

Economic impacts of energy efficiency investments : simulation of the 2012 IEA “Efficient World Scenario” in the OECD ENV-Linkages model

By Jean Chateau and Bertrand Magné¹

1. Introduction

1. 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).

2. 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.

3. 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.

4. 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

¹ OECD Environment Directorate, 2 Rue André-Pascal, 75775 Paris Cedex 16, France. Tel.: + 33 1 45 24 93 05; fax: + 33 1 44 30 61 84. E-mail address: jean.chateau@oecd.org.

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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.

5. Section 2 contains a short description of underlying policies and climate change implications of IEA scenarios. 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

6. 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.

7. 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

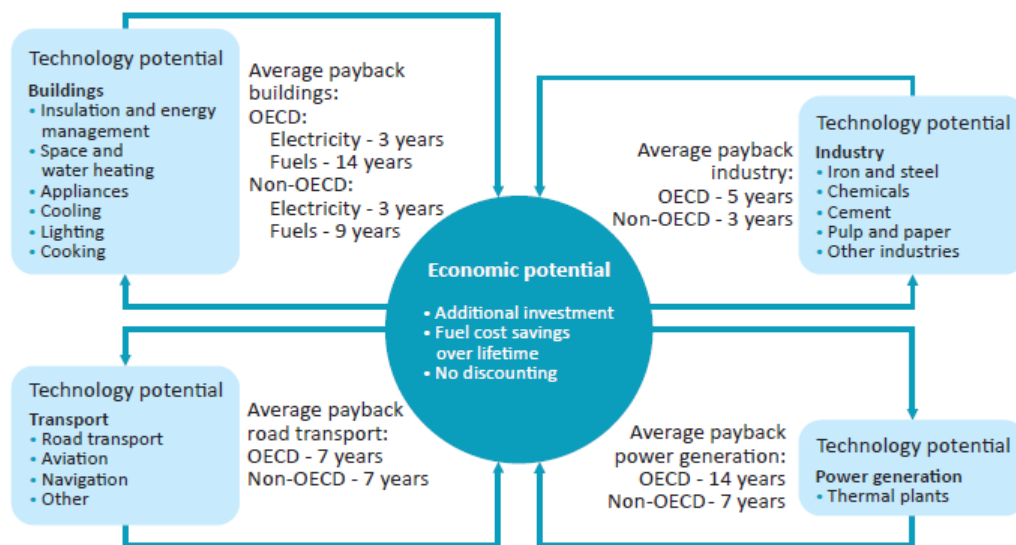
8. Energy efficiency curbs energy demand growth, reduces energy imports and mitigates pollution, and should be considered just as important to the future energy balance as unconstrained energy supply. An Efficient World Scenario (EWS) was constructed in the World Energy Outlook 2012 (IEA, 2012) to assess 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 sectors². Figure 2 illustrates the methodology for assessing the technical and economic potential.

² 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.

9. 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).

10. 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)

11. 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.

12. 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).

13. 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/>

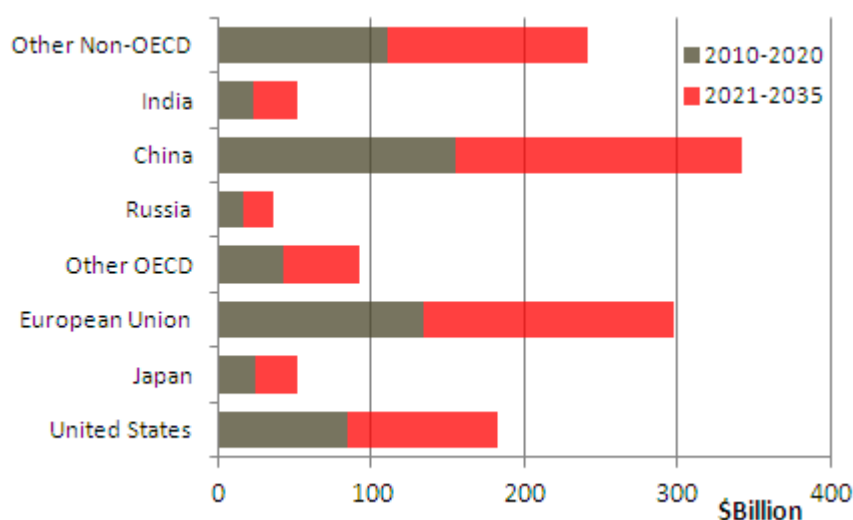
The Energy implications of this Efficient World Scenario is extensively given in the World Energy Outlook (IEA,2012) and for this reason are not reported here.

2.3 *Extra investments and energy expenditures savings from end-use energy efficiency*

14. The Efficient World Scenario incurs USD 11.8 trillion of cumulative additional investments³, 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.

³ 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.

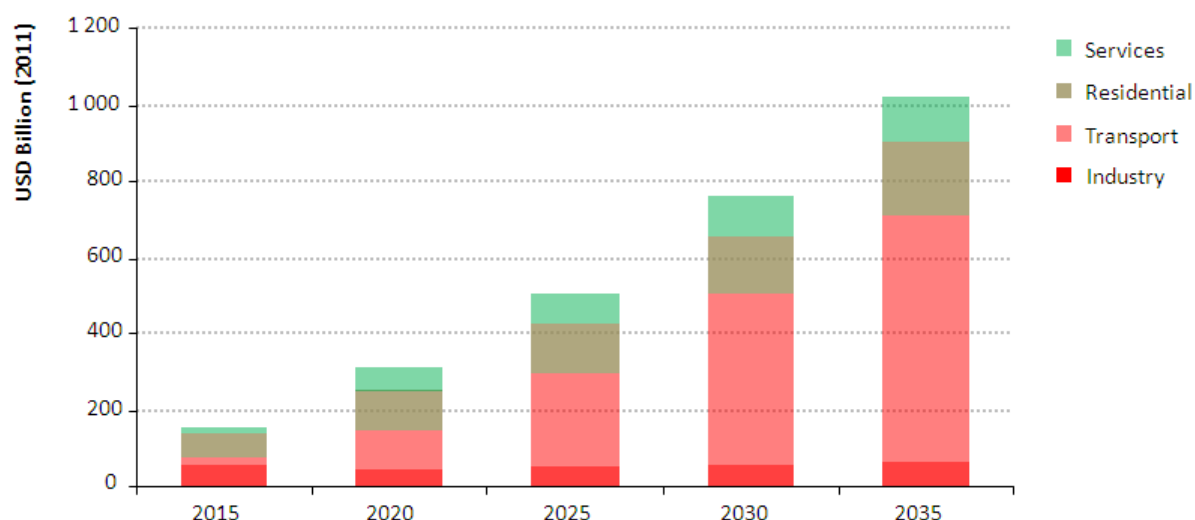
Figure 2. Additional investments in end-use energy efficiency by country in the Efficient World Scenario



Source: World Energy Outlook 2012 (IEA, 2012)

15. 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.

Figure 3. Global additional investment by end-use sector in the Efficient World Scenario relative to the New Policies Scenario



16. 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.⁴

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

3.1 Key model features and methodological issues

17. 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.

18. 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.⁵ This hybrid modelling approach addresses frequent concerns about the appropriate measurement of economy-wide effects associated with adopting more energy-efficient appliances.

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 decades⁶.

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,

⁴ 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.

⁵ 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.

⁶ More details about the model and some of its recent applications can be found on the following webpage: <http://www.oecd.org/environment/modelling>

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.

19. 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.

20. 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.

3.2 Fundamental policy channels: Decomposition of effects

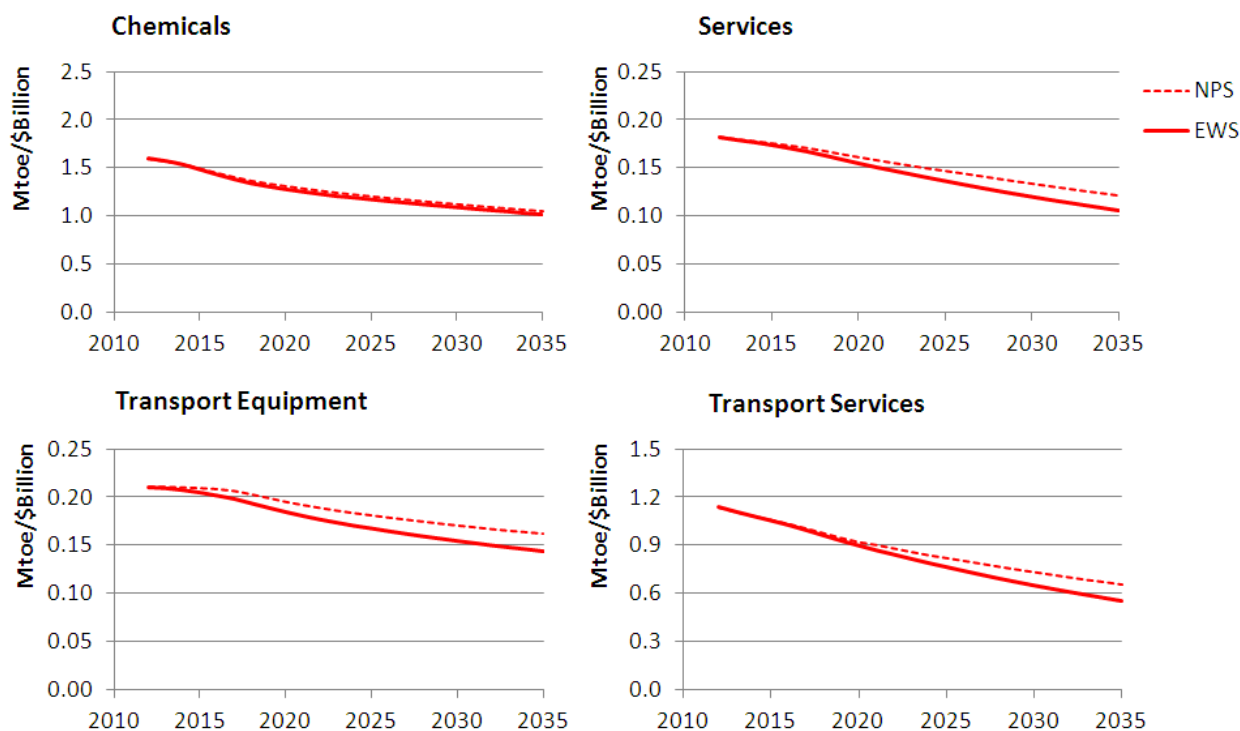
21. This section aims to shed light on the key mechanisms underlying this paper's analysis and provide insight on the way dedicated energy efficiency policies can help foster economic growth. For this reason, the focus in this section is solely on net energy-importing countries, i.e. countries whose 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.

22. 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.

23. The simulated policies imply, by construction, an increase 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 decreases capital expenditures. 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).

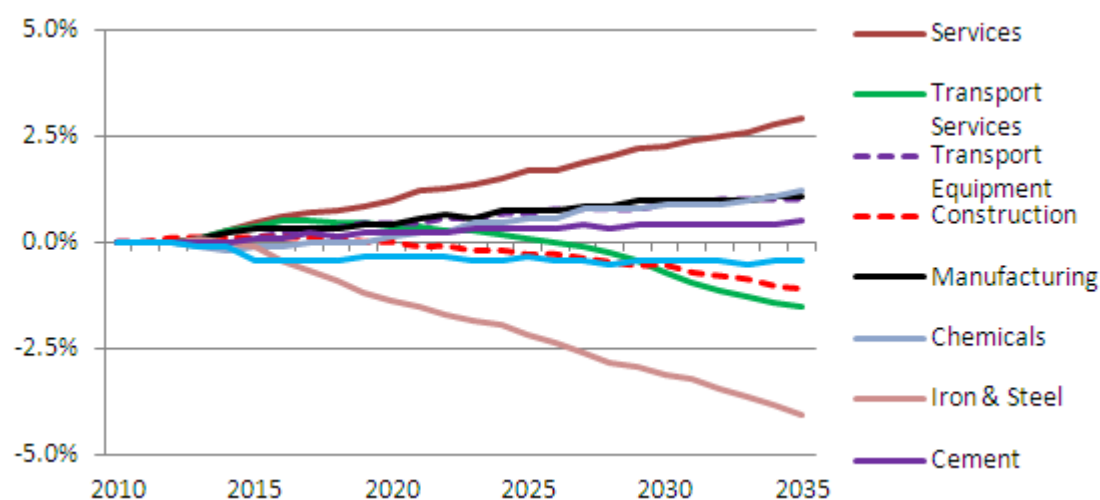
Figure 4. Global energy-capital ratio in the New Policies Scenario and the Efficient World Scenario for selected production sectors



Source: OECD ENV-Linkages model

24. 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 5. Per cent of deviation in Chinese output prices in the Efficient World Scenario



Source: OECD ENV-Linkages model

25. 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 6. 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*

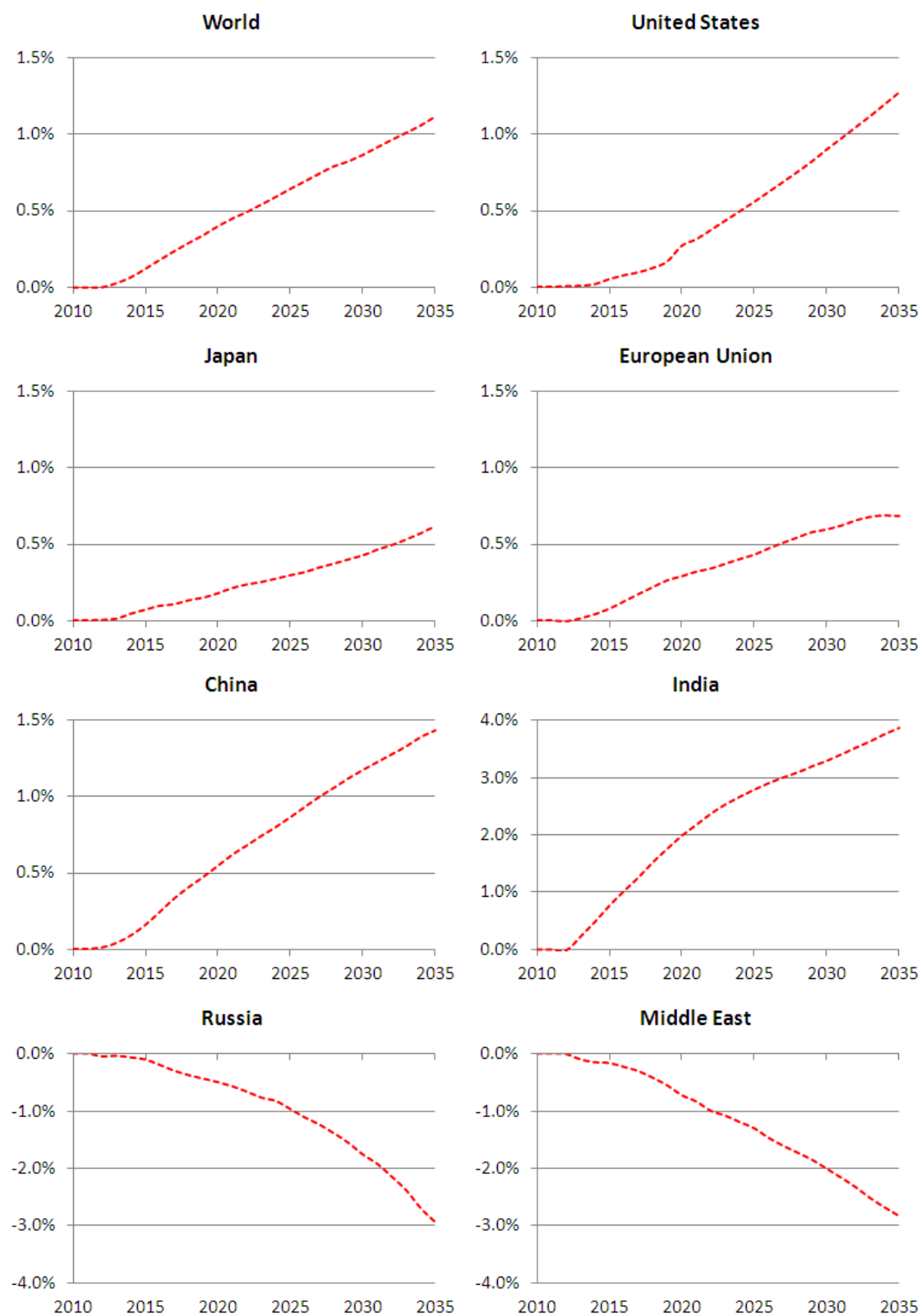
26. Achieving the Efficient World Scenario would result in a cumulative boost to the global economy of USD 19.7 trillion over the projection period, and in global GDP in 2035 being 1.1% higher than GDP in the New Policies Scenario. Increased economic activity reflects a gradual reorientation of the global 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.

