency are implemented in a similar fashion in both scenarios. In countries with carbon pricing, CO₂ prices are slightly lower than in the New Policies Scenario, as energy efficiency measures contribute targeted emission reductions (IEA, 2012).

Fossil fuel consumption subsidies are phased out by 2035 at the latest in all regions except in Middle East countries, where they are reduced to a maximum rate of 20% by 2035. OECD countries tax expenditures and other measures supporting fossil fuel production are not considered in this report (OECD, 2013).

Box 2. The World Energy Model

The projections for the scenarios presented in World Energy Outlooks (*WEO*) are derived from the IEA World Energy Model (WEM) – a partial equilibrium model characterised by high resolution in sectoral classification and detailed representation of energy technologies and policies.

The WEM was designed to replicate how energy markets function over the medium and longer term. Developed over many years, the WEM consists of six main modules:

- Final energy demand (with sub-models covering residential, services, agriculture, industry, transport and non-energy use);
- Power generation and heat;
- Refining/petrochemicals and other transformation;
- Oil, natural gas, coal, and biofuels supply;
- Carbon-dioxide emissions;
- Investment.

The WEM is designed to analyse:

- Global energy prospects: These include trends in demand, supply availability and constraints, international trade and energy balances by sector and by fuel (currently through to 2035).
- Environmental effects of energy use: CO₂ emissions from fuel combustion are derived from the detailed projections of energy consumption.
- Effects of policy actions and technological changes: Scenarios and cases are used to analyse the impact of policy actions and technological developments on energy demand, supply, trade, investment and emissions.

WEM produces investment calculation for energy (power generation, transmission and distribution, oil, gas and coal upstream, downstream and transport. It also assesses energy needs in the transport, buildings – including residential demand and services - and industry sector). Change in investment needs across scenarios, changes in fuel costs for every subsector, international fossil fuel prices, end user prices and subsidies to renewables were input to the ENV-Linkages model to determine the macroeconomic impact of the Efficient World Scenario.

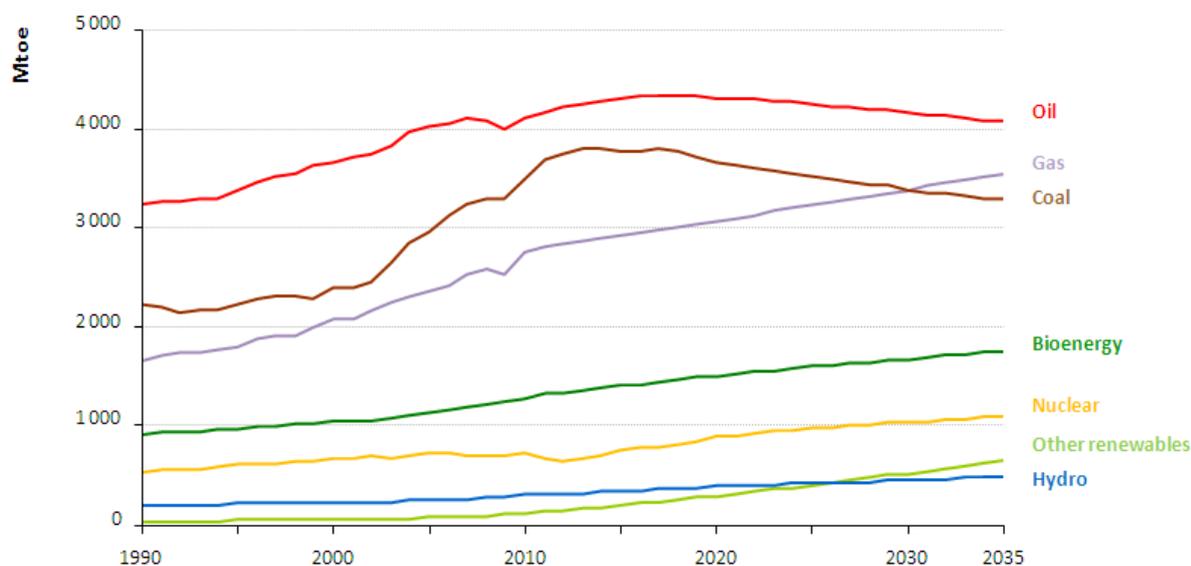
The detailed description of the WEO model can be found at <http://www.worldenergyoutlook.org/weomodel/>

2.3 Energy implications of the Efficient World Scenario

2.3.1 Energy demand trends

The Efficient World Scenario sees the adoption of more efficient equipment and processes in industry, improvements in building shells, windows, insulation, lighting and appliances, the use of more efficient vehicles and aeroplanes, and improvements in efficiency in power generation and grids. A summary of key policies by sector in the Efficient World Scenario is provided in the World Energy Outlook 2012 (IEA, 2012, Table 11.1, p. 329). These policies include retrofit of existing buildings in OECD countries, beyond the New Policies Scenario level. All new industrial equipment has efficiency levels matching best available technology by 2015. Pulp and paper production, for instance, offers scope for higher use of recycled fibre. The transport sector assumes deployment of the most efficient vehicle options by 2035, notably driven by mandatory fuel-economy standards and labelling.

Figure 2. World primary energy demand in the Efficient World Scenario by fuel type (Mtoe)



Source: World Energy Outlook 2012 (IEA, 2012)

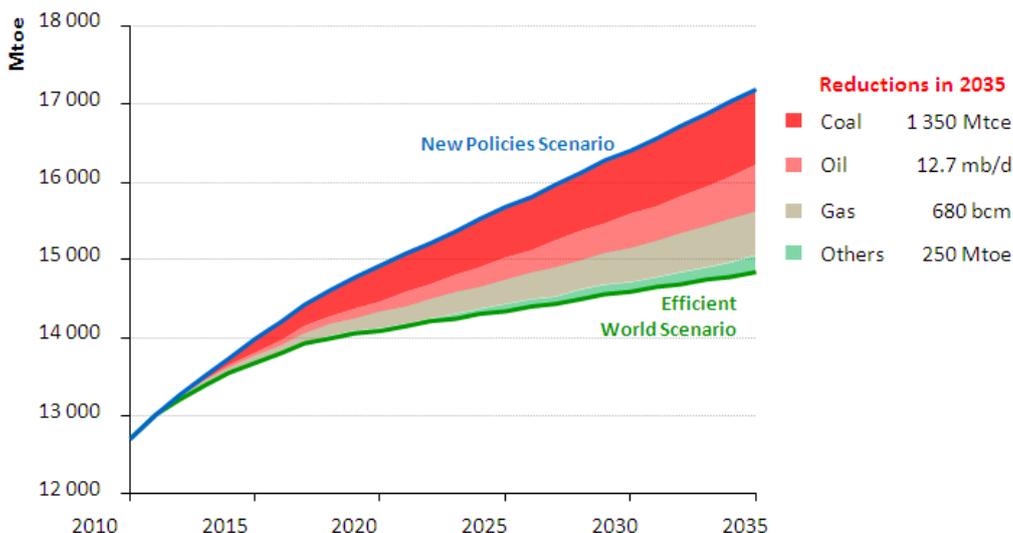
World primary energy demand reaches over 14 800 million tonnes of oil equivalent (Mtoe) in 2035. Figure 3 gives the world primary energy demand by fuel type in the Efficient World Scenario. All fuel types are affected although the reduction is greatest for fossil fuels (in both absolute and relative terms), as most efficiency measures are targeted towards their consumption reduction. Fossil fuels' share of primary energy consumption falls from 81% in 2010 to 74% in 2035, as demand for both oil and coal peaks before 2020 and then declines through 2035, according to the EWS.

Oil demand peaks at 91 million barrels per day (Mb/d) before 2020 and then declines to 87.1 Mb/d in 2035. The reduction of 12.7 Mb/d in 2035, as compared with the New Policies Scenario, is comparable to the total oil production today of Russia and Norway combined. Global coal demand peaks before 2020, at around 5 400 million tonnes of coal equivalent (Mtce), before dropping to about 4 700 Mtce in 2035, which is 22% lower than in the New Policies Scenario, and lower than today. Total demand for natural gas in the EWS reaches 3,700 billion cubic metres (bcm) in 2020 and almost 4 300 bcm in 2035. Nonetheless, demand is 14% (or 680 bcm) lower in 2035 than in the New Policies Scenario, which is roughly equivalent to US natural gas demand in 2010. Global demand for natural gas grows at an average annual rate of 1.0% in the EWS, compared with 1.6% in the New Policies Scenario, and natural gas overtakes coal in the early 2030s to become the second largest contributor to the energy mix, after oil.

2.3.2 Energy savings by fuel

As shown in Figure 4 below, world primary energy demand in the Efficient World Scenario achieves a reduction of 14% in 2035 relative to the New Policies Scenario (equivalent to 18% of global energy use in 2010). Global energy demand still grows in the Efficient World Scenario, but at an average annual rate of 0.6%, compared with 1.2% in the New Policies Scenario. The energy savings are less marked in the period to 2020, due to the energy sector's relatively low capital stock turnover in this period, but are still noteworthy: in 2020, demand is 6% lower than in the New Policies Scenario. Cumulatively, growth in global primary energy demand over 2010-2035 is halved while energy intensity improves at 2.6 times the rate of the last 25 years, according to the EWS.

Figure 3. Energy savings in the Efficient World Scenario (EWS)

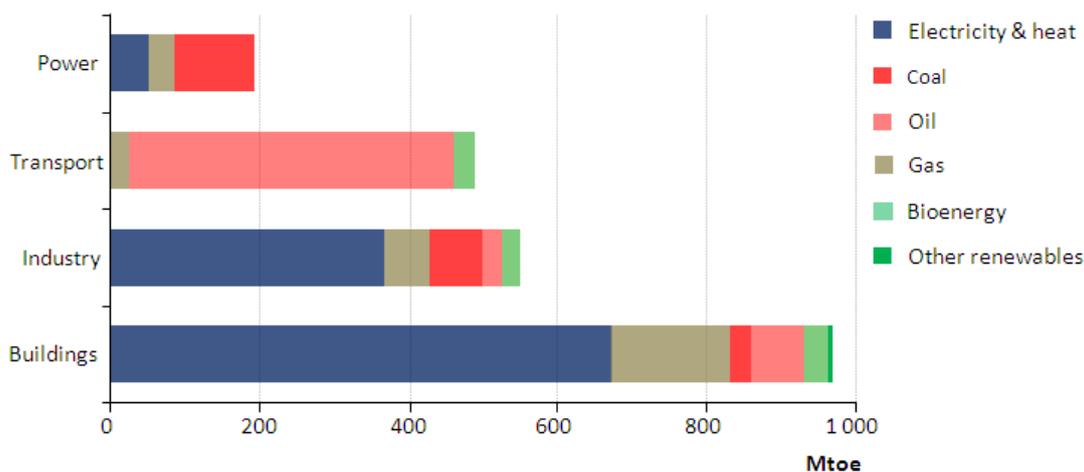


Source: World Energy Outlook 2012 (IEA, 2012)

2.3.3 Energy saving by sector

As mentioned in the previous section, the 14% reduction in primary energy demand in 2035, compared with the New Policies Scenario, corresponds to some 2 350 million tonnes of oil equivalent (Mtoe). From the perspective of sectoral distribution, the majority of the reduction occurs in the power sector (1 263 Mtoe). 85% of the savings made in the power sector are the result of demand-side savings in other sectors, especially buildings and industry. If those savings are attributed to the end-use sectors where the demand reduction occurs, the building sector accounts for almost 41% of the savings, mostly due to improvements made to the energy efficiency of building shells and electrical equipment (Figure 5). In 2035 almost two-thirds of the energy savings made in the industry and building sectors are in the form of electricity and heat. By contrast, savings in the transport sector are dominated by a reduction in oil demand, mainly driven by road vehicles' improved fuel efficiency.

Figure 4. Energy savings by sector in the Efficient World Scenario in 2035

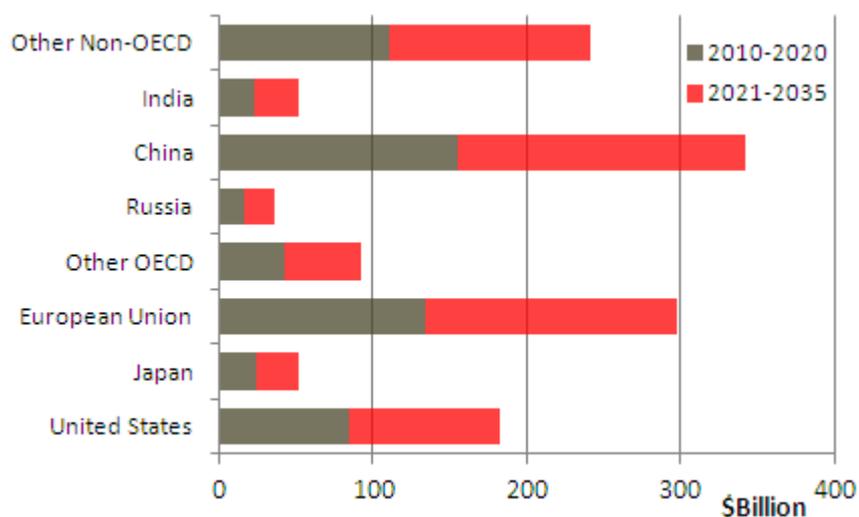


Source: World Energy Outlook 2012 (IEA, 2012)

2.3.4 Extra investments and energy expenditures savings from end-use energy efficiency

The Efficient World Scenario incurs USD 11.8 trillion of cumulative additional investments⁶, over the period 2010-2035, in more efficient end-use technologies (IEA, 2012). Figure 6 shows the breakdown by country and Figure 7 shows the breakdown by end-use sector.

Figure 5. Additional investments in end-use energy efficiency by country in the Efficient World Scenario



Source: World Energy Outlook 2012 (IEA, 2012)

Regarding regional distribution of investments in the EWS, China accounts for almost a quarter of the total. Slightly less than USD 2 trillion will have to be spent by 2035 in the United States, the European Union and EFTA countries if they are to fulfil their vast potential for energy efficiency improvement.

The building sector invests the most in the near term (before 2020), given the high potential for efficiency improvements in residential buildings. Over time, the additional investment in the transport sector is increasingly significant because of the diversified technology options and rapid stock turnover.

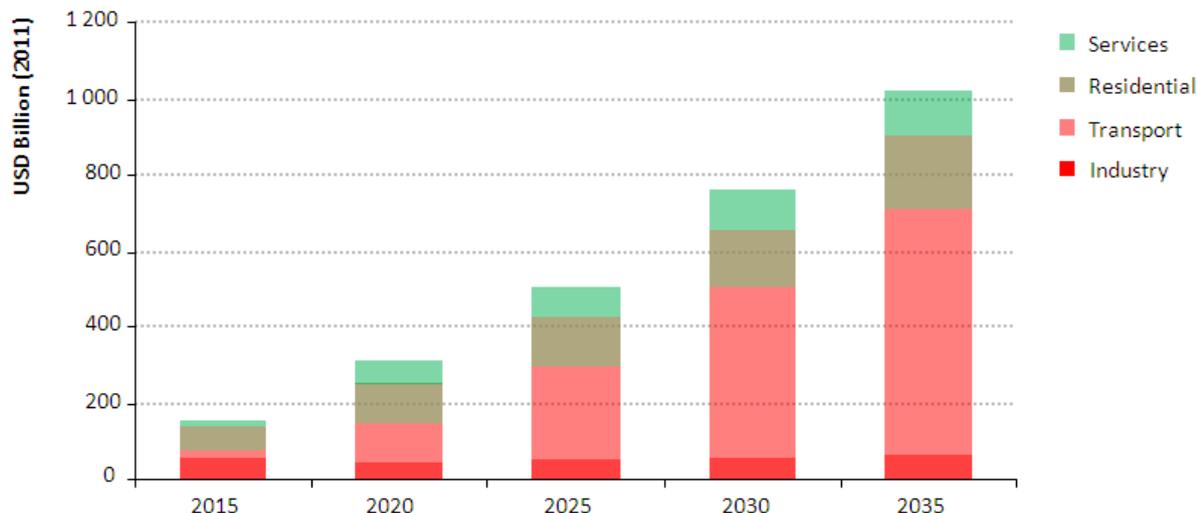
The bulk of additional investment is mobilised after 2020, as the cheapest efficiency measures will have already been used, and more expensive end-use technologies are being deployed. This holds true for all regions and sectors, according to the Efficient World Scenario.

This additional USD 17.5 trillion investment would be offset by reduced energy spending between 2021 and 2035. Moreover, USD 5.9 trillion less supply-side investment is needed in the Efficient World Scenario. The policy could thus be considered a “no-regret action” for its economic return alone, even before factoring in its environmental benefits. Imperfect information, among other factors, causes consumers and firms not to undertake privately profitable investments in energy efficiency.⁷

⁶ Energy efficiency investment is used to denote expenditure on a physical good or service which leads to future energy savings, compared with the energy demand expected otherwise. This section focuses on energy efficiency investment in end-use sectors – transport, residential, industry and services – as this is where most of the savings and additional investments occur.

⁷ Gillingham *et al.* (2009) and Allcott and Greenstone (2012) contain insightful, evidence-based, reviews of energy efficiency economics and policy. Allcott and Greenstone pinpoint various market failures, including energy use externalities and investment inefficiencies.

Figure 6. Global additional investment by end-use sector in the Efficient World Scenario relative to the New Policies Scenario

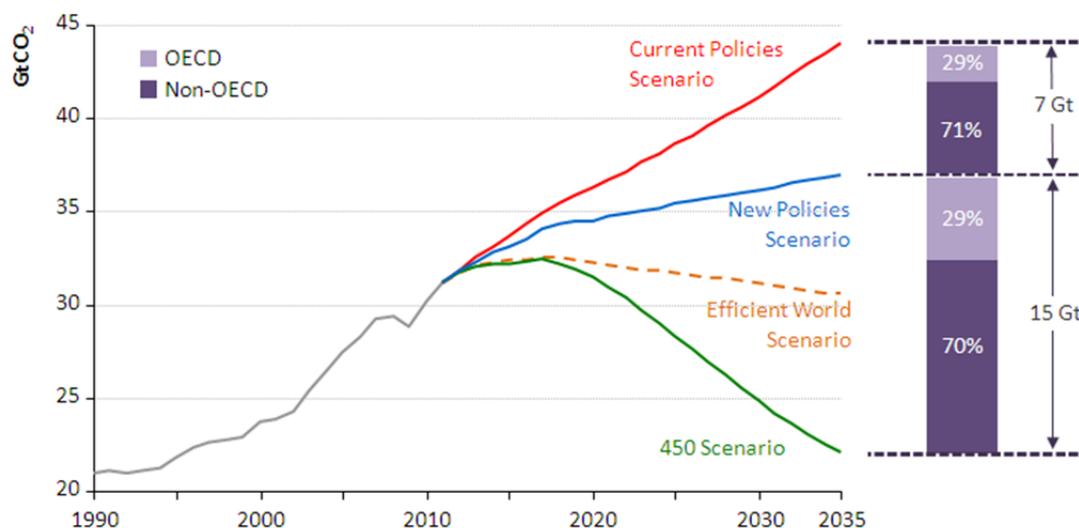


Source: World Energy Outlook 2012 (IEA, 2012)

2.4 Energy-related CO₂ emissions

The IEA World Energy Outlook derives detailed climate change implications from its energy-focused scenarios, notably in terms of energy-related CO₂ emissions. The four scenarios' trajectories are depicted in Figure 1, below. CO₂ emissions rise to 44.1 gigatonnes (Gt) in the Current Policies Scenario and 37 Gt in the New Policies Scenario by 2035. The 450 Scenario sees level of 22.1 Gt in 2035.

The policy incentives implemented in the Efficient World Scenario for acquiring energy efficient appliances and vehicles across the entire economy turn out to be very effective at addressing long-term climate change challenges at lowest cost. In the Efficient World Scenario, energy-related CO₂ emissions peak before 2020 and decline to 30.5 Gt in 2035. Importantly, additional policy measures implemented in the Efficient World Scenario provide almost half of the emissions savings needed to achieve the IEA 450 Scenario objective (IEA, 2012), relative to the IEA central New Policies Scenario. Emissions reductions achieved by 2035 in the Efficient World Scenario can therefore be an important building brick for a long term stabilisation of global average temperature increase to +3°C relative to pre-industrial levels (IEA, 2012). Achieving deeper emission reductions in line with +2°C long term goal would require additional policy and financial instruments, on top of Efficient World Scenario policies and measures, to support faster deployment of low carbon energy (e.g. renewable energy sources).

Figure 7. Global energy-related CO₂ emissions by scenario

Source: World Energy Outlook 2012 (IEA, 2012)

Other environmental benefits such as reduction in local air pollutants, particularly in China and India, are significant. These are documented in the World Energy Outlook (2012) for each IEA scenario and are not reproduced here.

3. Economic impact of the Efficient World Scenario: A CGE analysis

3.1 Key model features and methodological issues

Despite large differences in the nature and functioning of the ENV-Linkages and the World Energy Model, ENV-Linkages was calibrated to reproduce all energy-related patterns from the World Energy Outlook 2012 scenarios (including CPS, NPS and EWS) and to derive further economic implications allowed by the computable general equilibrium framework.

The assessment of energy efficiency measures, a vital element for the future energy balance, often stems from sector- and country- specific engineering analysis. Despite abundant literature on actual energy efficiency benefits on a small scale, less is known about economic impacts on a macro scale. This analysis aims at filling this gap by following a novel approach which consists of greater harmonisation of the global, energy-oriented (bottom-up) IEA World Energy Model, and the OECD's top-down ENV-Linkages model which describes disaggregated sectoral and regional economic activities within a global context.⁸ This hybrid modelling approach addresses frequent concerns about the appropriate measurement of economy-wide effects associated with adopting more energy-efficient appliances.

⁸ Very few attempts of such large-scale model linking exist in the literature. Labriet *et al.* (2010) and Scea *et al.* (2012) describe successful experiments of similar nature.

Box 3. The OECD ENV-Linkages model

The OECD ENV-Linkages Computable General Equilibrium (CGE) model is an economic model that describes how economic activities are linked to each other across sectors, regions and economic agents (i.e. intermediate sectors of production, households, and government). It also links economic activity to greenhouse gas (GHG) emissions. Economic activities and their corresponding GHG emissions are projected over several decades⁹.

