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Policy scenarios for a transition to a more resource efficient and circular economy

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POLICY SCENARIOS FOR A TRANSITION TO A MORE RESOURCE EFFICIENT AND CIRCULAR ECONOMY

ENVIRONMENT WORKING PAPER N° 169

By Ruben Bibas, Jean Chateau and Elisa Lanzi (1)

(1) OECD Environment Directorate

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Keywords: circular economy; resource efficiency; trade and environment; general equilibrium model

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Abstract

Global materials use is expected to grow in the coming decades in the absence of new policies, bearing substantial negative impacts for the environment. This report analyses the mechanisms through which resource efficiency and circular economy policies can achieve a decoupling between economic growth and material use. Using the OECD's ENV-Linkages model, the report examines the economic and environmental impacts of a global material fiscal reform, which implements taxes on primary metal and mineral resources, and uses the revenue of these taxes to finance subsidies to recycled goods and to secondary metal production.

The implementation of the material fiscal reform would allow a relative decoupling of primary material use from economic growth in future years. Model simulations show that, at the global level, primary materials use is reduced by 27% for metals and 8% for non-metallic minerals, with an overall reduction of around 7% compared to the baseline scenario for the year 2040. The projected reduction in materials use is achieved with a limited impact on global economic activity, with an overall loss of 0.2% of global GDP in 2040. The shift from primary to secondary materials resulting from the core policy reform is projected to reduce the environmental impacts of materials use.

Overall, the economic impacts are small but hide regional disparities, which depend on whether countries are net importers or exporters of raw materials, as well as on the production technologies available and the input costs of primary and secondary materials. Additionally, a few sectors are severely impacted and accompanying policies could help make the transition acceptable.

A partial regional implementation of the reform leads to competiveness losses for some countries as well as leakage effects: materials use increases in regions that are not implementing the material fiscal reform. The reductions in materials use for a combined energy and material transition shows synergies: the decrease in primary materials use attain 19% in 2040, while GDP costs remain limited. However, the combined energy and material transition scenario increases the number of sectors affected and further increases the shift towards green sectors. These changes in the structure of the economy facilitate the shift from primary materials to secondary materials.

Keywords*: circular economy; resource efficiency; trade and environment; general equilibrium model*

JEL codes*: C68 ; F18 ; O13 ; O44 ; Q53*

Résumé

Sans nouvelles mesures politiques, l'utilisation mondiale de matériaux devrait augmenter dans les décennies à venir, avec des impacts négatifs importants sur l'environnement. Ce rapport analyse les mécanismes par lesquels les politiques d'efficacité des ressources et d'économie circulaire peuvent parvenir à un découplage entre la croissance économique et l'utilisation des matériaux. En utilisant le modèle ENV-Linkages de l'OCDE, ce rapport examine les impacts économiques et environnementaux d'une réforme fiscale sur les matériaux au niveau mondial, qui met en œuvre des taxes sur les métaux primaires et les ressources minérales, et utilise les recettes de ces taxes pour financer les subventions aux produits recyclés et à la production de métaux secondaires.

La mise en œuvre de la réforme fiscale sur les matériaux permettrait un découplage relatif entre l'utilisation des matériaux et la croissance économique dans les années à venir. Ainsi, l'analyse quantitative montre qu'au niveau mondial, l'utilisation de matériaux primaires est réduite de 27% pour les métaux et de 8% pour les minéraux non métalliques, avec une réduction globale d'environ 7% par rapport au scénario de référence pour l'année 2040. La réduction prévue de l'utilisation de matériaux est atteinte avec un impact limité sur l'activité économique mondiale, avec une perte globale de 0,2% du PIB mondial en 2040. Les réformes déployées déclenchent la transition vers une utilisation accrue de matériaux secondaires, remplaçant les matériaux primaires, avec pour conséquence de réduire les impacts environnementaux de l'utilisation de matériaux.

Dans l'ensemble, les impacts économiques sont faibles mais cachent des disparités régionales, liées à plusieurs facteurs : selon que les pays sont importateurs ou exportateurs nets de matériaux primaires, et également en fonction des technologies de production disponibles et des coûts des intrants des matières primaires et secondaires. En outre, quelques secteurs sont gravement touchés et des politiques d'accompagnement pourraient contribuer à rendre la transition acceptable.

Une mise en œuvre régionale partielle de la réforme entraîne des pertes de compétitivité pour certains pays ainsi que des effets de fuite: l'utilisation de matériaux augmente dans les régions qui ne mettent pas en œuvre la réforme fiscale matérielle. La baisse de l'utilisation de matériaux dans le cas d'une transition énergie et matériaux combinée montre des synergies: la baisse de l'utilisation des matériaux primaires atteint 19% en 2040, tandis que les coûts du PIB restent limités. Cependant, le scénario de transition énergie et matériaux combinée augmente le nombre de secteurs concernés et accentue encore la transition vers les secteurs verts. Ces changements dans la structure de l'économie facilitent la transition des matériaux primaires vers les matériaux secondaires.

Mots clés *: économie circulaire; efficacité des ressources; commerce international et environnement; modèle d'équilibre général*

JEL codes *: C68 ; F18 ; O13 ; O44 ; Q53*

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This report presents results of the modelling projections of future trade consequences of a transition to a more resource-efficient, circular economy. It directly builds on the Global Material Resources Outlook to 2060 (OECD, 2019).

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Executive summary

Materials use is expected to grow in the coming decades, fostering the demand for raw materials extraction, processing and end-of-life management. The use of materials throughout their lifecycle bears substantial negative impacts for the environment, underscoring the need for policies that promote resource efficiency and the transition to a circular economy.

The present report analyses the mechanisms through which resource efficiency and circular economy policies can achieve a decoupling between economic growth and material use. Furthermore, this report quantifies the trade-offs between the environmental benefits and economic costs of the circular economy transition. It expands the existing literature by explicitly representing primary and secondary metal production sectors, as well as recycled goods, in a carefully calibrated CGE model.

The analysis in this report relies on simulations performed with the OECD's ENV-Linkages model, a dynamic computable general equilibrium (CGE) model, which links detailed projections of economic activity to 2040 to 60 different materials. This report examines the economic and environmental impacts of a core global policy scenario (a *material fiscal reform)* to promote the transition to a resource efficient and circular economy. The material fiscal reform implements taxes on primary mineral resources, and uses the revenue of these taxes to finance subsidies to recycled goods and to secondary metal production.

The implementation of the *material fiscal reform* would allow a relative decoupling of primary minerals use from economic growth in future years. Model simulations show that, at the global level, primary materials use is reduced by 27% for metals and 8% for non-metallic minerals, with an overall reduction of 7% compared to the baseline scenario for the year 2040. The projected reduction in materials use is achieved with a limited impact on global economic activity, with an overall loss of 0.2% of global GDP in 2040.

The shift from primary to secondary materials resulting from the policy reform is projected to reduce the environmental impacts of materials use. The environmental impacts include climate change, air, land, and water pollution, and the consequences on human health. This is a direct consequence of reduced primary materials use and of the lower environmental impact per tonne of secondary materials when compared to primary materials. In particular, emissions of fine particulate matter ($PM_{2.5}$), carbon monoxide (CO) and sulphur dioxide (SO_2) are projected to substantially decline in all regions. $PM_{2.5}$ decrease by 500 kt (-9%), CO by 4 Mt (-7%) and SO_2 by 1.3Mt (-9%). The largest share (90%) of these reductions take place in BRIICS countries. Greenhouse gas emissions, and most notably F-gas emissions, are also projected to decrease, as they are strongly linked to the production of primary materials.

Implementing the *material fiscal reform* separately on metals and non-metallic minerals shows that achieving significant economic decoupling for metals is an attainable goal, as secondary metals can be used as substitutes for primary metals for many uses. In contrast, achieving decoupling for non-metallic minerals is more difficult and expensive. In fact, non-metallic minerals are not substitutable for some uses, and many countries still need to build their stocks of non-metallic minerals before starting to reuse and recycle them. Furthermore, more progress is needed on the technologies for recuperation, separation and recycling of non-metallic minerals.

Overall, the economic impacts are small but hide some regional disparities. Regional GDP costs range from 0% to 0.9%. Such differences depend on whether countries are net importers or exporters of raw materials, as well as on the production technologies available and the input costs of primary and secondary materials. A high material intensity leads to higher costs in most Non-OECD countries (for instance 0.9 t/USD in Indonesia in 2017), while a low material intensity in OECD countries leads to lower costs (for instance 0.4 t/USD in 2017 in the USA and Europe). In addition, the regional differences stem from the fact that the tax reforms, as modelled in ENV-Linkages, are differentiated across countries to take into account existing taxes. This explains why India, where existing taxes are lower, records a higher GDP loss (-0.5%) than China (-0.25%) where existing taxes are higher. Moreover, whereas the overall employment impacts are limited (no change in global employment), employment in the secondary production and recycling sectors increase by 20% to 50%, with strongest impacts in BRIICS countries.

The core policy scenario is designed to be budget neutral and the fiscal reform remains modest. Indeed, the projected material tax revenues represent only 0.3% of total revenues for OECD countries and 0.9% globally in 2040. At the global level, the subsidies to secondary metals implemented reach 1.2% of global tax revenues in 2040 (from 0.4% in 2017), while subsidies to recycled goods only amount to 0.2%.

The *material fiscal reform* only affects few sectors severely, and accompanying policies could help make the transition acceptable. The sectors that are directly impacted by the policies are the ones that are most affected. While the reform reduces primary-based production of metals by 5% in 2040, the sectors that provide substitutes for the taxed commodities are stimulated. At the global level, secondary-based metal production increases by 25% to 36%, as compared to their baseline level in 2040, while the recycling sector increases by 66%. Not surprisingly, the reform implies large effects for the mining sector, especially for large producers, such as Indonesia and other ASEAN countries.

While the core scenarios consider global policy action, additional simulations show that a partial regional implementation of the reform reduces the benefits of the *material fiscal reform*. When only a few regions apply the reform, their production costs become higher, albeit still small, leading to some competitiveness losses for those countries. Furthermore, a partial implementation implies some leakage effects: materials use increases in regions that are not implementing the material fiscal reform, as they benefit from lower international prices for materials, resulting from the lower material demand in acting countries. For instance, a partial implementation in OECD and BRIICS countries would lead to higher materials use (+0.5%) with no change in GDP in the Rest of the World. However, this leakage effect is marginal as Rest of the World countries only represent 25% of materials use and implementation in OECD and BRIICS countries leads to a 6% decrease in global materials use (as opposed to 7% when the reform is global). The implementation of the material fiscal reform in OECD countries only leads to a net material use reduction worldwide of 1.1%.

The complementarity between policy action promoting the transition to a circular economy and a low carbon transition is particularly relevant in the context of the Paris Agreement and the climate emergency. An additional scenario reflects a *combined energy and material transition* at the global level. In this scenario, while policies promoting the energy transition mostly target fossil fuels use, the material fiscal reform reduces the use of metals and minerals. The reductions in materials use shows synergies: the reductions in primary materials use attain 19% in 2040 when both the energy and material transitions are considered.

The interaction between policy interventions reduces the GDP losses in most countries and further extends the transition to the energy sectors, shifting the energy system from fossil fuels towards renewables. GDP costs remain limited, with projected country impacts ranging from -0.8% to +0.1%, improving from the *Material fiscal reform* scenario alone (0% to -0.9%). In contrast, the *combined energy and material transition* scenario increases the number of sectors affected and further increases the shift towards green sectors. These changes in the structure of the economy facilitate the shift from primary materials to secondary materials: primary iron and steel is further reduced by 11% compared to the *Material fiscal reform* scenario, while primary copper, aluminium and other nonferrous metals are further reduced by 5%.