27. 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.

28. 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.

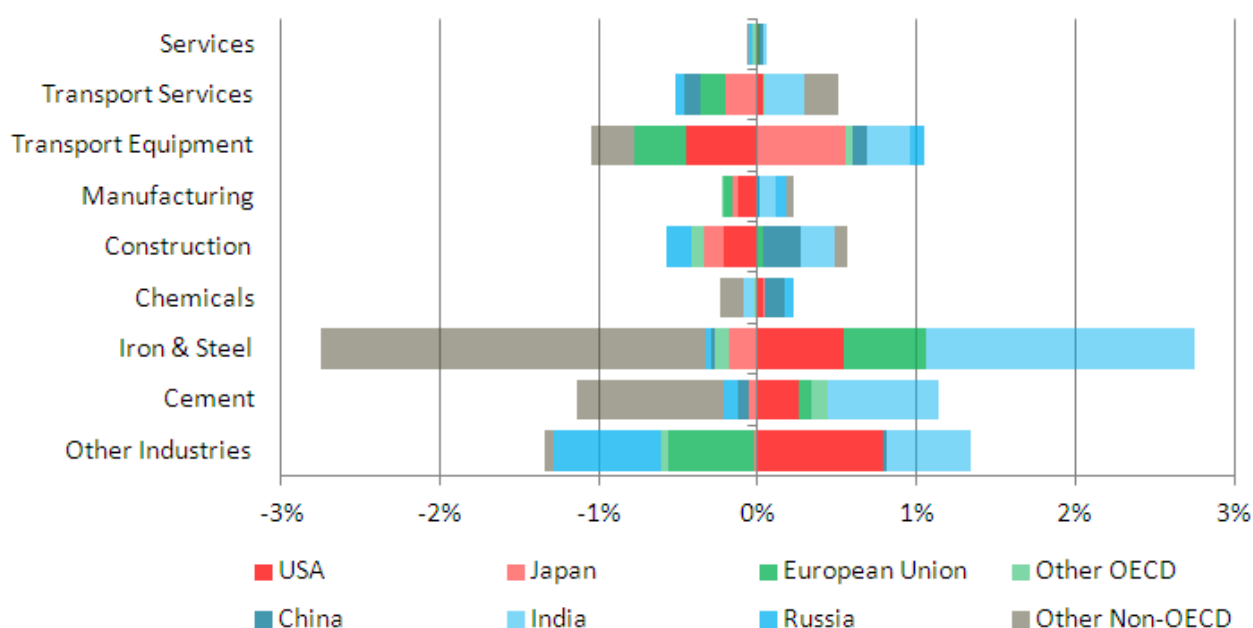
29. The Efficient World Scenario entails shifts in competitive position of different sectors across countries and thus a geographical reallocation of certain sectoral activities. Figure 12 shows the corresponding changes in production shares by country and by sector in 2035. The location of services, 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 7. Change in real GDP in the Efficient World Scenario



Source: OECD ENV-Linkages model

Figure 8. Sectoral changes in production by region in the Efficient World Scenario, 2035

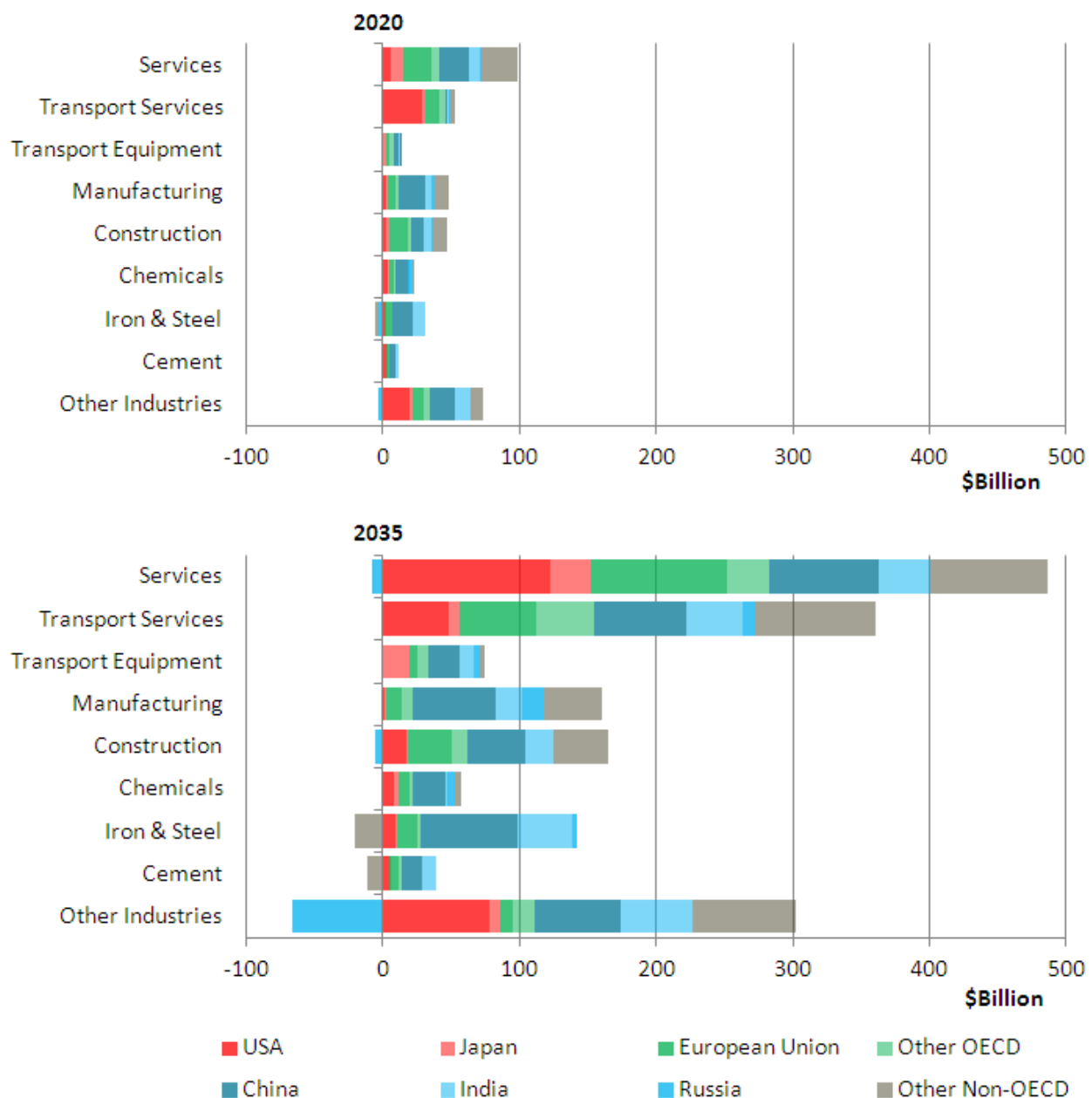


Source: OECD ENV-Linkages model

30. 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.

31. 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.

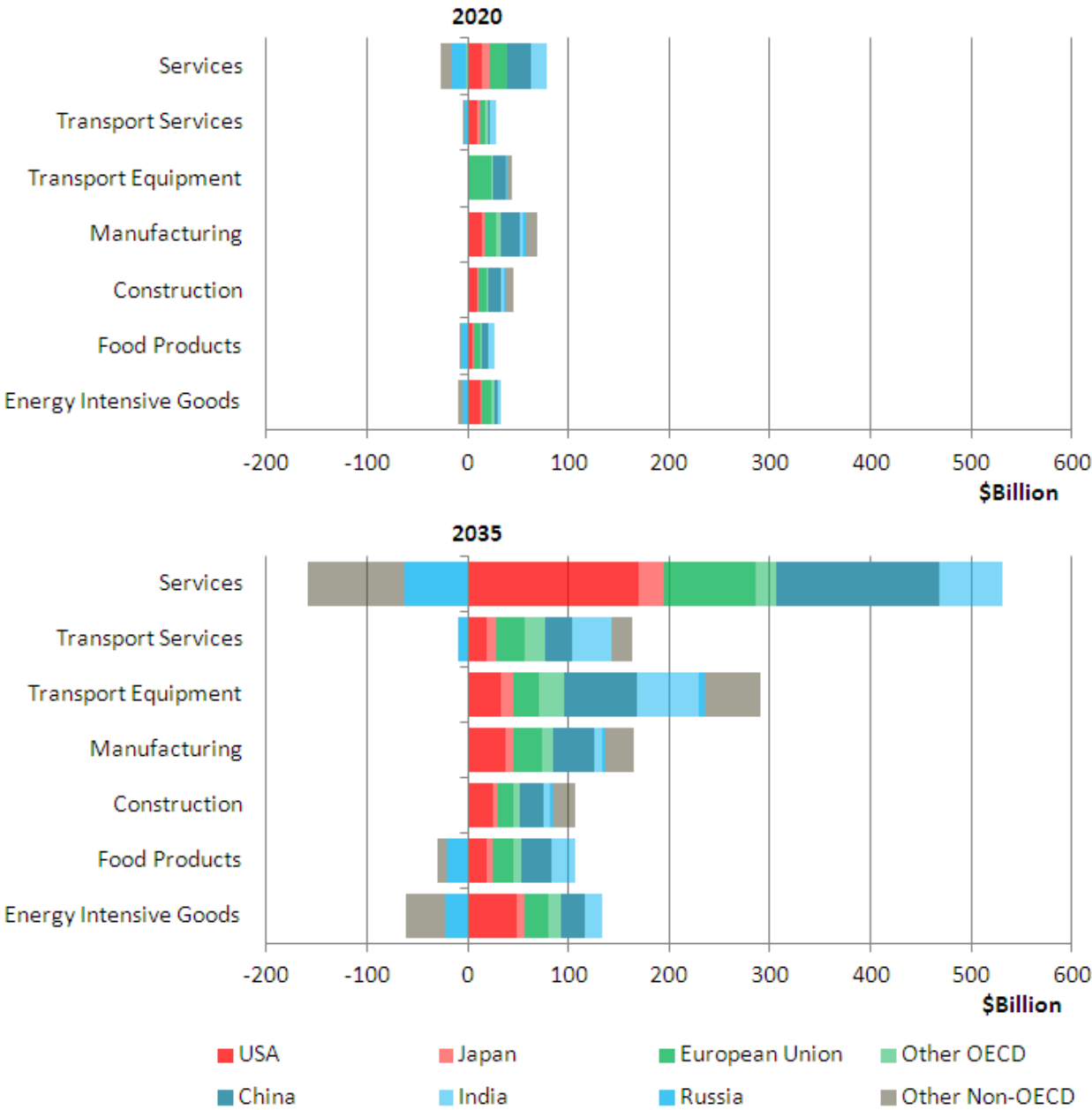
Figure 9. Changes in value-added by sector and region in the Efficient World Scenario compared with the New Policies Scenario, 2020 and 2035



Source: OECD ENV-Linkages model

32. 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 10. Sectoral changes in real household consumption in the Efficient World Scenario, 2020 and 2035

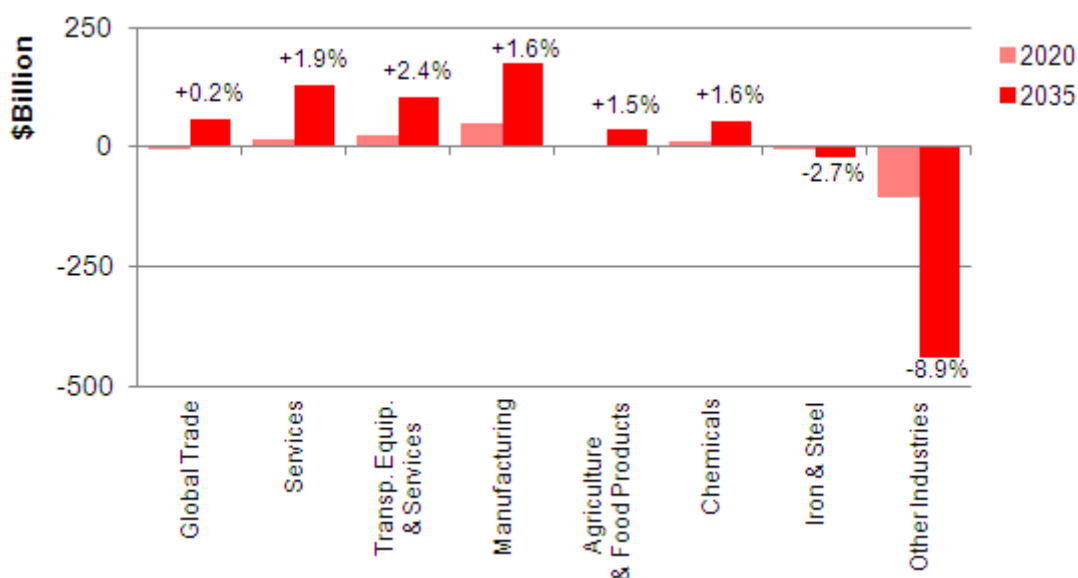


Source: OECD ENV-Linkages model

33. 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.

34. 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).⁷ This stems from a move to less 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 11. Change in global trade flows for selected sectors in the Efficient World Scenario, 2035

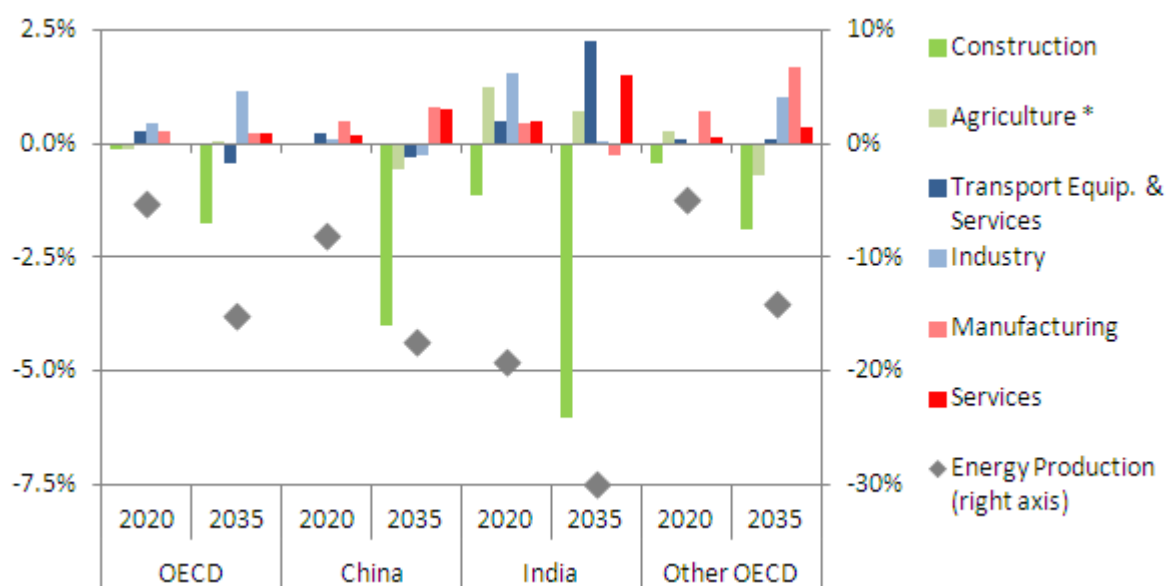


Source: OECD ENV-Linkages model

35. 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.