The ENV-Linkages model is a dynamic neo-classical general equilibrium model, featuring capital vintages. This global economic model draws primarily upon a database of national accounts and estimated world trade flows. Each regional activity is described by an economic input-output table (usually sourced from national statistical agencies and collected under the GTAP V8 database, Narayanan *et al.*, 2012).

The advantages of multi-sectoral, multi-regional, dynamic CGE models such as ENV-Linkages include their global dimension, their overall consistency accounting for economy-wide interactions and the fact that they are based on rigorous micro-economic foundations. They thus facilitate exploration and quantification of policy responses to a wide range of government initiatives. These models are best suited to analyse the medium- and long-term implications of large policy shifts. Such policy shifts generate significant reallocations of primary factors and consumption of goods and services across sectors and countries/regions and spill-over effects such as energy and environmental policies. Additional information on the ENV-Linkages model structure is provided in the Appendix.

The IEA Efficient World Scenario required the design of a set of policy scenarios that include detailed estimates of additional investment needed to improve the energy efficiency of the entire economy. These extra investments, depicted in Figures 5 and 6, are taken as input to the ENV-Linkages model in order to reproduce exact IEA energy savings for each type of energy demands (by sector, agent, fuel type etc.). Contrarily to the standard functioning of ENV-Linkages model, the rates of return for new capital are now sector-specific to ensure that sectoral demand for new capital equals extra energy-efficiency investments in addition to baseline investments.

The calibration phase also consisted in directly factoring in various policy instruments framing the WEO scenarios such as patterns of fossil-fuel subsidies reform, CO₂ markets as well as other types of regulations such as fuel economy standards for the transport sector and extra investment expenditures on energy-efficient appliances. Further calibration efforts were devoted to key trends on energy consumption by fuel, by sector and by country; on fossil-fuel supply by country; and on changes in electricity generation mix by country. These energy trends were apprehended indirectly by adjusting some of the model parameters such as the autonomous energy efficiency rates of improvement and technical progress experienced by sectors of fossil-fuel extraction to accurately reproduce the outcomes of the WEO scenarios. Appendix A.3 provides details on necessary calibration steps to link the IEA WEM and OECD ENV-Linkages models.

The direct impacts of energy efficiency measures assume implicitly that agent behaviours, as well as macro-economic environment are not reacting to the policies themselves. In practice, some additional

⁹ More details about the model and some of its recent applications can be found on the following webpage: <http://www.oecd.org/environment/modelling>

effects are affecting the expected net energy savings: like the decrease in energy demand negative impact on energy prices, in turn could lead to some increases in energy consumption. Such “rebound” effects are automatically captured in a CGE model, as is the case in the present paper, which is an advantage of this approach

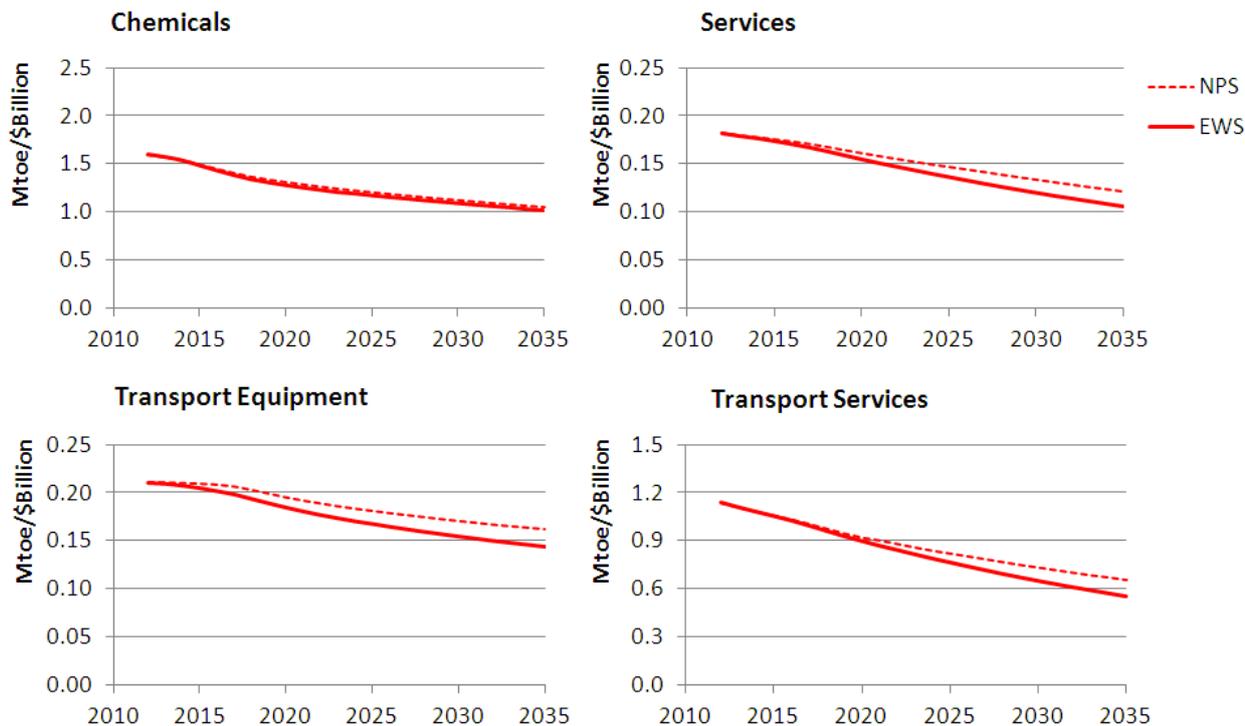
3.2 *Fundamental policy channels: Decomposition of effects*

This section aims to shed light on the key mechanisms underlying this paper’s analysis and provide insight on the way dedicated energy efficiency policies can help foster economic growth. For this reason, the focus in this section is solely on net energy-importing countries, i.e. countries whose revenues from energy exports are limited. Large energy exporters shall also see benefits of conducting ambitious energy efficiency policy but the net impact on GDP remains negative because of reduced global energy demand. Obviously, the scenario analysis is done for all regions, and results for other regions will also feature in the next sections.

In the Efficient World Scenario, the deviation in real GDP relative to the New Policies Scenario results from a combination of mechanisms. Although the magnitude and direction of these mechanisms’ impacts on GDP remain difficult to identify and assess, as the CGE framework encompasses them all simultaneously, the following channels can be distinguished: the policy induces changes in capital allocation across sectors and alters savings and global investment. In addition, the reinforced energy efficiency objectives discourage energy consumption, enhance the overall efficiency of all sectors, and energy spending is thereby reduced in energy-importing countries. Importantly, the broad allocation of capital in certain countries could be suboptimal in the sense that capital allocated to energy efficiency could turn out to be more profitable in other sectors. Finally, additional measures included in the policy package, such as the removal of fossil-fuel consumption subsidies, could alleviate the burden and enhance resource efficiency in oil and natural gas-rich economies.

The simulated policies imply, by construction, a decrease in the energy-capital ratio in sectors conducting energy-efficient investments (Figure 8). The consequences appear to be more limited in energy intensive sectors than in services or transport-related sectors. More abundant capital allocated to these sectors also decreases capital rate of return. This direct change in the production structure implies a gradual decrease in production costs and output prices in more energy-intensive sectors, as energy savings materialise (i.e. in sectors such as iron and steel production, transport services or construction sectors).

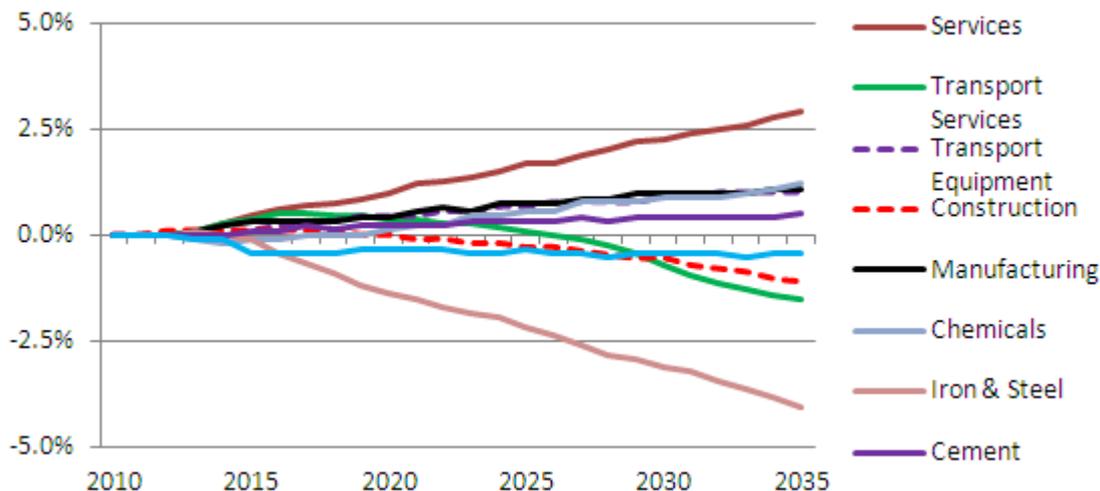
Figure 8. Global energy-capital ratio in the New Policies Scenario and the Efficient World Scenario for selected production sectors



Source: OECD ENV-Linkages model

Figure 9 depicts the time evolution of output prices in China. Upwards and downwards price movements of the different commodities remain modest, generally in the order of 1% to 2% by 2035. Services and iron and steel prices are slightly more sensitive as demand for services rises swiftly through 2035, and as iron and steel production costs are particularly responsive to falling energy prices.

Figure 9. Per cent of deviation in Chinese output prices in the Efficient World Scenario



Source: OECD ENV-Linkages model

The observed cost reduction gradually stimulates intermediate demand for e.g. iron and steel, and in turn affects gross production as shown in Figure 10, below. Figure 10 also illustrates the magnitude of the second effect generated by the policy: a strong stimulation of demand for services, construction and transport equipment (through boosted transport services). Extra demand for these goods and services is a direct consequence of energy-efficient investments made by households and firms. In the short run, the small changes in input mix for goods' production impact demand only moderately.

Figure 10. Deviation in intermediate and final demand by good or service in China in the Efficient World Scenario relative to the New Policies Scenario, in 2020 and 2035



Source: OECD ENV-Linkages model

3.3 *Assessing the implications for the global economy*

Achieving the Efficient World Scenario would result in a cumulative boost to the global economy of USD 19.7 trillion over the projection period, and in global GDP in 2035 being 1.1% higher than GDP in the New Policies Scenario. Increased economic activity reflects a gradual reorientation of the global economy, encouraging production and consumption of less energy-intensive goods and services (thereby freeing up resources to be allocated more efficiently). The reduction in energy use and the resulting savings in energy expenditures increase levels of disposable income and encourage additional spending elsewhere in the economy.

GDP changes are relatively steady over time, a third of the cumulative impact to 2035 taking place by 2020 (Figure 11). While the global economy benefits overall in the Efficient World Scenario, the impact differs across countries. In 2035, the United States economy is 1.3 % larger in the Efficient World Scenario, increasing its economic output by almost the equivalent of Austria's economy today (over USD 330 billion), and economic growth is driven mainly by services. The European Union GDP grows 0.7% faster, and, in addition to services, also sees a notable increase in domestic production and consumption of more energy-efficient road vehicles.

In many non-OECD countries, investments and exports play a large role in the economy, besides household consumption. This means that, in addition to the shift towards consumption of domestically produced goods and services, there is a more significant impact observed in manufacturing, construction and energy-intensive industries. In 2035, GDP in China is USD 600 billion higher — a 1.4% increase or almost the equivalent of current South African economy. India and Indonesia receive the largest relative boost in the Efficient World Scenario, with their economies being respectively 3.9% and 2.4% larger in 2035. The Indian economy experiences a stronger push in the short run due to the benefits of multilateral reform on fossil fuel consumption subsidies. African countries capture about 10% of overall investments in energy efficiency and also benefit from the global economic context. On average, their GDP rises by an extra 1.3% in 2035. In contrast to most other countries, the economies of the largest oil and gas exporters, such as Russia, experience lower levels of economic growth, mainly as a result of lower growth in oil and gas export revenues (due to reduced demand and prices). These countries also incur other short-term economic losses, some of which are linked to fossil fuel subsidy reform.

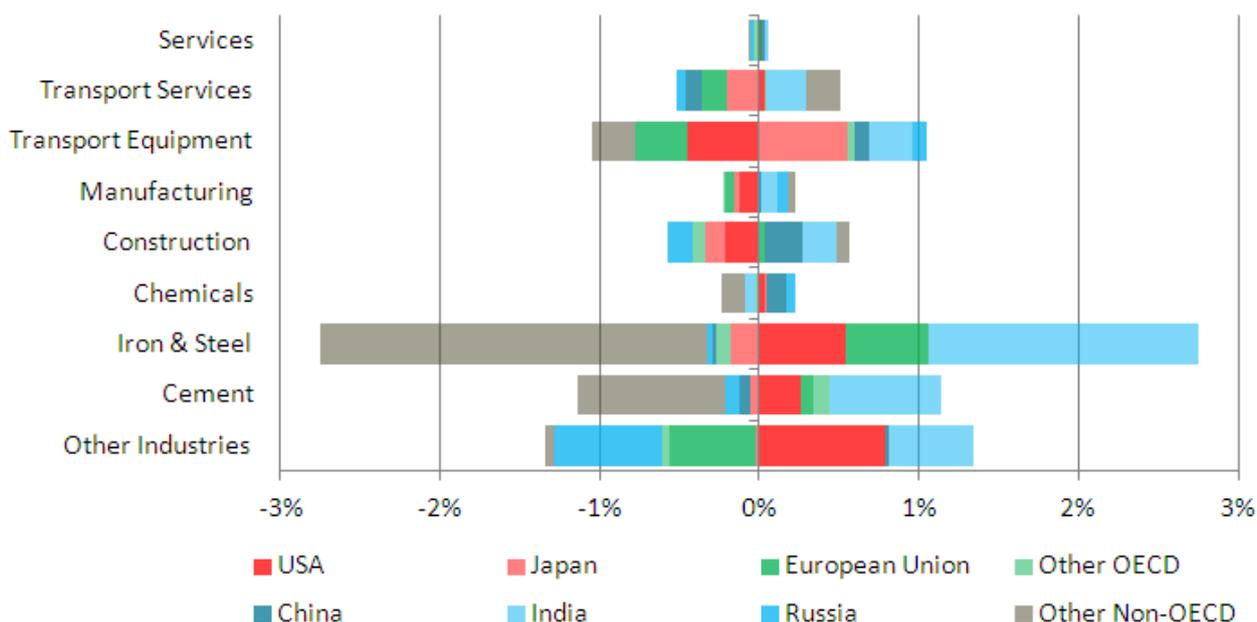
The Efficient World Scenario entails shifts in competitive position of different sectors across countries and thus a geographical reallocation of certain sectoral activities. Figure 12 shows the corresponding changes in production shares by country and by sector in 2035. The location of services, manufacturing and chemicals production remains, in share terms, relatively immune to the policy incentives. By contrast, other productive sectors, particularly energy intensive sectors, experience a more sizeable reaction to extra investments dedicated to energy efficiency improvement. The production of iron and steel sees the most notable change as almost 3% of total value-added in this sector shifts from least developed countries to the United States, the European Union and India, whose production costs diminish via policies. The United States' sectoral competitiveness also increases slightly for other industries such as Pulp and Paper production. But India, whose production costs decrease most significantly, remains the largest recipient of rebalanced activities and captures about a third of global production deviation in almost every sector.

Figure 11. Change in real GDP in the Efficient World Scenario



Source: OECD ENV-Linkages model

Figure 12. Sectoral changes in production by region in the Efficient World Scenario, 2035

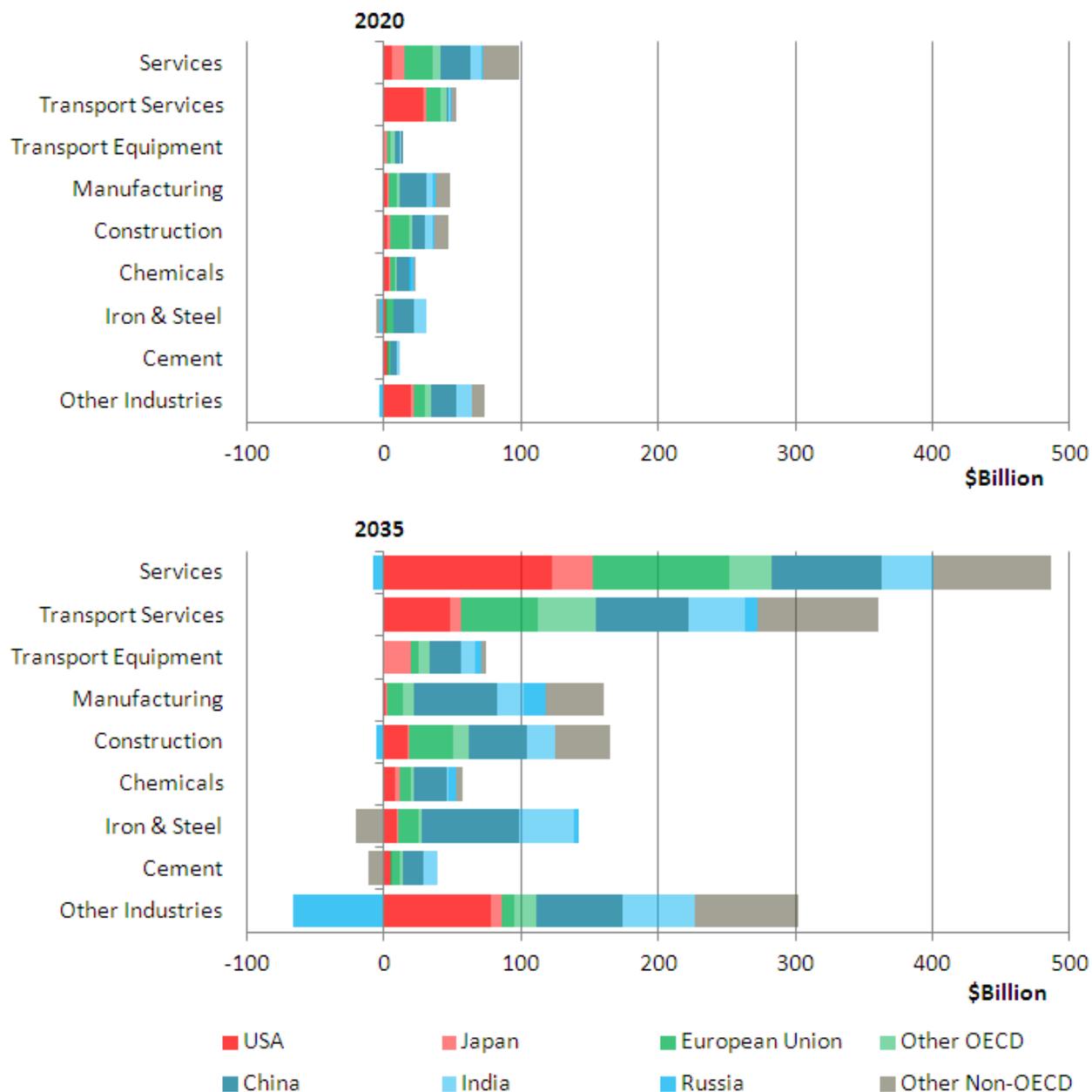


Source: OECD ENV-Linkages model

As seen earlier, the Efficient World Scenario encompasses a 1.1% increase in overall economic activity, resulting from complex reactions to changes in prices of primary factors (e.g. capital, labour, energy) and goods and services which are supplied to intermediate productive sectors. Figure 13 provides an overview of changes in value-added by sector across countries. Progressive deployment of energy efficiency measures materializes incrementally in all sectors. By 2020, an additional USD 400 billion of value is created globally and rises more than four-fold to reach USD 1 700 billion in 2035, relative to the New Policies Scenario. The deviation trends initiated in the short run are reinforced in the long run. Services embody more than half of economic activity worldwide. Therefore the USD 500 billion increase in the volume of Services in 2035 in the Efficient World Scenario account for less than a percentage point in overall additional Services activity but account for a third of total growth in value-added. Alternatively, transport services, with a more modest contribution to global activity, increase their global production level by 5.5%, or USD 360 billion, led by OECD countries and China. Heavy industries such as iron, steel and non-metallic minerals (e.g. cement) see the biggest change in activity level, ranging from 2.5% to 7% increases in the case of iron and steel, to the benefit of China which accounts for 60% of additional production, and to a lesser extent India.

These Efficient World Scenario results directly translate to increased household demand for more energy-efficient goods and services (Figure 14). The magnitude of changes in household consumption is similar to that of production, albeit slightly less. The remaining changes in production are absorbed by intermediate sectors. Overall changes in consumption account for USD 280 billion in 2020 and above USD 1 200 billion in 2035. These sectoral deviations are largely driven by changes in household behaviour in OECD countries, whose consumption generally accounts for a large share of GDP. 60% of changes in global consumption occur in OECD countries, half of which occurs in the United States and a third of which in the European Union. On a global basis, all sectors but energy transformation sectors experience a net overall expansion, reflecting the positive income effect of the policies.