A comparison of the revenues from carbon and materials taxes shows that the possibilities of using the transition to a circular economy as a stepping-stone for an environmental fiscal reform is more limited than it would be with a carbon tax. Indeed, in the *combined energy and material transition* scenario, revenues in OECD countries are seven times higher for the carbon tax than they are for the materials tax.

There are certain limitations to the current analysis. Due to lack of data, the analysis does not fully account for stocks of materials. There is also need for more empirical information to characterise secondary markets (to represent imperfect substitutability of secondary materials in certain uses) and to include non-market based policies in the scenarios (such as information campaigns, labelling, R&D investments in resource efficiency, eco-design requirements, extended producer responsibility or green public procurement). Efficiency investments in particular would need to be investigated further, as they are the main reason for economic benefits from the transition in existing studies. However, given the lack of strong evidence on their costs and effectiveness, they were not implemented in the *material fiscal reform*. These limitations notwithstanding, this report highlights the prospects of policies to address the different objectives that governments have regarding the transition to a more resource efficient and circular economy.

1. Introduction

The 20th century was an age of unprecedented growth in the use of natural resources and materials. Global raw materials use rose during the 20th century at about twice the rate of population growth. In the last decades, the rate of growth was, not surprisingly, fastest in rapidly developing economies. By contrast, resource use partially decoupled from GDP growth in OECD economies. These recent trends will however not be enough to counteract the rising demands of a world population headed to more than 10 billion people by 2060 and the on-going quest for higher living standards. According to the *OECD Global Material Resources Outlook to 2060*, global primary materials use is projected to increase from 89 Gt in 2017 to 167 Gt in 2060 (OECD, 2019[1]). Therefore, several environmental impacts linked to material extraction, processing and use are projected to more than double to 2060.

Given the increasing importance of this global environmental issue, many governments are putting in place measures to improve resource efficiency and/or to promote materials circularity. Four benefits tend to be highlighted in discussions of a transition to a more resource efficient and circular economy (OECD, 2009[2]; OECD, 2012[3]; EEA, 2016[4]): (i) reducing environmental pressure throughout the full lifecycle of materials, (ii) reducing the risks of raw material supply shocks, (iii) slowing down long-term resource depletion, and (iv) stimulating economic growth and jobs creation.

Circular economy and resource efficiency policies imply significant structural changes leading to the decline of some economic activities and sectors and the expansion of others. There is an emerging body of modelling work that assesses the potential magnitude of these shifts, but much of it has focussed on individual countries and a small subset of policy instruments (Winning et al., 2017[5]; Cambridge Econometrics, 2014[6]). However, the EU project on Policy Options for a Resource Efficient Economy (POLFREE) project (Hu, Moghayer and Reynès, 2015[7]; Distelkamp and Meyer, 2019[8]) and analysis of the International Resource Panel (IRP) (UNEP, 2019[9]; UNEP, 2017[10]) took a global perspective, and examined comprehensive policy mixes, assessing the feasibility of decoupling materials use from economic growth.

The IRP reports (Schandl et al., 2016[11]; Hatfield-Dodds et al., 2017[12]) find that the global application of selected market-based instruments may lead to a stabilisation of greenhouse gas (GHG) emissions and materials use at around or even below current levels "with little impact on economic growth". In the POLFREE project, Distelkamp and Meyer (2019[8]) use a different approach, considering not only market-based instruments but also a set of stylised circular economy policies and alternative growth scenarios. The simulations of these scenarios demonstrate that, in principle, an absolute decoupling of materials use from economic growth is feasible, even if this might mean accepting lower levels of economic growth.

In line with this literature, this report aims at showing with numerical simulations how policies can be used to achieve a more resource efficient and circular economy with limited impact on economic growth. The analysis is done using the OECD's ENV-Linkages dynamic computable general equilibrium model (Chateau, Dellink and Lanzi, 2014[13]). Compared with the other modelling work discussed above, the ENV-Linkages model was enhanced to include projections of materials use, resulting from carefully calibrated and detailed projections of economic activity,[1] and to represent explicitly primary and secondary metal production and the role of recycled goods. In this setting, primary and secondary metals are substitutable technologies to produce processed metals. The modelling framework also provides the evaluation of the environmental consequences of materials use, tracking air pollutant and fluorinated gas (F-gas) emissions as well as the full range of environmental damages associated with materials lifecycle, differentiating the impacts of primary and secondary technologies.

This report evaluates the main economic and environmental consequences of implementing a core policy scenario – a *material fiscal reform* – that aims at reducing the use of primary materials and supporting the production of secondary materials and at developing the recycling sector over the period 2018-2040. The transition to a circular economy includes reducing the extraction and use of primary materials, the increase in use time, reuse and recycling of products and materials. This report focuses on materials recycling and reducing the inputs of primary materials in the economy. Given the scope of materials studied, and the breadth of the climate policies, there are links between the transition to a more circular and resource efficient economy and the transition to a low carbon economy. Thus, the report also presents an additional scenario in which this material fiscal reform is implemented in the context of an alternative *energy transition* baseline.

The structure of this report is as follows. Section 2 describes the economic and material projections as well as the associated environmental damages in world with no new policy action to promote resource efficiency and the transition to a circular economy. Section 3 introduces the *material fiscal reform* scenario, as well as other future changes in the policy landscape that could reduce materials use. Section 4 presents the macroeconomic consequences of a gradual implementation of a material fiscal reform scenario. Section 5 explains how the implementation of this fiscal reform affect differently sectors and regions but also the environmental benefits of such action. Section 6 outlines results on the *combined energy and material transition*. Finally, Section 7 provides a discussion of the results.

[1] Annex A gives a brief overview of the methodology and modelling assumptions used in this report. More details about the methodology can be found in OECD (2019[1]), in particular how the 60 material flows (in tonnes) are associated to economic flows for the 55 economic sectors of the model.

2. Materials use and related environmental impacts in the absence of additional policies

The *OECD Global Material Resources Outlook to 2060* shows that, without additional policy action, the use of material resources is projected to substantially increase in the coming decades (OECD, 2019[1]). The increase in materials use leads to serious environmental impacts.[2] This section provides an overview of baseline projections: Section 2.1 illustrates the main results on projected material resource use while Section 2.2 on the environmental impacts related to materials use.

2.1. Materials use in the coming decades

Increasing population and income drive the growth of materials use. GDP is projected to continue growing, steadily in OECD countries and with higher growth in non-OECD countries (Table 1 illustrates key indicators). The projected growth for emerging and developing economies is characterised by a material-intensive boost in infrastructure construction, reflected in the increase in the capital to GDP ratio.

Table 1. Key indicators, for aggregate regions, 2017-2060

	OECD			BRIICS			Rest of the World			WORLD		
	2017	2040	2060	2017	2040	2060	2017	2040	2060	2017	2040	2060
Population [a]	1.29	1.41	1.45	3.36	3.70	3.66	2.83	4.03	5.07	7.48	9.15	10.17
GDP growth [b]		1.9%	1.9%		3.9%	2.3%		3.7%	3.4%		3.0%	2.5%
Share in world GDP	44%	34%	31%	35%	42%	41%	21%	24%	29%			
GDP per capita [c]		1.5%	1.8%		3.4%	2.4%		2.1%	2.3%		2.1%	1.9%
Employment rate [d]	0.93	0.92	0.89	0.93	0.88	0.83	0.94	0.97	0.98	0.93	0.92	0.91
Labour productivity growth [e]		1.7%	2.2%		3.1%	2.8%		2.0%	2.1%		1.7%	2.0%
Capital to GDP ratio [f]	3.1	3.6	3.8	3.6	4.8	5.4	3.1	3.9	4.5	3.2	4.0	4.4
Services share [g]	72%	74%	76%	54%	58%	61%	49%	53%	54%	64%	67%	68%
Material intensity [h]	0.46	0.39	0.34	1.17	0.66	0.50	0.75	0.58	0.49	0.77	0.55	0.45
Greenhouse gas emissions [i]	15.8	15.7	18.1	20.3	27.5	33.3	10.7	17.3	28.7	46.8	60.5	80.1

Notes:
a Total population in billions of individuals.
b Average annual growth rate of real GDP at 2011 PPPs exchange rate (percentages).
c Average annual growth rate (over the period) of the real GDP in PPP per habitant (percentages)
d Total employment over total population.
e Average annual growth rate of real GDP to employment (percentages).
f Aggregate capital to GDP (real terms).
g Gross value added of services at basic prices in percentage of GDP.
h Materials use per unit of real GDP at 2011 PPPs exchange rates.
i Total greenhouses gas emissions (excluding CO_2 LULUCF emissions) billion tonnes of CO_2-equivalent.
Source: OECD ENV-Linkages model, baseline of the Global Material Resources Outlook to 2060 (2019[1]).

[2] See Annex B for further information on the baseline scenario of the Global Material Resources Outlook to 2060 (OECD, 2019[1]).

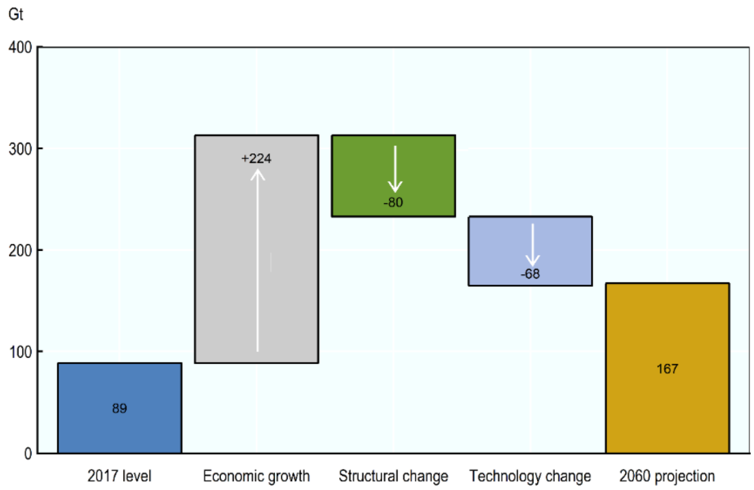
This report, following the Global Material Resources Outlook to 2060 (OECD, 2019[1]), models 60 primary (virgin) materials. These materials cover the main groups of materials: biomass, metals, non-metallic minerals and fossil fuels. Global primary materials use is projected to almost double from 89 gigatonnes (Gt) in 2017 to 167 Gt in 2060. Non-metallic minerals – such as sand, gravel and limestone – represent the largest share of total materials use. These non-metallic minerals are projected to grow from 44 Gt to 86 Gt between 2017 and 2060. Metal use is smaller when measured in weight, but is projected to grow more rapidly and metal extraction and processing is associated with large environmental impacts. The strongest growth in materials use is projected to occur in emerging and developing economies. Even in the OECD, where economic growth rates are more modest, materials use grows between 1% and 2% per year on average.

For developed economies, the projected economic growth is characterised by a shift towards sectors with low material intensity. This happens through structural change in the economy and is illustrated by the increase of share of services in GDP. Furthermore, in the future there will be improved technologies with lower material intensity.

The balance of these forces leads to a doubling of materials use (Figure 1). While structural change (green bar) and technology changes (light blue bar) lead to lower material intensity, they cannot offset the increases in materials use driven by economic growth (grey bar).

Figure 1. Drivers of materials use to 2060

Decomposition of the increase of materials use between 2017 and 2060 in Gt



Note: The four bars read as follows (from left to right):

1. *Economic growth* represents a counterfactual projection in which materials use is assumed to grow at the same speed as GDP and thus in which the regional material intensity of GDP stays constant.
2. *Structural change* identifies the contribution of sectoral shifts to reducing global materials use by differentiating sectoral growth rates.
3. *Technology change* identifies the contribution of technology improvements to reducing global materials use by differentiating growth rates of materials inputs to sectoral output.
4. The combined effects lead to the projected growth of the *central baseline scenario*.