⁷ 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.

Figure 12. Deviation in employment by sector in the Efficient World Scenario



Source: OECD ENV-Linkages model

36. 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 smoothen the transition process and ensure workers have the newly required skills (OECD, 2012b).

3.4 Impact on global GHG emissions

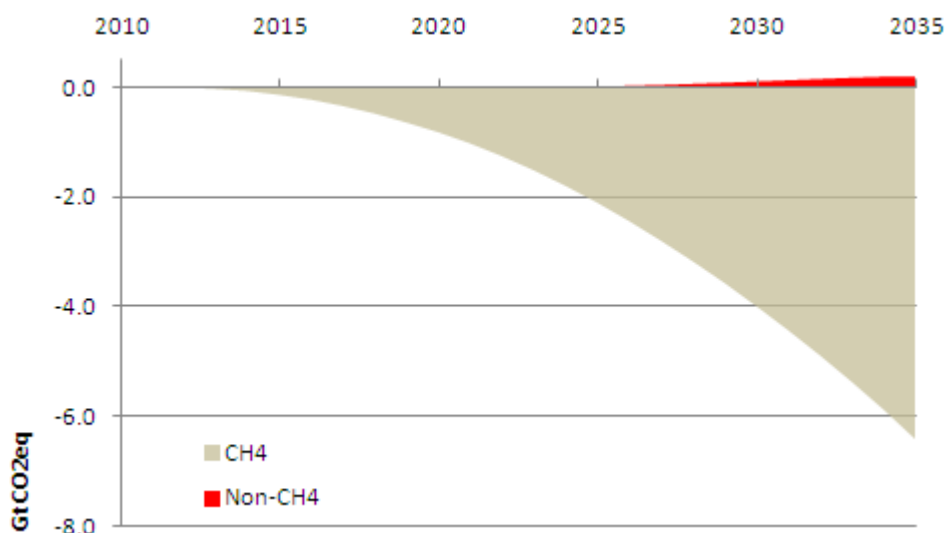
37. In 2035, the Efficient World Scenario entails an 18% drop in energy-related CO₂ emissions relative to the New Policies Scenario level (and 31% relative to business-as-usual level given by the IEA Current Policies Scenario) because of reduced fossil fuel consumption worldwide, as discussed in Section 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.

38. 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.

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



Source: OECD ENV-Linkages model

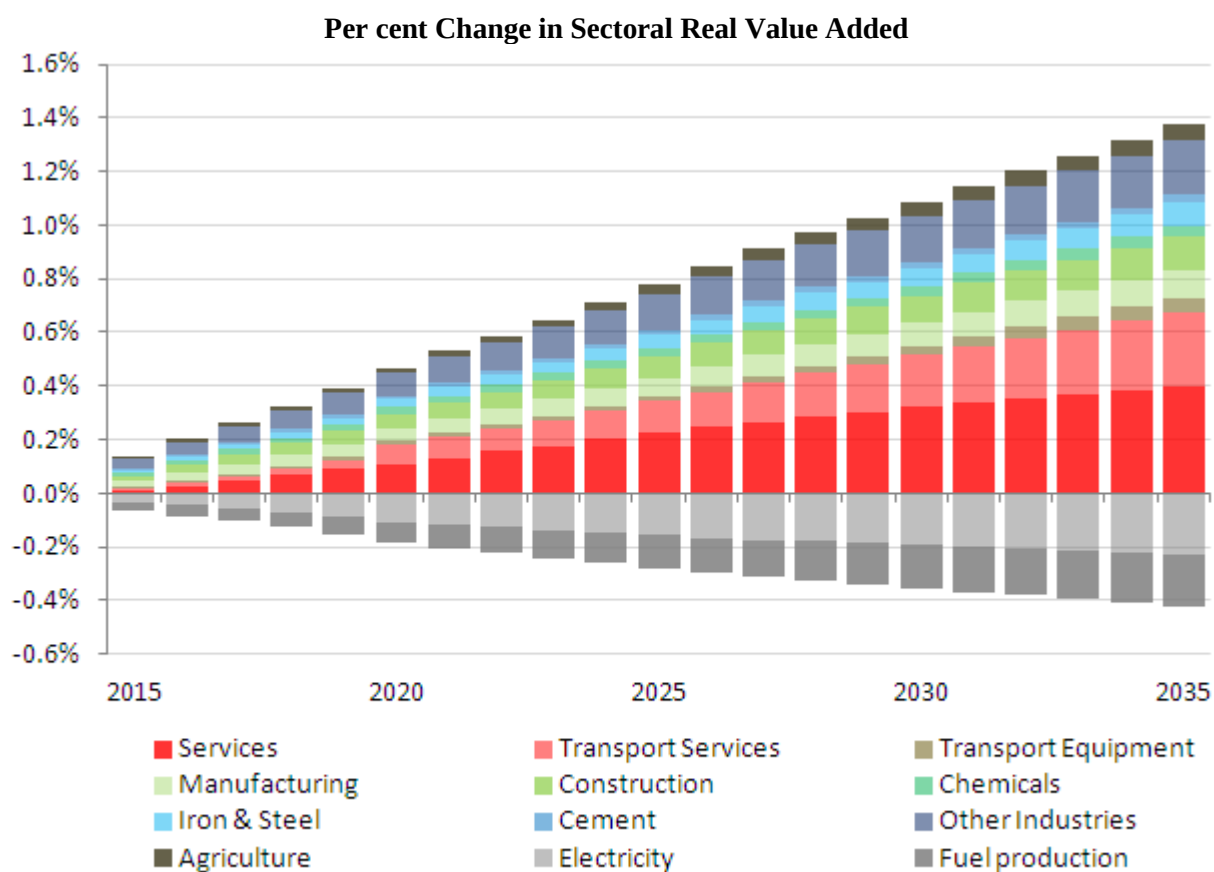
3.5 Country/region profiles

40. 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 messages

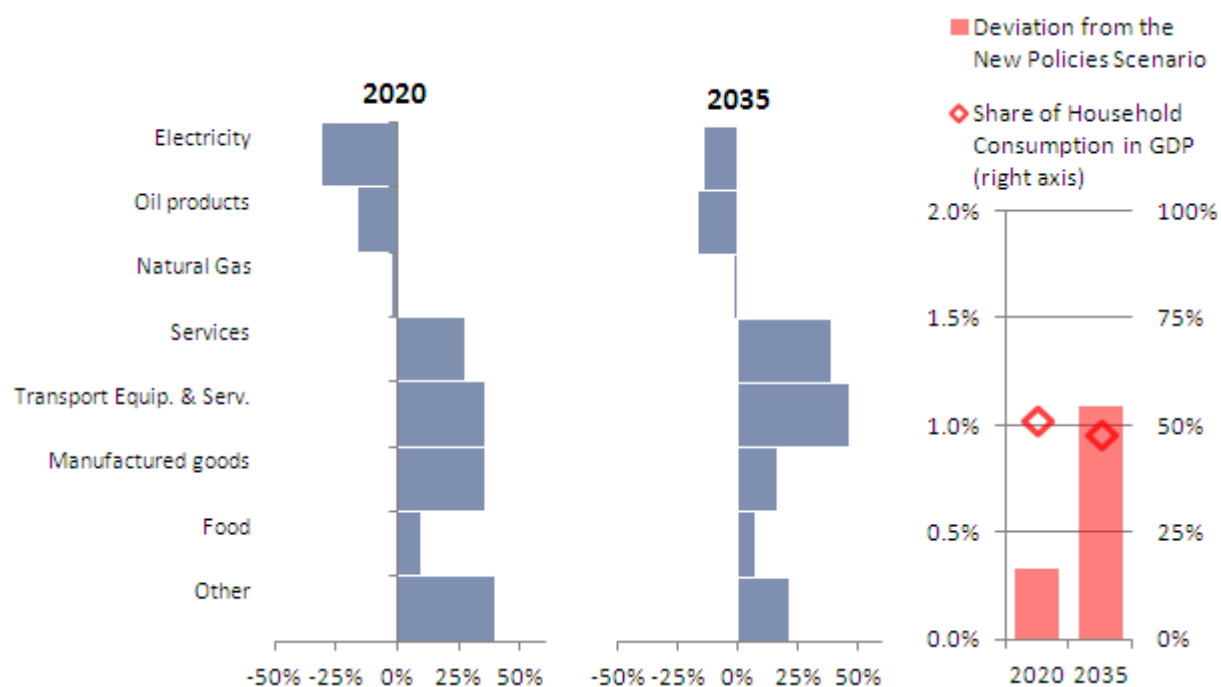
- In 2035: GDP increase: +1.1% (+USD790 billion on average p.a.) / Household consumption: +1.2%
- Intermediate sectors boost economy
- Strong stimulus of household demand for services. Domestic production supplemented by enhanced imports of services
- Large demand for imported manufactured products and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