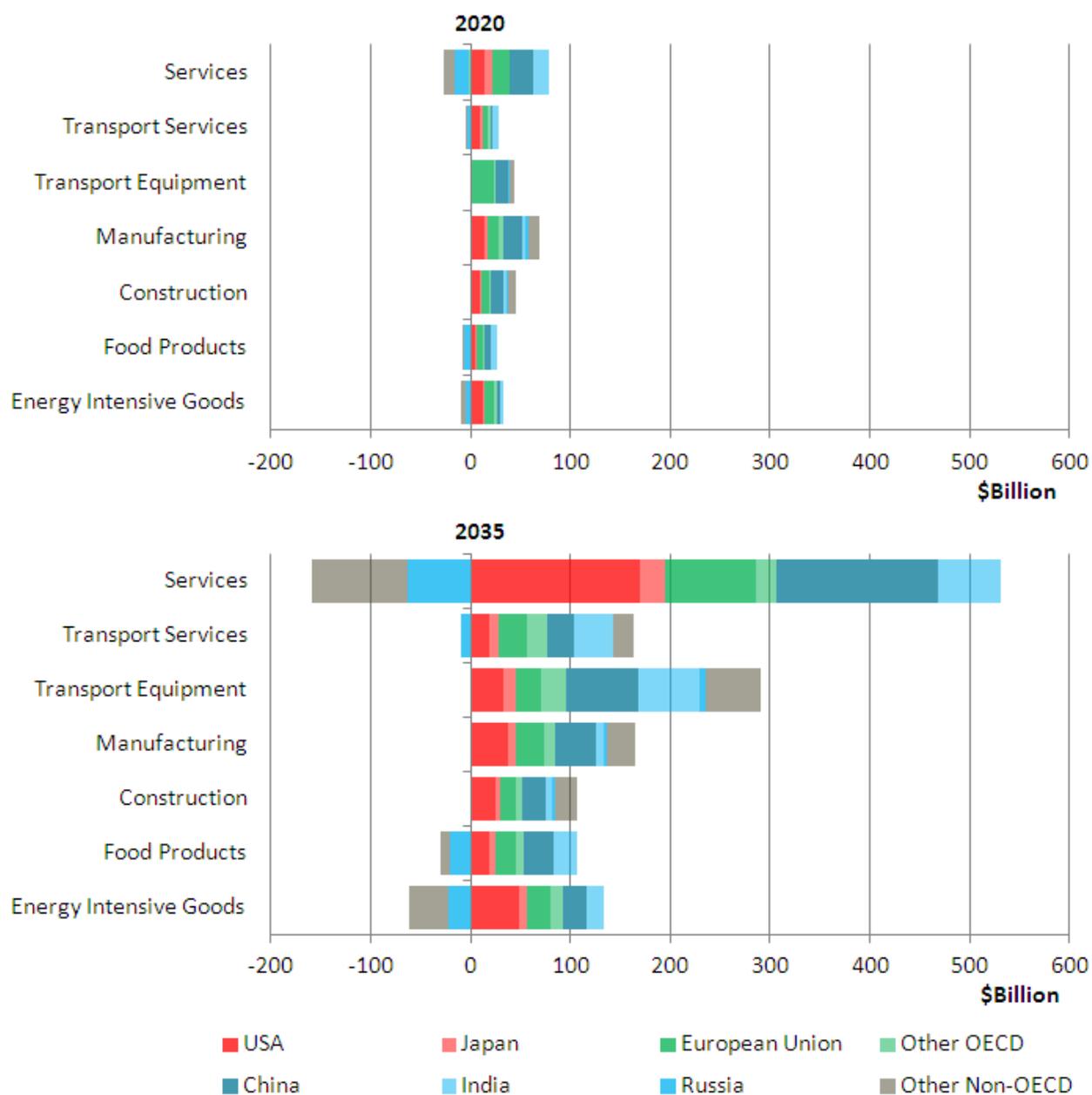
Figure 13. Changes in value-added by sector and region in the Efficient World Scenario compared with the New Policies Scenario, 2020 and 2035



Source: OECD ENV-Linkages model

Services consumption sees the largest net growth in the Efficient World Scenario in 2035 (+USD 370 billion). Transport equipment consumption (+USD 290 billion) sees particularly strong growth in the United States and in the European Union, driven by the enforcement of stringent fuel economy standards and the rapid uptake of energy-efficient vehicles. Consumption of manufacturing goods grows in all countries, and is focussed on more energy-efficient products, such as greener cars and energy-efficient electrical appliances. The construction sector sees increased activity in the Efficient World Scenario, as inefficient buildings are refurbished and new buildings must comply with stringent energy-efficiency standards.

Figure 14. Sectoral changes in real household consumption in the Efficient World Scenario, 2020 and 2035



Source: OECD ENV-Linkages model

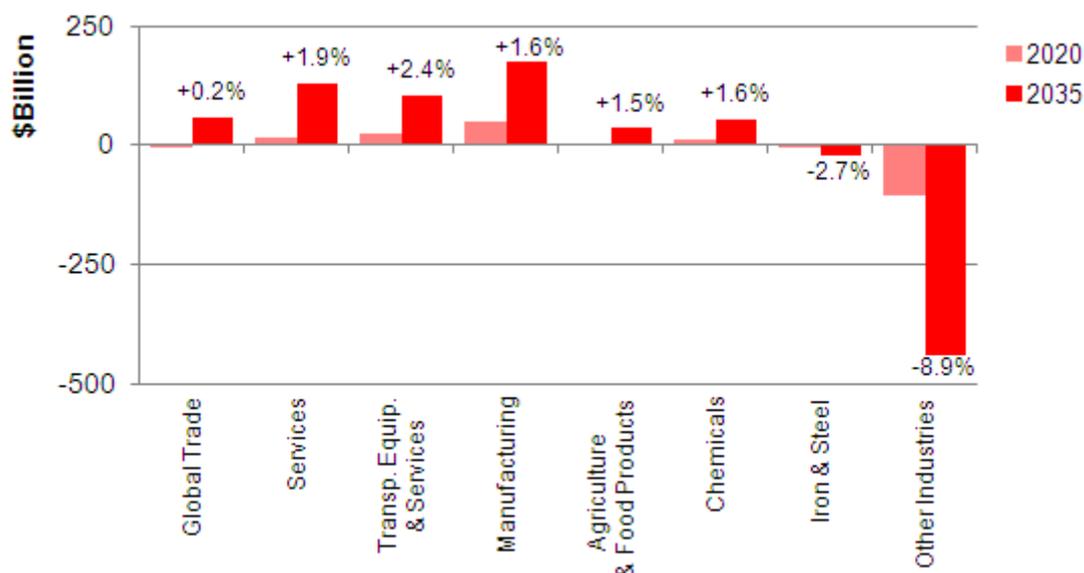
By contrast, Russia and the Middle-East see a decline in households' consumption of services and energy-intensive goods as their whole economy is negatively affected by global energy savings.

Whilst the global economy is larger in 2035, global trade is only 0.2% higher in the Efficient World Scenario, equivalent to USD 50 billion in goods and services (Figure 15).¹⁰ This stems from a move to less

¹⁰ Global trade deviation relative to the New Policies Scenario published in the IEA World Energy Outlook 2012 exhibited a 2% decrease in 2035 (IEA, 2012). This figure had been obtained with a 15 region model. The qualitative difference with the present analysis comes mainly from enhanced regional disaggregation. The 25 region model employed in this analysis increases the number of bilateral trade flows across regions, which has a significant impact on overall trade value.

energy-intensive goods and services. Indeed, service-related sectors in OECD countries are strongly stimulated by the Efficient World Scenario and capture two-thirds of additional investments, thereby inducing some redistribution of sectoral activities across regions, as illustrated above. Other industries include energy transformation industries which experience a slowdown in activity and trade. Hence the sharp decline illustrated in Figure 15. Detailed descriptions of changes in trade patterns on a country basis are provided in subsequent section on regional analysis.

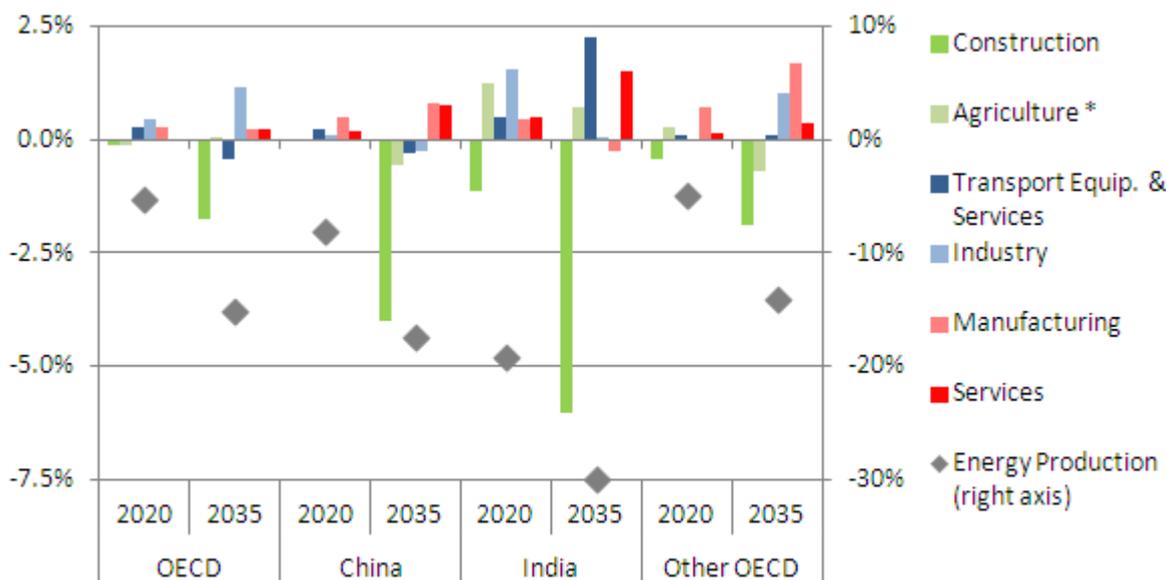
Figure 15. Change in global trade flows for selected sectors in the Efficient World Scenario, 2035



Source: OECD ENV-Linkages model

Despite a preserved level of employment as assumed across all scenarios, our Efficient World Scenario results in a small shift towards jobs in manufacturing and most importantly services, and away from the construction sector and energy-intensive industries which gradually substitute capital for labour (Figure 16). In 2035, the 10% reduction in labour-intensive, energy production activities is followed by a decrease in this sector's employment ranging from 15% in OECD countries to 30% in India. However, the Indian energy sector remains small relative to population in India; this sector employs less than 1% of labour supply in India. Employment in the construction sector also sees a notable decrease by 2035, in the order of 2% in OECD countries, 4% in China and 6% in India. Overall employment shift is equivalent to 0.7% of total employment in non-OECD countries in 2035.

Figure 16. Deviation in employment by sector in the Efficient World Scenario



Source: OECD ENV-Linkages model

In OECD countries, this shift remains very limited and is mainly directed towards industrial and services production. Employment in industry increases by slightly more than one percentage point in 2035 compared to the New Policies scenarios. In non-OECD countries, there is a more significant move from the energy sector towards services, but is still equivalent to less than 0.5% of all employment in non-OECD countries in 2035. Energy-intensive industries in non-OECD countries, whose activity is boosted in the Efficient World Scenario, also increase their share of capital in production at the expense of labour. The Services sector in India alone captures a third of reshuffled employment. Importantly, additional intra-sectoral job reallocations that result from the policies implemented in the Efficient World Scenario are not represented here. Changes in skill requirements are also not quantitatively assessed, but sectoral shifts do indicate a likely need for an active policy to smooth the transition process and ensure workers have the newly required skills (OECD, 2012b).

3.4 Impact on global GHG emissions

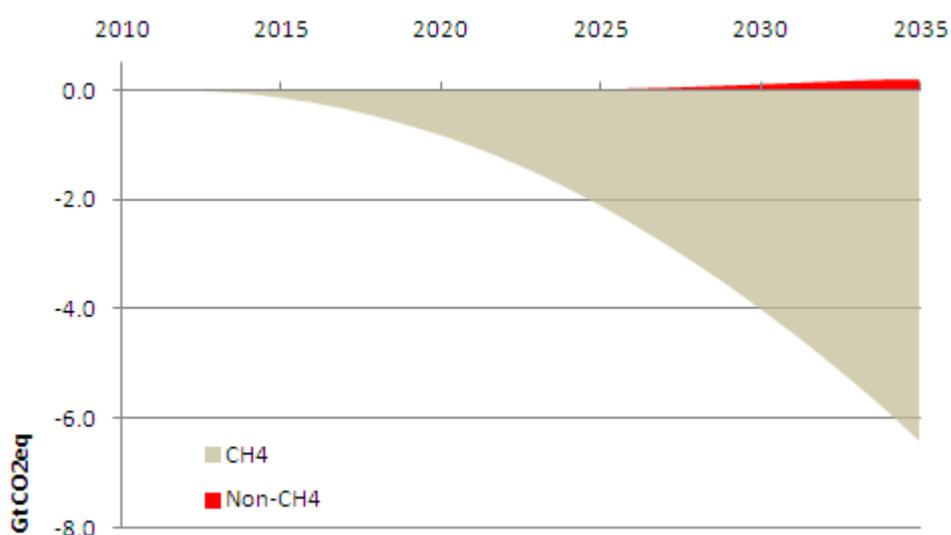
In 2035, the Efficient World Scenario entails an 18% drop in energy-related CO₂ emissions relative to the New Policies Scenario level (and 31% relative to business-as-usual level given by the IEA Current Policies Scenario) because of reduced fossil fuel consumption worldwide, as discussed in Section 2.2. But additional benefit for global climate change mitigation stem indirectly from the Efficient World Scenario policy measures analysed in this report. Non-energy-related CO₂ emissions are also linked to economic activity levels. As seen above, the energy-targeted policy measures in the Efficient World Scenario induce various shifts in economic activity which, in turn, impact non-CO₂ GHG emissions.

By 2035, non-CO₂ GHG gases emissions are 3.5 % lower than the New Policies Scenario level (This corresponds to a 6% reduction relative to business-as-usual level given by the IEA Current Policies Scenario). The bulk of this reduction relates to methane emissions. Methane emissions are primarily produced by energy extractive industries (i.e. fugitive emissions from natural gas and petroleum systems, and coal mining) and by the agricultural sector. The overall methane reduction in energy production relative to the New Policies Scenario leads a cumulative 6.7 GtCO₂eq by 2035. Conversely, agriculture

activity slightly increases in the scenario incentives and releases an additional 0.8 GtCO₂eq. This translates into net cumulative methane emission abatement of 6.2 GtCO₂eq over 2010-2035, equivalent to methane emitted globally by energy and agriculture sectors in 2010 (Figure 17). In other words, within the next 25 years or so, the Efficient World Scenario policies help save about a year of current methane emissions on top of direct CO₂ abatement.

By contrast, HFC emissions arising from boosted chemical industries exhibit a small cumulative 0.2 GtCO₂eq increase by 2035. Emissions of other gases from the Kyoto-basket of greenhouse gases, together with CO₂ emissions from industrial chemical processes (i.e. not released from fossil fuel combustion) remain about identical to the New Policies Scenario's levels. In cumulative terms, GHG emissions, other than CO₂ and methane, increase only marginally.

Figure 17. Cumulative GHG abatement other than non-energy-related CO₂ over 2010-2035, relative to New Policies Scenario



Source: OECD ENV-Linkages model

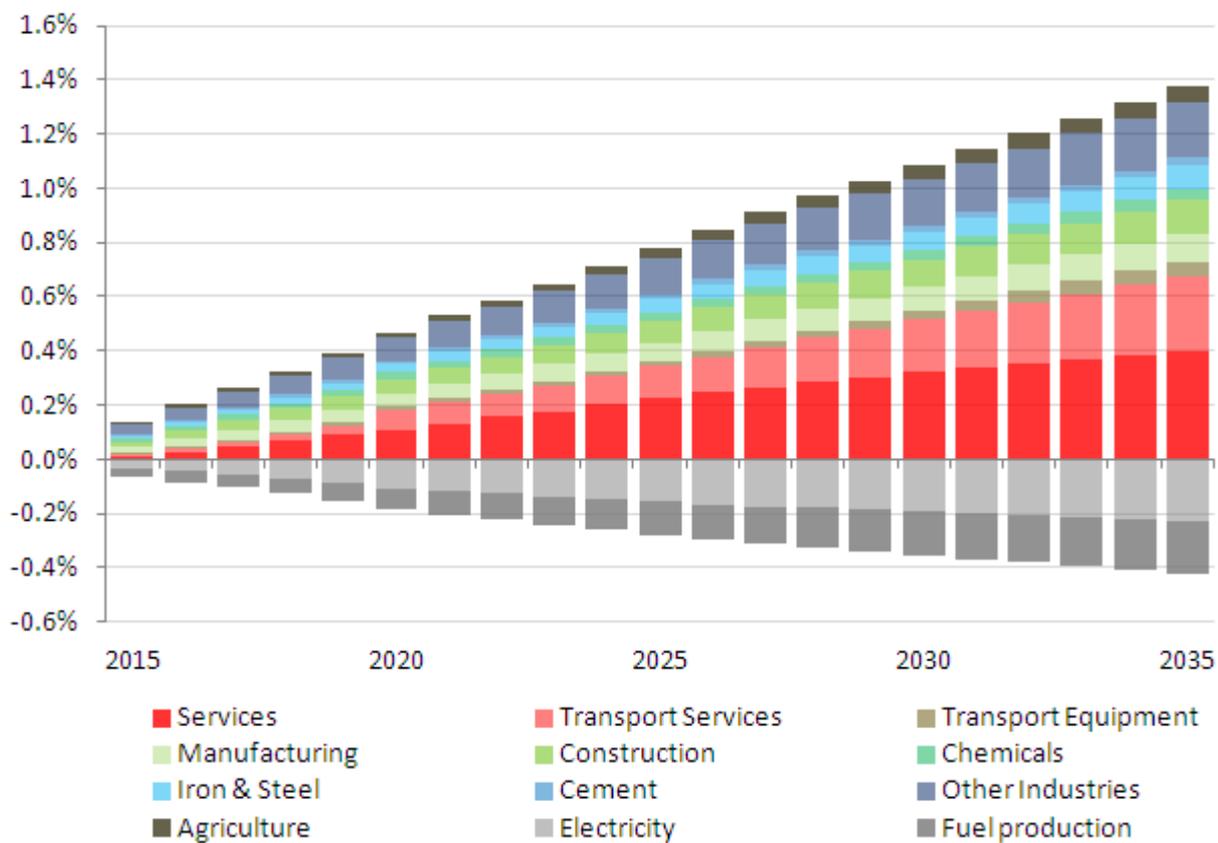
3.5 Country/region profiles

This section complements the previous section with a global overview. The section contains a systematic and more detailed representation of the Efficient World Policy outcomes on the dynamics of domestic / regional activity. The subsequent country / region charts provide a breakdown of changes in sectoral value-added relative to the New Policies Scenario levels and thus reflect how the composition of economic growth evolves over time. This information highlights how sectors react to policy stimulus implemented in the Efficient World Scenario. Real household consumption and international trade patterns react to price changes. Their deviations are highlighted through the lens of their evolving contribution to domestic GDP. All deviations are relative to the New Policies Scenarios. All figures depicted in this subsection are derived from OECD ENV-Linkages model simulations.

World: Key facts

- In 2035: GDP increase: +1.1% (+USD790 billion on average p.a.) / Household consumption: +1.2%
- Intermediate sectors boost economy
- Strong stimulus of household demand for services. Domestic production supplemented by enhanced imports of services
- Large demand for imported manufactured products and transport equipment in 2035

Figure 18. Per cent Change in Sectoral Real Value Added



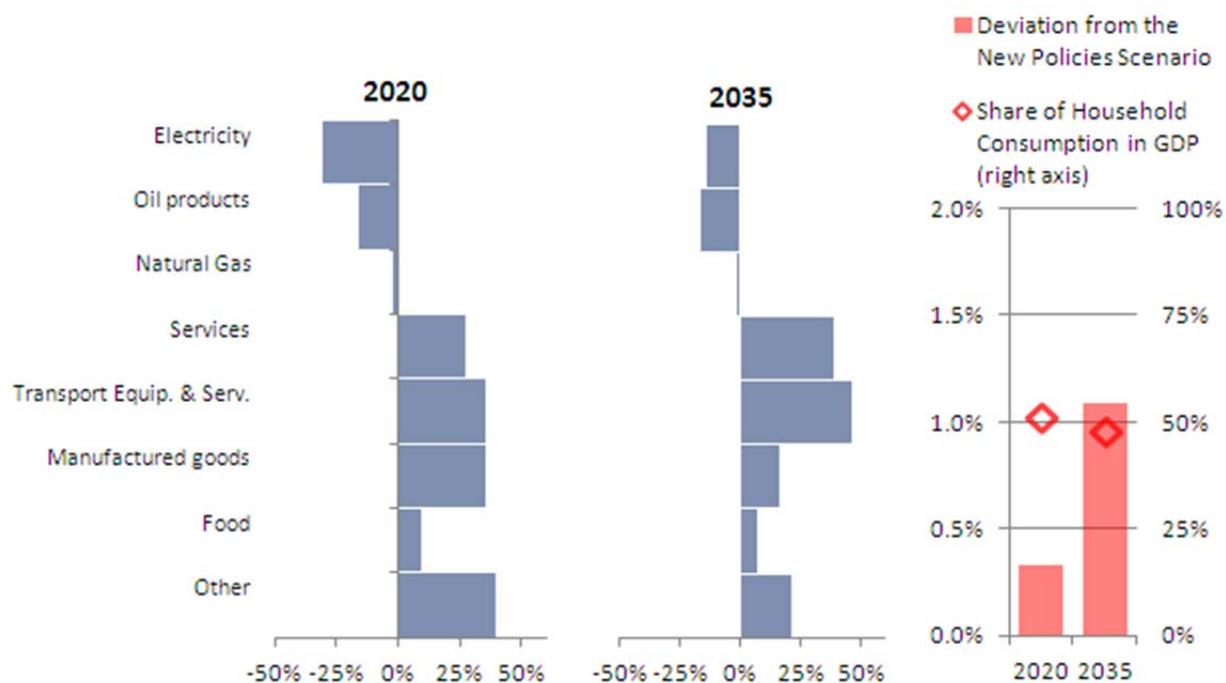
Note: Value-added measured at basic prices