Source: Global Material Resources Outlook to 2060 (OECD, 2019[1]).

Resource efficiency and circular economy policies aim at increasing the size of the two beneficial effects on material use that appear in the baseline (structural change and technology change), without harming the potential for growth.

2.2. Environmental impacts related with materials use in the coming decades

The projected increase in materials use implies a significant increase in a wide range of environmental impacts, as outlined in the *Global Material Resources Outlook to 2060* (OECD, 2019[1]). These impacts include acidification, climate change, eutrophication, land use, as well as water, human and terrestrial ecotoxicity. They have been quantified at the global level for a selection of metals and non-metallic minerals (cf. Figure 2).

Most global environmental impacts are projected to at least double in the next 40 years. Despite ongoing improvements in production efficiency (and thus gradually declining environmental impacts per unit of production), declining ore grades and the increased scale of extraction and production of materials significantly worsen environmental impacts between now and 2060.

The projected growth of environmental impacts challenges the achievement of the Sustainable Development Goals (SDGs), and particularly SDG 12, which aims at "ensuring sustainable consumption and production patterns". Box 1 summarises the SDGs targets associated with material use. While (OECD, 2019[1]) shows that relative decoupling has occurred and is projected to continue to occur in the near future, overall materials use and the related environmental impacts are still projected to increase, putting SDGs 8 and 12 and other goals at risk. For these reasons, policy action for the transition to a more resource efficient and circular economy aims at accelerating the decoupling between growth and material use.

Box 1. Materials use is linked to Sustainable Development Goals

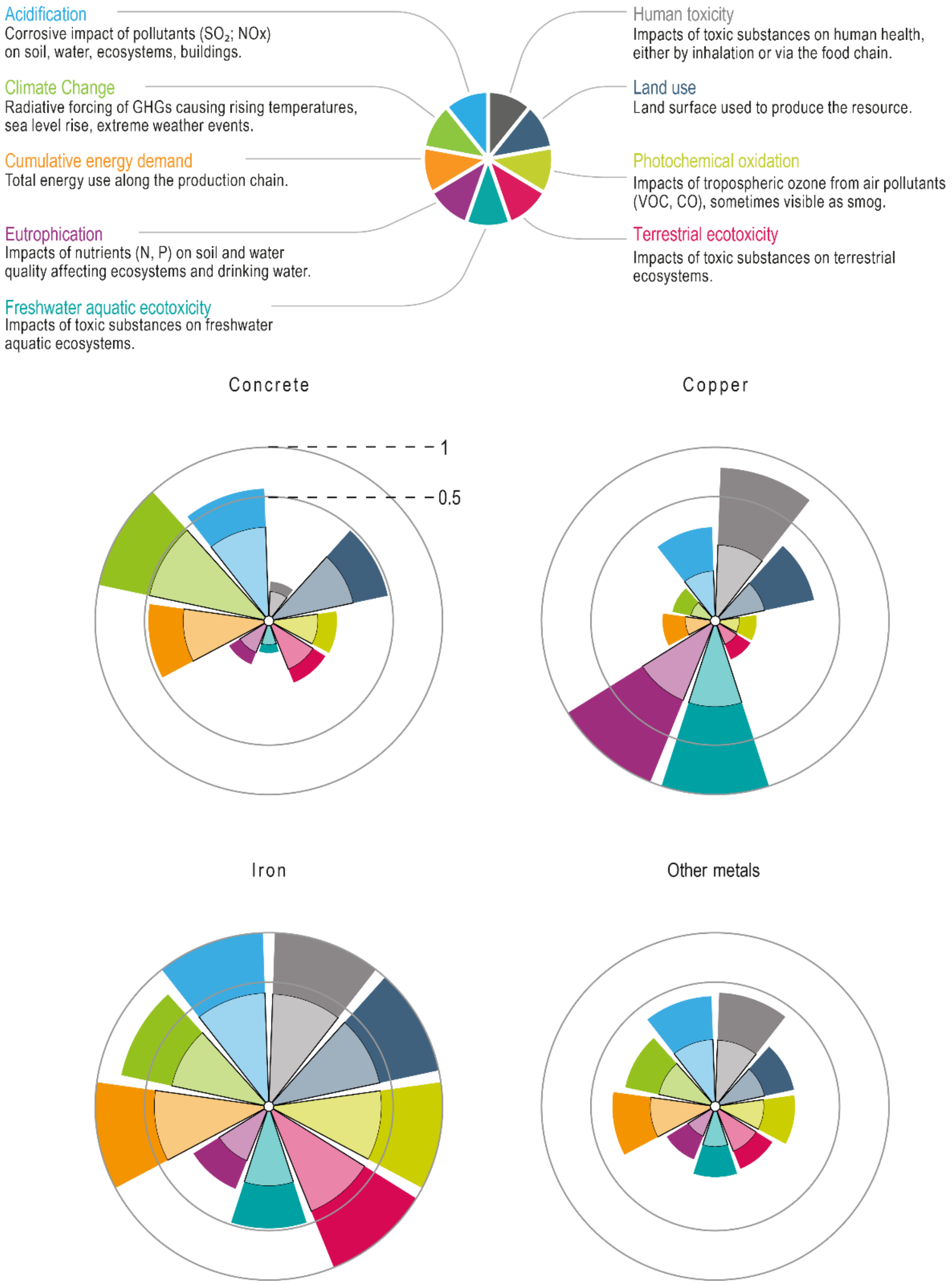
Materials use, their economic drivers and their environmental consequences are central components of several SDGs. The topic is represented most prominently in SDG 12, which aims to "ensure sustainable consumption and production patterns", explicitly targeting sustainable management and efficient use of natural resources (SDG 12.2). While extraction and processing of primary materials leads to GDP growth and creates jobs (and thus contributes to SDG 8), these may not be sustainable, given their impact on the environment. Decoupling of materials use and environmental degradation from GDP growth is desirable and targeted in SDG 8.4.

Materials use indirectly affects other SGDs, such as SDG 7 (universal access to affordable, reliable, sustainable and modern energy), SDG 9 ("Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation"), SDG 14 (sustainable use of oceans and marine ecosystems) or SDG 15 (sustainable use of terrestrial ecosystems). Policies to stimulate resource efficiency and the transition to a circular economy can also contribute more indirectly to achieving other SDGs. These include the links between biomass resources and ensuring sustainable food production systems (SDG 2.4), and the links between pollution caused by materials use (not least fossil fuels) and the objective to reduce health impacts from hazardous chemicals and air, water and soil pollution (SDG 3.9).

Source: Global Material Resources Outlook to 2060 (OECD, 2019[1]).

Figure 2. Global environmental impacts related with materials use to 2060

Total environmental impacts in 2015 (lighter shaded area) and 2060 (full coloured area), index 1 for most polluting material in 2060



Note: Environmental impacts are presented for primary and secondary production combined. The lighter shading represents the value in 2015; the full coloured area reflects values in 2060. Impacts for "Other metals" reflect the combined impacts of aluminium, lead, manganese, nickel and zinc.
Source: Global Material Resources Outlook to 2060 (OECD, 2019[1]).

3. Description of the resource efficiency and circular economy scenarios

This section outlines the policy scenarios considered in this report. Section 3.1 provides a brief overview of existing resource efficiency and circular economy policies. Section 3.2 describes how these policies have been represented in the modelling scenarios analysed in the report. Finally, Section 3.3 describes the additional scenario on the interactions between circular economy policies and the energy transition.

3.1. Resource efficiency and circular economy policies overview

In recent years, countries have strengthened their interest in resource efficiency not only to address environmental issues, but also to achieve other objectives, such as economic growth, employment and resource security. Governments are aware of the environmental issues related to resource use and have already started to put in place policies to address these issues. Indeed, as already stated over a decade ago in OECD (2005[14]), "the case for policy action to reduce the use of virgin materials […] rests not on its impact on the depletion of the non-renewable resource stock, but on various externalities and other market failures involved in the production of virgin materials…".

Several countries have established national strategies on resources and materials use. Circular economy roadmaps were introduced in the People's Republic of China (hereafter China) in 2013, in the European Union in 2015, in Finland, France, the Netherlands, and Scotland in 2016 and in Slovenia and Portugal in 2017. Other countries have introduced national policy frameworks related to resource efficiency or materials management. Japan's Fundamental Law for Establishing a Sound Material-Cycle Society and the Sustainable Materials Management Program Strategic Plan in the United States are two such examples.

A varied range of policies addresses the issues of "circular economy" and resource efficiency. These policies aim at decoupling natural resource extraction and use from economic output, i.e. increasing resource efficiency. In this report, the term resource efficiency represents the efficiency with which material resources are used in the economy. This indicator measures the need for materials per unit of output. It does not necessarily imply better allocative or productive efficiency in the sense of theoretical economic. OECD (2020[15]) defines circular economy as seeking to maximise the value of materials and products in the economy, minimise material consumption and their environmental impacts, prevent waste and reduce hazardous components in waste and products.

Resource efficiency and circular economy are two intertwined notions. Resource productivity is one indicator of resource efficiency and can be measured as output – GDP – per unit of materials used, in USD/tons. Therefore, examining this indicator assesses both resource efficiency and the circularity of the economy (the raw addition of materials to the economy at a given time). Regarding policies to achieve a transition to a circular economy, circularity is presented as a means to achieve several environmental and economic objectives. Since the indicator that captures resource efficiency (namely resource productivity) also captures circularity (the flows of material use through the economy), a policy that aims to increase resource efficiency could also achieve higher circularity.

Resource efficiency policies do not aim at reducing the use of resources per se, which is generally a source of economic growth, but instead they address the environmental impacts associated with materials use throughout its life cycle, from extraction to production, use and waste management. As such, the market failure addressed is not the use of material resources, but the failure to include the environmental externalities linked to the use of resources.

The wide range of resource efficiency and circular economy (RE-CE) policies can be classified according to three different purposes and means to achieve decoupling, following (McCarthy, Dellink and Bibas, 2018[16]), as summarised in Table 2. First, some policies aim at *closing the resource loop*, in contrast with the traditional linear economic system. These policies aim at reducing the use of primary materials by increasing recycling and the use of secondary materials. Second, some policies aim at *slowing the resource loop*. These policies aim at enhancing product durability; either in the initial production or in improving re-use and repair possibilities. Finally, policies aim at *narrowing the resource flow*, by expanding the sharing and service economy and, often, encouraging changes in individual behaviour.

Table 2. Characteristics of circular economy

	Features	Key effect	Policy examples
Closing the resource loop	• Recycling • Product repairing and remanufacturing	• Decreased demand for primary materials • Increased use of secondary materials	• Subsidies to secondary materials • Subsidies to recycling sector
Slowing the resource loop	• Longer-lived products • Product reuse and repair	• Decreased demand for primary and secondary materials • Better quality and durability of goods but at higher prices	• Extended Producer Responsibility (EPR) • Product design standards
Narrowing the resource flow	• Increased material productivity • Improved asset utilisation • Changes in individual behaviour	• Decreased demand for primary materials • Expanded sharing and services economy	• Resource efficiency standards • Carpooling driving allowances • Material Tax

Source: (McCarthy, Dellink and Bibas, 2018[16]).

3.2. Modelling of resource efficiency and circular economy policies

3.2.1. Description of the policy package

In this report, the modelling of the transition to a more resource efficient and circular economy focuses on closing the resource loop and narrowing the resource flow. The modelling was carried out using the OECD ENV-Linkages model and focuses on market-based policies.[3] Modelling non-market policies that aim at slowing the resource loop is a difficult endeavour in a Computable General Equilibrium setting, due to the lack of sufficient data on their costs and impacts. Consequently, they are not considered in the modelling analysis.