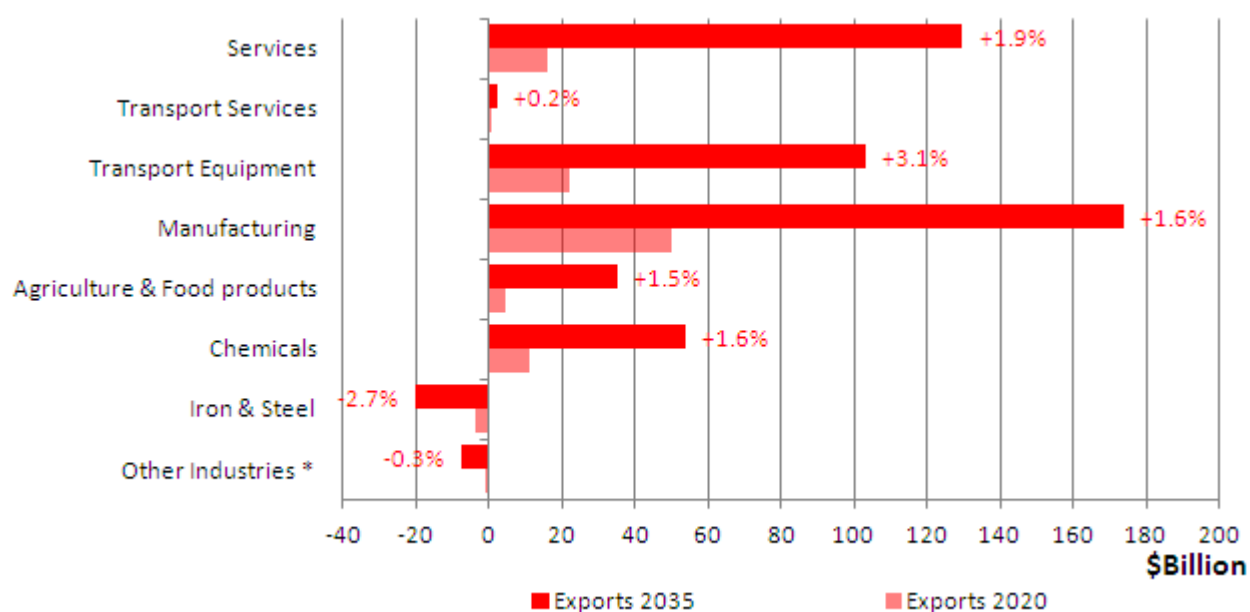
World

Per cent deviation in household real consumption patterns

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



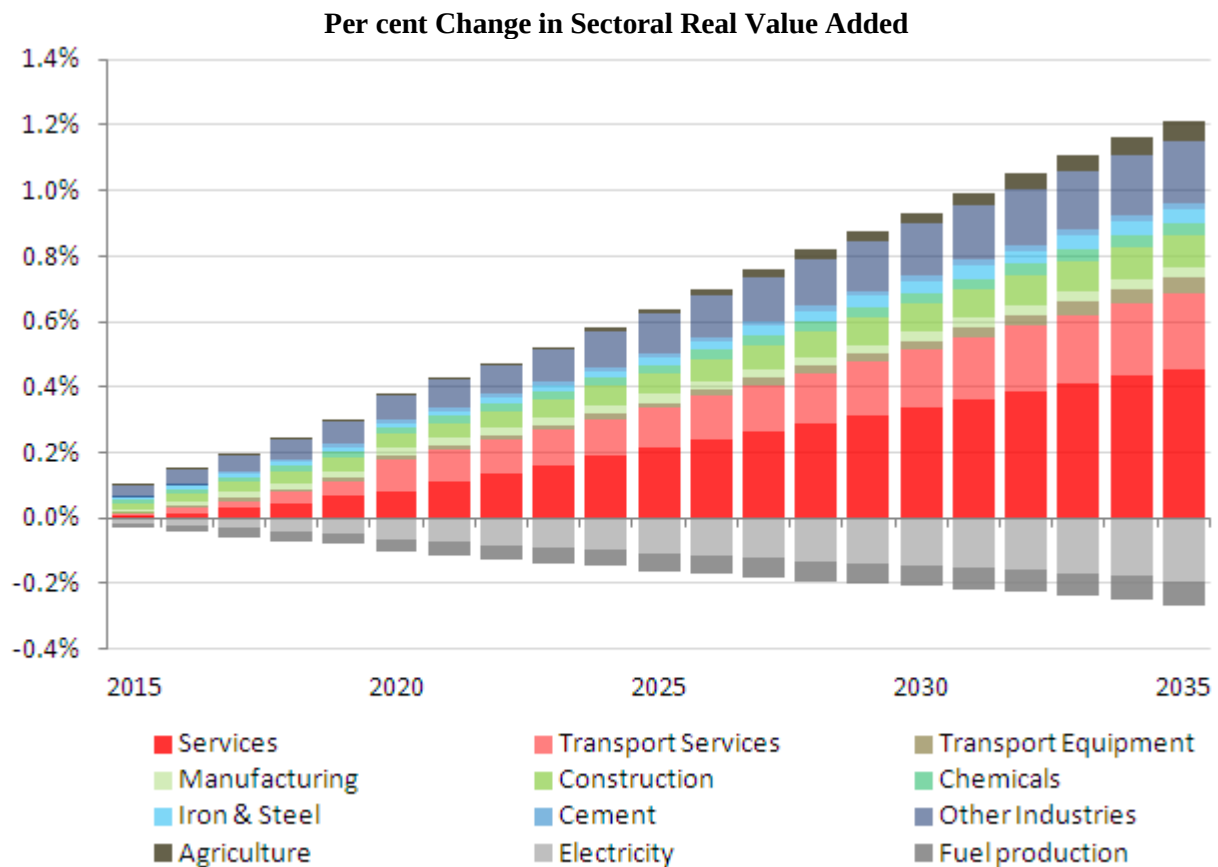
Per cent Change in Sectoral Trade



OECD

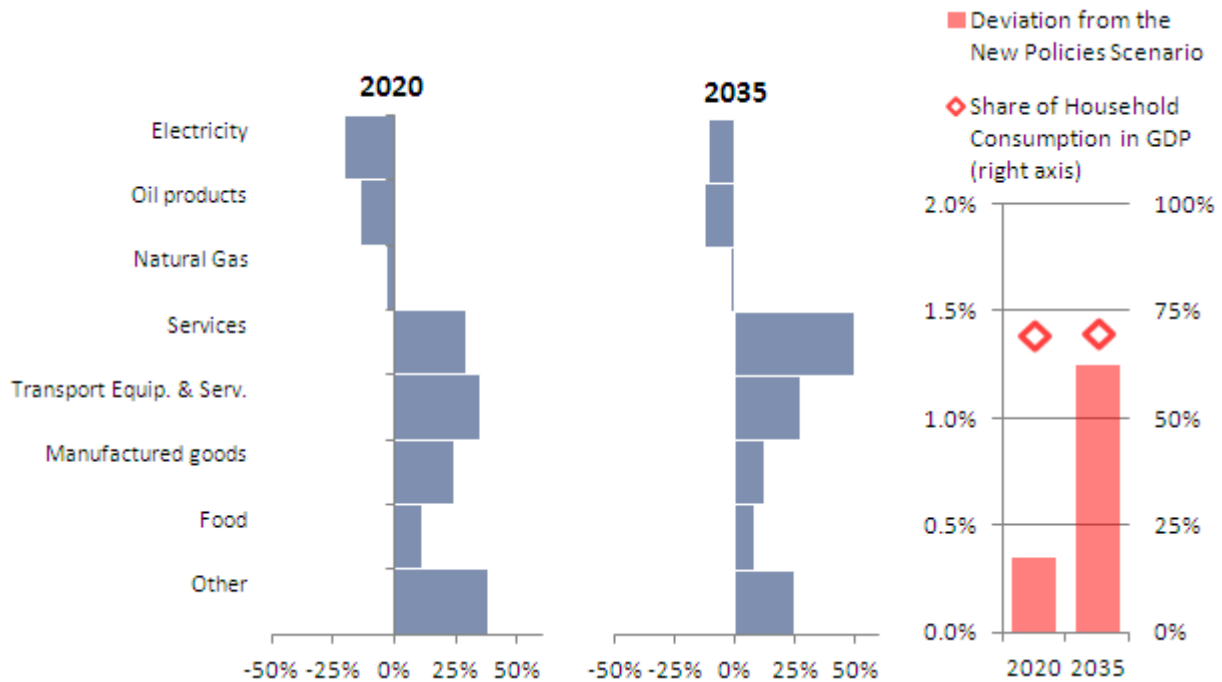
Key messages

- 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

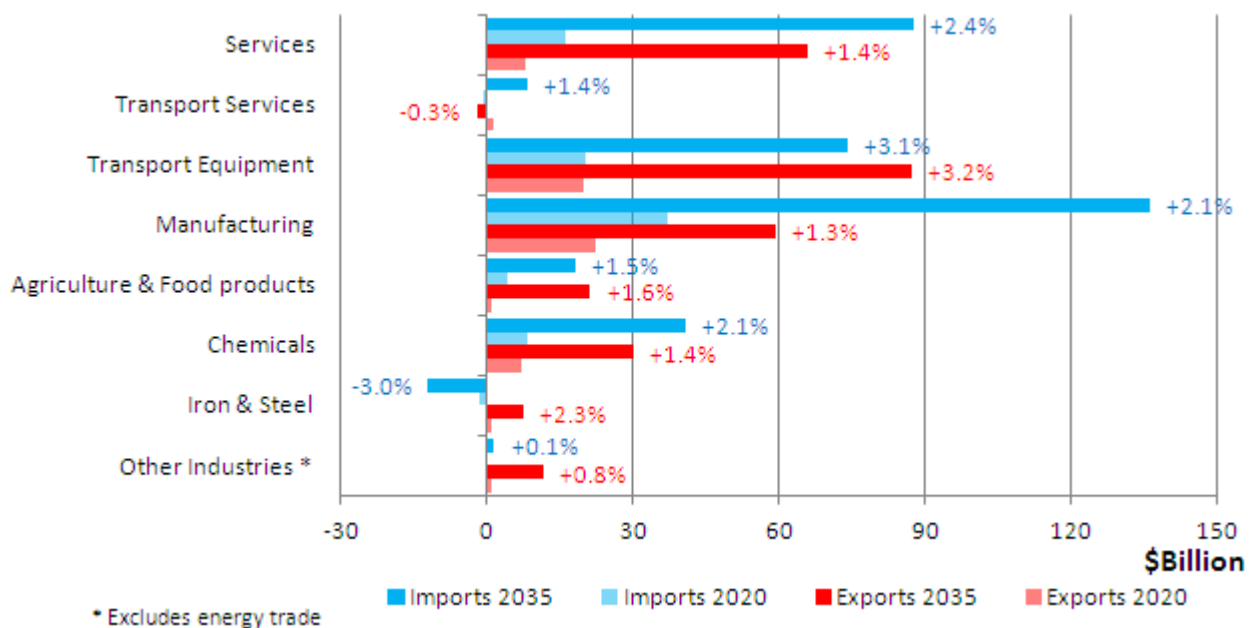


Per cent deviation in household real consumption patterns

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



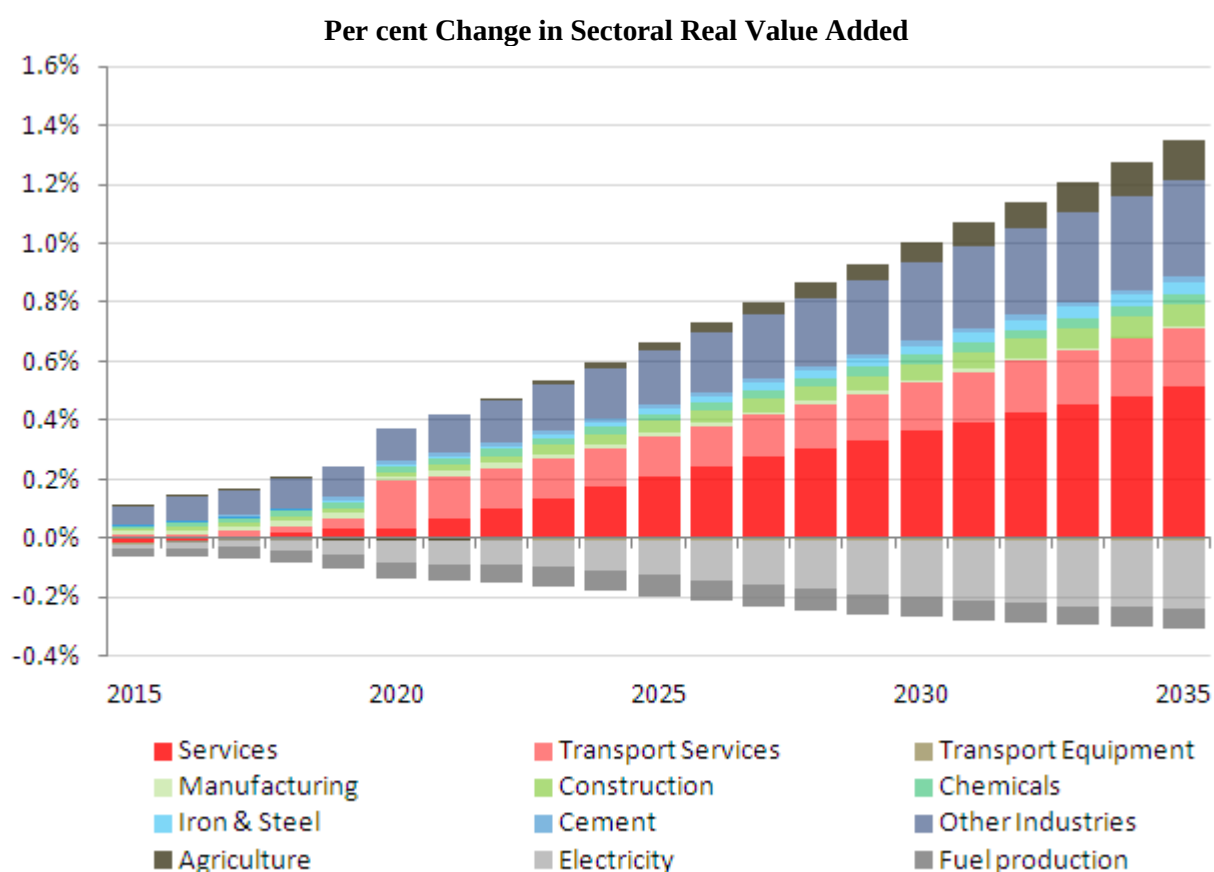
Per cent Change in Sectoral Trade



United States

Key messages

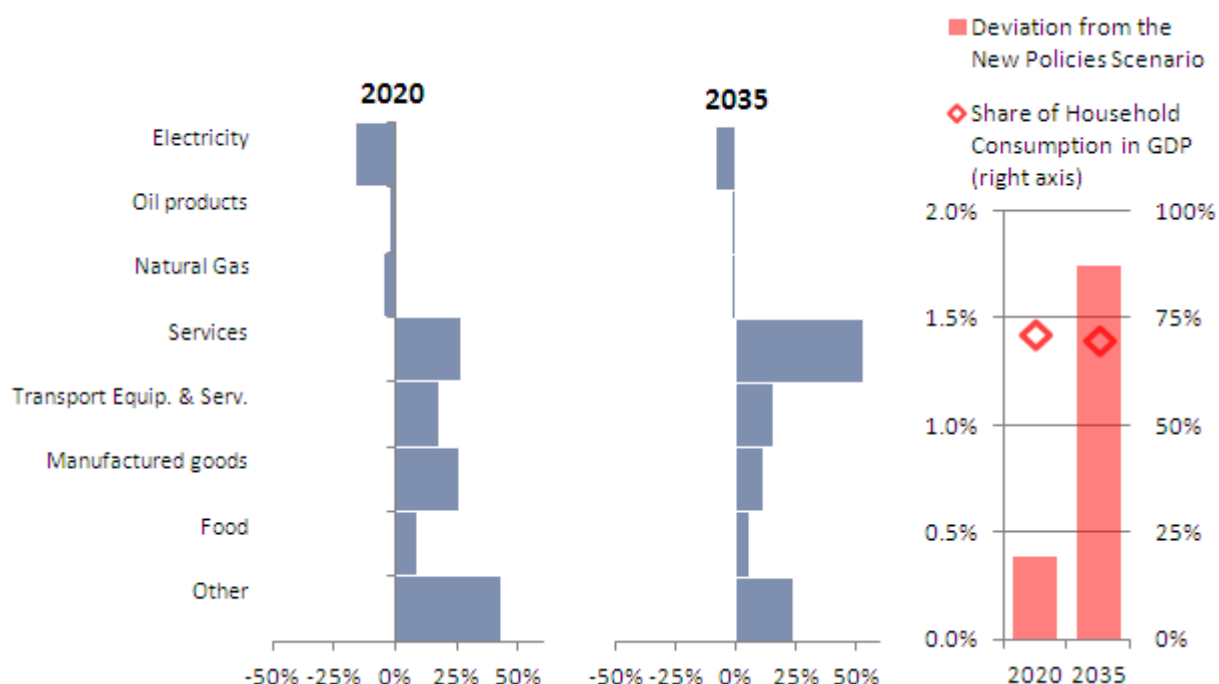
- In 2035: GDP increase: +1.3% (+USD115 billion on average p.a.) / Household consumption: +1.7%
- Intermediate sectors boost economy
- Strong stimulus of household demand for services. Domestic production supplemented by enhanced imports of services
- Large demand for imported manufactured products and transport equipment in 2035