Source: OECD ENV-Linkages model

World

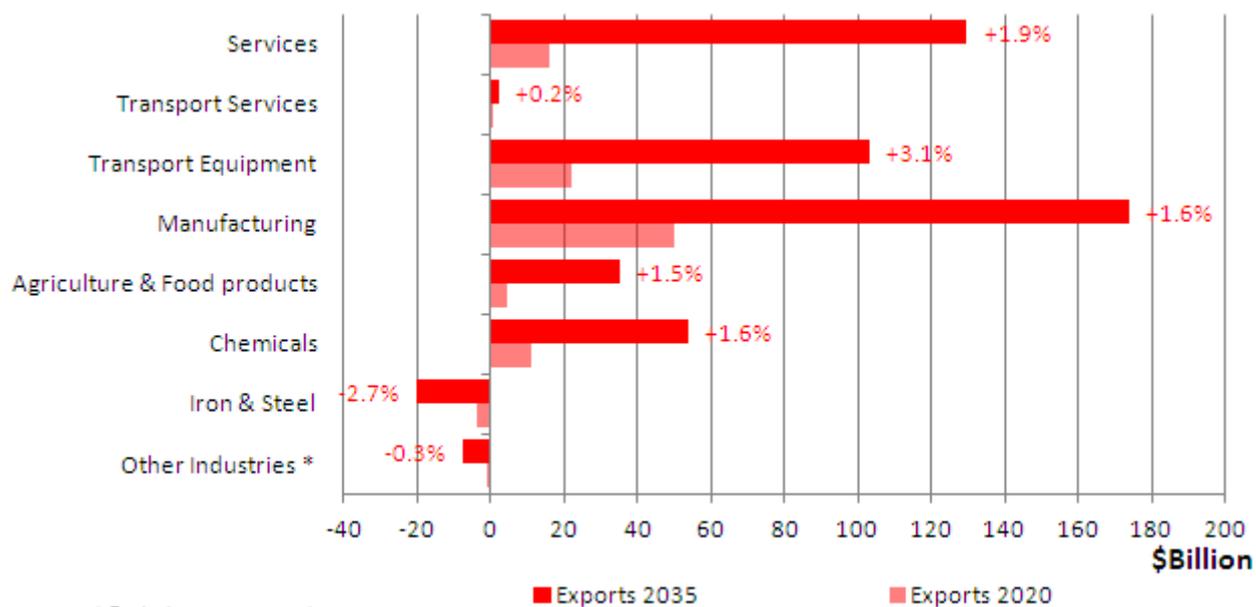
Figure 19. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 20. Per cent Change in Sectoral Trade



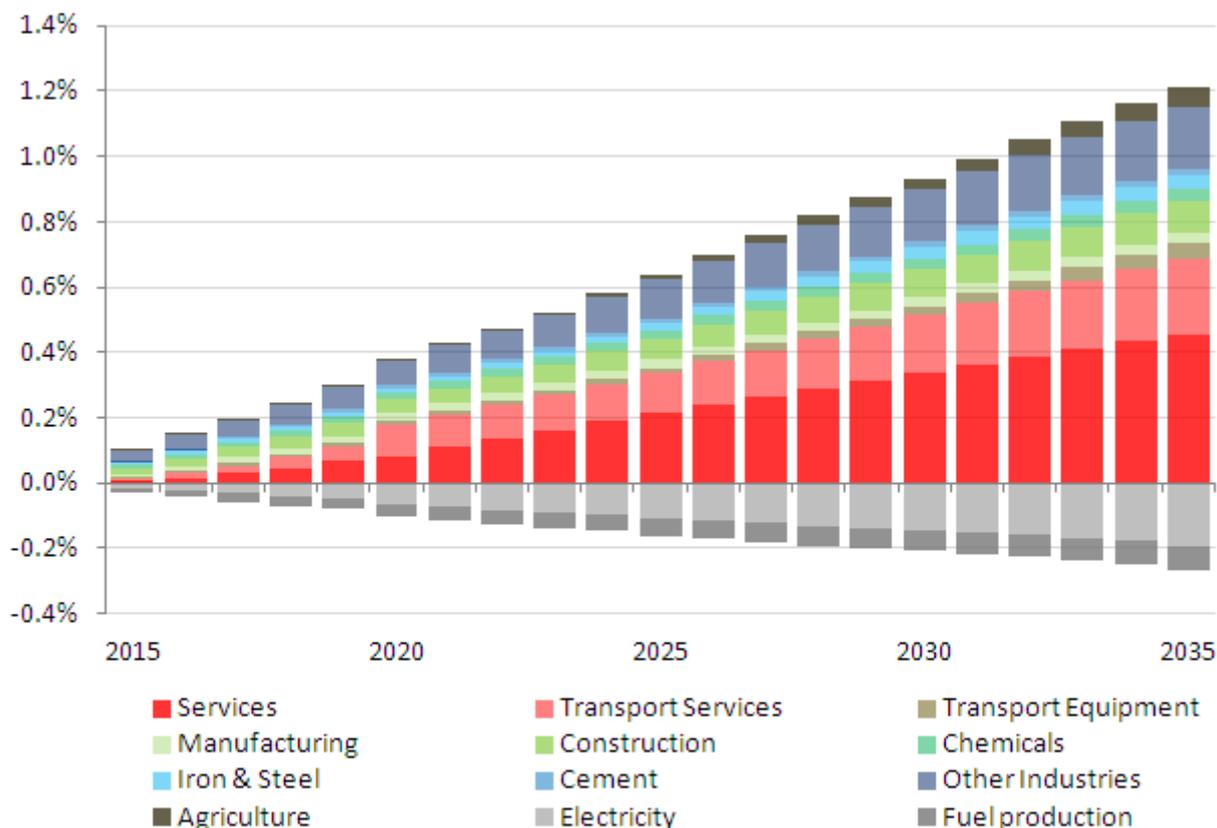
* Excludes energy trade

Source: OECD ENV-Linkages model

OECD: Key facts

- In 2035: GDP increase: +0.9% (+USD237 billion on average p.a.) / Household consumption: +1.3%
- Intermediate sectors boost economy, particularly services, embedding less energy for production
- All bilateral trade flows are impacted by policy measures

Figure 21. Per cent Change in Sectoral Real Value Added



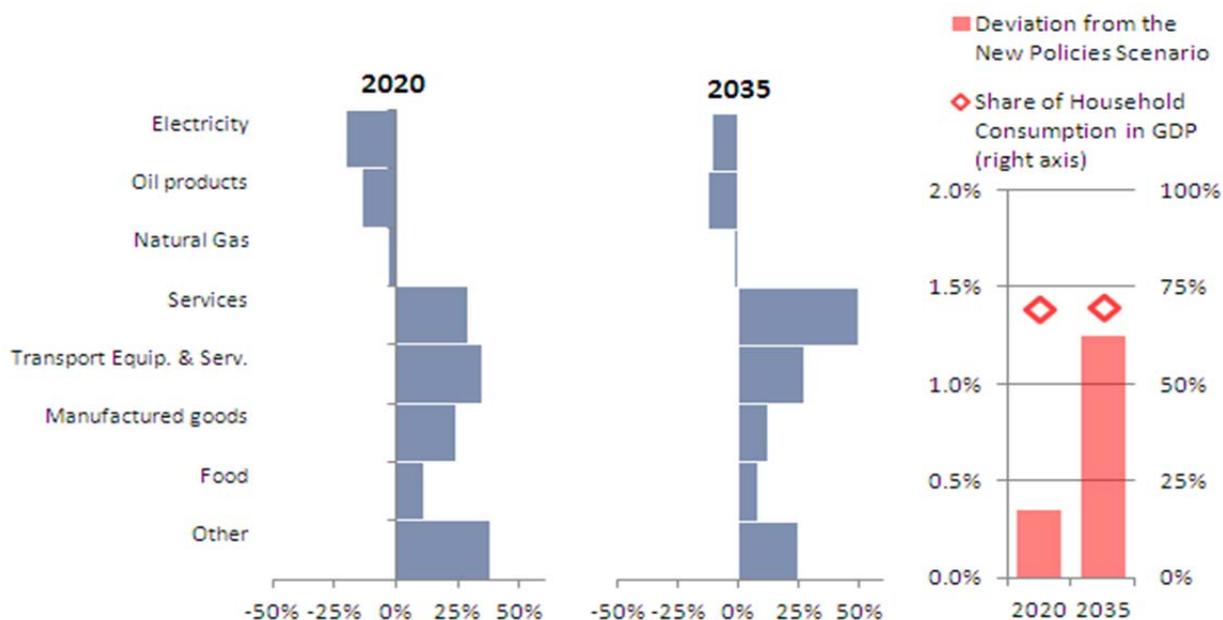
Note: Value-added measured at basic prices

Source: OECD ENV-Linkages model

OECD

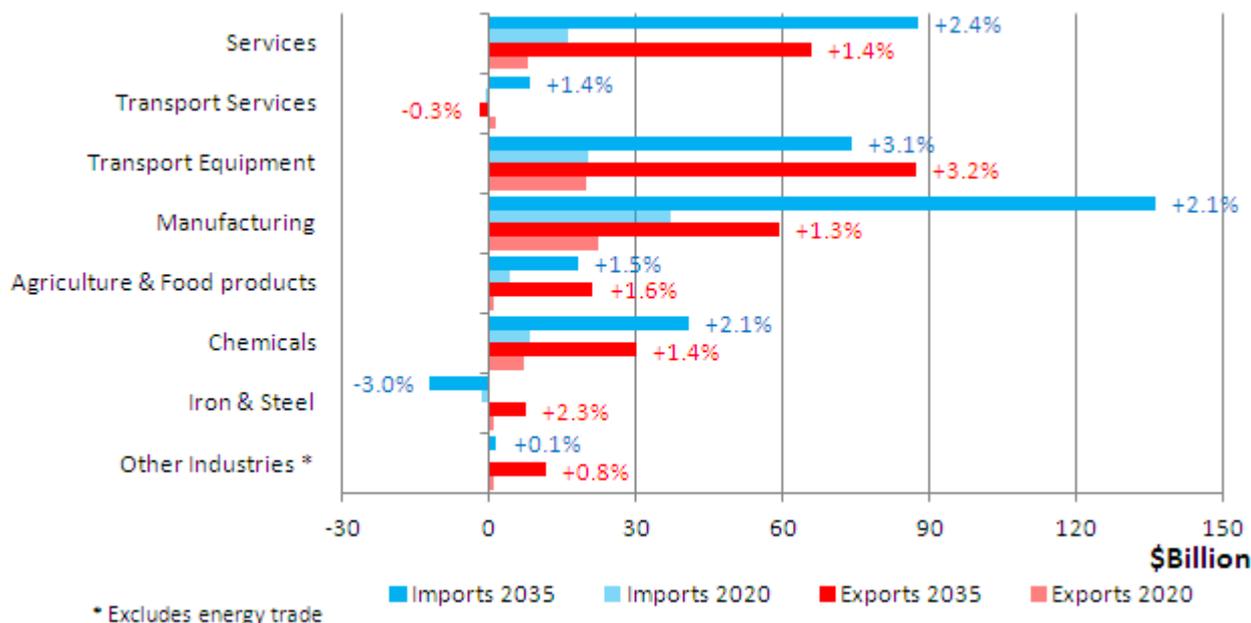
Figure 22. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 23. Per cent Change in Sectoral Trade

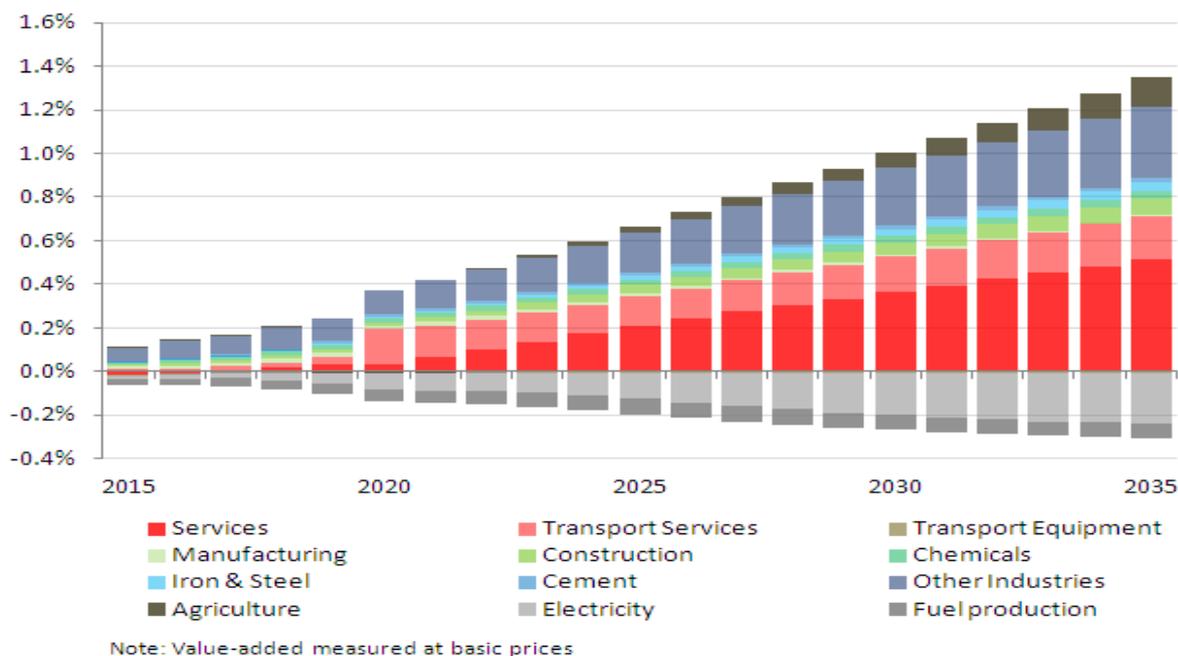


Source: OECD ENV-Linkages model

United States: Key facts

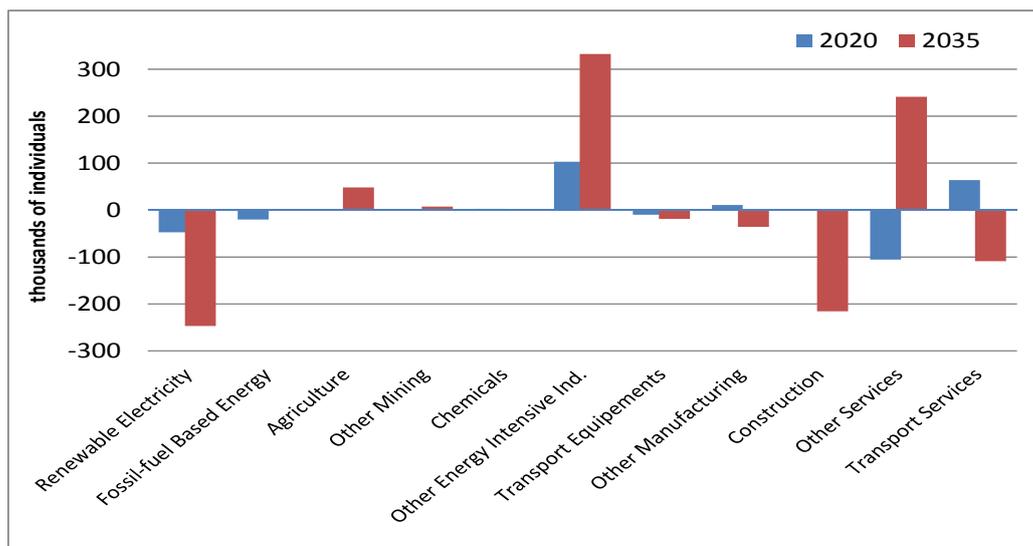
- In 2035: GDP increase: +1.3% / Household consumption: +1.7%
- Intermediate sectors boost economy. Large demand for imported manufactured products and transport equipment in 2035
- Strong stimulus of household demand for services. Domestic production supplemented by enhanced imports of services

Figure 24. Per cent Change in Sectoral Real Value Added



Source: OECD ENV-Linkages model

Figure 25. Change in Sectoral composition of employment

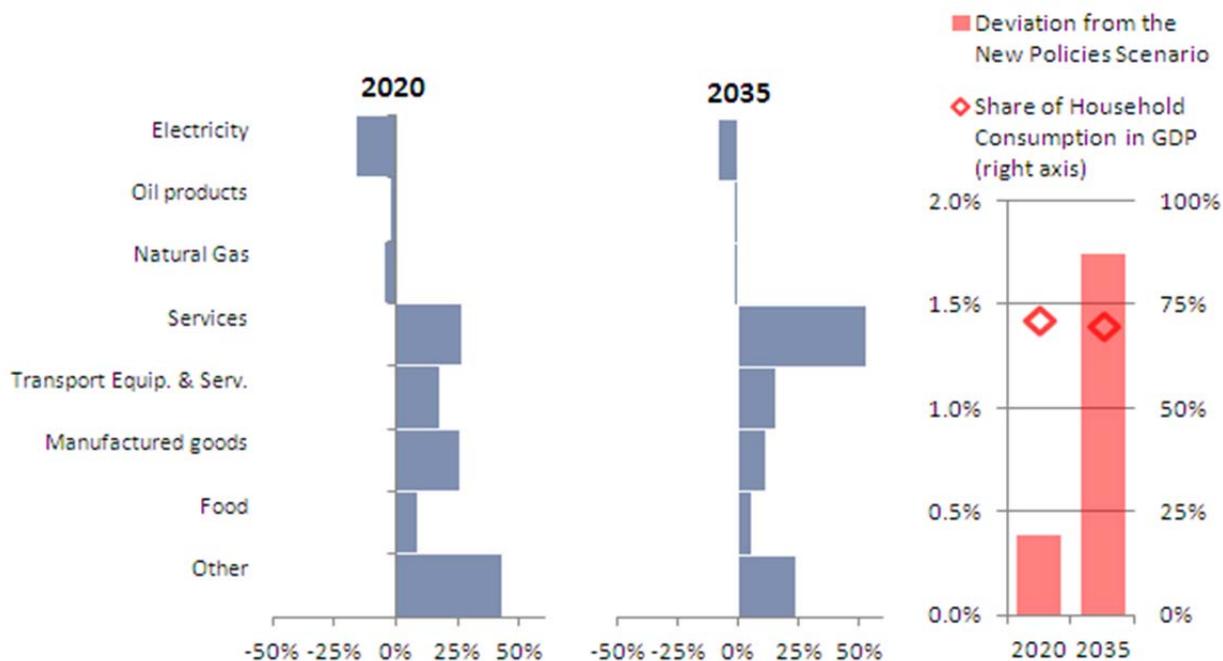


Source: OECD ENV-Linkages model

United States

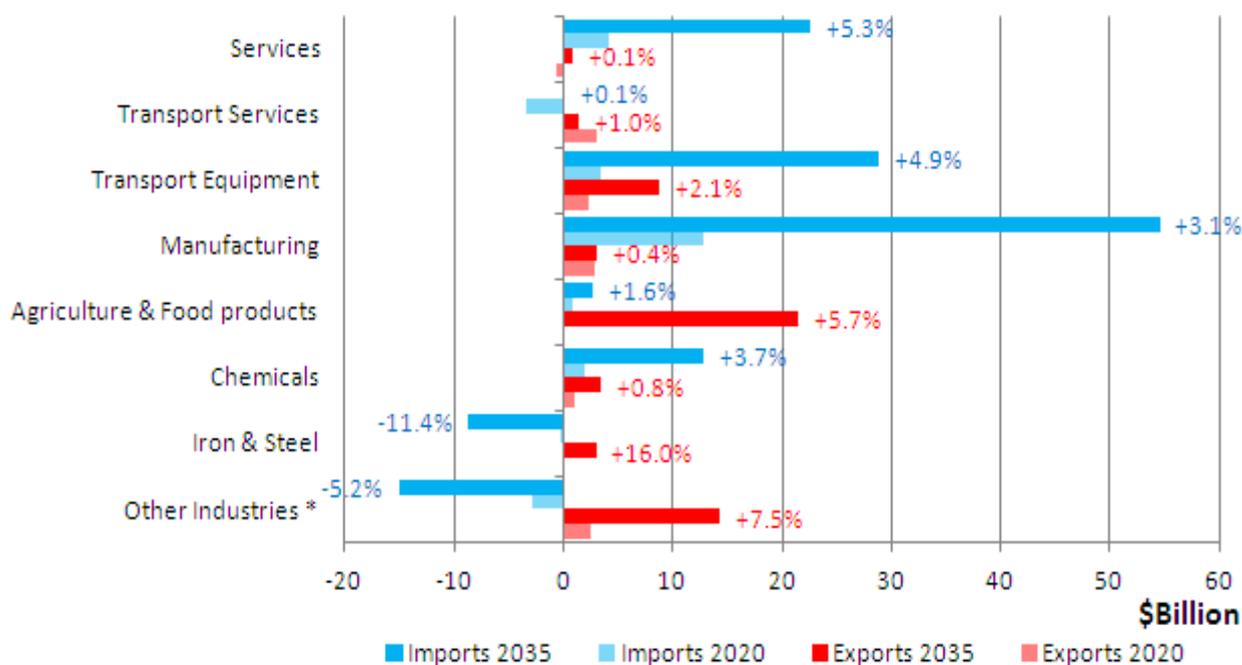
Figure 26. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 27. Per cent Change in Sectoral Trade



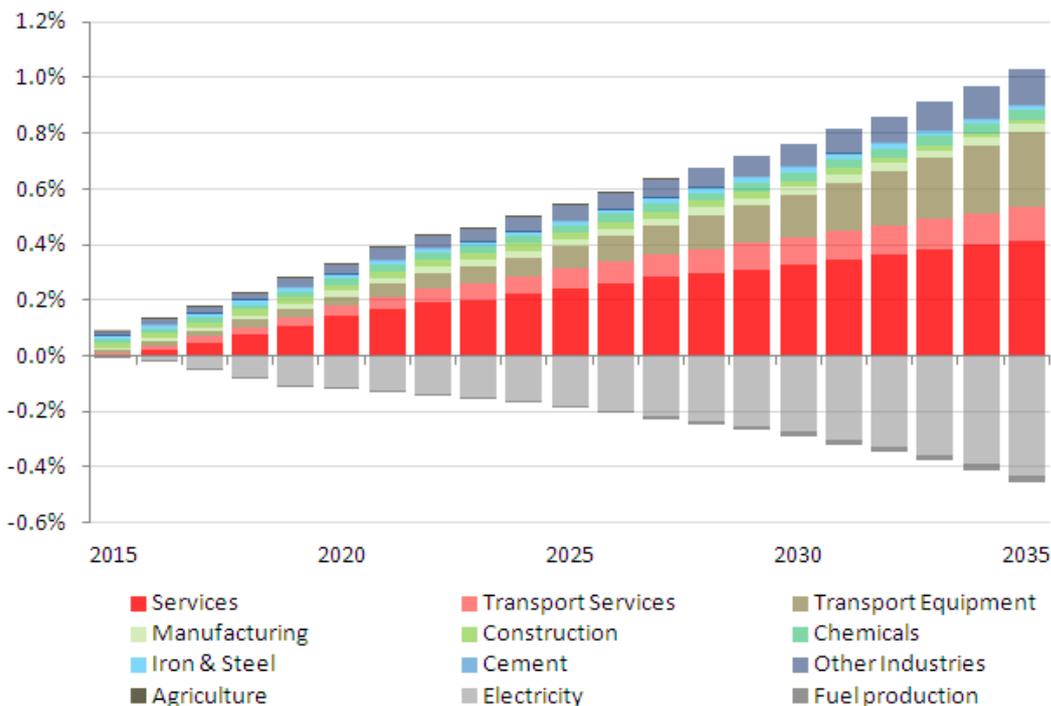
* Excludes energy trade

Source: OECD ENV-Linkages model

Japan: Key facts

- In 2035: GDP increase: +0.6% / Household consumption: +1.1%
- Large potential for energy efficiency improvement
- Large reduction of electricity demand and direct fossil fuel consumption by households
- Increased production and domestic consumption of transport equipment
- Significant increase in exports of transport equipment (+7%)