The core policy scenario analysed in this report is a *material fiscal reform* that combines excise taxes on material use with *ad-valorem* subsidies on secondary metals production and on recycling goods (see Box 1 for a discussion on the type of instruments included in the modelling).

[3] Annex B provides a list of key parameters of the model, including substitution elasticities.

Box 2. How to model RE-CE policies?

The policies modelled in the *material fiscal reform* include fiscal instruments (taxes and subsidies) on primary and secondary materials. These instruments are not only representative of fiscal instruments implemented by governments (national and local) to promote resource efficiency and the transition to a circular economy, but they can also serve as proxies for the impact of some other policies as well.

Many instruments can be modelled using fiscal tools in a CGE model. One example is the representation of recycling standards, where any product containing a metal has a required minimal content of secondary metal. In a CGE model, such a constraint on metal contents actually translates with a mathematical relationship between primary and secondary metal production similar to that of a tax. That example would of course be similar when examining recycling standards for plastics, paper, textiles or any other material. The impact of a tax on primary materials and a subsidy on secondary metals could thus be equivalent to that of recycling standards.

Different policy instruments nevertheless have different effects in their implementation, their costs, and their effectiveness. Not all instruments can be represented through fiscal tools. Information campaigns for instance are difficult to represent well in CGE models, without robust macroeconometric studies on their effects.

The set of fiscal instruments considered enables an environmental fiscal reform that is budget-neutral: governments take advantage of the additional government revenues from the various taxes on materials to finance subsidies on secondary-based metal production and on the use of recycled inputs. Table 3 summarizes the targets for the different fiscal tools of the *material fiscal reform* scenario (Section 3.2.2 discusses their calibration).

Table 3. Description of the *material fiscal reform* scenario

Instrument	Description	Global Targets (2040)
Material tax	Tax on primary metals and non-metallic minerals	• 10 USD/tonne of iron ores, • 50 USD/tonne of aluminium ores, • 20 USD/tonne of copper ores, • 15 USD/tonne of other nonferrous metals ores • 5 USD/tonne of non-metallic minerals
Subsidy to recycling	Subsidy for recycling input uses	A 75% subsidy rate on the purchasing price of the recycling commodity for firms.
Subsidy on secondary metal production	Subsidy on production price for secondary metal production	This subsidy rate is used to equilibrate the income of the material taxes and the spending of subsidies to recycling and secondary metals, so that the material fiscal reform is budget-neutral.

All these fiscal instruments are implemented from 2018 to gradually reach their target in 2040.

This report carries out the analysis to 2040, since the national level strategies currently implemented or planned by governments target 2040 at the latest. Specific quantitative targets set by governments to achieve resource efficiency improvements, material use reductions, higher recycling rates, or lower final disposal volumes have a time horizon of 15-20 years (EEA, 2016[4]). For example, the Netherlands is aiming for a 50% reduction in the use of virgin resource inputs by 2030 (Government of the Netherlands, 2016[17]). Similarly, Japan is targeting a cyclical material use rate of 17% by 2020 (MoE Japan, 2013[18]).

The *material fiscal reform* scenario focuses only on metallic and non-metallic minerals and does not target fossil fuels and biomass material uses. The main reason is that biomass and fossil fuels tend to be spent after their use (fuel combustion or food consumption) while minerals are not destroyed by their usage but generally transformed and can be recycled. Furthermore, the case of fossil fuels is examined when the material fiscal reform is implemented in the context of an alternative baseline describing an energy transition scenario (see Sections 3.3 and 6).

3.2.2. The calibration of taxes on primary materials use

Taxes on materials use create incentives for reducing materials use. Taxes on refined material consumption are widely used, both in the form of excise taxes (for instance on fuel consumption), and of *ad-valorem* taxes (for example differentiated value added taxes on food products). However, taxes on primary non-metallic minerals are scarce, and have only been used by a small number of countries and principally on stone and gravel (OECD, 2014[19]).

In modelling exercises, material taxes on minerals generally take the form of excise taxes: taxes per tonnes of primary materials paid by the firms/sectors when they use the corresponding material in their production process. The technical implementation of such taxes is straightforward in ENV-Linkages, since material uses are linked to economic flows. This link allows the calculation of the material inputs (in tonnes) for each sector, which can then directly be taxed using excise taxes (in value per tonne).

In this study, the tax rates result from a careful calibration in which polluting industries are taxed more. By essence, materials are different (a tonne of iron ore is different from a tonne of sand) and their use (as well as their extraction) has different environmental impacts. Thus, there is no reason that tax rates on these different primary materials should be identical. The global level of metal tax rates in 2040 (Table 3) have been calibrated following standard theoretical principles of optimal taxation (Atkinson and Stiglitz, 1980[20]). In this setting, the levels of the tax rate for each metal are calculated, at global level, to target the same ratio for the marginal environmental benefit to its (GDP) costs.[4] However, the different environmental impacts calculated with the model (presented in Figure 2) are not comparable.[5] Thus, the evaluation of the overall environmental benefits has been arbitrarily determined by taking same weight for each environmental impact.[6] The impacts of the policy package is detailed for each environmental indicator in Section 5.1.

[4] Technically specific scenarios which implement taxes on each metal separately have been simulated, allowed finding tax rates that imply a ratio of global environmental benefits to GDP cost roughly equivalent across the different types of primary metals.

[5] For example, SO_2 emissions as a proxy for acidification and tonnes of ethylene as a proxy of photochemical oxidation cannot be added.

[6] Terrestrial ecotoxicity was excluded from this calculation as for this indicator, some secondary metals can have higher per unit impact than primary metals (see the OECD *Global Material Resources Outlook* (OECD, 2019[1]) for more details). Thus, the effect of the tax would be ambiguous and make it difficult to calibrate.

The tax rates on primary metals imposed at the global level are designed to increase linearly from 2018 to 2040 to reach the following calibrated levels: 10 USD/tonne for iron ores, 20 USD/tonnes for copper ores, 50 USD/tonnes for aluminium ores, 15 USD/tonne for other nonferrous metals ores and 5 USD/tonnes for non-metallic minerals.

Most countries already impose direct taxes on mining extraction as well as royalties at different rates. As discussed in (Brodway and Flatters, 1993[21]), reasons for taxing resource industries include rent collection, capital income taxation, industrial policy, risk pooling and financing, the taxation of foreigners, exercising monopoly powers in global markets, and conservation of resources. Increasingly, taxing resource industries also allows the taxation of environmental externalities.

These existing taxes should be taken into account to harmonise the fiscal burden of the total taxes of raw mineral on their use and extraction across countries. Current material use across countries already integrates the response to those existing taxes. Thus, the material tax rates at the country level were adjusted from the existing mining tax revenues, as reported in Table 4.[7]

The tax adjustment incorporates the pre-existing tax levels to reach similar (and higher) levels of taxes between countries.[8] Annex D compares the effect of differentiated taxes to reach a similar fiscal burden in each country to the effect of uniform taxes where the environmental share of the burden is the same for all countries.

Since environmental benefits associated with the reduction of non-metallic minerals are difficult to compare to those associated to the reduction of primary metals use, the choice of 5 USD/tonnes for the former has been determined differently. This tax rate at the global level is determined such that the total amount of extra tax revenues of taxing non-metallic minerals is equivalent to extra revenues from taxing all primary metals (as a percentage of GDP).

Table 4. Average material taxes implemented in ENV-Linkages by region

		Mining Taxes [a]	Average additional tax rates in 2040 (2017 USD/tonnes)		Average Subsidy rates in 2040 [b]
		Revenues in 2017 (as % of total tax revenues)	Non-metallic minerals	Primary metals	Secondary metal Production (as % of production costs)
OECD America	Canada	0.7%	2.8	9.7	13.4%
	Chile	3.7%	1.1	4.2	9.7%
	Mexico	0.9%	2.5	8.0	22.6%
	USA	0.2%	5.3	17.4	21.5%
OECD Europe	OECD EU 17	0.3%	3.6	10.6	14.3%
	OECD EU 4	0.1%	5.3	15.1	5.1%

[7] Technically, in a first step, all country-level material tax rates are adjusted, country by country, such that the total revenues from material taxes plus the total revenues of (minerals) mining tax on extraction are equal in 2040 to the total revenue that would be obtained with material tax rates fixed at the uniform global targets. The world average of the resulting adjusted material tax rates would therefore be lower than the global targets. Therefore, to recover the global target, all the country-specific tax rates are in a second step uniformly scaled up and the result is reported in the table.

[8] An alternative with uniform taxes in all countries is presented in Annex F.

	Other OECD Eurasia	0.2%	3.9	10.3	16.3%
OECD Pacific	Australia & New Zealand	3.5%	3.2	10.0	25.3%
	Japan	0.1%	5.0	15.4	1.6%
	Korea	0.1%	7.1	19.8	7.6%
Other America	Brazil	1.2%	3.2	7.7	13.7%
	Other Latin America	0.7%	2.8	9.6	36.2%
Eurasia	Caspian region	1.2%	0.7	2.4	30.5%
	Other EU	0.2%	5.3	20.5	21.2%
	Other Europe	0.8%	2.8	7.0	11.4%
	Russia	0.1%	6.0	18.2	6.7%
Middle East & Africa	Middle East	0.5%	4.3	13.6	26.6%
	North Africa	1.2%	2.8	7.7	50.3%
	Other Africa	1.4%	3.6	13.9	30.6%
	South Africa	1.0%	0.7	2.2	38.6%
Other Asia	China	1.2%	4.3	11.1	19.2%
	India	0.0%	7.1	15.7	23.3%
	Indonesia	1.2%	2.5	8.4	34.4%
	Other ASEAN	0.3%	3.0	17.7	49.4%
	Other non-OECD Asia	0.6%	4.3	12.6	18.3%

Notes:
[a] Mining taxes comprise specific mining tax (e.g. "royalty") on mineral exploitation (excluding fossil fuels) and if relevant specific mining production taxes. The general income tax and production tax that applies to all firms in all sectors are excluded from this calculation. Mining tax revenues are very fluctuating and highly depend of international prices of natural resources.
[b] The average subsidy to secondary metal productions are endogenously calculated in the "material tax reform" scenario to balance government budget, in a neutral way.
Source: Authors' calculations based on the GTAP database (version 9), the OECD's "Environmentally related tax revenue" database and the OECD ENV-Linkages model.

3.2.3. Subsidies to secondary material production and recycling

Subsidies to secondary metal productions and to recycling help support the transition to a circular economy. Reducing primary materials use through taxation may not be sufficient, and some countries envision complementing the taxes on primary with a subsidy to secondary materials use and to recycling. These two subsidies help stimulate the increase of the recovery and use of secondary materials, by targeting two different steps in the secondary material production process: the supply of secondary raw materials and the production of secondary metals. The first targets the input cost in the production process while the second targets the output price (the price of refined metals).

Direct subsidies for secondary metal production are available in a number of countries, albeit at a small scale (OECD, 2017[22]). Most common are the indirect support to secondary metal production through landfill taxes and ban (McCarthy and Börkey, 2018[23]). Their more widespread implementation could reduce the cost of material recovery activities, and thereby improve the competitiveness of secondary material production.

The *material fiscal reform* scenario assumes that extra revenues from the material taxes will finance (i) a 75% subsidy on the price of the recycled scrap inputs in 2040; this subsidy is progressively implemented linearly from 2018, and (ii) country specific subsidy rates on the production price of secondary metal processing sectors. The rate of subsidies to secondary metal production is adjusted each year such that government budget is always balanced under the *material fiscal reform* scenario (i.e. the reform is budget-neutral). The taxes apply to the domestic use of materials, whether they are domestically sourced or imported. The revenues from the taxes are used to finance the subsidies, without international transfers (i.e. taxes apply to material use whether it is domestically produced or imported, and the revenues are used to subsidize production in that country). Because the model does not currently separates recycled concrete and other secondary non-metallic minerals from primary, the subsidies of the *material fiscal reform* scenario only target metals.