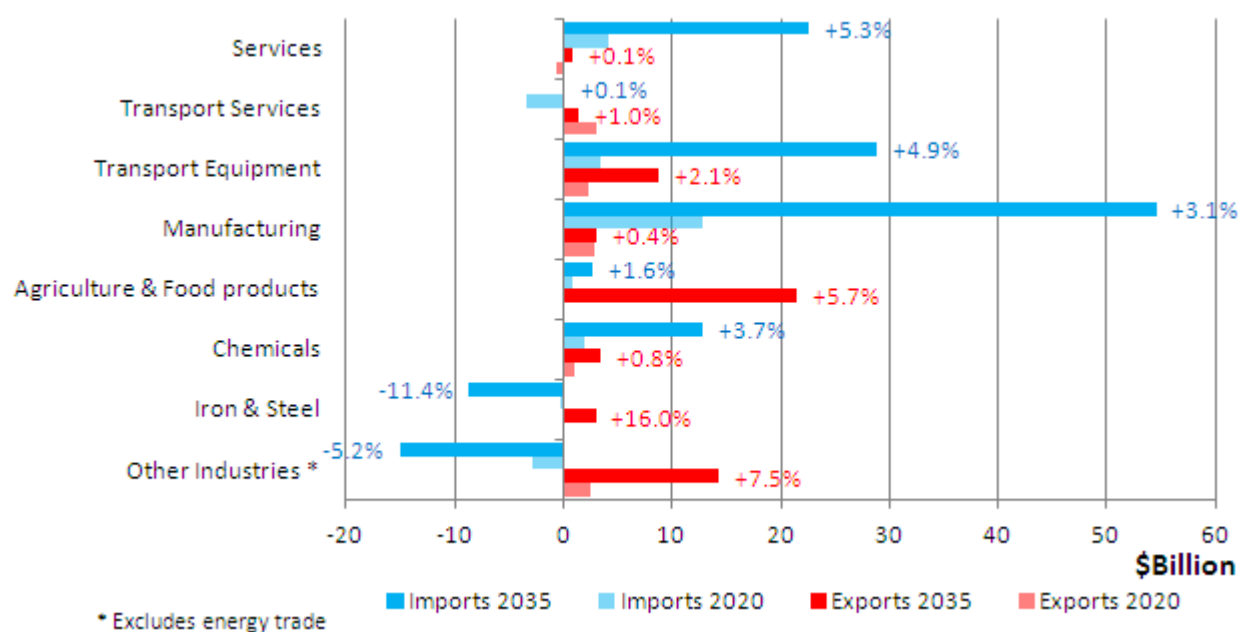
United States

Per cent deviation in household real consumption patterns

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



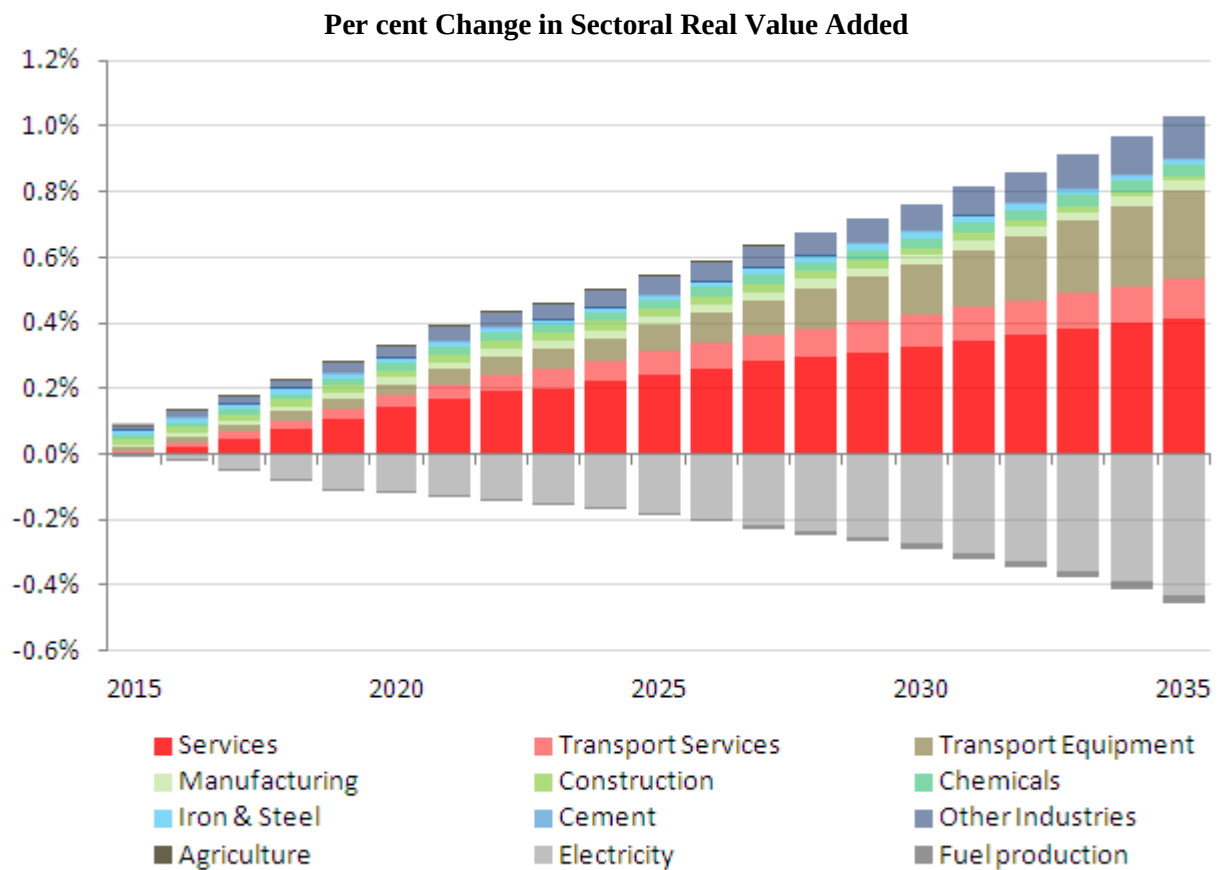
Per cent Change in Sectoral Trade



Japan

Key messages

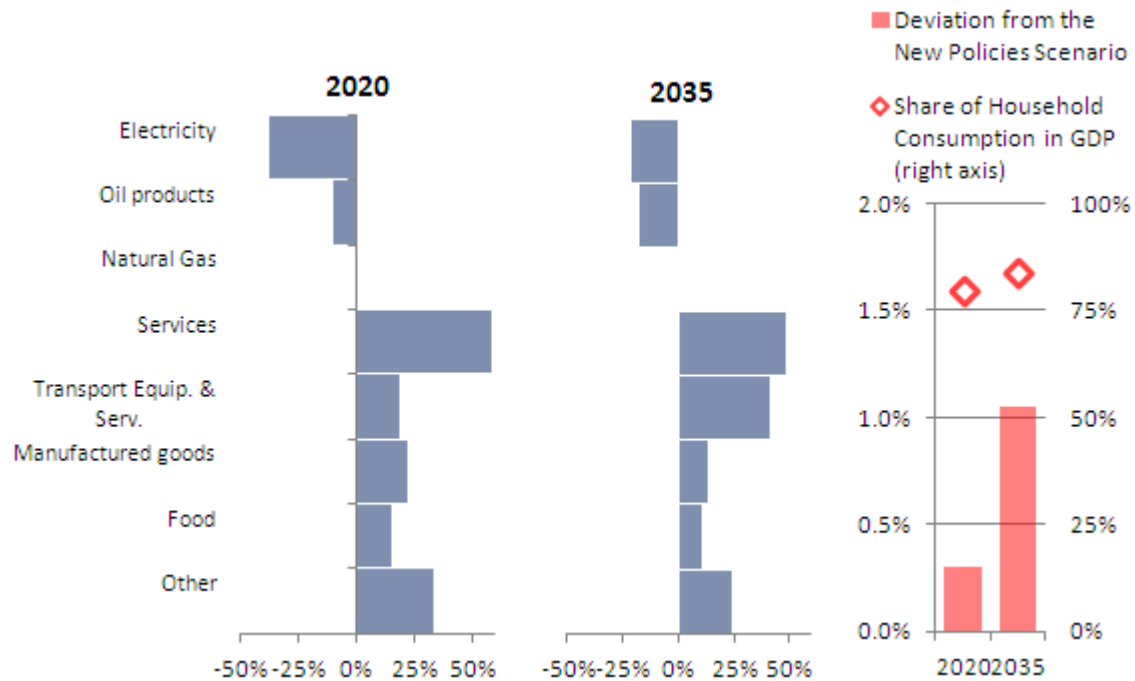
- In 2035: GDP increase: +0.6% (+USD15 billion on average p.a.) / Household consumption: +1.1%
- Large potential for energy efficiency improvement
- Large reduction of electricity demand and direct fossil fuel consumption by households
- Increased production and domestic consumption of transport equipment
- Significant increase in exports of transport equipment (+7%)



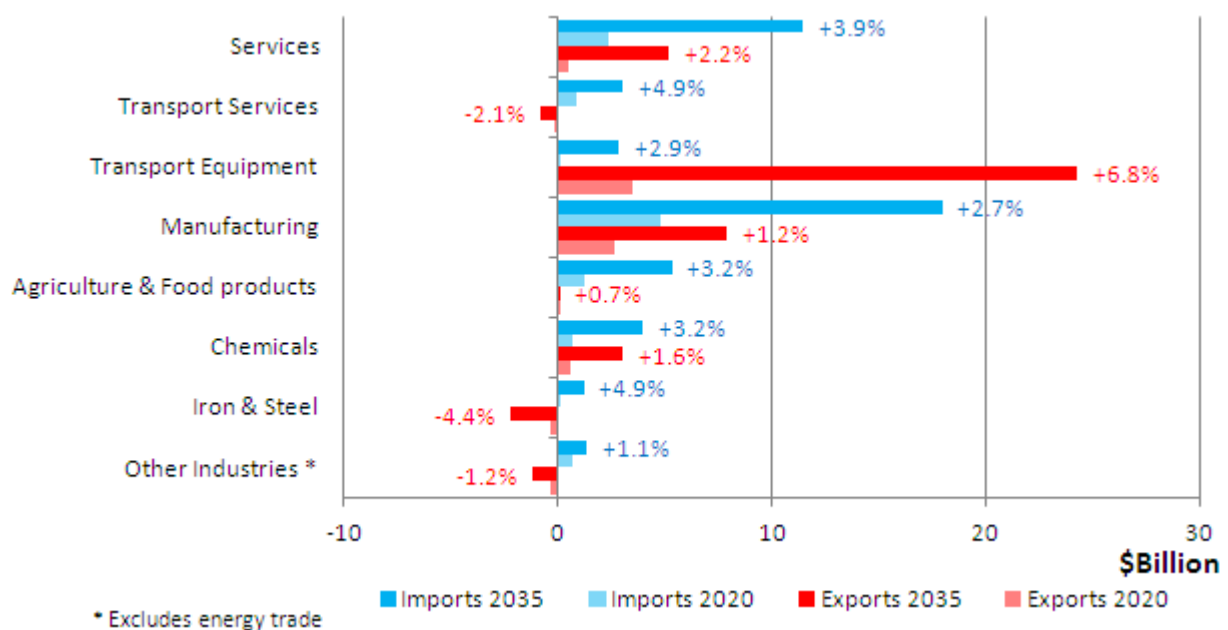
Japan

Per cent deviation in household real consumption patterns

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



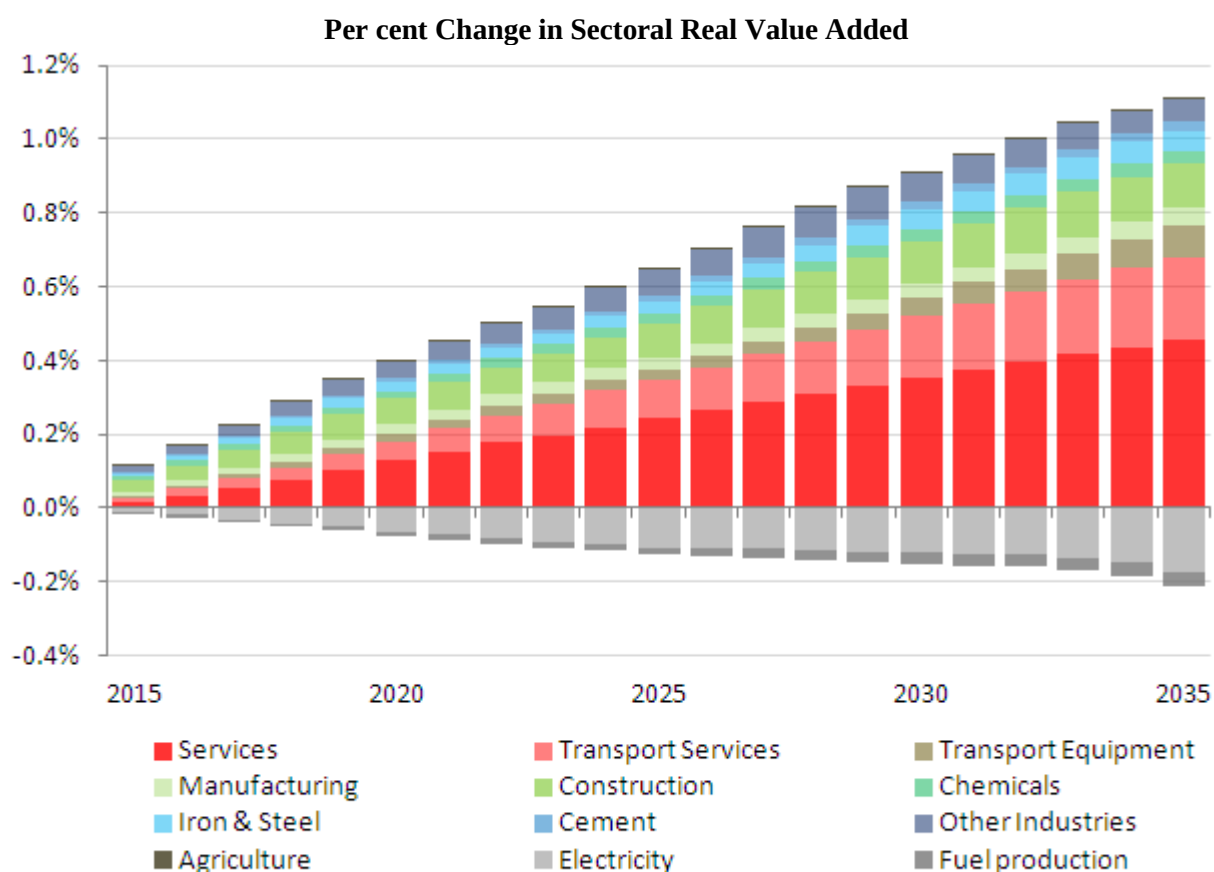
Per cent Change in Sectoral Trade



European Union

Key messages

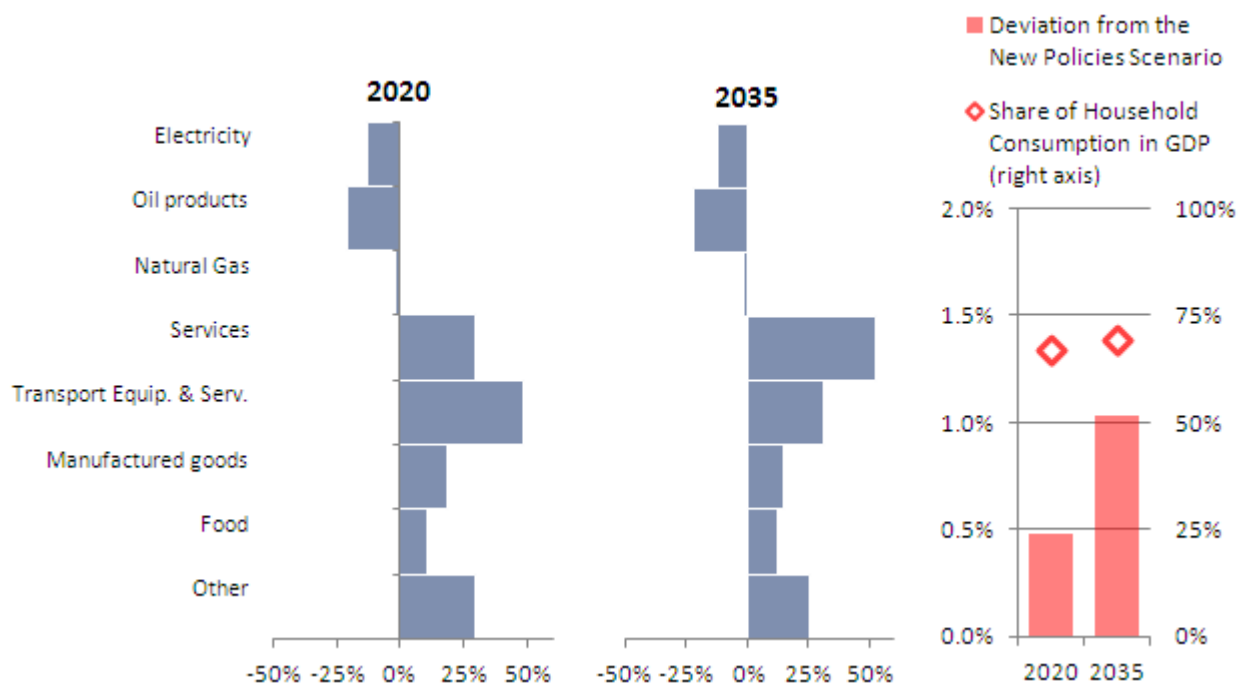
- In 2035: GDP increase: +0.7% (+USD77 billion on average p.a.) / Household consumption: +1%
- Production of transport services encouraged by rapid uptake of energy-efficient vehicles
- Reinforced demand for imported goods, including manufactured products and services
- All trade flows (exports and imports) stimulated