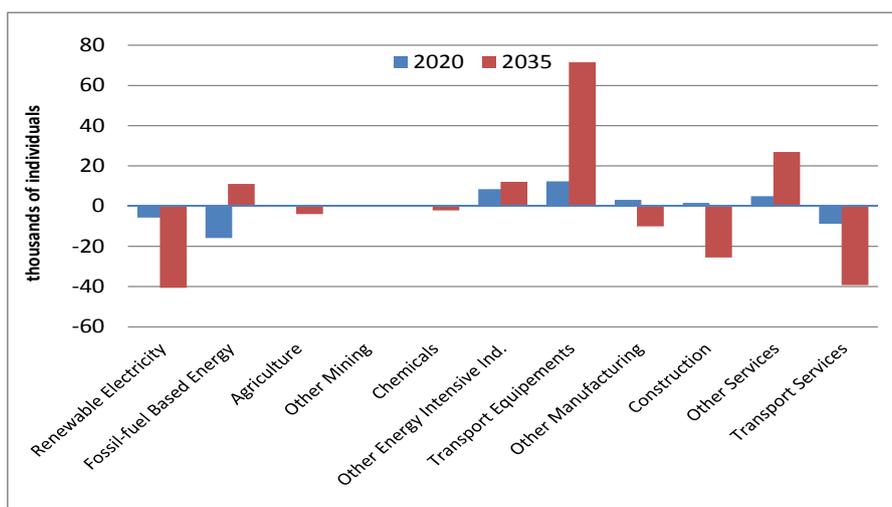
Figure 28. Per cent Change in Sectoral Real Value Added



Note: Value-added measured at basic prices

Source: OECD ENV-Linkages model

Figure 29. Change in Sectoral composition of employment

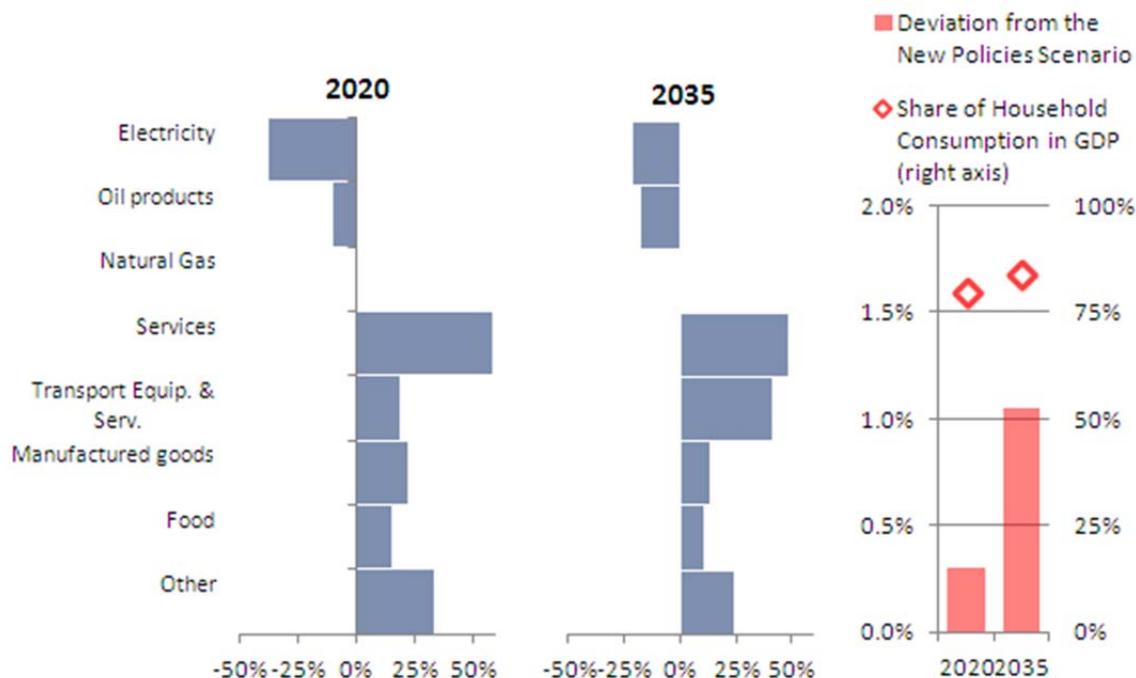


Source: OECD ENV-Linkages model

Japan

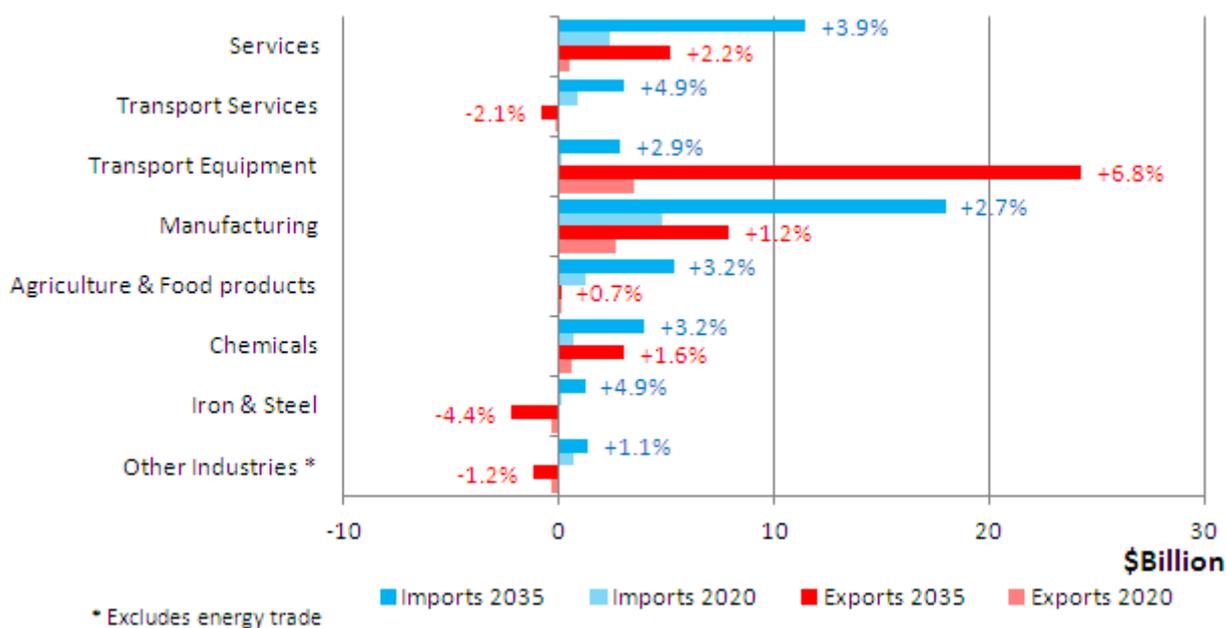
Figure 30. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 31. Per cent Change in Sectoral Trade

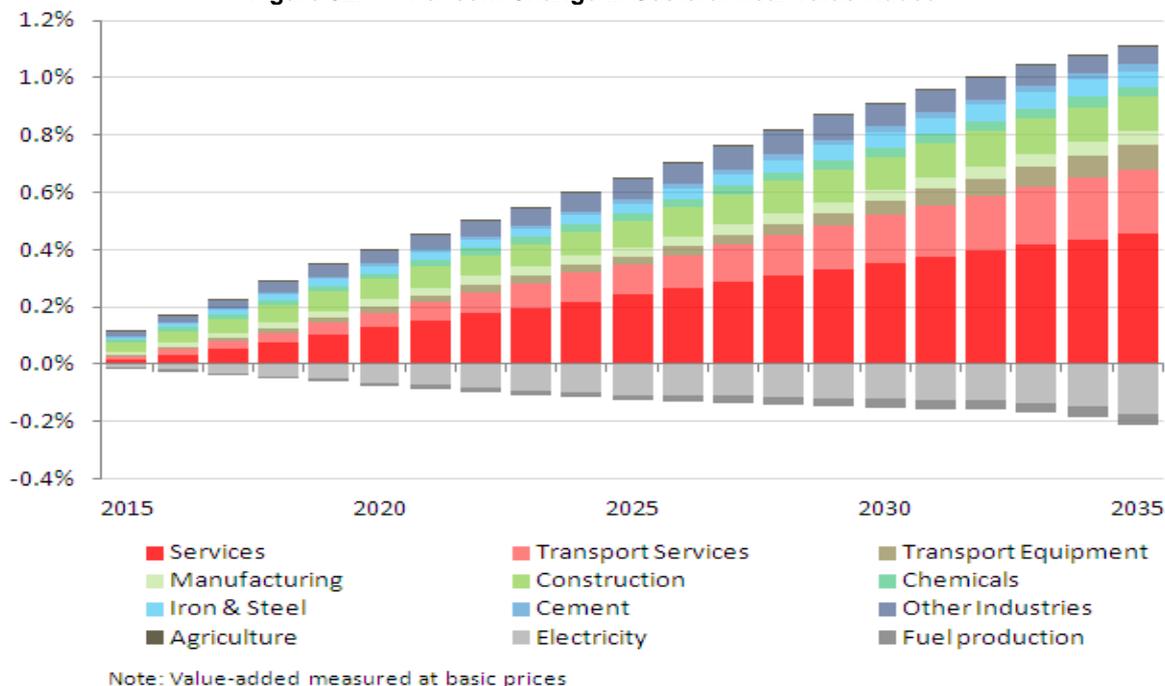


Source: OECD ENV-Linkages model

European Union: Key facts

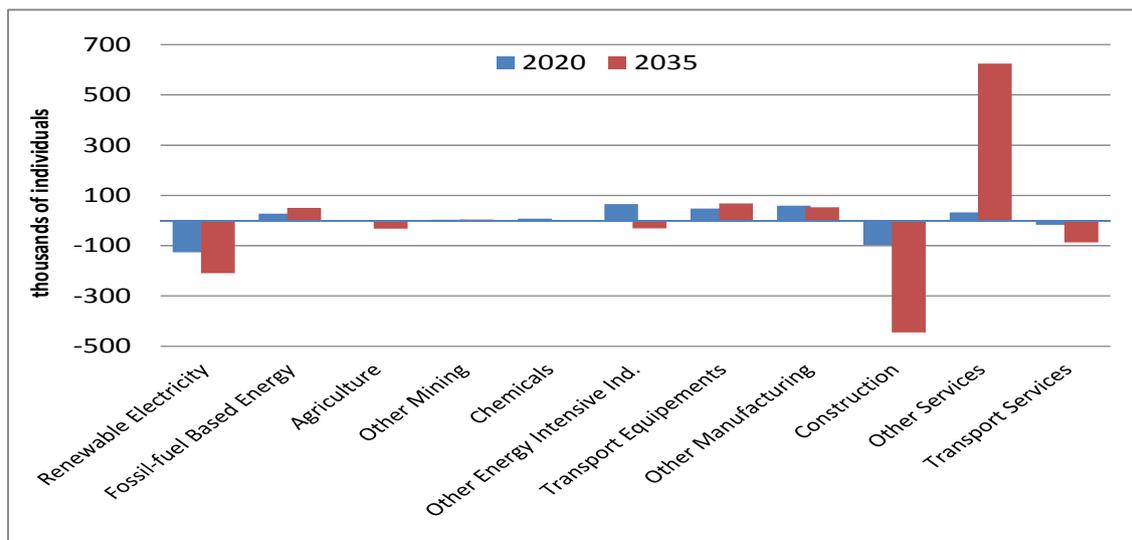
- In 2035: GDP increase: +0.7% / Household consumption: +1%
- Production of transport services encouraged by rapid uptake of energy-efficient vehicles
- Reinforced demand for imported goods, including manufactured products and services
- All trade flows (exports and imports) stimulated

Figure 32. Per cent Change in Sectoral Real Value Added



Source: OECD ENV-Linkages model

Figure 33. Change in Sectoral composition of employment

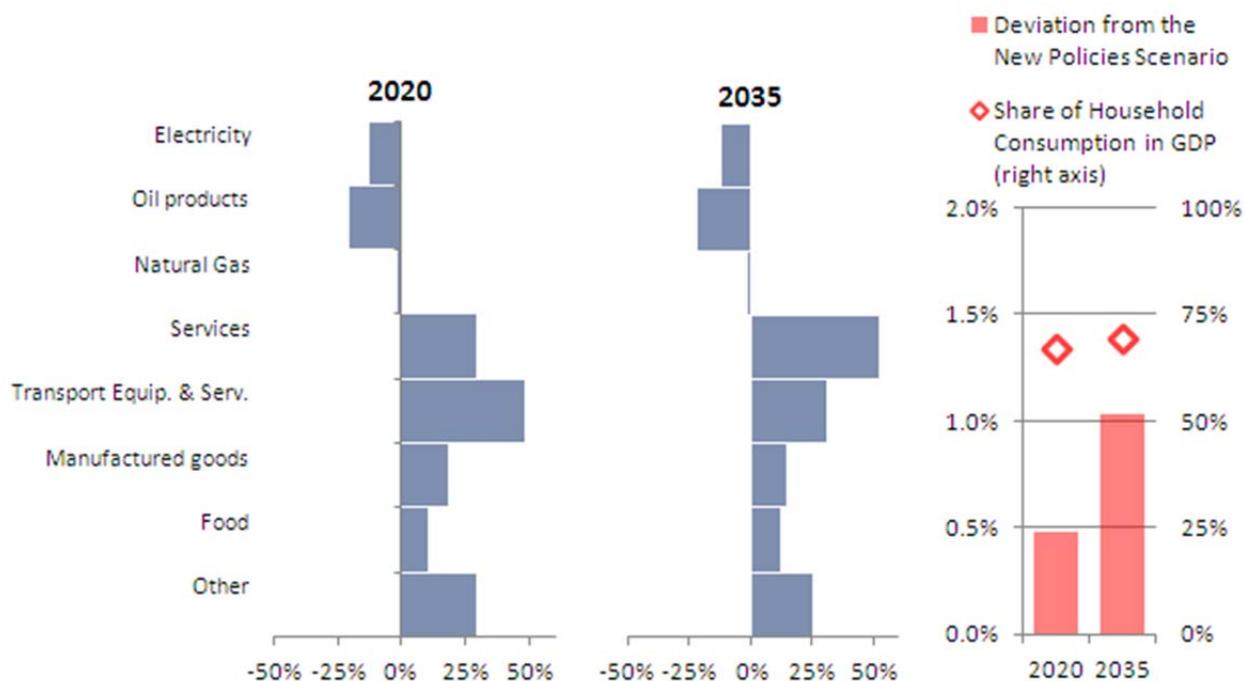


Source: OECD ENV-Linkages model

European Union

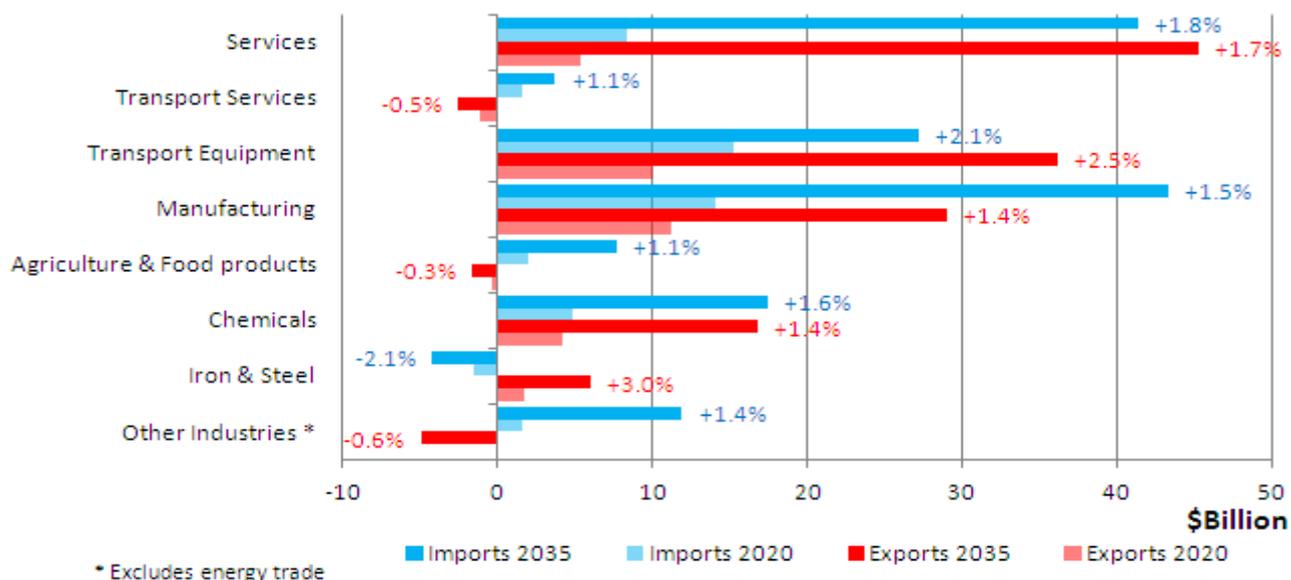
Figure 34. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 35. Per cent Change in Sectoral Trade

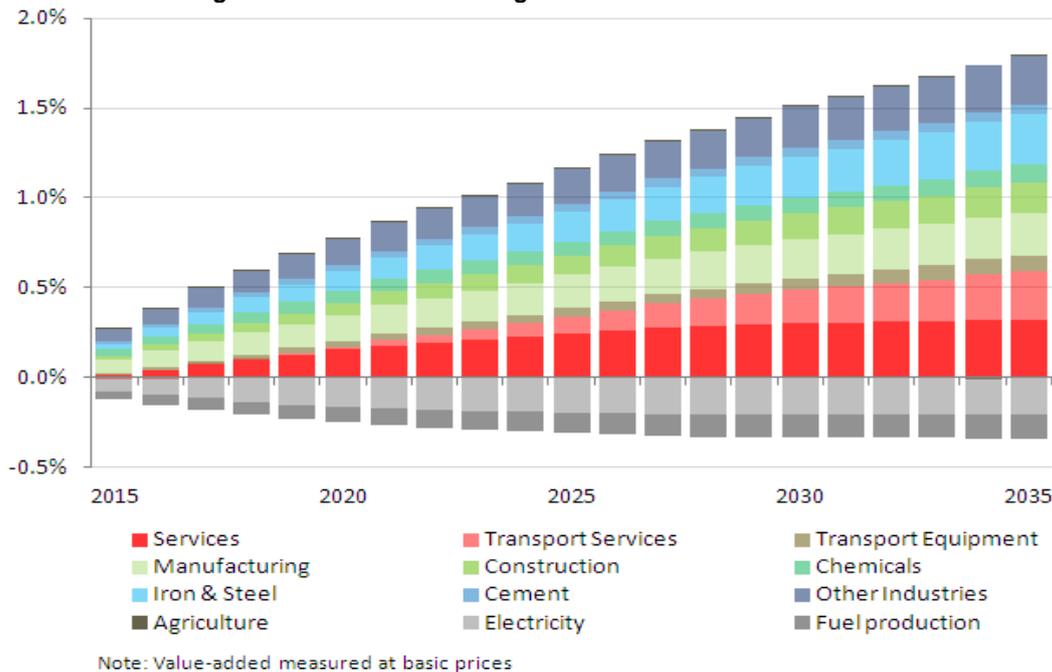


Source: OECD ENV-Linkages model

China: Key facts

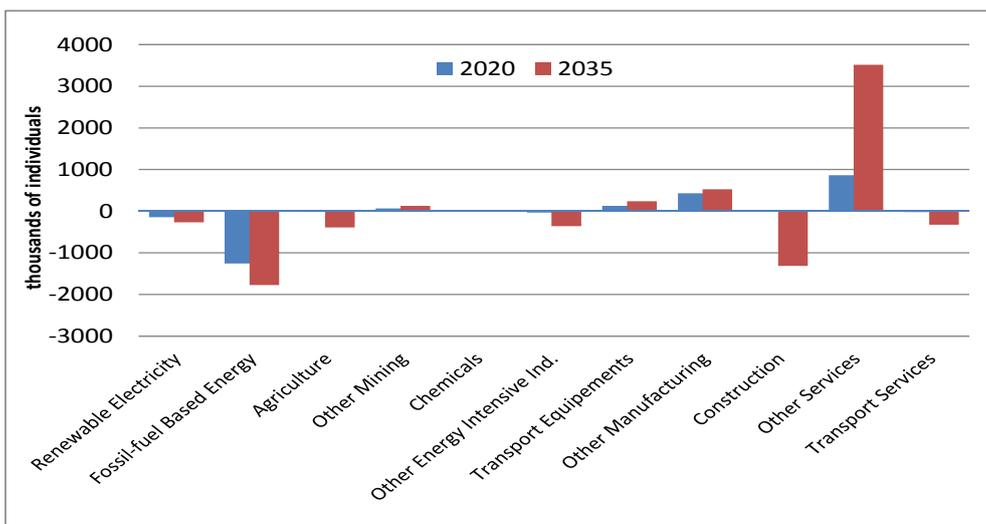
- In 2035: GDP increase: +1.4% / Household consumption: +2.5%
- Increased household spending
- Acceleration of economic development, mainly driven by boosted industrial
- Extra domestic demand for services supplied by increased imports
- Boosted demand for imported services (+5%), and on imported transport equipment (+6%)