3.3. *Interactions between resource efficiency transition and energy transition*

In addition to the *material fiscal reform* instruments described in Section 3.2, other policies may influence materials use in the future as, for example, the policies to address energy transition to low carbon economy. These policies target different objectives from RE-CE policies but are relevant for resource use as they affect the demand for fossil fuels and have indirect impacts on sectoral productions through change in energy costs.

In this report, the *energy transition* scenario is considered as an alternative long-term pathway to the baseline. This *energy transition* scenario will be enabled by climate and energy policies as well as by technological improvements specified by the International Energy Agency (IEA) for the elaboration of its Sustainable Development Scenario (SDS) for the 2018 World Energy Outlook report (IEA, 2018[24]). The implementation of the *energy transition scenario* consists in representing the policy tools of the SDS in the OECD's ENV-Linkages model. Box 3 gives more details about the SDS scenario and the policy tools implemented in ENV-Linkages to elaborate the *energy transition* scenario. Annex H provides details on the transformation of the energy system and the macroeconomic impacts of the *energy transition* scenario.

Box 3. The IEA Sustainable Development Scenario (SDS)

The IEA's SDS (IEA, 2018[24]) describes a path for the global energy sector that is aligned with the Paris Agreement by holding the rise in global temperature to "well below 2°C… and pursuing efforts to limit [it] to 1.5°C", and that can achieve the outcomes of the UN SDGs closely related to energy. In particular, it works out how the energy sector should transform in order to achieve universal access to energy (SDG 7), to reduce the health impacts of air pollution (part of SDG 3), to tackle climate change (SDG 13) and to achieve universal access to clean water and sanitation (SDG 6). In addition, the SDS scenario takes into consideration a series of existing and planned sector-specific regulations (e.g., within infrastructure and construction).

A substantial transformation of the energy sector is necessary to meet these objectives, enabled by several instruments (Table 5). These instruments are implemented in the ENV-Linkages model. In more detail, carbon prices rise and vary between 121.5 to 140 USD dollars per tCO_2 in 2040 across countries and sectors, while fossil fuel subsidies are removed gradually during this period. In parallel, the share of non-fossil power sources rises to 40% in 2040, and energy efficiency[9] increases. Energy efficiency is measured by the decline in energy intensity of GDP that drops from 110 tonnes/$1000 in 2017 to 40 tonnes/$1000 in 2040 (IEA, 2018[24]).

Table 5. Policy instruments of IEA's Sustainable Development Scenario

Instruments	Target (2040)	Countries implementing the scenario
• Carbon prices increase • Fossil-fuel subsidy removal • Support to renewable electricity • Energy efficiency investment	• Hold temperature rise to 1.7-1.8°C above pre-industrial levels. • Global CO_2 emissions peak at 2020 and fall thereafter, in line with the Paris Agreement objectives. • Reductions in major air pollutants such that by 2040 there are half a million fewer premature deaths linked to outdoor air pollution than today, and 2 million fewer deaths due to household pollution.	All OECD and non-OECD countries

Source: (IEA, 2018[24]).

[9] ENV-Linkages does not fully incorporate the investment cost of energy-saving technologies in non-power industries, services and agricultural sectors, because of lack of information.

4. Macroeconomic and material use consequences of the *material fiscal reform*

This section details a progressive implementation of the different fiscal components of the *material fiscal reform*. Specifically, it sequentially assesses the implementation of a taxation on primary metal use in Section 4.1, then the combination of a taxation on both primary metals and non-metallic minerals in Section 4.2. Finally, in the context of stimulating more efficient use of resources, Section 4.3 shows that it is appropriate to use the extra revenues of material taxation to finance subsidies to promote recycling and secondary materials. This final scenario constitutes the *material fiscal reform.* For each of these cumulative scenarios, the macroeconomic consequences of the policy instruments and their effects on materials use are analysed.

4.1. *Taxes on primary metal use scenario*

Taxes on primary metal use are implemented for the four metal categories included in the model: Ferrous metals (Iron and steel), Aluminium, Copper, and Other nonferrous metals. The metal taxes increase the price of ore inputs for the metal processing sectors. In this section, the government revenues from these taxes on primary metal use are given back to households as a lump sum payment.

Following the implementation of the tax on primary metals, the quantity of primary metal ores used decreases substantially (Table 6). At world level, ferrous metal ores decrease by 7.5%, Aluminium by 24%, Copper by 21.9% and Other nonferrous metals by 45.3%. The variation in the decrease mainly depends on the tax rates, the cost share of the mining inputs and the price differential and elasticity of substitution with the secondary material.

Table 6. Evolution of metal ore quantities by region, *taxes on primary metal use* scenario

Percent change for metal ores (primary materials) w.r.t. central baseline scenario in 2040.

	Iron and steel	Aluminium	Copper	Other Nonferrous metals
OECD America	-1.9%	-1.1%	-33.5%	-15.8%
OECD Europe	-0.4%	0.0%	-1.0%	-0.1%
OECD Pacific	-12.5%	-28.6%	-9.3%	-12.4%
Other America	-8.1%	-23.9%	-12.0%	-39.5%
Eurasia	-7.2%	-0.9%	-4.8%	-0.3%
Middle East & Africa	-11.4%	-21.8%	-36.4%	-20.4%
Other Asia	-5.7%	-27.2%	-16.2%	-63.6%
World	-7.5%	-24.0%	-21.9%	-45.3%

Source: OECD ENV-Linkages model.

The impact of metal taxes is, however, very asymmetrical across countries, as shown in Table 6. These differences stem from the countries' characteristics regarding material endowment, use, costs, and production as well as existing taxes on mining production and royalties that imply different targets for metal tax by country (see Section 3).[10]

The increase of the net-of-tax price paid for purchases of mining inputs by metal processing sectors triggers two mechanisms. The first mechanism is a decrease in the use of mining inputs in primary production (first line of Table 7). For "Iron and steel", it is necessarily limited as this primary production cannot substitute easily iron ore inputs, even if productivity gains can be found when using more capital. This decrease in inputs is counterbalanced in the cost share since prices increase more than the quantity decreases. The second mechanism is a substitution away from primary ferrous metals (line 5), either for the corresponding secondary metal (line 6) or for other materials.

Table 7. Sectoral consequences, *taxes on primary metal use* scenario

Percent change in 2040 w.r.t. central baseline scenario, world average.

Metal Sector / Indicator	Iron and Steel	Aluminium	Copper	Other Nonferrous metals
Purchase of mining input (real value)	-3.2%	-8.8%	-14.0%	-11.2%
Mining input cost share in primary processing	7.1%	8.6%	27.2%	13.2%
Primary production price	2.1%	2.8%	7.3%	4.0%
Secondary production price	0.3%	0.7%	2.2%	0.3%
Primary production (real value)	-2.4%	-2.8%	-3.4%	-2.2%
Secondary production (real value)	1.1%	1.5%	7.2%	5.7%

Source: OECD ENV-Linkages model.

There is an apparent difference between production reduction (by at most 3%) and metal use reduction (-26%). This difference is explained by shifts in production away from regions with material-intensive primary metal processing. This composition effect reflects that generally regions that have the largest decrease in materials use also have the highest material intensity initially. Therefore, their metal use decreases much more than the global average.

The macroeconomic impacts following the implementation of a tax on primary metal are small (see Table 8). GDP is projected to decrease by 0.2% globally, with a minimal impact on OECD countries, and mostly affecting other regions. Household consumption present similar decrease, while the depressive shock on labour market is split between decreases in real wage rates and decreases in employment. These small impacts are not surprising since the metal processing sectors represent a small share of the economy (about 3% of GDP), and since only mining ores are taxed in this policy (and not the other inputs).

The main conclusion is that primary metal taxes allow for a strong reduction of metal use (- 26% in 2040) but with limited impact on both overall materials use (-3.2 % in 2040), as metals represent a small share of total materials use.

[10] Annex D presents the alternative case were uniform taxes across countries and still the differences of impact are important. Thus, the imposition of country specific levels for tax rates only exacerbates these differences on the impact but it is not the main source.

Table 8. Aggregate indicators by aggregate region, *taxes on primary metal use* scenario

Percent change in 2040 w.r.t. central baseline scenario.

	OECD	BRIICS	Rest of the world	World
GDP (constant PPP)	0.0%	-0.3%	-0.2%	-0.2%
Household consumption	-0.1%	-0.2%	-0.2%	-0.1%
Employment (prs)	-0.1%	-0.1%	-0.1%	-0.1%
Wage rate (real)	0.0%	-0.3%	-0.2%	-0.3%
All materials (volume)	-2.7%	-4.0%	-2.0%	-3.2%
Metals (volume)	-15%	-35%	-21%	-26%
Minerals (volume)	-0.1%	-0.3%	-0.3%	-0.3%
Material intensity	-2.7%	-3.8%	-1.8%	-3.0%

Source: OECD ENV-Linkages model.

4.2. *Taxes on primary metal and non-metallic mineral use scenario*

In this section, the simulation combines taxes on both metals and non-metallic minerals. The extra revenues from these taxes are still given back to households as a lump sum payment. Globally, taxing metals and non-metallic minerals is projected to lead to a reduction of materials use by 7.3% (Table 9). The global GDP losses resulting from implementation of this policy is limited at 0.4%, with the highest impacts in BRIICS and other developing economies that rely more on primary mineral resources (reaching 0.7% of GDP in BRIICS). In contrast, OECD countries are almost not affected (0.1% of GDP). The losses in consumption are even lower at 0.2% in 2040 globally (line 3 in Table 9).

Comparing Table 8 and Table 9 indicates that it is relatively more costly to reduce non-metallic mineral uses than metals uses with a material tax. In the *taxes on primary metal use* scenario, global GDP losses averaged at 0.2% with a reduction of metal ore use by 26% (Table 8). While in the *taxes on primary metal and non-metallic mineral use* scenario (Table 9), GDP losses are around 0.4% with a reduction of non-metallic mineral use by 8.5% and same reduction of metal ore use. The higher costs of reducing non-metallic minerals uses is explained first, by the limited substitution possibilities for this material, and second because construction is an essential activity for all countries, and ultimately the burden of the tax falls almost entirely on this sector.

Table 9. Aggregate indicators by aggregate region, *taxes on primary metal and non-metallic mineral use* scenario

Percent change in 2040 w.r.t. central baseline scenario.

	OECD	BRIICS	Rest of the world	World
GDP (constant PPP)	-0.1%	-0.7%	-0.4%	-0.4%
Household consumption	-0.1%	-0.2%	-0.3%	-0.2%
Employment (prs)	-0.1%	-0.2%	-0.1%	-0.1%
Wage rate (real)	-0.1%	-0.6%	-0.4%	-0.5%
All materials (volume)	-5.0%	-9.8%	-5.1%	-7.4%
Metals (volume)	-16%	-35%	-21%	-26 %
Minerals (volume)	-4.6%	-11.0%	-6.6%	-8.5%
Material intensity	-4.9%	-9.2%	-4.7%	-7%

Source: OECD ENV-Linkages model.

4.3. The *material fiscal reform* scenario

The ultimate objective of environmental tax policies considered in this report is to decouple economic growth and raw materials use. To this extent, it is possible to reduce the metals and non-metallic minerals intensity further by using extra fiscal revenues from material taxes to stimulate both the recycling and secondary material processing with dedicated subsidies.[11] The *material fiscal reform* scenario (MFR) scenario presented now thus includes three elements: (i) the taxation of primary metals and non-metallic minerals, (ii) subsidies to recycling and, (iii) subsidies to secondary material processing.