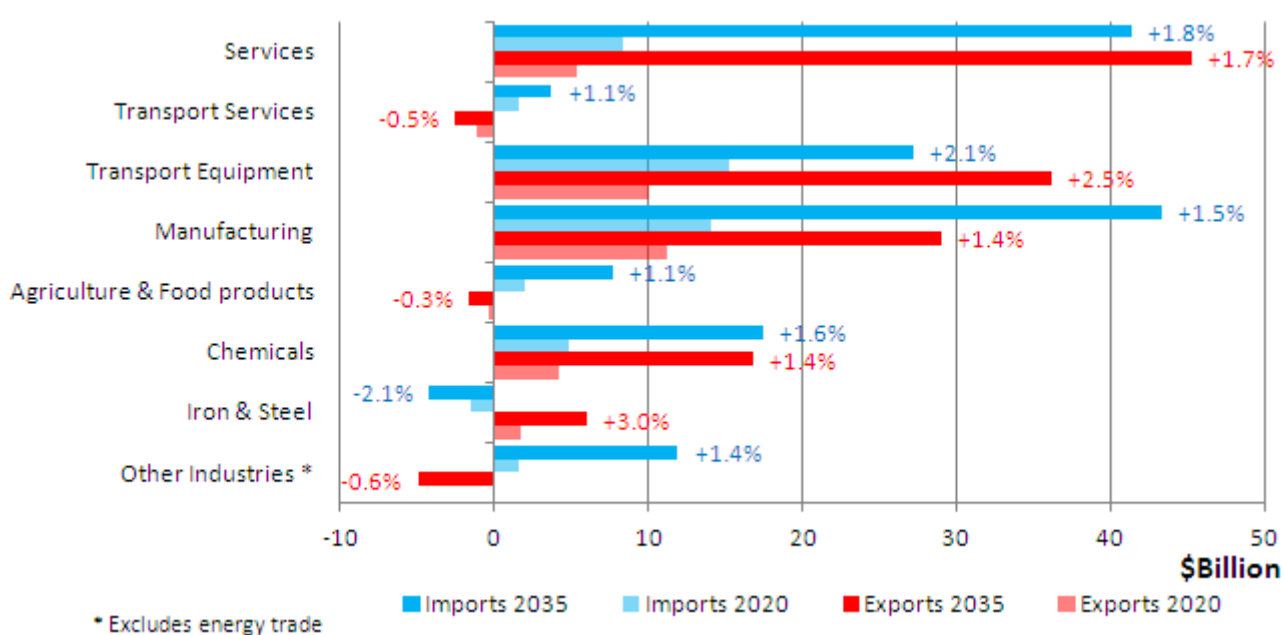
European Union

Per cent deviation in household real consumption patterns

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



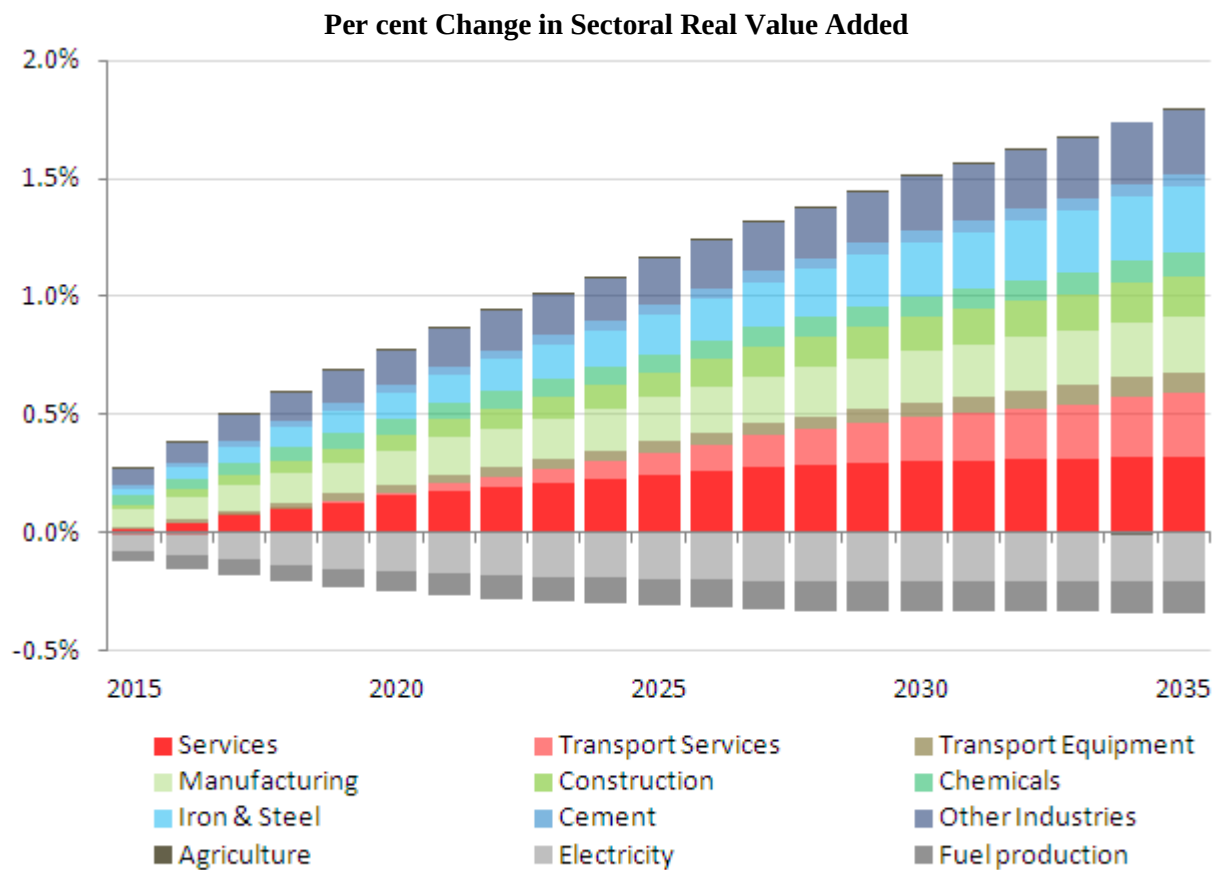
Per cent Change in Sectoral Trade



China

Key messages

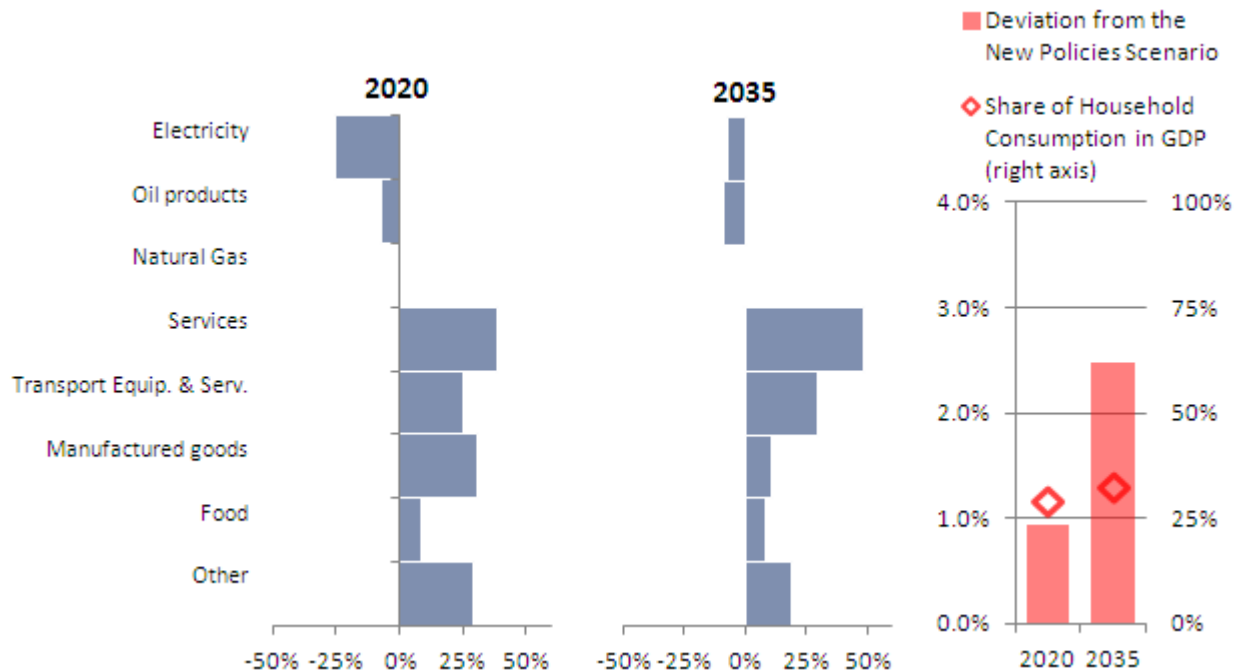
- In 2035: GDP increase: +1.4% (+USD231 billion on average p.a.) / Household consumption: +2.5%
- Increased household spending
- Acceleration of economic development, mainly driven by boosted industrial activity (two-thirds of additional economic activity)
- Extra domestic demand for services supplied by increased imports
- Boosted demand for imported services (+5%), and large reliance on imported transport equipment (+6%)



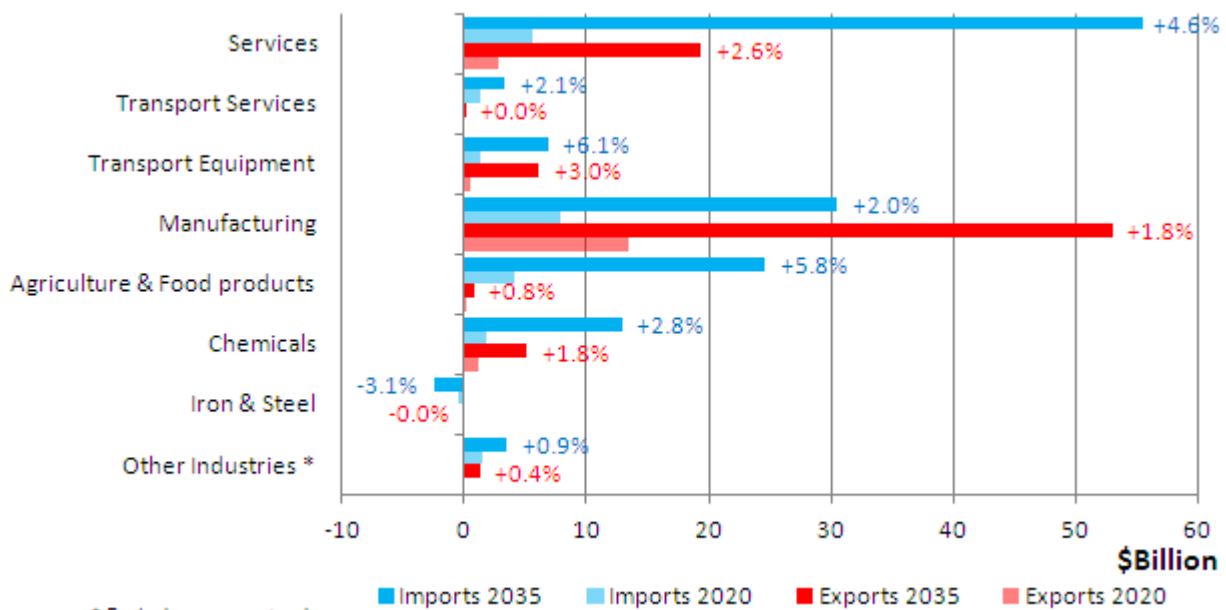
China

Per cent deviation in household real consumption patterns

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



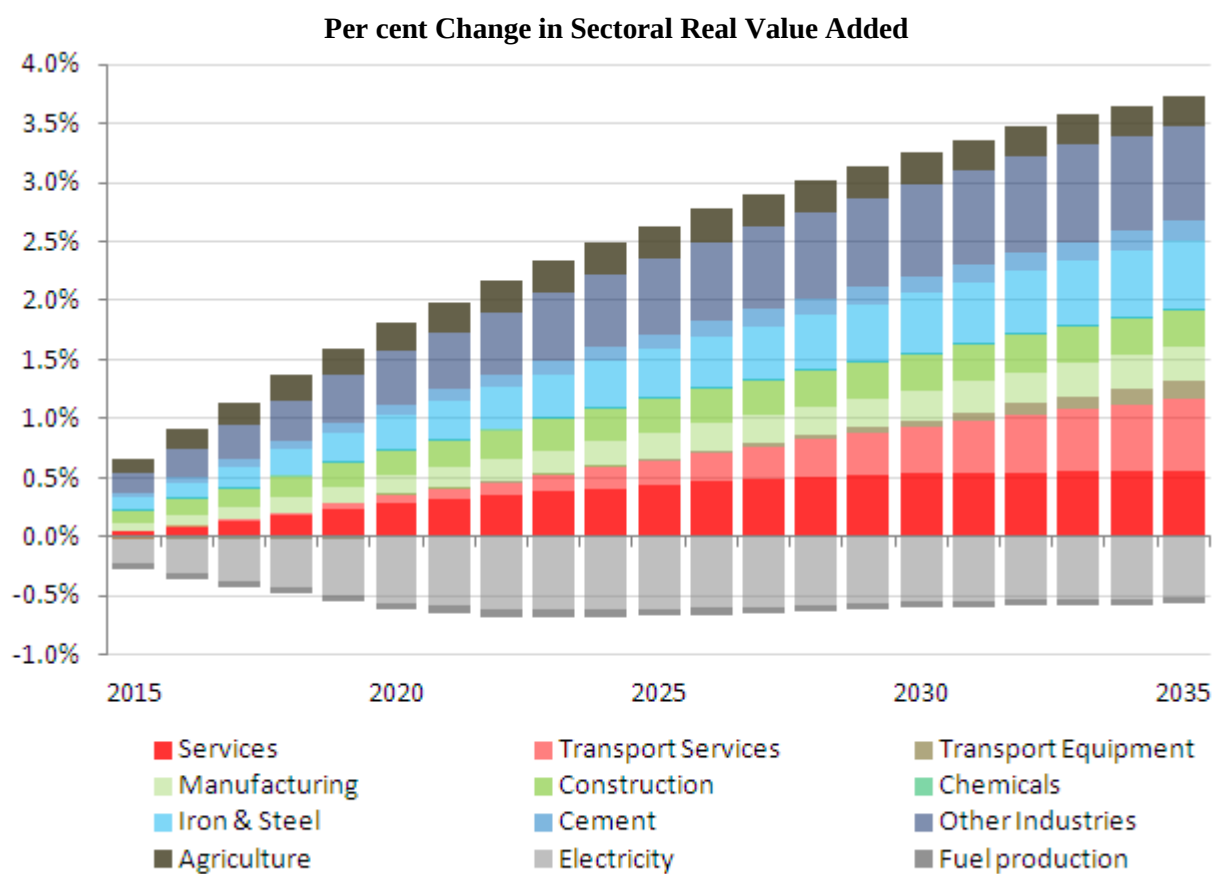
Per cent Change in Sectoral Trade



India

Key messages

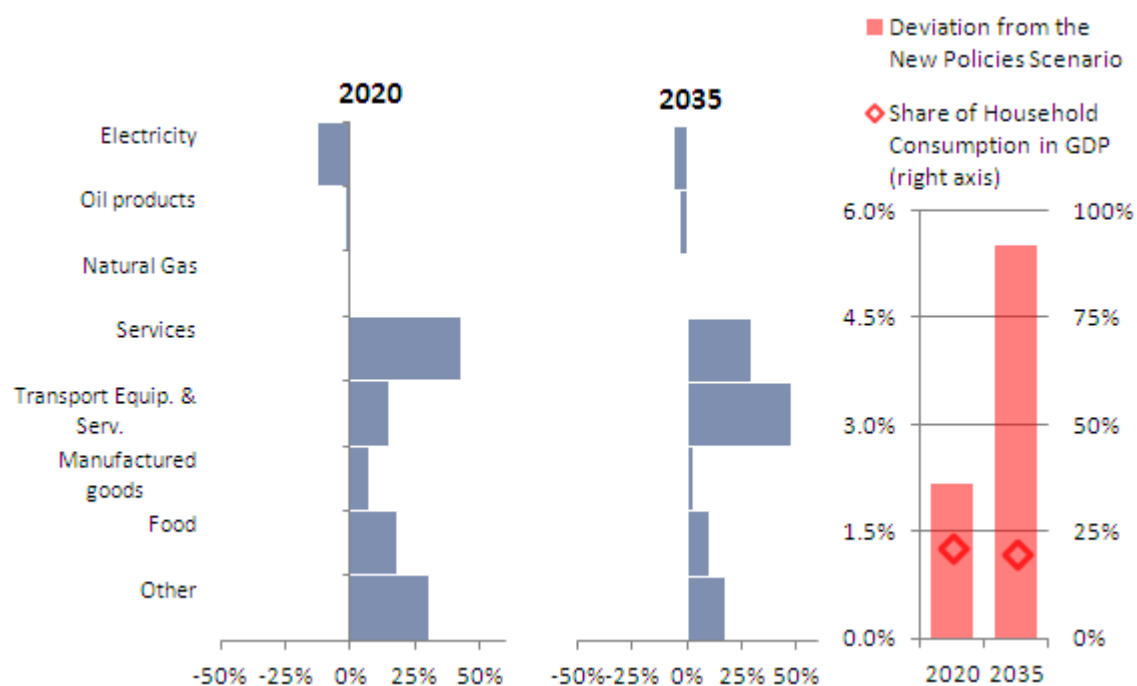
- In 2035: GDP increase: +3.9% (+USD293 billion on average p.a.) / Household consumption: +5.5%
- Strong policy stimulus on overall economic activity
- Specialisation in heavy, energy-intensive industries
- Strong stimulation of imported goods, but starting from low volumes in transport equipments (+35%), services (+11%) or chemicals (+10%)