Figure 36. Per cent Change in Sectoral Real Value Added



Source: OECD ENV-Linkages model

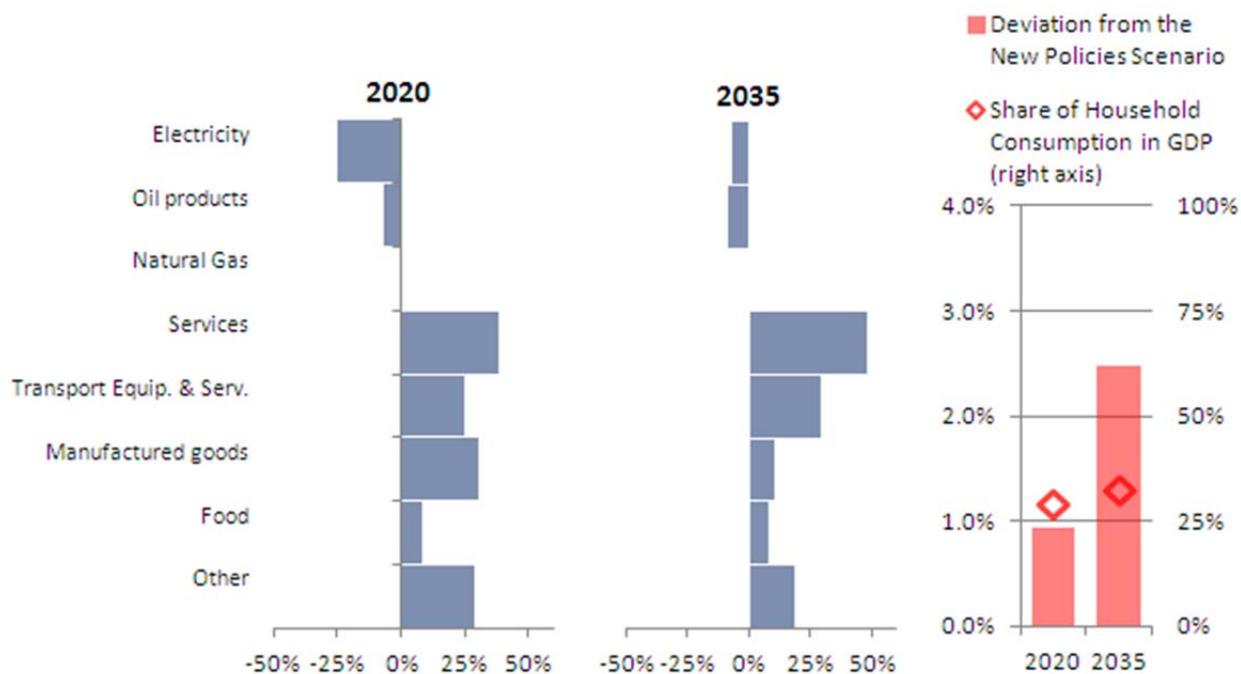
Figure 37. Change in Sectoral composition of employment



Source: OECD ENV-Linkages model

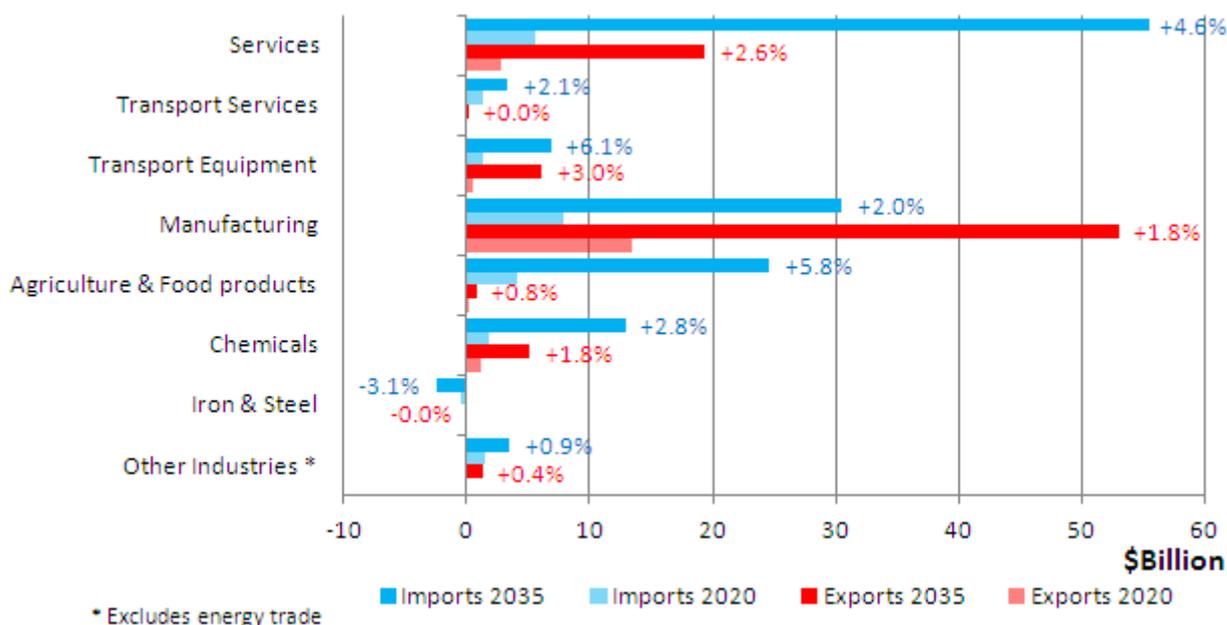
China

Figure 38. Per cent deviation in household real consumption patterns
 Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 39. Per cent Change in Sectoral Trade

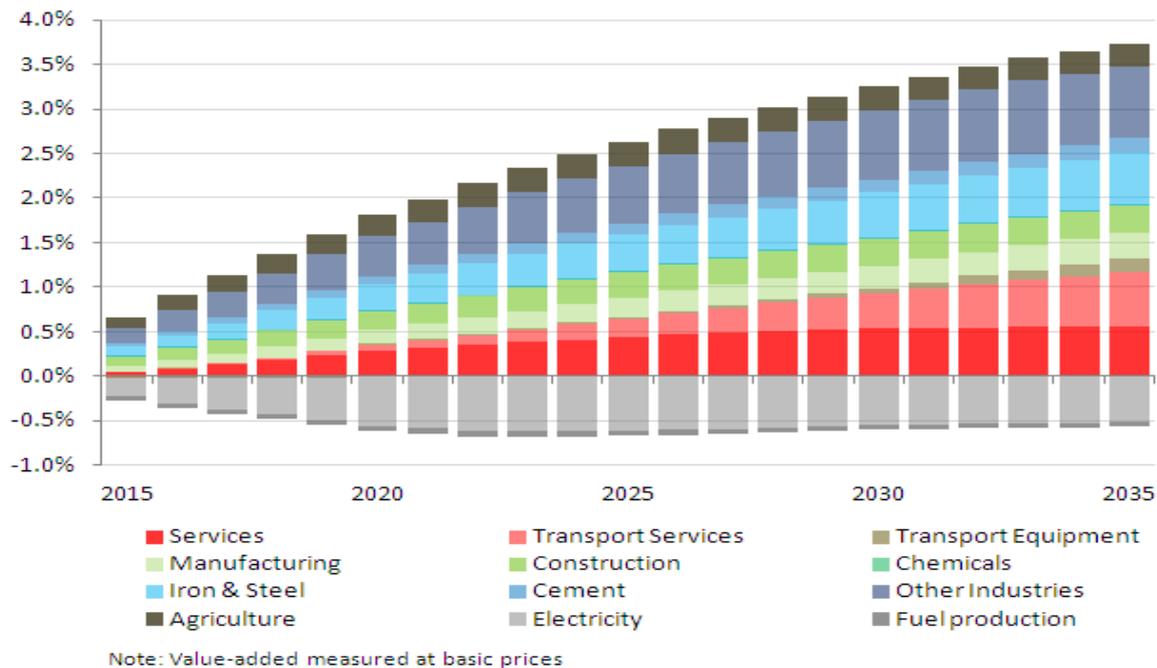


Source: OECD ENV-Linkages model

India: Key facts

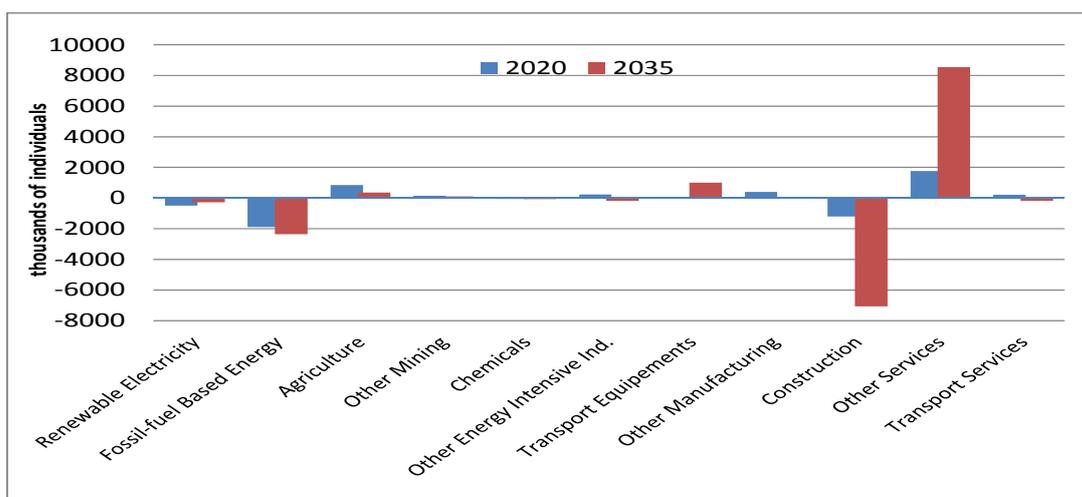
- In 2035: GDP increase: +3.9% / Household consumption: +5.5%
- Strong policy stimulus on overall economic activity
- Specialisation in heavy, energy-intensive industries
- Strong stimulation of imported goods, but starting from low volumes in transport equipments (+35%), services (+11%) or chemicals (+10%)

Figure 40. Per cent Change in Sectoral Real Value Added



Source: OECD ENV-Linkages model

Figure 41. Change in Sectoral composition of employment

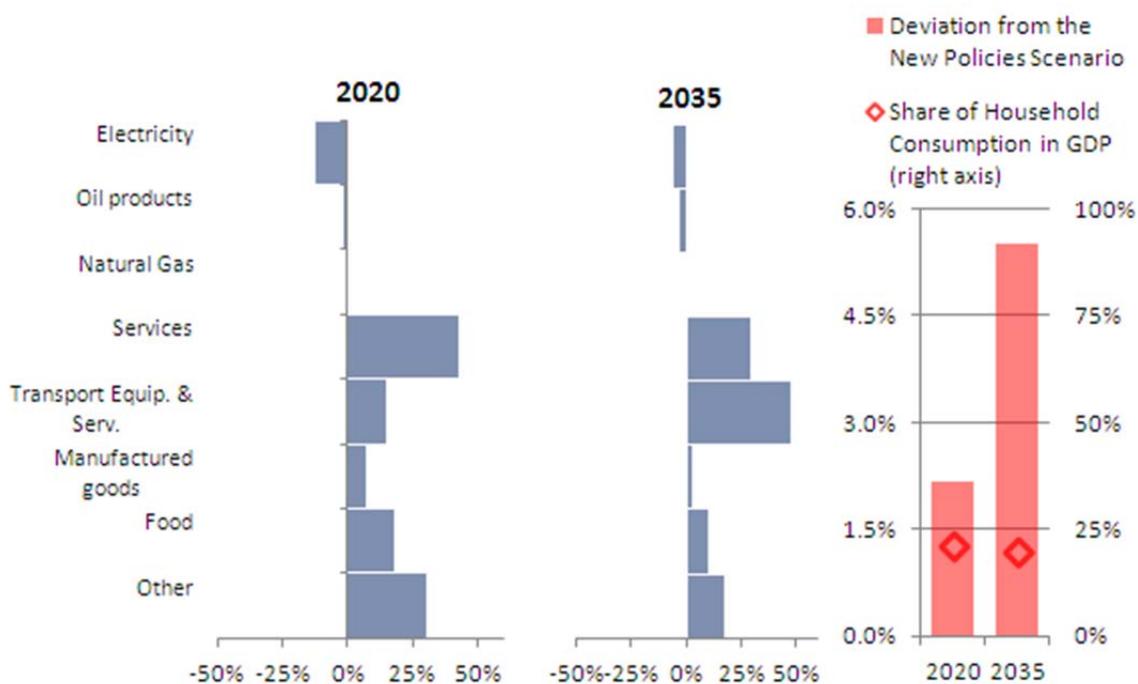


Source: OECD ENV-Linkages model

India

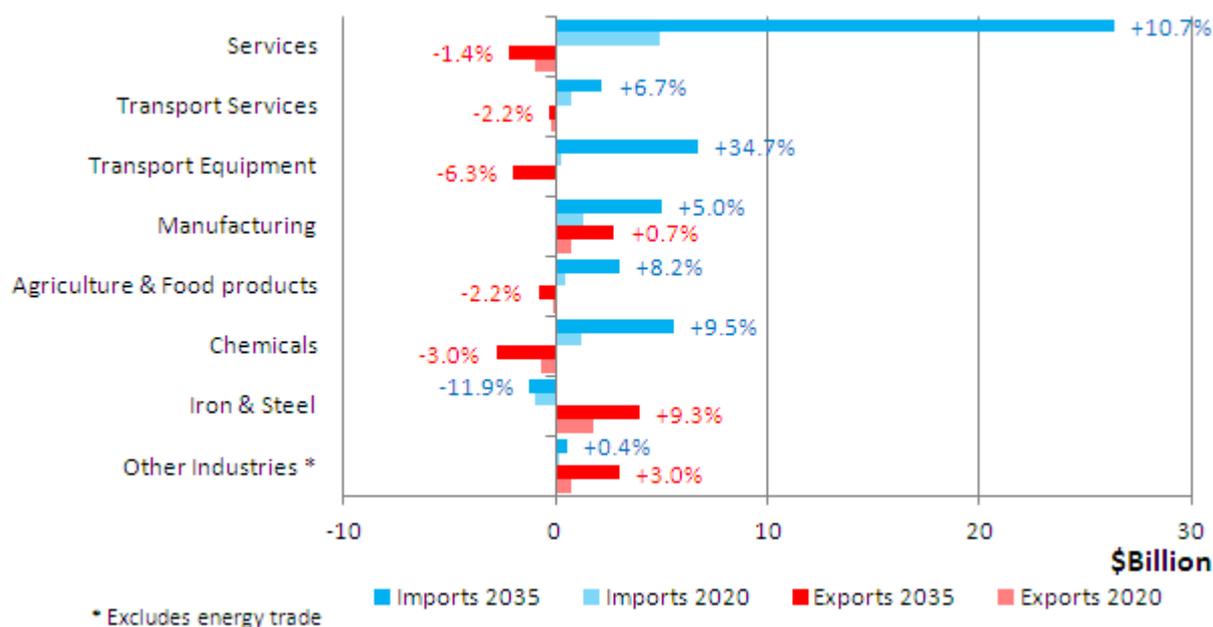
Figure 42. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 43. Per cent Change in Sectoral Trade

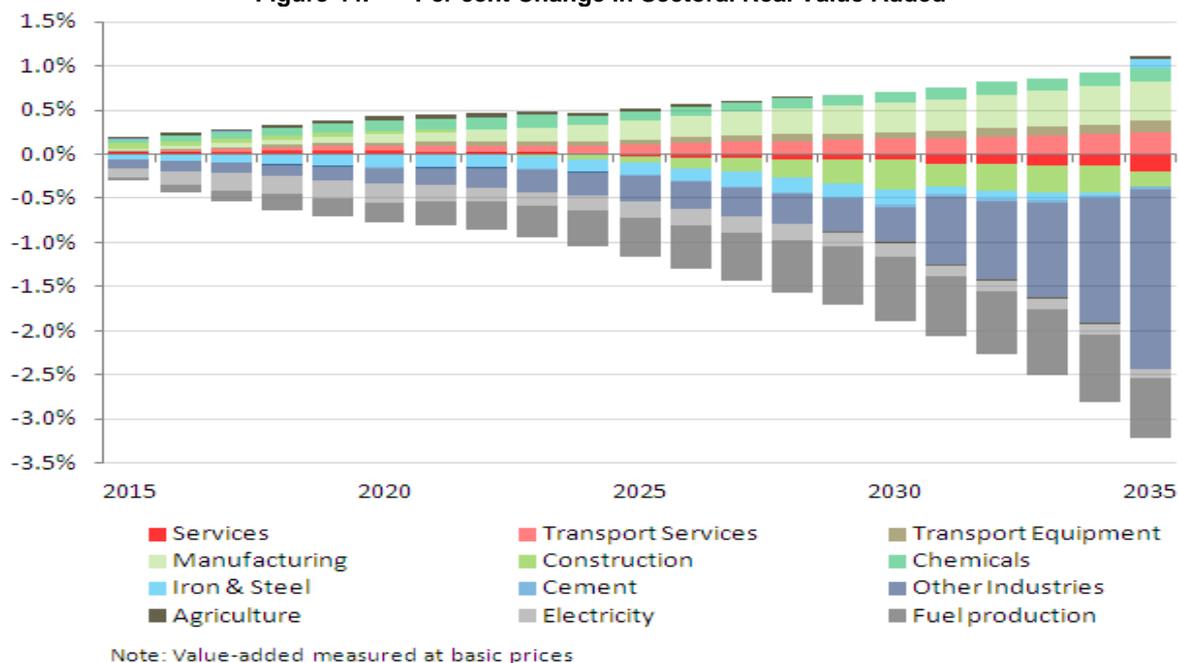


Source: OECD ENV-Linkages model

Russia: Key facts

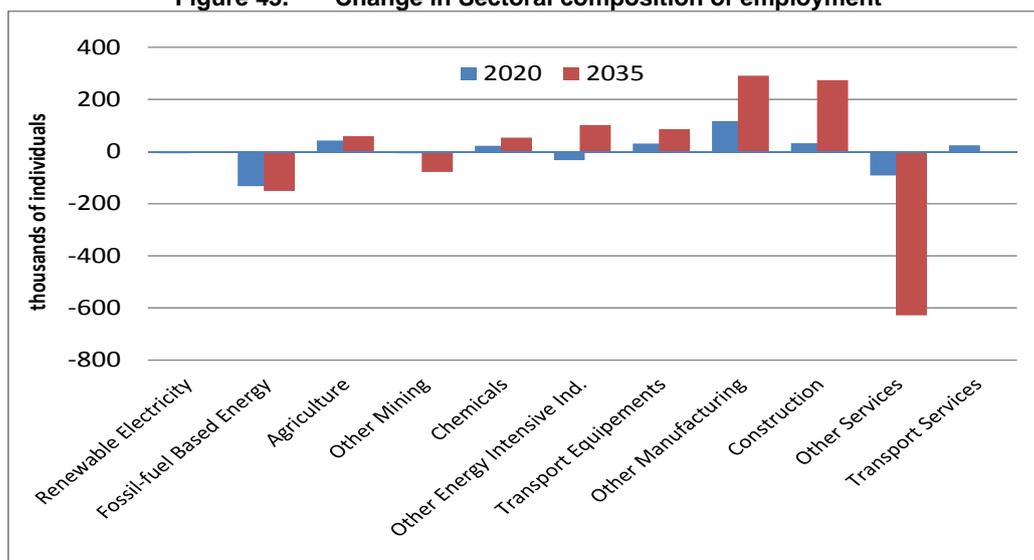
- In 2035: GDP increase: -2.9% / Household consumption: -4.8%
- Large slowdown of economic activity due to sizable reduction in energy export revenues
- Manifest policy stimulation of construction sectors thanks to investment-induced buildings refurbishment, insulation enhancement and rationalized energy consumption
- Large impact on trade flows: cheaper domestic production and lower demand encourages exports

Figure 44. Per cent Change in Sectoral Real Value Added



Source: OECD ENV-Linkages model

Figure 45. Change in Sectoral composition of employment

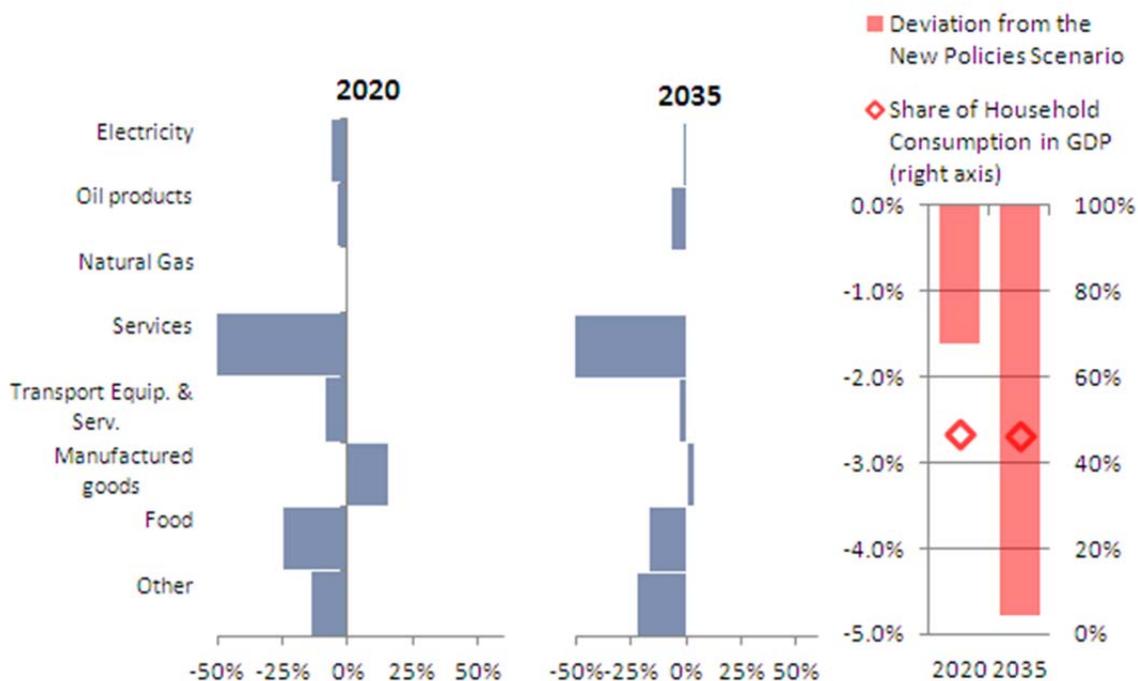


Source: OECD ENV-Linkages model

Russia

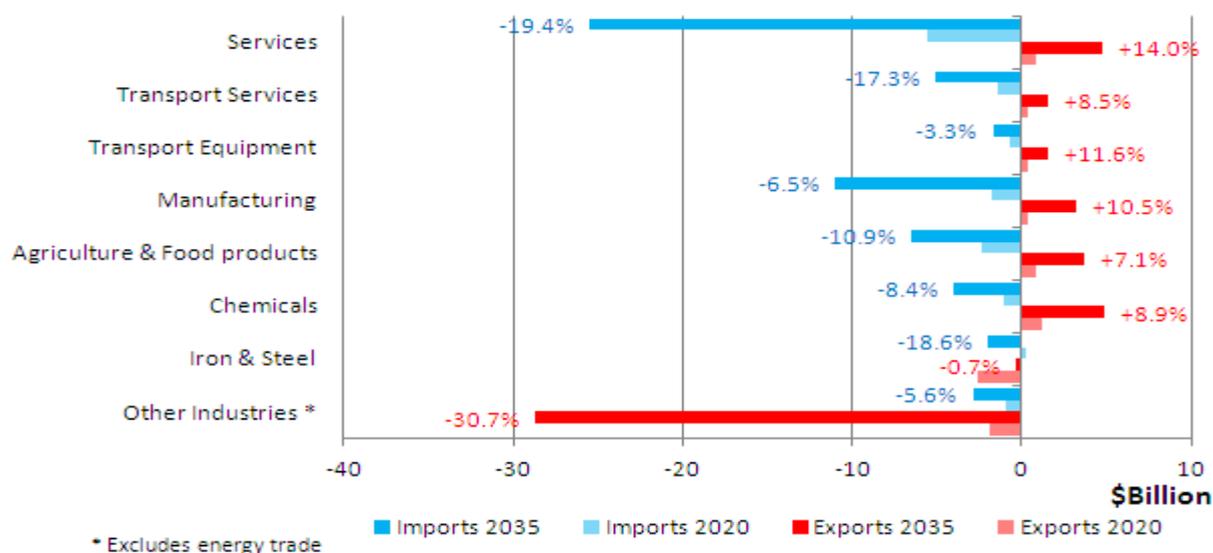
Figure 46. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 47. Per cent Change in Sectoral Trade