In the *taxes on primary metal and non-metallic mineral use* scenario, implementing primary material taxes implies small negative GDP impacts. These costs partly result from the assumption that governments redistribute the extra revenues from material taxation as a lump sum to households. However, it is actually more realistic to suppose that governments take advantage of these extra revenues to further encourage the transition to a circular economy by subsidising secondary materials and recycling, as described in Section 3. An alternative would be for governments to decrease the labour fiscal wedges (see Box 4), as discussed in a previous report (Chateau, Bibas and Lanzi, 2018[25]).[12]

Box 4. Reduction of labour income taxation with extra revenues from material taxes

Using the extra revenues from material taxes to reduce labour income taxation is a natural way to reduce GDP and consumption losses implied by the implementation of the material taxation scheme (Table 10), without change to the material use reduction. The reduction of labour income tax rate will increase substantially the net-of-tax real wage rate received by households (column 5), contrarily to the case discussed before where extra revenues were redistributed as a lump sum (column 4). In turn, this will stimulate household labour supply in such a way that total employment impact is now slightly positive at world level (column 9), despite that some regions still record employment losses, while it was always negative in the case with lump sum recycling for all the regions (column 8). The resulting increase in employment levels, relative to the case with lump sum transfers, will in turn limit the GDP losses (column 7 relative to column 6).

Table 10. Aggregate impacts of *taxes on primary metal and non-metallic mineral use* under alternative government revenue recycling schemes

Percent change in 2040 w.r.t. central baseline scenario.

	Material use		Net-of-tax wage rate		Real GDP		Employment	
Recycling scheme	Lump sum transfer	Wage income tax	Lump sum transfer	Wage income tax	Lump sum transfer	Wage income tax	Lump sum transfer	Wage income tax

[11] See Marten and van Dender (2019[34]) for a discussion on the use of environmental tax revenues (focused on carbon taxes).

[12] The report on "The jobs potential of a transition towards a resource efficient and circular economy" (Mavroeidi and Chateau, 2020[33]) further explores the consequences of different revenue recycling choices for labour markets and economic growth.

World	-7.4%	-7.3%	-0.3%	0.3%	-0.4%	-0.3%	-0.1%	0.0%
OECD	-5.0%	-4.9%	-0.1%	0.2%	-0.1%	-0.1%	-0.1%	0.0%
BRIICS	-9.8%	-9.6%	-0.5%	0.5%	-0.7%	-0.5%	-0.2%	0.0%
Rest of the world	-5.1%	-5.0%	-0.4%	0.2%	-0.4%	-0.3%	-0.1%	0.0%
OECD America	-5.4%	-5.4%	-0.1%	0.1%	-0.1%	-0.1%	-0.1%	0.0%
OECD Europe	-3.2%	-3.1%	-0.1%	0.2%	-0.1%	0.0%	0.0%	0.0%
OECD Pacific	-7.4%	-7.3%	-0.1%	0.5%	-0.1%	-0.1%	-0.1%	0.0%
Other America	-4.9%	-4.8%	-0.1%	0.1%	-0.2%	-0.1%	-0.1%	-0.1%
Eurasia	-2.4%	-2.3%	-0.1%	0.3%	-0.1%	0.0%	-0.1%	0.0%
Middle East & Africa	-5.4%	-5.2%	-0.4%	0.3%	-0.4%	-0.3%	-0.1%	0.0%
Other Asia	-9.7%	-9.5%	-0.6%	0.5%	-0.7%	-0.5%	-0.2%	0.0%

Source: OECD ENV-Linkages model.

Taxing primary materials and subsidising secondary materials is key in shifting the balance of production towards secondary materials, but do not curb the appetite for more materials overall. Table 11 shows that the global demand evolution compared to the baseline (BAU) increases for some metals, as a response to materials being made cheaper by the subsidies. The total demand (accounting for both primary and secondary materials) for ferrous metals increases by 6%, while that of aluminium increase by 5%. In contrast, the demand for copper decreases by 1% and the demand for other nonferrous metals remains constant.

However, the increase of total demand translates into a decrease for primary materials share and an increase for secondary materials share. While primary metal use decrease, relative to the baseline, the increase in secondary materials is needed to address this extra demand. For instance, primary ferrous metals decrease by 7%, secondary ferrous metals increase by 30%, leading to the overall increase of 6% for total demand.

Table 11. Production of primary and secondary metal sectors, *material fiscal reform* scenario

Percent change in 2040 real gross output w.r.t. baseline scenario – world average.

		Share in total production BAU	Share in total production MFR	Evolution of metal use w.r.t. baseline	Total metal use evolution w.r.t baseline
Iron and steel	Primary	65%	57%	-7%	6%
	Secondary	35%	43%	30%	
Aluminium	Primary	67%	60%	-6%	5%
	Secondary	33%	40%	25%	
Copper	Primary	94%	91%	-3%	-1%
	Secondary	6%	9%	36%	
Other nonferrous metals	Primary	96%	94%	-2%	0%
	Secondary	4%	6%	35%	

Notes: Total metal demand evolution represents the evolution of metal use, including both primary and secondary metals.
Source: OECD ENV-Linkages model.

The corollary of this result is that given the increase in demand to 2040 and the positive effect supporting secondary materials may have on demand, other measures are needed to curb the increased need for materials. Those measures need to target the structural evolution of demand. They can do so by reducing the amount of physical goods consumed (reduce construction and manufactured goods). However, increase in capital goods has been a fundamental driver of materials market in the past century and may prove very difficult to reverse, in particular in emerging economies that are still undergoing a growth boom. Another possible angle would be to shift the type of materials used (wood to replace metals and plastics for instance) but these substitution possibilities remain limited.

Compared to the *taxes on primary metal and non-metallic mineral use* scenario, the *material fiscal reform* amplify the reductions in metal use (-27.3% in Table 12) but is less efficient in curbing non-metallic minerals (-8.1%), both implying an equivalent change in total material uses in both scenarios (-7.3%).

However, global GDP and consumption losses (respectively -0.2% and -0.1%) under the *material fiscal reform* scenario are lower than under the *taxes on primary metal and non-metallic mineral use* scenario. Furthermore, this material fiscal reform has almost no consequences for budget policy: it is budget neutral and does not significantly affect the composition of government revenues (as discussed in Box 5).

Table 12. Aggregate indicators by aggregate region, *material fiscal reform* scenario

Percent change in 2040 w.r.t. baseline scenario.

	OECD	BRIICS	Rest of the world	World
GDP (constant PPP)	0.0%	-0.3%	-0.4%	-0.2%
Household consumption	0.0%	-0.1%	-0.3%	-0.1%
Employment (prs)	0.0%	0.1%	0.0%	0.0%
Wage rate (real)	-0.1%	-0.2%	-0.3%	-0.2%
Capital stock to GDP ratio	0.0%	0.0%	0.1%	0.0%
All materials (volume)	-5.0%	-9.5%	-4.8%	-7.3%
Metals (volume)	-17%	-37%	-21%	-27.3%
Minerals (volume)	-4.4%	-10.4%	-6.3%	-8.1%
Material intensity	-5.0%	-9.2%	-4.4%	-7.0%

Source: OECD ENV-Linkages model.

Box 5. What are the impacts of material fiscal reform on government budgets?

Despite the implementation of non-negligible taxes on materials use, the macroeconomic impacts of the *material fiscal reform scenario* remain limited because the imposed taxes do not really change the composition of government budgets. Indeed, the total amount of material taxes reaches around 0.9% of total tax revenues in 2040 at the global level, and only 0.3% for OECD countries, as indicated in . Material taxes remain very moderate compared to other sources of tax revenues. For example, labour taxation accounts for 21% in 2040, while indirect taxes of commodities like VAT (not presented here) account for around 50% of total tax revenues. This explains partly why the recycling effect through labour taxation reduction (discussed in Box 4) remains limited.

In most regions, two thirds of the total material tax revenues are associated with taxing non-metallic minerals and one third with taxing metals. This could be seen as surprising since tax rates have been originally fixed such to imply equivalent levels of tax revenues (see Section 3.2). The divergence in tax contributions between non-metallic minerals and metals results from the inclusion of subsidies in the *material fiscal reform*. In particular, the subsidies to secondary metals in the *material fiscal reform* accelerate the substitution away from primary-based metals and therefore reduce the tax base of primary metal use.

The *material fiscal reform* also implements subsidies with varying importance on the composition of government budgets. While subsidies on the consumption of recycling goods remain marginal (around 0.2% at global level), the subsidies on secondary metals are important, around 2.5% of global tax revenues. Actually, even in 2017 before the implementation of the reform, the subsidies to secondary metal production already absorbed 0.4% of total tax revenues.

Table 13. Changes in composition of government budgets, material fiscal reform scenario

			Tax on labour income	Tax on primary metals	Tax on Non-metallic minerals	Subsidy on recycling good use	Tax on primary metals production[a]	Subsidy on secondary metals production	Total Taxes
OECD	*Bn USD*	*2040*	6907	44	64	36	95	101	27769
	Pct of tax revenues	2017	25.0%	-	-	0.0%	0.4%	0.1%	100%
		2040	24.9%	0.2%	0.2%	0.1%	0.3%	0.4%	100%
BRIICS	*Bn USD*	*2040*	977	51	147	38	-74[b]	268	9081
	Pct of tax revenues	2017	12.5%	-	-	0.0%	-1.2% [b]	1.2%	100%
		2040	10.8%	0.6%	1.6%	0.4%	-0.8% [b]	2.9%	100%
Rest of the world	*Bn USD*	*2040*	957	23	49	12	55	127	5693
	Pct of tax revenues	2017	20.0%	-	-	0.0%	1.2%	1.0%	100%
		2040	16.8%	0.4%	0.9%	0.2%	1.0%	2.2%	100%
World	*Bn USD*	*2040*	8841	119	260	86	76	495	42544
	Pct of tax revenues	2017	22.3%	-	-	0.0%	0.2%	0.4%	100%
		2040	20.8%	0.3%	0.6%	0.2%	0.2%	1.2%	100%

Notes:
a. Tax rates on primary metal production are fixed, in all scenarios, at their baseline levels.
b. Negative tax revenues on primary metals production in BRIICS reflect subsidies on production in China as recorded in the GTAP database.
Source: OECD ENV-Linkages model.

5. Environmental, regional and sectoral impacts of the *material fiscal reform*

This section dives deeper into the detailed effects of the *material fiscal reform* scenario. It first details in section 5.1 the environmental impacts of the *material fiscal reform* scenario, which result from the lower use of material resources as well as the substitution between primary and secondary materials. Section 5.2 provides further details on country-specific results and section 5.3 details sectoral impacts, as the limited aggregate impacts of the material fiscal reform hide significant differences among sectors and countries. These differences reflect the heterogeneous dependence of various countries and firms to materials use.