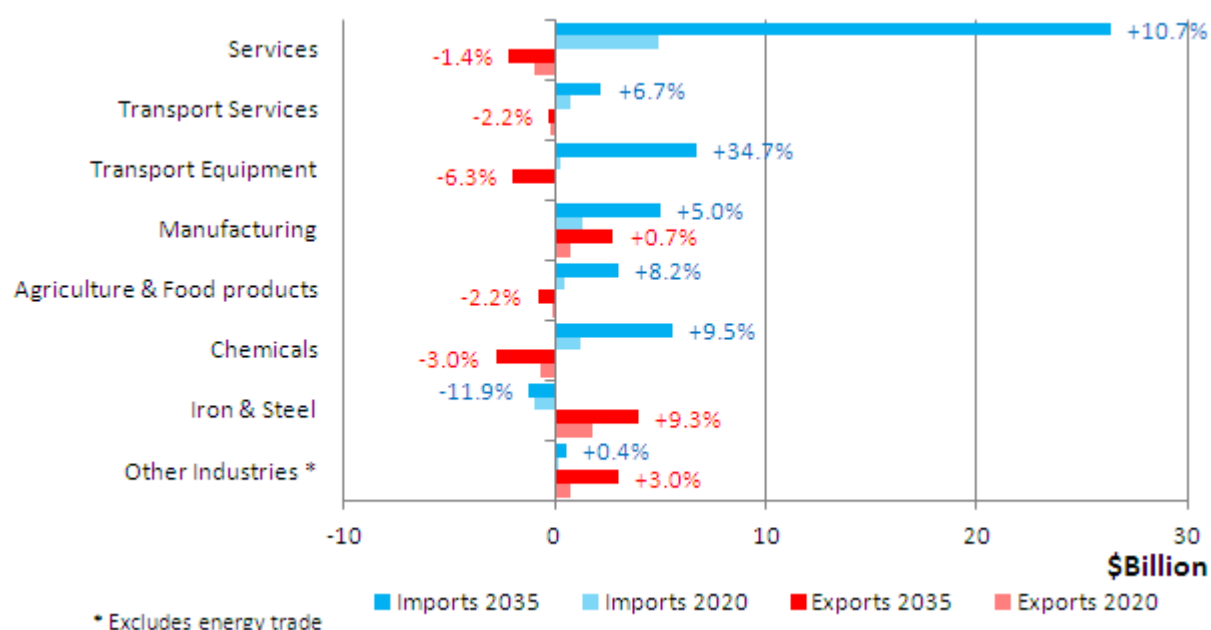
India

Per cent deviation in household real consumption patterns

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



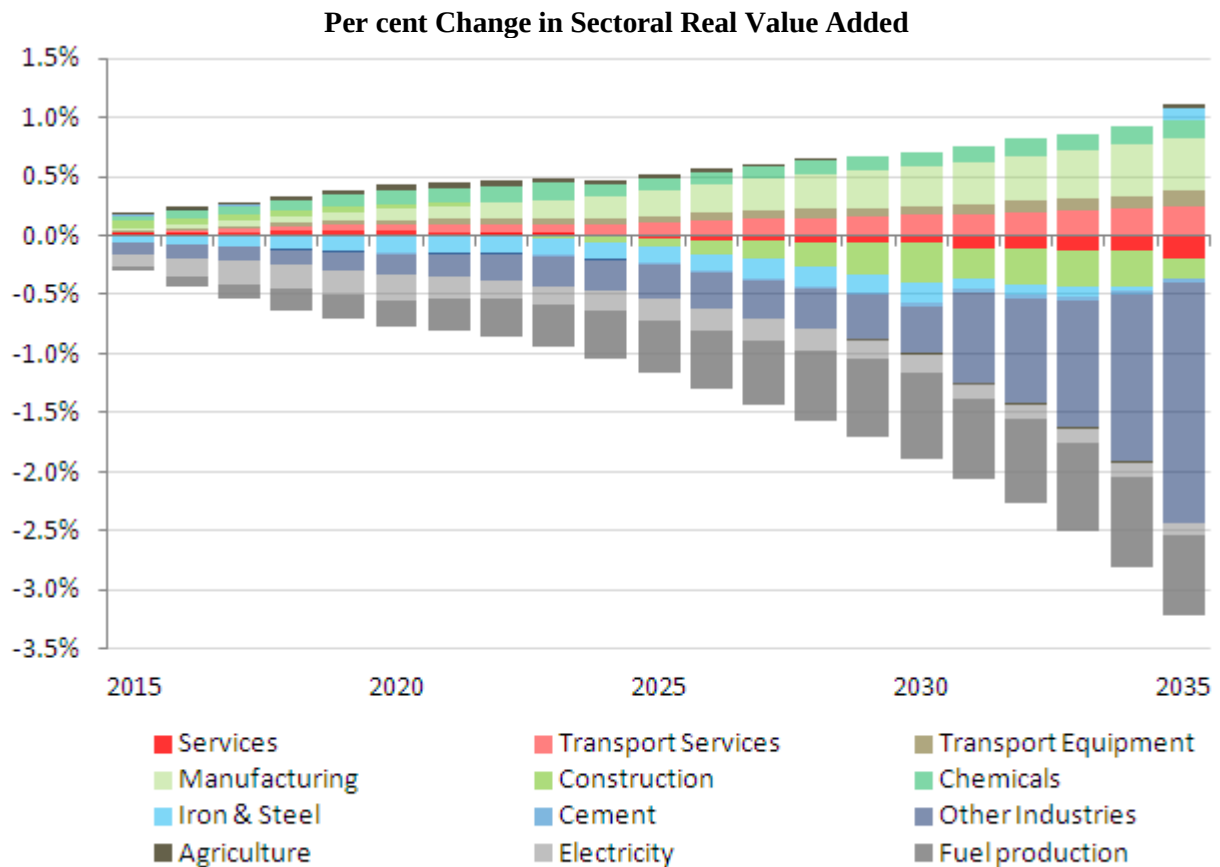
Per cent Change in Sectoral Trade



Russia

Key messages

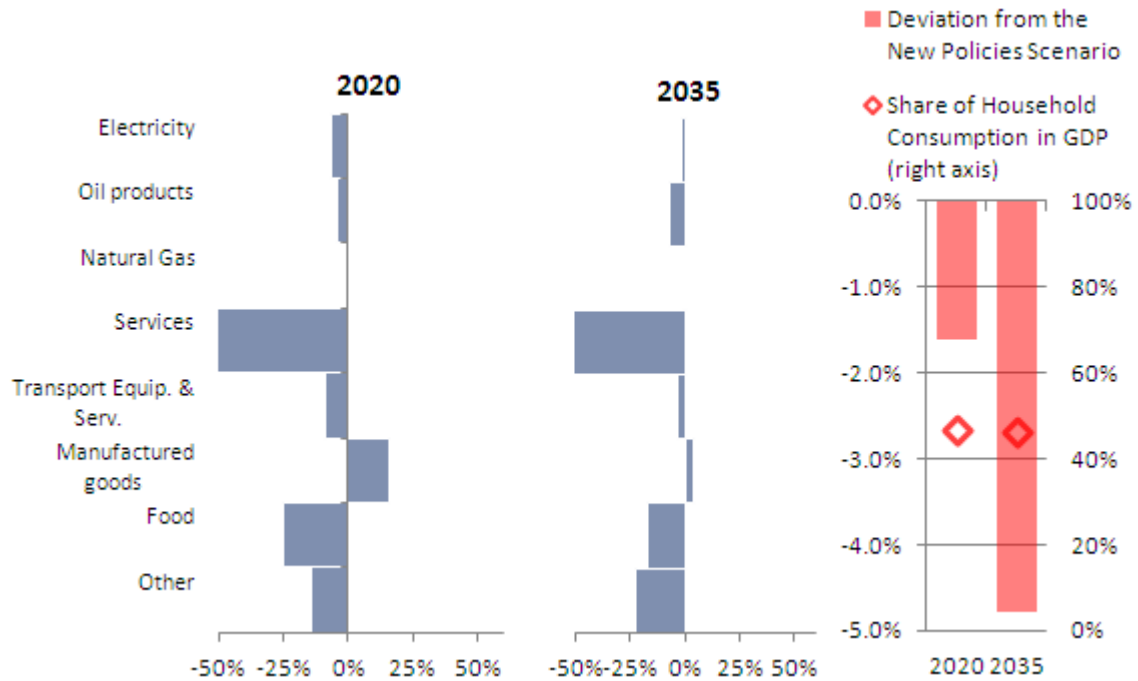
- In 2035: GDP increase: -2.9% (-USD45 billion on average p.a.) / Household consumption: -4.8%
- Large slowdown of economic activity due to sizable reduction in energy export revenues
- Households increase their services consumption
- Manifest policy stimulation of construction sectors thanks to investment-induced buildings refurbishment, insulation enhancement and rationalized energy consumption
- Large impact on trade flows: cheaper domestic production encourages production and exports of most goods



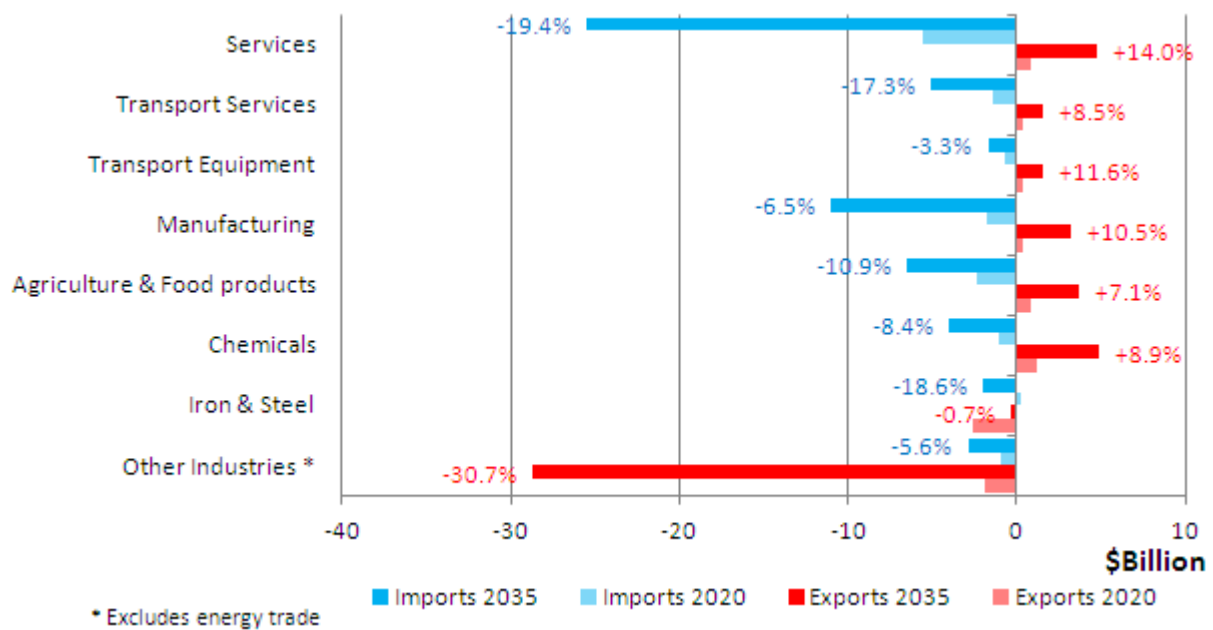
Russia

Per cent deviation in household real consumption patterns

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



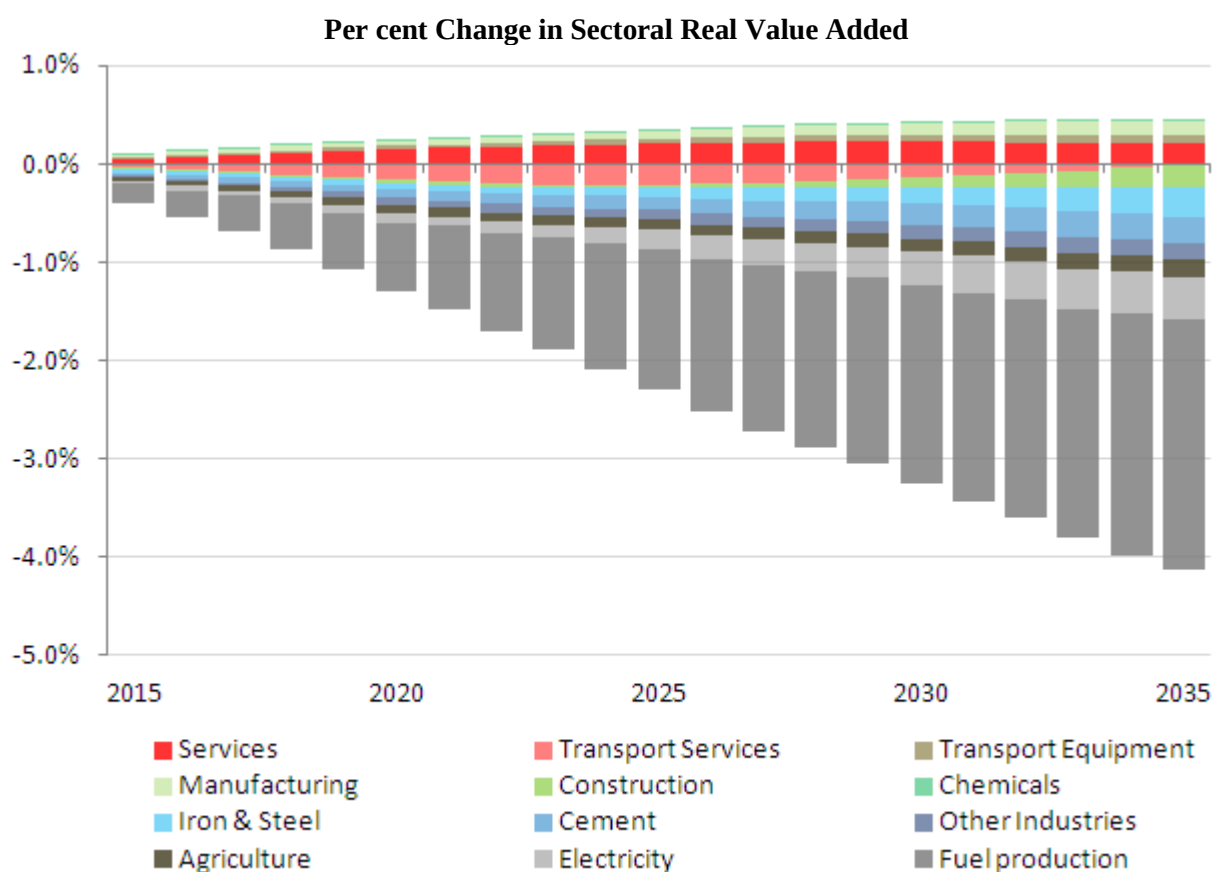
Per cent Change in Sectoral Trade



Middle East

Key messages

- In 2035: GDP increase: -3.8% (-USD64 billion on average p.a.) / Household consumption: -7.8%
- General slowdown of economic activity due to reduction in energy export revenues, relative to the New Policies Scenario. In absolute terms, Middle East economy grows on average at 3.8% per annum between 2010 and 2035.
- Households consumption decreases appreciably
- Reduced domestic demand reduces demand for imported goods. Cheaper domestic production of services encourages exports (+13%)