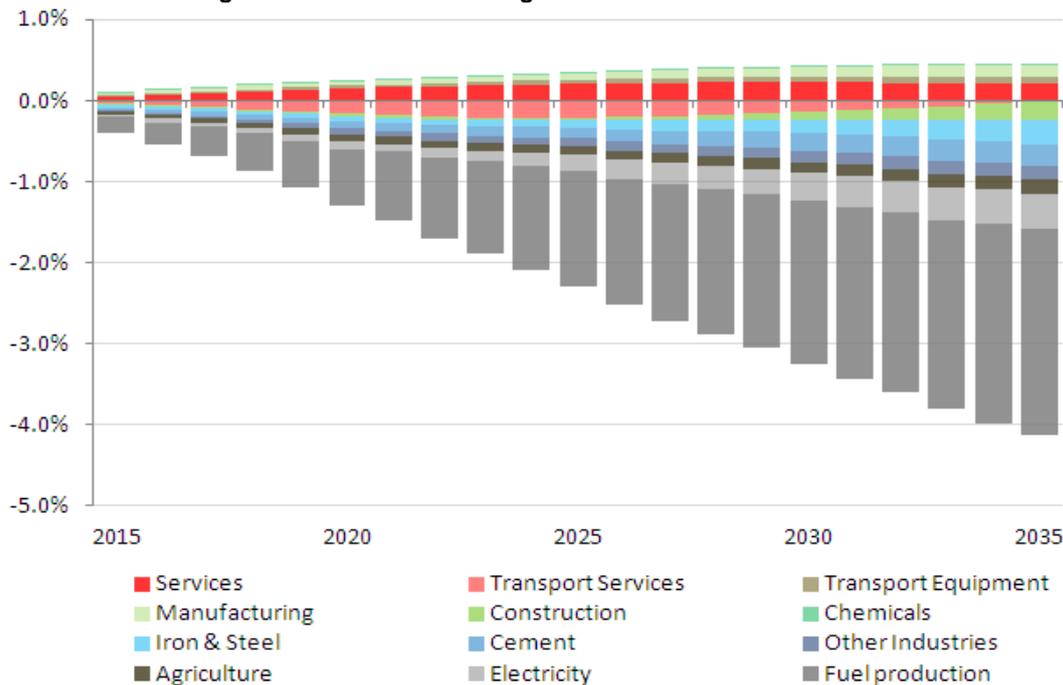


Source: OECD ENV-Linkages model

Middle East: Key facts

- In 2035: GDP increase: -3.8% / Household consumption: -7.8%
- General slowdown of economic activity due to reduction in energy export revenues, relative to the NPS. In absolute terms, Middle East economy grows on average at 3.8% per annum between 2010 and 2035.
- Reduced domestic demand reduces demand for imported goods. Cheaper domestic production of services encourages exports (+13%)

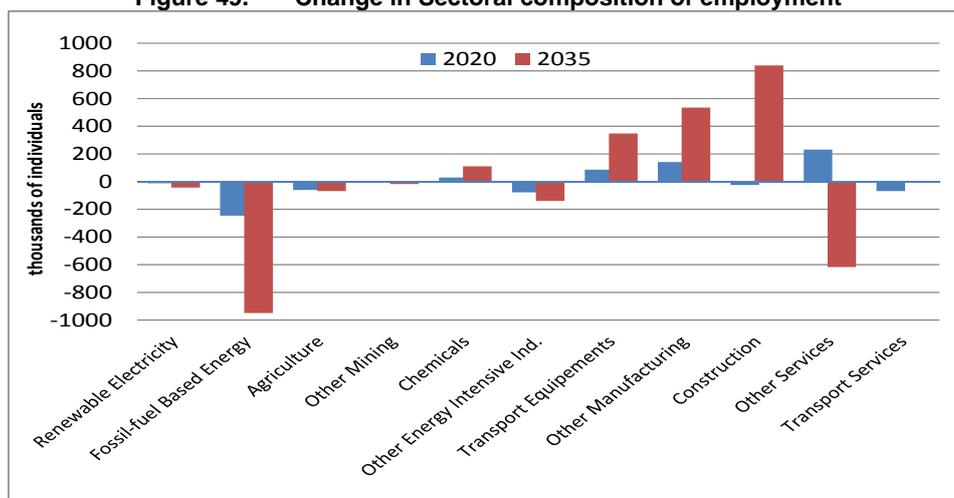
Figure 48. Per cent Change in Sectoral Real Value Added



Note: Value-added measured at basic prices

Source: OECD ENV-Linkages model

Figure 49. Change in Sectoral composition of employment

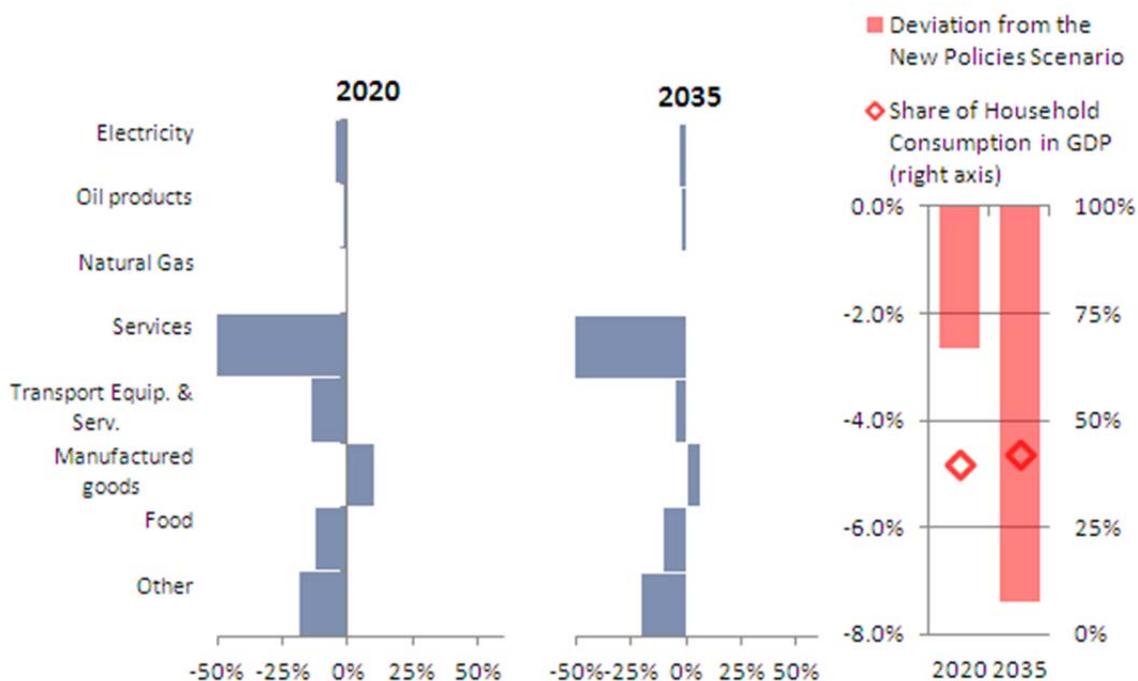


Source: OECD ENV-Linkages model

Middle East

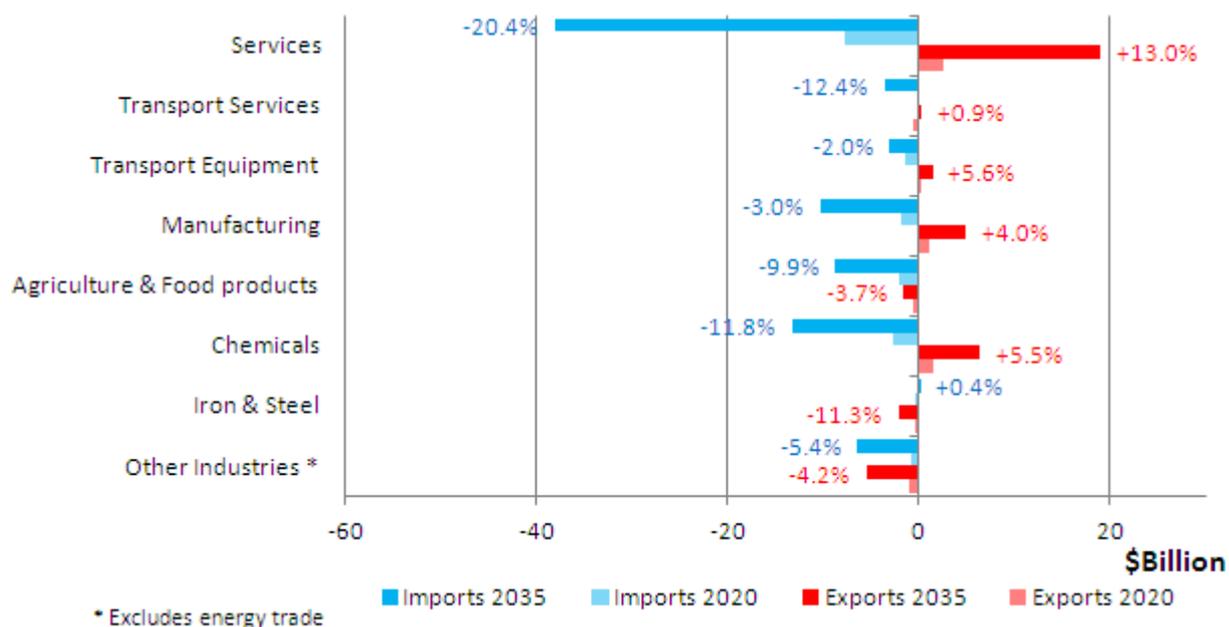
Figure 50. Per cent deviation in household real consumption patterns

Changes in consumption by goods or services (left panel) / Changes in overall consumption (right panel)



Source: OECD ENV-Linkages model

Figure 51. Per cent Change in Sectoral Trade



Source: OECD ENV-Linkages model

3.6 Sensitivity analysis: Impact of fossil fuel subsidy reform

The Efficient World Scenario stipulates the accelerated multilateral reform of fossil fuel consumption subsidies in emerging and developing economies relative to the New Policies Scenario¹¹. This section aims to assess the impact of the reform on the global patterns depicted earlier. The sensitivity analysis consists in fixing subsidisation rates at the same levels as is used in the New Policies Scenario in order to isolate the sole impact of enhanced energy efficiency investments. Fossil fuel consumption subsidies are thus phased out in all net-importing regions, by 2020 at the latest, and in net-exporting regions where specific policies have already been announced. Other policy assumptions are unchanged. These dedicated investments are assumed unchanged in this alternative scenario and remain an effective instrument to foster the adoption of more energy-efficient appliances and production modes. Of particular importance in the context of the Efficient World Scenario are the impacts on Russia, countries of the Middle East and of the Caspian Sea region¹², and North Africa, as they currently exhibit the highest levels of fossil fuel consumption subsidies (IEA, 2012). In this alternative scenario, household demand levels and energy demand from productive intermediate sectors now reacts endogenously to changes in relative prices after the modified reform. For the sake of simplicity, the analysis is restricted to changes in primary consumption of fossil fuels and corresponding GDP changes in selected countries.

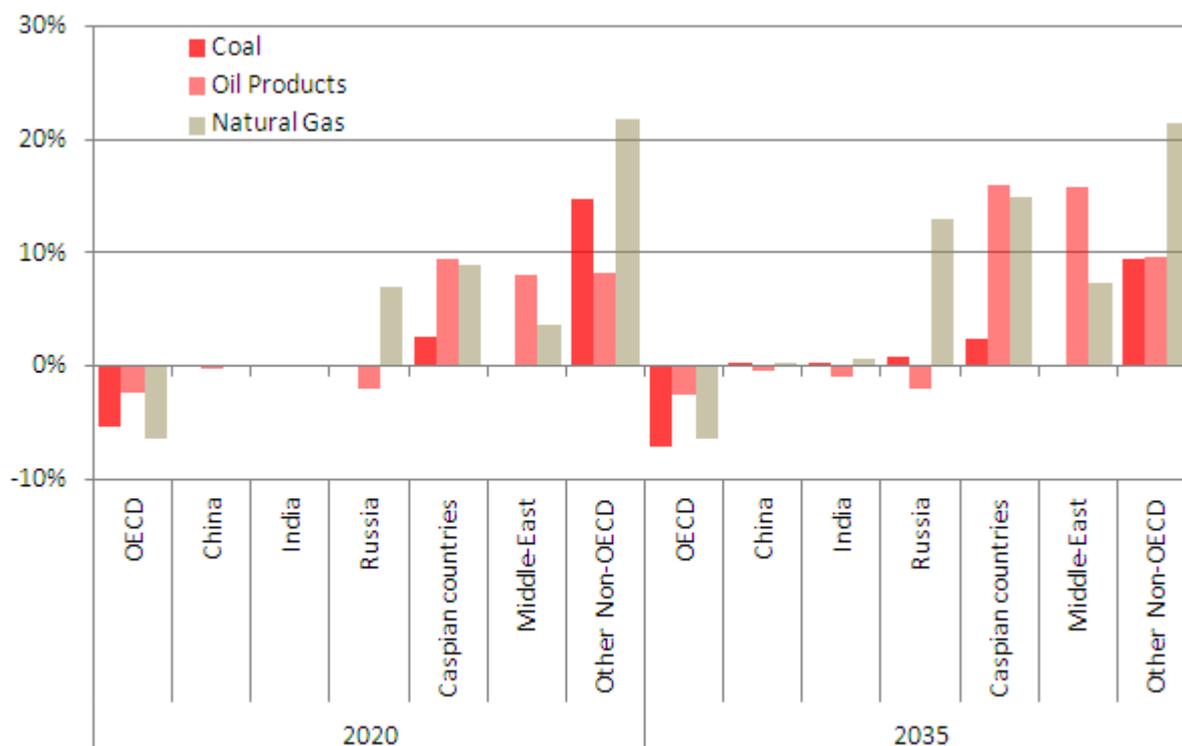
Assuming a slower implementation of the fossil fuel subsidy reform decreases domestic prices of fossil fuels in the (mainly non-OECD) countries conducting the reforms. This decrease stimulates global demand for fossil fuel energy (Figure 18). In this alternative scenario, higher global demand raises international oil price by more than 10% by 2035 relative to Efficient World Scenario level, although the 2035 oil price still remains below the New Policies Scenario level (USD 125 per barrel in real terms). Natural gas and coal reference prices also grow by about 5% and 1% respectively. The percentage deviation in domestic energy demand tends to augment between 2020 and 2035 when the pace of fossil fuel subsidy reform is slower.

Maintaining higher subsidy levels in Russian consumption of electricity and natural gas through 2035 mainly encourages overall Russian natural gas consumption, to the detriment of oil products and coal. Middle-East countries, whose average subsidisation rate of fossil fuel consumption currently amounts to 80%, see a net increase in their oil consumption by 8% in 2020. The reaction to cheaper domestic oil prices in the longer run is reinforced to reach an additional 16% of oil consumption by 2035 relative to the Efficient World Scenario. A slower fossil fuel subsidy reform in Caspian countries also causes an increase of over 15% in their consumption of oil products and natural gas. Other non-OECD fossil fuel consumption appears particularly responsive to higher subsidisation rates. Their natural gas consumption is notably pushed by an extra 22% as early as 2020, corresponding to an additional 140 Mtoe.

Conversely, coal and natural gas consumption in OECD countries diminishes by about 6% in 2035, as these net importers of fossil fuel energy are only indirectly affected, especially by international price increases. This reduction of almost 200 Mtoe corresponds to about a quarter of the coal currently consumed in OECD countries. However, strengthened demand for fossil fuel energy in non-OECD countries more than offsets energy savings in OECD countries. Overall, reducing the pace of fossil fuel subsidy reform leads to a global 0.7 % and 1.4% increase in total primary energy consumption in 2020 and 2035, respectively, to the detriment of reduced energy consumption objectives.

¹¹ In recent years, the OECD ENV-linkages model has been used extensively to pinpoint the global economic benefits of reforming existing subsidies on fossil fuel consumption (Burniaux and Chateau, 2011, Burniaux *et al.*, 2011, Magné *et al.*, 2014).

¹² According to WEO regional disaggregation, countries of the Caspian region include Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan.

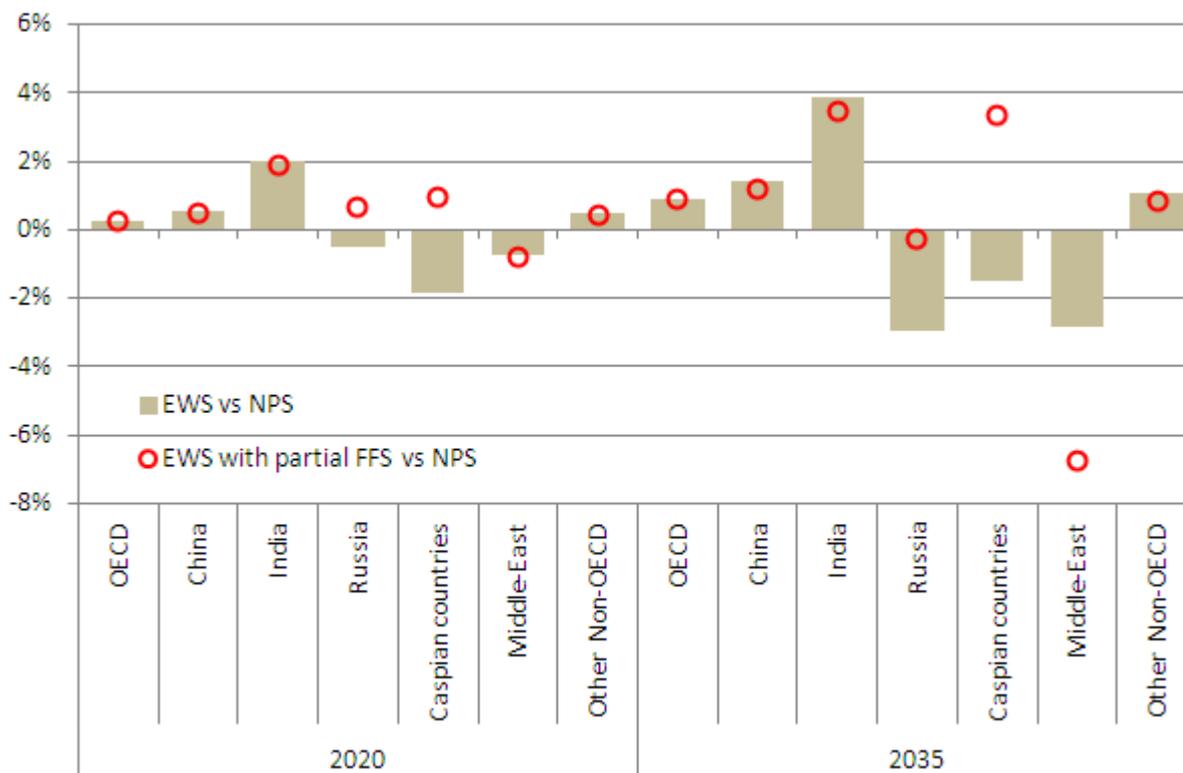
Figure 52. Per cent change in primary fossil fuel consumption with slower fossil fuel subsidy reform

Source: OECD ENV-Linkages model

The alternative subsidy scenario translates into an insignificant reduction in OECD GDP gains compared to the Efficient World Scenario (Figure 19). In China and India, economic drivers such as fast-growing populations and high rates of technological development coupled with specific energy efficient measures are predominant, leaving their GDP growth rates almost unchanged. Middle East countries, whose oil and natural gas breakeven production costs are the lowest in the world (IEA, 2012), are the principal beneficiaries of an accelerated, global reform of fossil fuel consumption subsidies as assumed in the Efficient World Scenario (see also Magné *et al.* 2014 for a detailed discussion of economic implications of fossil fuel subsidy reform using the same modelling framework). In the alternative scenario, less ambitious reform on fossil fuel consumption subsidies is detrimental to Middle East countries whose reduction is GDP relative to the New Policies Scenario almost doubles in 2035 (-6.7% in this alternative case vs -2.8% in the Efficient World Scenario). Increased international fossil fuel prices allow other countries, notably Russia and Caspian countries, to increase their shares in global supply, thereby forcing Middle East countries to lose market shares. Consequently, economic growth in Russia and Caspian countries benefit from enhanced fossil fuels exports revenues compared to the central EWS scenario, in spite of slower domestic fossil fuel subsidy reform. Their GDP impact is thus reversed and becomes even positive in the case of Caspian countries (+3.4%), which are amongst the least energy-efficient countries in the world, and where the scope for improvement is the greatest (IEA, 2010). Overall GDP in 2035 decreases from 1.1% to 0.9% and the amount of energy-saving is lower compared to the Efficient World Scenario.