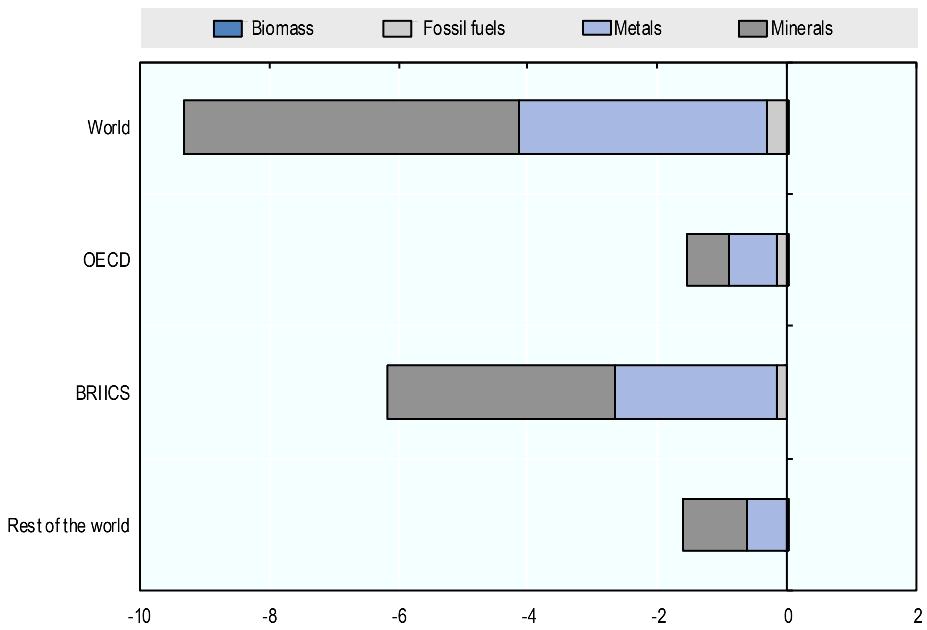
5.1. Materials use reduction and the environmental benefits

5.1.1. Impacts on materials use

The *material fiscal reform* scenario achieves a reduction in materials use of 9.3 Gt compared to the baseline scenario, at the global level by 2040 (Figure 3). Thanks to the material fiscal reform, large amounts of materials are reduced, both for metals (4 Gt, representing -27.3% of baseline levels) and for non-metallic minerals (5.4 Gt, representing -7.2% of baseline levels). The material fiscal reform indeed targets these two categories of materials. Other materials use are also reduced indirectly (for instance, fossil fuel use decreases because primary metal processing sectors are energy-intensive).

Figure 3. Change in materials use, *material fiscal reform* scenario

Materials use in Gt – change w.r.t. baseline scenario in 2040.



Source: OECD ENV-Linkages model.

The decrease in materials use is stronger in non-OECD countries, as these countries characterised by a more resource intensive production structure. The reduction in OECD counties reaches 1.5 Gt (-5%) while BRIICS countries reach 6.2 Gt (-9.5%) and the Rest of the world reaches 1.6 Gt (-4.8%).[13] Because the increase in material use is projected to be higher in BRIICS countries (as described in (OECD, 2019[1])), that is where the fiscal reform is most impactful.

The shift towards the use of more secondary and less primary metals however does not fully reverse the global increase of raw material use identified in the *OECD Global Material Resources Outlook to 2060*, (OECD, 2019[1]). Although total materials use decreases with respect to the baseline scenario, the use of materials is still projected to increase compared to the current levels. The projected increase in wealth and development goes along an increase in materials use (Table 13). However, the implementation of primary material tax and secondary material subsidies allows steering that growth towards a more resource efficient and circular economy. For instance, primary iron and steel is projected to grow by 52% to 2040, instead of 72% in the baseline scenario. In contrast, secondary Iron and Steel is projected to triple (a 194% growth), a faster growth than in the baseline scenario. However, primary Iron and Steel is still projected to account for more than 50% of metal use in 2040. Similar trends can be identified for other metals: a doubling of primary metal use (e.g. a growth by 95% for aluminium, or 103 % for copper) versus a larger growth of secondary metal use (e.g. a 151% growth for aluminium, 141% for copper).

Table 13. Evolution of global metal use, baseline and *material fiscal reform* scenario

		Mt			Growth 2015[a]-2040	
Metal	Type	2015[a]	Baseline 2040	Fiscal reform scenario 2040	Baseline	Fiscal reform scenario
Aluminium	Primary	45.8	93.9	89.3	105%	95%
	Secondary	24.7	48.9	61.9	98%	151%
Copper	Primary	18.5	38.3	37.5	108%	103%
	Secondary	4	6.9	9.6	71%	141%
Iron and steel	Primary	1193.8	2055.7	1820.4	72%	52%
	Secondary	455.6	791.7	1339.0	74%	194%
Lead	Primary	4.4	9	8.9	106%	102%
	Secondary	6.1	9.3	13.2	53%	116%
Manganese	Primary	12	24.6	24.4	106%	104%
	Secondary	7.3	11.3	15.9	53%	118%
Nickel	Primary	1.5	3.1	3.0	106%	102%
	Secondary	0.7	1.1	1.5	53%	121%
Zinc	Primary	12.6	25.9	25.7	106%	104%
	Secondary	1.2	1.8	2.5	53%	112%

Note: [a] here the reference year of 2015 is chosen because it is the last year with full historical data.
Source: OECD ENV-Linkages model.

[13] A material footprint analysis would show that a significant share of the material consumption of emerging and developing economies is used for industrial production destined to developed economies. (Lutter, Giljum and Bruckner, 2016[30]) presents a review of the methodologies to perform such analysis. (Giljum, Bruckner and Martinez, 2014[31]) for instance shows that a sizeable portion of domestic material use in non-OECD Asia, Africa and Latin America is destined for OECD countries' markets.

5.1.2. Global environmental impacts

Environmental impacts by metal

The reduction of materials use overall leads to a reduction of the environmental impacts projected in the baseline scenario (Table 14). Environmental impacts decrease for most metals (aluminium, copper, iron, manganese, nickel and zinc). However, the reduction of environmental impacts is particularly strong for aluminium and Iron and steel, which reflects mainly that the reduction in the use of these metals are stronger than for the other materials. Annex E details the impacts by examining the effect of the policy on one metal at a time.

The evolution of the environmental impacts depends on both the level of material use and on the level of pollutants associated with a ton of material used. As described in (OECD, 2019[1]), both affects the evolution of the environmental impacts for primary metals as well as secondary metals. As described above, while the use of primary metals decreases, the use of secondary metals increases. In addition, most of the per ton pollutant coefficient are much larger for primary materials than for secondary materials.

The environmental impacts related to iron generally decrease. While the use of iron and steel increases (Table 13), this results from the net effect of a decrease in primary iron and steel and an increase in secondary iron and steel. Therefore, the environmental impacts of iron and steel use decrease because the per ton impacts of primary iron and steel are much larger than secondary materials. The exception is terrestrial ecotoxicity, for which secondary iron and steel has higher per ton impacts.

The environmental impacts related to lead increase, but they are the lowest of all seven metals studied (OECD, 2019[1]). While the use of primary lead slightly decreases with the material fiscal reform, the growth of secondary lead use doubles compared to the baseline for the period between 2015 and 2040 (Table 13), overcompensating the small decrease in primary lead use.

Table 14. Indicators of global environmental impacts, *material fiscal reform* scenario

Variation w.r.t. baseline scenario in 2040.

	Aluminium	Copper	Iron	Lead	Manganese	Nickel	Zinc
Acidification	-4%	-2%	-5%	7%	-1%	-1%	-2%
Climate Change	-5%	-2%	-5%	6%	-1%	-2%	0%
Cumulative Energy Demand	-5%	-2%	-4%	9%	-1%	-1%	0%
Eutrophication	-3%	-3%	-5%	0%	-1%	-2%	-2%
Freshwater aquatic ecotoxicity	-4%	-3%	-1%	1%	-2%	-2%	-2%
Human toxicity	-5%	-3%	-6%	0%	-2%	-1%	-2%
Land use	-3%	-3%	-4%	4%	-1%	-2%	-1%
Photochemical oxidation	-5%	-2%	-6%	9%	-1%	-2%	-1%
Terrestrial ecotoxicity	-2%	-2%	19%	7%	0%	-1%	-2%

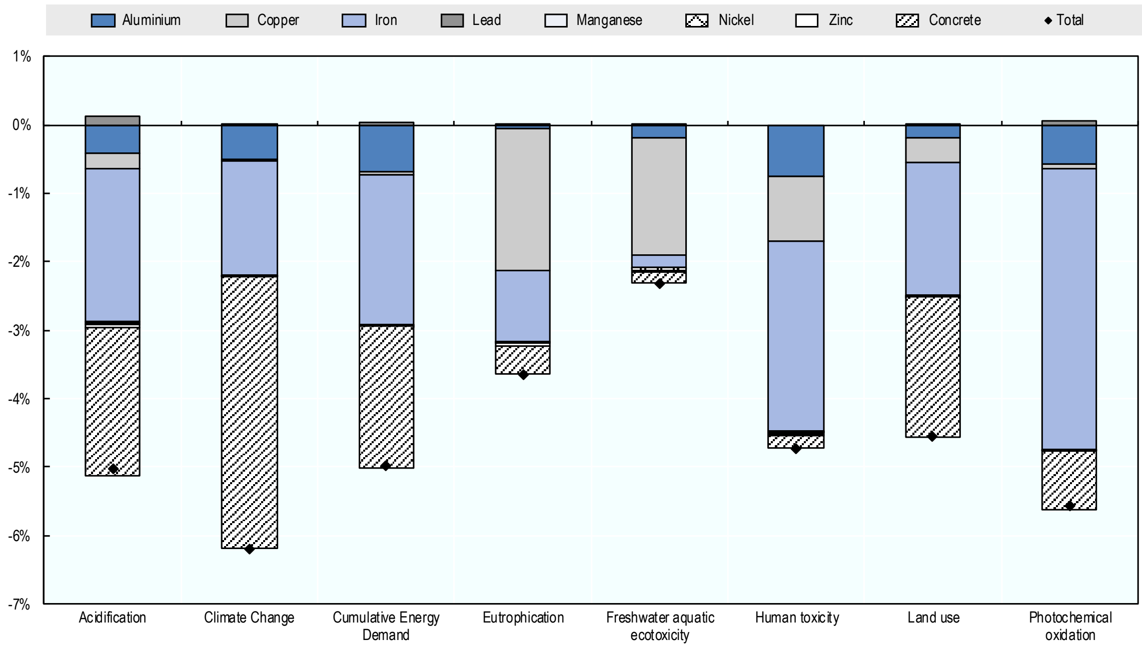
Source: OECD ENV-Linkages model, based on coefficient from the CML’s CMLCA model.

Overall environmental impacts

The reduction of materials use leads to a reduction of the environmental impacts projected in the baseline scenario (Figure 4). Over the eight materials considered for the calculation of these indicators (the seven metals described above and concrete), the environmental indicators decrease between 2.3% and 6.2% compared to 2040 baseline levels.

Figure 4. Global environmental impacts from metals, *material fiscal reform* scenario

Variation in 2040 w.r.t. baseline scenario



Source: OECD ENV-Linkages model, based on coefficients from the CML's CMLCA model.

The main contributors to the decrease in environmental indicators are ferrous metals and concrete and to a lesser extent aluminium, for most indicators. For those two indicators for which copper is the main pollutant (eutrophication and freshwater toxicity), the reduction in primary copper is the main contributor.

The only exception is terrestrial ecotoxicity (the impacts of toxic substances on species in terrestrial ecosystems, not displayed in Figure 4), which increases by 14%. This relates directly to the increase in secondary steel production, which has a stronger impact (almost 5-fold) for terrestrial ecotoxicity than primary iron and steel. Secondary steel is made in a different process from most of the primary steel production. The assumption is made that blast furnace is used for primary steel and electric arc furnace for secondary steel. This is a simplification from reality but for a rough assessment, it is a valid assumption. Electric arc furnace causes toxic emissions, at least more so than the blast furnace process, hence the increased terrestrial ecotoxicity compared to baseline levels.

There are nonetheless caveats to this analysis. First, these evolutions are a rough quantification, given the lack of regional differentiation, which is especially relevant given the strong regional shifts in production. Second, this analysis only quantifies "cradle-to-gate" impacts, which omits the part of the lifecycle of the materials after its use.