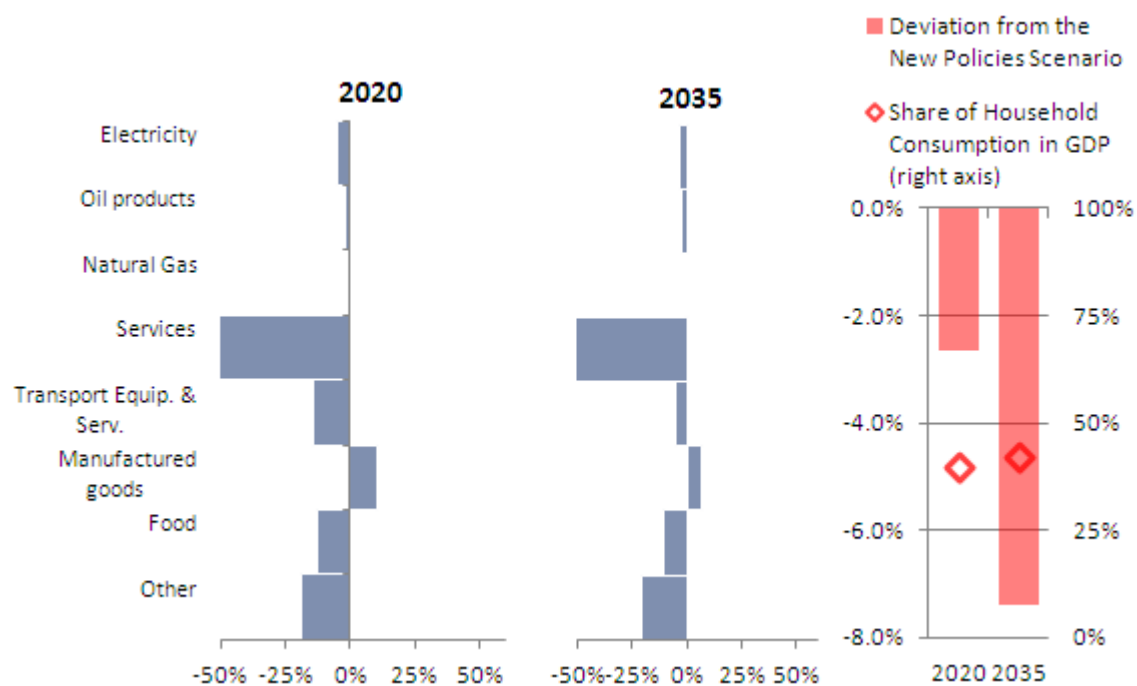


Note: Value-added measured at basic prices

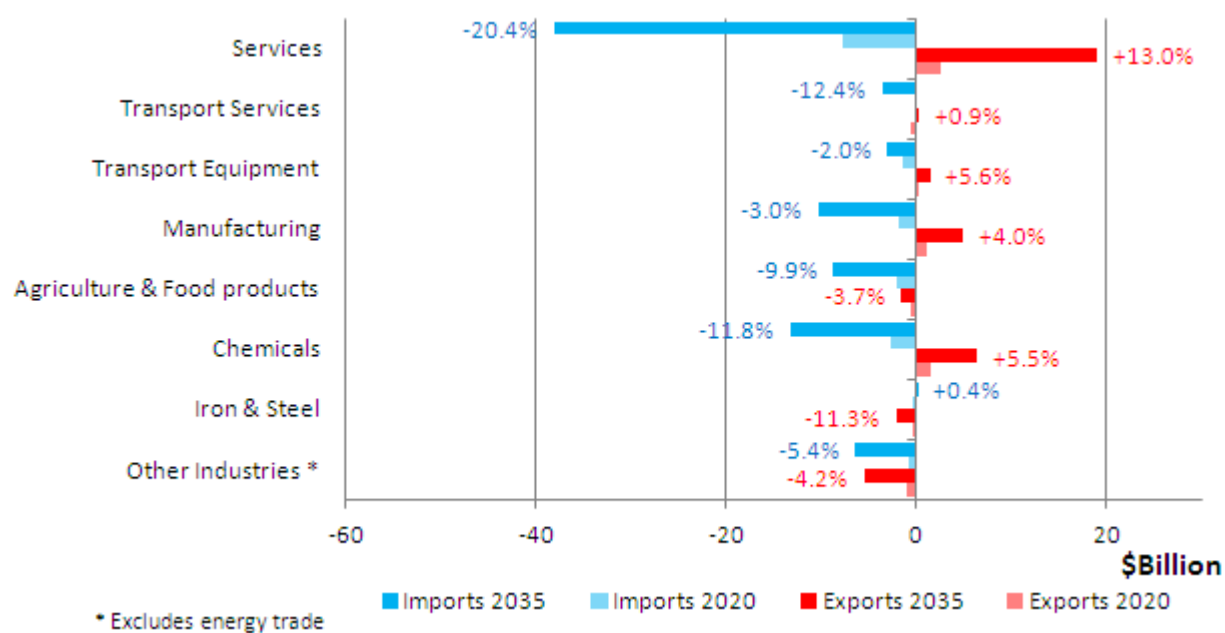
Middle East

Per cent deviation in household real consumption patterns

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



Per cent Change in Sectoral Trade



3.6 Sensitivity analysis: Impact of fossil fuel subsidy reform

41. The Efficient World Scenario stipulates the accelerated multilateral reform of fossil fuel consumption subsidies in emerging and developing economies relative to the New Policies Scenario⁸. 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 region⁹, 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.

42. 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.

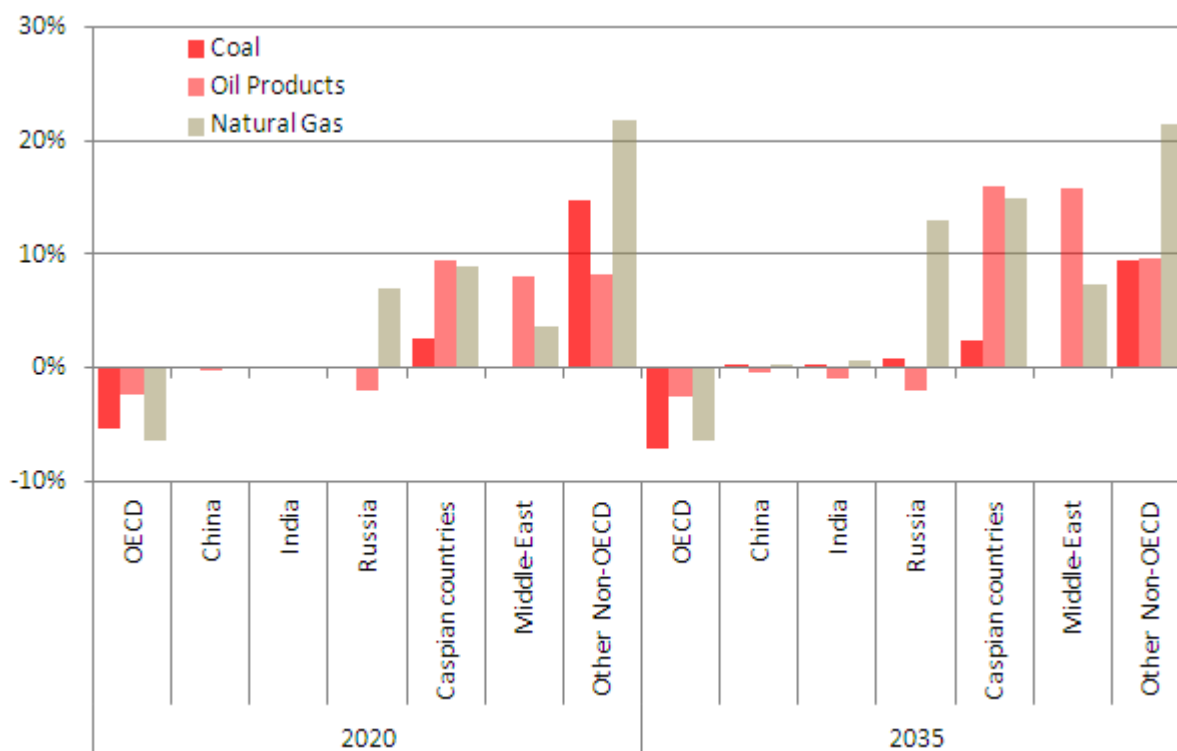
43. Maintaining higher subsidy levels in Russian consumption of electricity and natural gas through 2035 mainly encourages overall Russian natural gas consumption, to the detriment of oil products and coal. Middle-East countries, whose average subsidisation rate of fossil fuel consumption currently amounts 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.

44. 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.

⁸ 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.*, 2013).

⁹ According to WEO regional disaggregation, countries of the Caspian region include Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan.

Figure 14. Per cent change in primary fossil fuel consumption with slower fossil fuel subsidy reform

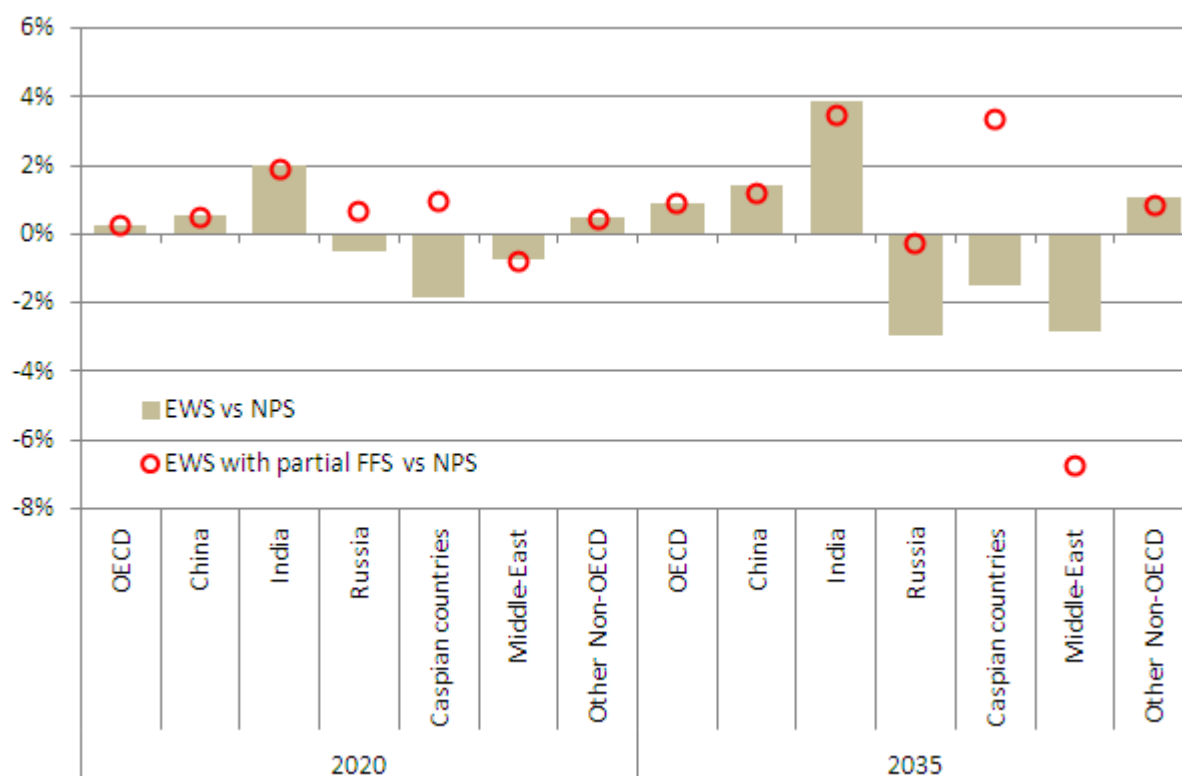


Source: OECD ENV-Linkages model

45. 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.* 2013 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.

46. 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 15. Per cent change in real GDP with slower fossil fuel subsidy reform



Source: OECD ENV-Linkages model

4. Final remarks

47. 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 allowed by coupling two complex modelling frameworks, using the best information available. These projections are inherently subject to a number of uncertainties, regarding data, model specification and not least projections of future behaviour of households and firms. Nonetheless, a number of interesting general observations can be made.

48. The IEA Efficient World Scenario projects halved global primary energy demand by 2035. Fossil fuel consumption accounts for the lion's share of total 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 of specific investments.

49. In 2035, the Efficient World Scenario entails an 18% drop in energy-related CO₂ emissions because of reduced fossil fuel consumption worldwide. By 2035, non-CO₂ GHG gases emissions are 3.5 % lower than the New Policies Scenario level. The bulk of this reduction relates to CH₄ emissions. The net, cumulative methane emission abatement is 6.2 GtCO₂eq over 2010-2035, equivalent to methane emitted globally by energy and agriculture sectors in 2010.

50. 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 global GDP in 2035 being 1.1% higher than 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.

51. Finally, the reform of fossil fuel consumption subsidies also plays a key role in reducing global fossil fuel consumption and in restoring more efficient allocation of resources throughout the entire economy. Slowing down the pace of the reform entails an increase in fossil fuel consumption in many countries which benefits economic development of large energy exporters such as Russia or countries from the Caspian region. 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. In 2035, global GDP benefits, relative to the central IEA New Policies Scenario, decrease from 1.1% to 0.9%. This alternative implementation of the fossil fuel subsidy reform partially hinders the Efficient World Scenario core objective to reduce overall energy consumption. Therefore an ambitious reform of fossil fuel consumption subsidy is needed to accompany energy-efficiency specific measures as part of a comprehensive policy package aiming at less reliance on fossil fuel and at effective climate change mitigation at the lowest cost.

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APPENDIX

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

52. 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. For an overview of the ENV-Linkages model, see Chateau *et al.* (2012).

53. 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.* (2012).

54. 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

55. 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).

56. 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.

57. The allocation of goods-services and primary factors of production between the different agents of the economy (households, government, firms, foreign consumers, etc.) rests on the assumption of perfect markets 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.

58. 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.

59. 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 A1. 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

60. New capital perfect mobility and homogeneity as well as perfect markets assumption 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.

61. 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.

62. 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.

63. 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.

64. 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

65. 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.

66. 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).

67. 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.

68. 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 A2. ENV-Linkages model sectors and regions

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

* 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.

69. 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 A3. Breakdown of extra investments by key sectors/agents and countries (%). Efficient World Scenario relative to New Policies Scenario

	Households / Buildings	Households / Equipment	Manufacturing	Services	Transport Services	Energy Intensive Industries	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 & Nor	20%	41%	6%	18%	10%	4%	100%
Rest of the world	18%	35%	14%	17%	13%	3%	100%
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 & Nor	22%	45%	4%	13%	14%	3%	100%
Rest of the world	22%	45%	7%	10%	14%	2%	100%

70. 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

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

72. First, the ENV-Linkages model replicates all GDP trends assumed in the IEA partial equilibrium Word 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 reproduce the full set of energy demands and supply correctly. 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) regarding the features of the IEA partial equilibrium model. Therefore a set of exogenous parameters of ENV-Linkages (like AEE parameters) need be adjusted at each time period and for each country to reproduce WEO energy projections over the whole time horizon (2010-2035).

73. Since ENV-Linkages' quantity and price variables are fully determined by equilibrium relationships across all markets of goods and services, it is virtually impossible to match WEM price assumptions, demand and supply at a 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.

74. 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

75. Apart from the policy prices instruments listed above in item (vi) that are directly implemented in the CGE model, other variables could logically not be directly imposed since they are determined endogenously through markets mechanisms and agents behaviour.

76. 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:¹⁰

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

77. 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.

78. 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.*

79. 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. The implementation of the New Policies and the Efficient World Scenario

80. 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.

81. 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

¹⁰ 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.

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).