These results suggest that a timely, ambitious and multilateral reform of fossil fuel subsidies is a key element of a comprehensive and efficient policy package to accompany the economy-wide adoption of energy efficiency measures at lowest global cost. The reform also reduces the wasteful consumption of fossil energy and associated carbon emissions, and thereby tackling the climate change imperative.

Figure 53. Per cent change in real GDP with slower fossil fuel subsidy reform



Source: OECD ENV-Linkages model

4. Final remarks

This study sheds light on the global and regional economic implications of an ambitious energy efficiency resource conservation policy described in the IEA Efficient World Scenario. The analysis carried out in this paper is done by coupling two complex modelling frameworks and using the best available information. These projections are inherently subject to a number of uncertainties, regarding data, model specification and projections of future behaviour of households and firms. Nonetheless, a number of interesting general observations can be made.

The IEA Efficient World Scenario projects global primary energy demand being cut in half by 2035. Fossil fuel consumption accounts for the lion’s share of this reduction. Energy demand-side savings, from both buildings and industries, primarily take the form of lower electricity consumption. The adoption of energy-efficient appliances, as well as fuel-efficient road vehicles, requires almost USD 12 trillion in specific investments.

In 2035, the Efficient World Scenario foresees an 18% drop in energy-related CO₂ emissions due to reduced fossil fuel consumption worldwide. By 2035, non-CO₂ GHG emissions are 3.5 % lower than the New Policies Scenario level. The bulk of this reduction is owed to a decrease in CH₄ emissions. The net, cumulative methane emission abatement is 6.2 GtCO₂eq over 2010-2035, which is equivalent to the amount of methane emitted globally (by energy and agriculture sectors) in the year 2010.

The reduction in energy use and the resulting savings in energy expenditures increase levels of disposable income and encourage additional spending elsewhere in the economy. Achieving the Efficient World Scenario targets would, according to the model simulations, result in a cumulative boost to the

global economy of almost USD 20 trillion over the projection period, and in a global GDP in 2035 being 1.1% higher than the 2035 GDP in the IEA New Policies Scenario. Increased economic activity reflects a gradual reorientation of the global economy, encouraging production and consumption of less energy-intensive goods and services, accompanied by moderate, cross-sectoral employment shifts.

Finally, the reform of fossil fuel consumption subsidies also plays a key role in reducing global fossil fuel consumption and restoring a more efficient allocation of resources throughout the entire economy. Slowing down the pace of such a reform would increase fossil fuel consumption in many countries, thereby benefiting the economic development of large energy exporters such as Russia and Caspian region countries. Overall, slowing the pace of fossil fuel subsidy reform would lead to a global increase in total primary energy consumption of 0.7% in 2020 and 1.4% in 2035. In 2035, global GDP benefits in the central IEA New Policies Scenario decrease from 1.1% to 0.9%. This alternative implementation of fossil fuel subsidy reform partially hinders the Efficient World Scenario's core objective of reducing overall energy consumption. In conclusion, an ambitious reform of fossil fuel consumption subsidies is needed to complement specific energy-efficiency measures in any comprehensive policy package aiming to decrease reliance on fossil fuel and promote effective climate change mitigation at least cost.

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APPENDIX

A.1 The ENV-Linkages modelling framework: An overview

The analysis herein is based on the OECD ENV-Linkages model, a global CGE model, featuring recursive dynamics and capital vintages. In recent years this model has been extensively used to study various impacts of fossil-fuel subsidy reforms (Burniaux and Chateau, 2011, Burniaux *et al.*, 2011, the IEA, OPEC, OECD, and World Bank joint report, 2011). The model version used in this paper has benefited from a major Baseline calibration overhaul in order to accurately reproduce most energy trends from the IEA *Current Policies Scenario* (IEA, 2012) for the period 2011-2035. Even though other OECD climate change-related studies typically project trends to 2050 (e.g. OECD, 2012a), the 2035 time horizon is sufficient to shed light on the mechanisms underlying the policies scrutinized in this paper

ENV-Linkages, as a successor of the OECD GREEN model (Burniaux *et al.*, 1992), shares its basic structure with models such as ENVISAGE and MIT-EPPA, featuring recursive dynamics and capital vintages. A more comprehensive model description is given in Chateau *et al.* (2014).

Production in ENV-Linkages is assumed to operate under cost minimisation with perfect markets and constant return to scale technology. The production technology is specified as nested Constant Elasticity of Substitution (CES) production functions in a branching hierarchy. This structure is replicated for each output, while the parameterisation of the CES functions may differ across sectors. The nesting of the production function for agricultural sectors is further re-arranged to reflect substitution between intensification (e.g. more fertiliser use) and extensification (more land use) of activities; or between intensive and extensive livestock production. The structure of electricity production assumes that a representative electricity producer maximises its profit by using the various available technologies to generate electricity using a CES specification with a large degree of substitution. Non-fossil electricity technologies have a structure similar to the other sectors, except for a top nest which combines a sector-specific natural resource with all other inputs. This specification acts as a capacity constraint on the supply of these electricity technologies. The model adopts a putty/semi-putty technology specification, where substitution possibilities among factors are assumed to be higher with new vintage capital than with old vintage capital. This implies a relatively smooth adjustment of quantities to price changes. Capital accumulation is modelled as in the traditional Solow/Swan neo-classical growth model.

General functioning of the ENV-Linkages model: Market-based allocation of resources

The nested model structure gives marginal costs and represents the different substitution (and complementarity) relations across the various inputs in each sector. The “value-added” bundle incorporates some material inputs – including energy as well as primary factor (i.e. capital and labour). In some sectors the material inputs also include natural resources (e.g. trees in forestry or land in agriculture).

The energy bundle is of particular relevance for this analysis. Energy is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and a bundle of “other fossil fuels”. At the lowest nest, the composite “other fossil fuels” commodity consists of crude oil, refined oil products and natural gas. The value of the substitution elasticities are chosen to imply a higher degree of substitution with other fuels than with electricity and coal.

The allocation of goods-services and primary factors of production between the economy's various actors (households, government, firms, foreign consumers, etc.) rests on the assumption of perfect market functioning. This implies a unique equilibrium price on each market of commodity, factor, etc., so that supply always meets demand. The model still includes some real adjustment rigidities. An important feature is the distinction between old and new capital goods. While old capital is assumed to be only partially mobile across sectors, reflecting differences in the marketability of capital goods across sectors, investment or the corresponding new capital is, in the standard version of the model, assumed to be perfectly homogenous and perfectly mobile across sectors.

In each period, aggregate investment is residually determined and is equal to the sum of government savings, consumer savings and net capital flows from abroad induced by trade. Foreign and government saving time-streams are assumed to be the same across scenarios.

Aggregate final government and investment demands are assumed to be a basket of given goods and services. Table A1 shows the average composition of the investment bundle in 2004 at world level according to the GTAP8 database: Half of total expenditures (Xbillion) are allocated to the consumption of construction services and goods, 12% are transport equipments, 20% of other equipments and 12% of other services.

Table A.1. Composition of investment in goods in 2004 – World Level (percentage share)

Other Goods	5.2%
Metal products	3.5%
Motor vehicles	5.2%
Transport equipment	4.7%
Electronic equipment	9.4%
Machinery and equipment	9.7%
Manufacturing	0.8%
Construction	50.2%
Trade	4.3%
Business services	7.0%

Source: GTAP8 database

New capital perfect mobility and homogeneity as well as perfect market assumptions insure that, given the aggregate amount of investment and the level of installed capital, the sectoral return to new capital is the same for the entire economy and drive the optimal allocation of aggregate new capital (net investment) across sectors. In a parallel way, labour supply is allocated between activities in such a way that the real wage is the same across sectors.

Household consumption demand is the result of static maximization behaviour which is formally implemented as an "Extended Linear Expenditure System". A representative consumer in each region – who takes prices as given – optimally allocates disposal income among the full set of consumption commodities and savings. Saving is considered as a standard good in the utility function and does not rely on forward-looking behaviour by the consumer. The government in each region collects various kinds of taxes in order to finance government expenditures. Assuming fixed public savings (or deficits), the government budget is balanced through the adjustment of the income tax on consumer income. In each period, investment net-of-economic depreciation is equal to the sum of government savings, consumer savings and net capital flows from abroad.

International trade is based on a set of regional bilateral flows. The model adopts the Armington specification, assuming that domestic and imported products are not perfectly substitutable. Moreover, total imports are also imperfectly substitutable between regions of origin. Allocation of trade between partners then responds to relative prices at the equilibrium. Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated between the demands (both final and intermediary) addressed to domestic producers and the import demand.

ENV-Linkages is fully homogeneous in prices and only relative prices matter. All prices are expressed relative to the *numéraire* of the price system that is arbitrarily chosen as the index of OECD manufacturing exports prices. Each region runs a current account balance, which is fixed in terms of the *numéraire*. As a consequence, real exchange rates are immediately adjusted to restore current account balance when countries start exporting/importing emission permits.

CO₂ emissions from combustion of energy are directly linked to the use of different fuels in production. Other GHG emissions are linked to output in a way similar to Hyman *et al.* (2002). The following non-CO₂ emission sources are considered: *i*) methane from rice cultivation, livestock production (enteric fermentation and manure management), fugitive methane emissions from coal mining, crude oil extraction, natural gas and services (landfills and water sewage); *ii*) nitrous oxide from crops (nitrogenous fertilizers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); *iii*) industrial gases (SF₆, PFC's and HFC's) from chemicals industry (foams, adipic acid, solvents), aluminium, magnesium and semi-conductors production.

A.2 Linking the OECD ENV-Linkages and IEA WEM models

This section describes the key features of the modelling tool employed to derive the economic implications of the IEA Efficient World Scenario, as well as some model refinements developed specifically for the calibration of ENV Linkages.

The version of the model used here represents the world economy in 25 countries/regions, according to IEA-WEO aggregation, each with 28 economic sectors, as illustrated in Table A2. These include five electric generation sectors, five agriculture-related sectors (including fishing and forestry), five energy-intensive industries, three fossil fuel extraction sectors, transport, refineries and distribution of petroleum products, services, construction and four other manufacturing sectors. The core of the static 2004 starting year equilibrium is formed by a set of Social Account Matrices (SAMs) that describe how economic sectors are linked; these are based on the GTAP 8 database (Narayanan *et al.*, 2012). Many key parameters of the model are set on the basis of information drawn from various empirical studies and data sources (details given in Burniaux and Chateau, 2008).

A specific market for capital for each sector where IEA designed energy efficiency investment is implicitly assumed (see below). Then the “new” capital inflow is given for these sectors. This capital stock is calculated as the sum of the capital level simulated in the baseline scenario with the standard version of the model (herein the CPS scenario) augmented with extra investments which are targeted to energy efficiency and which are derived by the IEA analysis. As a consequence, the return to new capital is then sector-specific. For remaining sectors, equalization of rates of return still applies.

Changing the specification of capital allocation rule across simulations could appear odd in the sense that the incorporation of additional real rigidity (or market distortion) to the model prevents the consistent comparisons across simulations. As a matter of fact this criticism does not hold in the actual context, since as it is explained below, the simulation of the CPS scenario with ENV-Linkages is done for calibration purpose only while the policy experiment presented in this paper compares the EWS scenario relative to the NPS, where both scenarios have been simulated with specific markets for capital.

Table A.2. ENV-Linkages model sectors and regions

Commodities	Countries and regions
Energy	OECD regions
Coal Crude oil Gas Refined oil products Electricity*	European Union : EG4, EU17 Other OECD Europe (OE5) United States of America Canada Mexico Chile
Energy-intensive & trade-exposed sectors	Japan South Korea Australia and New Zealand
Chemicals Non-metallic minerals Iron and steel industry Non-ferrous metals	Non-OECD Regions
Forestry, agriculture and fisheries	European Union Non OECD (EU6) Russia Non-EU Eastern Europe (OEU) Middle-East North Africa South Africa Other African Countries (OAF)
Rice Other crops Livestock Forestry Fishery	Brazil Other Latin America (OLA) China India Indonesia Other ASEAN countries Other Developing Asia(ODA) Caspian
Other industries and services	
Transport services Paper-pulp-print Fabricated Metal Products Manuf. of Transportation Equipment Other Manufacturing Services Construction & Dwellings Other Mining Food Products	

Source: OECD ENV-Linkages model

Note: Electricity is split into 5 sectors: nuclear power, solar and wind electricity, renewable combustibles and waste electricity, fossil fuel based electricity, and hydro and geothermal electricity.

Importantly, the composite investment good (or the implied physical capital goods) is built by using a given composition of expenses on goods that include essentially construction (investment in buildings), services (e.g. investment in R&D, software) and equipments (e.g. transportation vehicles and other manufacturing goods). The implementation of the Efficient World Scenario policies has two direct effects on services production. First, extra investments, as derived from WEM, result in an additional capital stock in this sector together and come in addition to a reduced energy bill. Second, additional demand for services from sectors that have increased their own energy efficiency investments further stimulates activity levels in the services sector. Alternatively, only the first effect applies in the chemicals sector, for example, as the demand for chemical products remains fairly rigid, their production level is thus poorly affected by increased investment expenses elsewhere in the economy. Conversely, changes in sectors like construction or non-metallic mineral products are almost entirely driven by additional demand from other sectors and households; energy efficiency gains from the cement industry itself have already largely been

tapped into and exhibit only limited scope for further improvement. A similar effect, purely demand-driven, also takes place in fossil-fuel extractive industries, although negatively.

Table A.3. Breakdown of extra investments by key sectors/agents and countries (%). Efficient World Scenario relative to New Policies Scenario

	Household s / Buildings	Household s / Equipment	Manufacturin g	Service s	Transpor t Services	Energy Intensive Industrie s	Total
2020							
United States	18%	36%	6%	19%	10%	11%	100%
Canada	15%	30%	11%	23%	12%	8%	100%
Mexico	22%	44%	10%	11%	8%	5%	100%
Japan & Korea	15%	30%	11%	25%	9%	10%	100%
OECD							
Oceania	18%	35%	11%	15%	19%	3%	100%
EU & EFTA	24%	47%	6%	15%	4%	4%	100%
Brazil	17%	33%	16%	7%	17%	10%	100%
Russia	22%	44%	4%	15%	10%	4%	100%
India	17%	34%	29%	14%	4%	2%	100%
Indonesia	15%	30%	43%	8%	14%	-9%	100%
China	22%	44%	11%	11%	6%	6%	100%
South Africa	17%	34%	7%	26%	12%	4%	100%
Middle East & North Africa	20%	41%	6%	18%	10%	4%	100%
Rest of the world	18%	35%	14%	17%	13%	3%	100%
	Household s / Buildings	Household s / Equipment	Manufacturin g	Service s	Transpor t Services	Energy Intensive Industrie s	Total
2035							
United States	21%	42%	2%	19%	14%	3%	100%
Canada	20%	41%	3%	20%	13%	2%	100%
Mexico	26%	52%	5%	7%	8%	3%	100%
Japan & Korea	23%	46%	4%	17%	8%	3%	100%
OECD							
Oceania	24%	49%	3%	7%	16%	1%	100%
EU & EFTA	22%	44%	4%	18%	10%	3%	100%
Brazil	25%	49%	5%	4%	14%	3%	100%
Russia	20%	41%	3%	10%	24%	3%	100%
India	29%	58%	7%	4%	3%	0%	100%
Indonesia	20%	40%	23%	4%	19%	-6%	100%
China	23%	47%	7%	9%	10%	4%	100%
South Africa	22%	45%	3%	15%	14%	2%	100%
Middle East & North Africa	22%	45%	4%	13%	14%	3%	100%
Rest of the world	22%	45%	7%	10%	14%	2%	100%

Source: OECD Analysis Based on data from World Energy Outlook 2012 (IEA, 2012)

Energy efficiency investments are assumed to increase over time. Households investments account for more than 55% of total investments on average in 2020 and almost 70% in 2035 (Table 1). 16% and 11% of investments are dedicated to Services in 2020 and 2035, respectively while transportation services capture 11% and then 13% of total spending. Industrial needs are less than 20% of the total in 2020 and 10% by the end of the projection period.

A.3 Calibration steps for the Efficient World Scenario

Step 1. Calibration of the Current Policies Scenario

The calibration of the Current Policies Scenario is crucial for the derivation of the other three scenarios and is therefore explained here in more detail.

First, the ENV-Linkages model replicates all GDP trends assumed in the IEA partial equilibrium World Energy Model in combination with energy supply patterns of the Current Policies Scenario. However, embedding this information with other baseline assumptions from OECD databases would not be suffice to warrant a consistent storyline for the Current Policies Scenario and to correctly reproduce the full set of energy demands and supply. This is due to the specific ENV-Linkages model structure (i.e. a nested Constant Elasticity of Substitution or CES structure) and its functioning (full general equilibrium obtained by adjustments in relative prices) with regard to the features of the IEA partial equilibrium model. Therefore a set of exogenous parameters of ENV-Linkages (like AEE parameters) needs be adjusted at each time period and for each country to reproduce WEO energy projections over the whole time horizon (2010-2035).

Since ENV-Linkages' quantity and price variables are fully determined by equilibrium relationships across all goods and services markets, it is virtually impossible to match WEM price assumptions, demand and supply at one time. In a first step, only physical flows of energy demand and supply are reproduced. In a second step, other parameters are adjusted to be consistent with the WEM time profiles of energy prices. At the end of this stage, ENV-Linkages and WEM share a consistent reference scenario, the Current Policies Scenario.

ENV-Linkages takes the following set of information forming the IEA CPS scenario as given:

1. Projection of intermediate demands for energy carriers (refined oil, coal, gas and electricity) by firms for each sector and country.
2. Projection of final demands for energy carriers by households
3. Projections of country-based fossil fuel supply
4. GDP assumptions expressed in real 2011 USD
5. Detailed electricity generation mix (fossil fuels, nuclear, hydro, solar & wind as well as other renewable combustibles)
6. Carbon prices and fossil-fuel subsidies by sector and country

Apart from the policy price instruments listed above in item (vi), which are directly implemented in the CGE model, other variables could not logically be directly imposed since they are determined endogenously through market mechanisms and agent behaviour.

In order to match trends (i)-(v) for the time horizon 2010-2035, several additional levers are activated to construct the CPS scenario. The respective parameters tweaked to match these trends are listed below:

- i. Autonomous Energy Efficiency (AEE) parameters accruing to intermediate demands by firms for every sector and country. Precisely, the intermediate demand in ENV-Linkages of a fuel e by a sector s , noted as $xap(e, s)$, writes as:¹³

$$\begin{aligned} \text{Log}[xap(e, s)] = & \text{Log}[a(e, s)] + [\sigma(e, s) - 1]. \text{Log}[AEE(s)] \\ & + \sigma(e, s). \{ \text{Log}(P(s)) - \text{Log}(P(e)) + \text{Log}Y(s) \} + \text{Additional term} \end{aligned}$$

where a is a CES coefficient, $AEE(s)$ is the autonomous energy efficiency in sector s , $\sigma(e, s)$ is the constant elasticity of substitution of energy, $P(s)$ is the marginal cost of production of the good s , $P(e)$ is the price of the fuel for the firm and $Y(s)$ is the gross-output.

At the equilibrium, the firm demand $xap(e, s)$ is endogenous given structural parameters: a , $\sigma(e, s)$ and $AEE(s)$. Alternatively, in the baseline construction, one could invert the causality and have AEE adjusted to replicate a given demand (e.g. extracted from another study like a WEO scenario).

- ii. Minimum subsistence level of fuel consumption by households
- iii. The volume of natural resource extraction for a given unit of fossil fuel production sectors is kept constant while the autonomous technical progress in the fossil fuel production sectors production are adjusted
- iv. Given the relative changes in sectoral labour productivity growth and total employment projection, the average labour productivity growth are adjusted to match GDP
- v. Total factor productivity and electricity demands share are calibrated to match the electricity mix.
- vi. *Not applicable.*

Further assumptions are needed to build an economic baseline for the ENV-Linkages models. Amongst them is the convergence in household income elasticities, shifts in production structure towards more service-intensive production, population and employment prospects and trade patterns shifting towards enhanced imports of goods from emerging countries.

Step 2. Implementation of the New Policies Scenario and the Efficient World Scenario

All parameters determined for the Current Policies Scenario are taken as given to simulate the New Policies Scenario. The core information for the New Policies Scenario consists in a set of energy policies integrated into the modelling for the WEO scenarios: these policies include a reform on fossil fuel subsidies, carbon prices, other regulation instruments (e.g. fuel economy standards) and additional investments relative to the Current Policies Scenario needed to reach targets in the New Policies or Efficient World Scenario. This information is provided for every WEM-subsector. Moreover, sectoral investments in ENV-Linkages are described as an increase in the capital stock of the sector. These increases in capital stocks in conjunction with AEE parameters are the key elements needed to reproduce energy demands in the New Policies Scenario or the Efficient World Scenario. This methodology, which consists in using extra investments as policy levers, ensures the compatibility between all endogenous mechanisms of the OECD model and the exact energy savings obtained in the WEO scenarios. For instance, rebound effects stemming from cheaper energy prices in the Efficient World Scenario are fully taken into account in all measured economic impacts.

¹³ For the sake of simplicity, the real representation of demands in the ENV-Linkages makes abstraction of vintage-capital structure of the model as well as exact nesting of input in the production function.

The second and foremost component of the Efficient World Scenario lies in changes in households' behaviour which increase their demands for more energy efficient goods and services. The retained assumption is that IEA projections are driven by regulatory or standard measures (or quantity constraints in term of a CGE modelling framework). Then households' expenses on construction, equipment or motor vehicles are assumed to be directly fixed in the EWS scenarios. Extra expenses for such goods correspond to additional energy demand savings derived in the Efficient World Scenario on top of NPS levels. It is worth noting that because IEA and OECD models differs in their definition of some goods and activities, additional assumptions were made to allocate IEA extra investments across household demands for goods according to ENV-Linkage own specifications: First, all investments in passenger light-duty vehicles are translated into additional demand for transport vehicles by households. Second, investments from *residential efficiency savings* are assumed to be shared in equal proportion between demands for both Construction and Manufactured products (equipment).