Detailed air pollutant and greenhouse gas emission changes

The emission of air pollutants in the atmosphere is one of the key environmental consequences of materials use. Air pollutants are emitted throughout all stages of materials extraction and production. A large share of emissions occurs during the combustion processes that underlie the production of metals, such as iron and steel, as well as other materials. The combustion of fossil fuels – and especially of coal – leads to the emission of fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO). In addition, the processing of raw materials is often responsible for additional emissions: for example, the processing of rocks containing sulphur determines high sulphur dioxide (SO_2) emissions. Box 6 explains the stakes of reducing air pollutant emissions.

Box 6. What are the impacts of air pollution?

The health consequences of air pollution are one of the most serious environmental concerns, causing additional cases of illnesses and premature deaths. According to the World Health Organisation (WHO), air pollution is responsible for 7 million premature deaths every year, thus representing one of the major health threats at global level (WHO, 2018[26]).

The impacts of air pollution can also be costly to the economy, as they lead to lower labour productivity, higher health expenditures, and lower agricultural productivity, as well as the welfare costs associated with the numerous premature deaths. Based on ENV-Linkages model simulations, OECD (2016[27]) shows that by 2060, the market costs of outdoor air pollution are projected to equal 1% of global GDP. Thus, reducing air pollutants emissions would lead to significant benefits, thanks to the reduced impacts and costs.

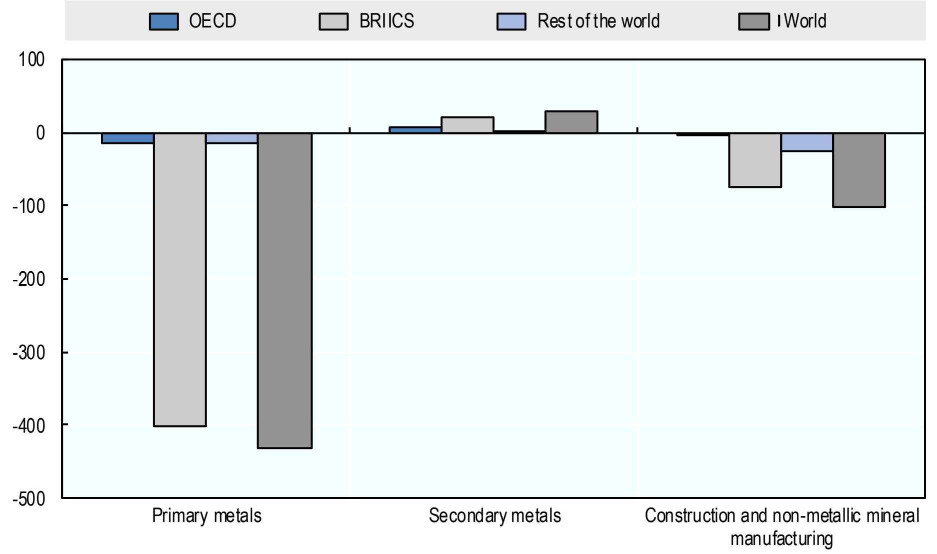
These emissions of air pollutants have direct and indirect impacts on human health, as included in the human toxicity indicator, which covers the impacts on human health of toxic substances by either inhalation or the food chain. Indeed air pollution can also affect the quantity and quality of food available; most notably, it has impacts on crop yields. Furthermore, air pollution also has impact on photochemical oxidation, as it contributes to the formation of reactive chemical compounds (e.g. Volatile Organic Compounds and Carbon Monoxide), which can contribute to the formation of ozone, affect visibility (phenomenon known as smog), and lead to damages to health, ecosystems and crops. Finally, emissions to the atmosphere inevitably also affect land quality, as reflected by the indicator on terrestrial ecotoxicity.

Emissions of air pollutants are projected to diminish substantially under the *Material fiscal reform* scenario relative to their baseline levels (Figure 7). In all regions, emissions of $PM_{2.5}$, CO and SO_2 show the most significant reductions. Emissions reductions under the *Material fiscal reform* scenario are particularly strong in BRIICS countries, as they are characterised by high production levels and a higher reliance on coal-based production processes, which lead to higher emissions. Furthermore, OECD countries are further along in adopting technologies that reduce air pollution. Consequently, the latter are projected to experience lower emission reductions rates under the *Material fiscal reform* scenario.

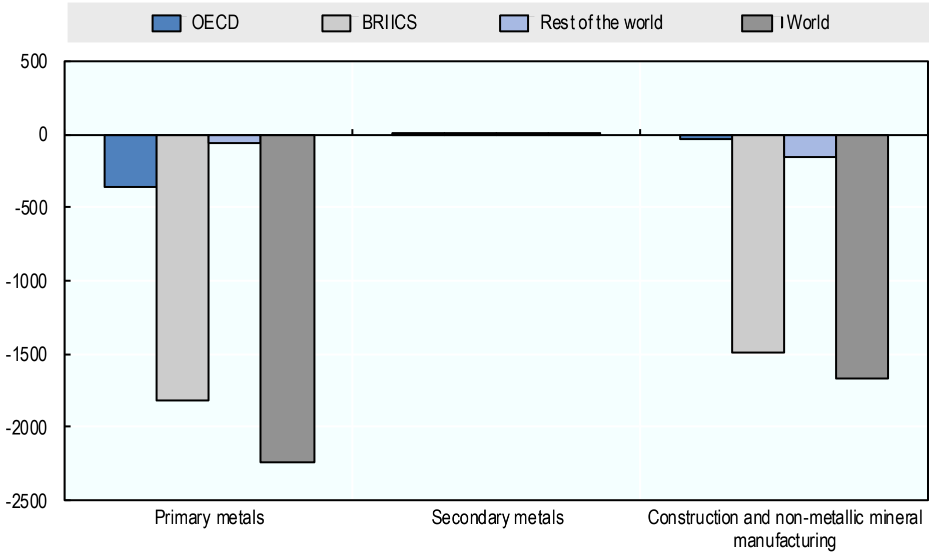
Conversely, emissions of $PM_{2.5}$ and SO_2 linked with secondary materials are projected to slightly increase, especially in BRIICS countries. However, this increase is very small when compared to the substantial decrease in emissions related to primary materials use. Overall, the *Material fiscal reform* scenario leads to improved air quality in different regions of the world.

Figure 5. Emissions of selected air pollutants in metal production and construction sectors, *material fiscal reform* scenario

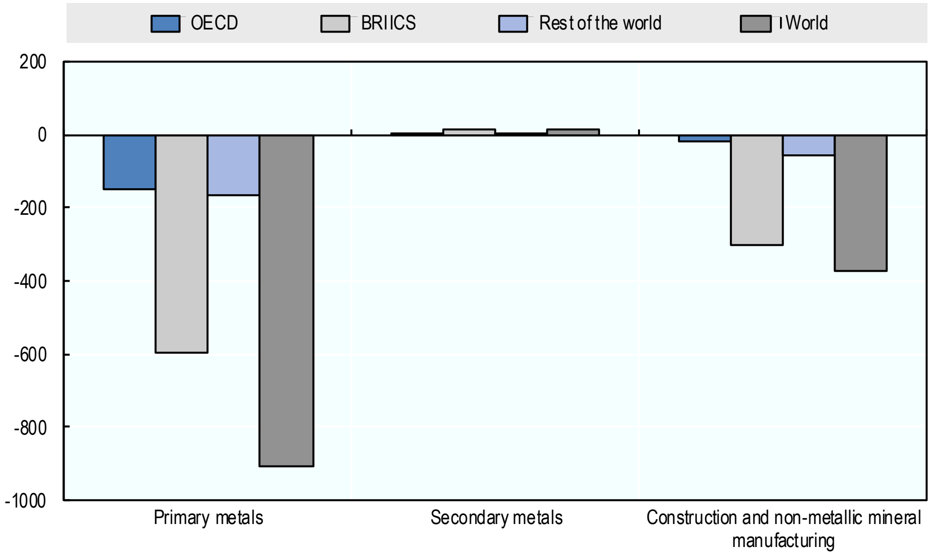
Panel A. $PM_{2.5}$ (Thousands of tonnes) - difference to the baseline - 2040



Panel B. CO (Thousands of tonnes) - difference to the baseline – 2040



Panel C. SO_2 (Thousands of tonnes) - difference to the baseline - 2040



Source: OECD ENV-Linkages model.

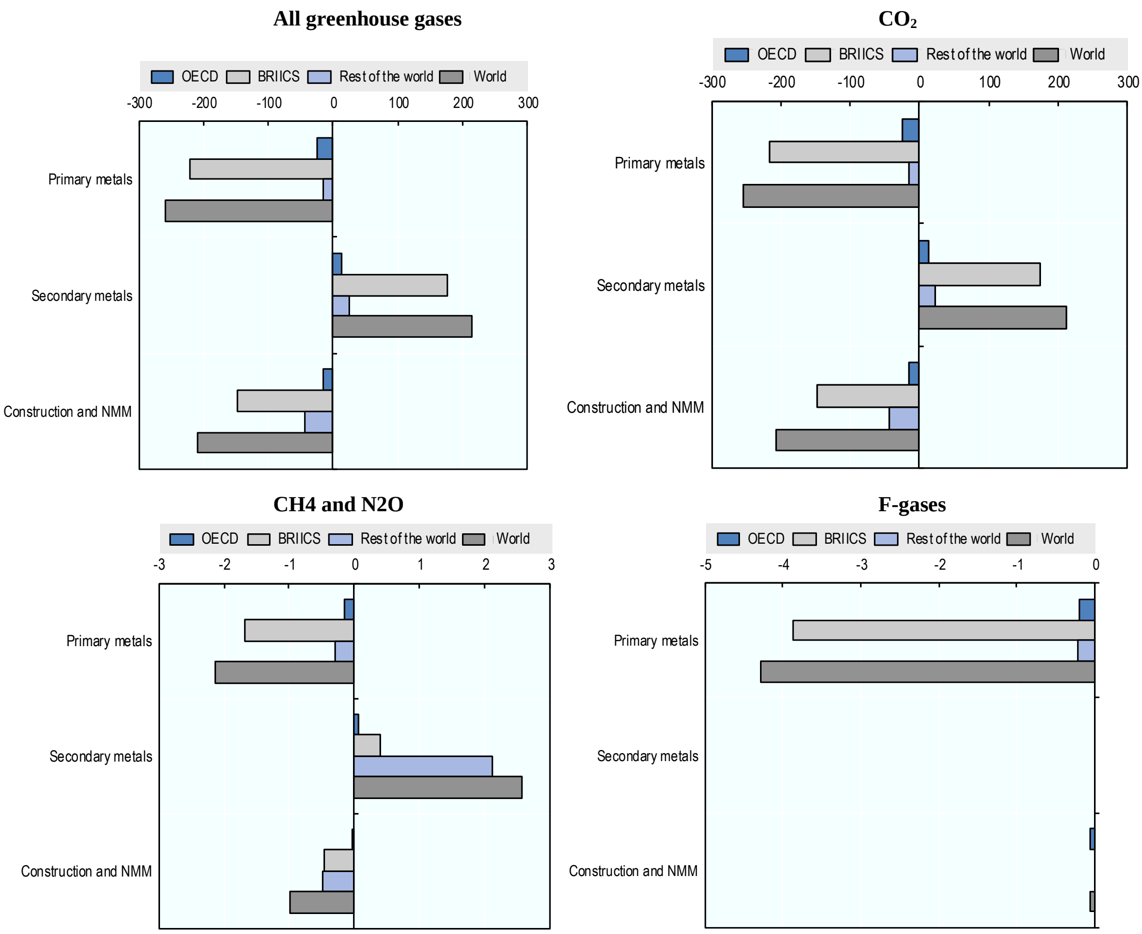
The emission levels of greenhouse gases (GHGs) are also affected by the shifts in materials use that follow the fiscal reform scenario (Figure 6). This figure details the evolution of the "Climate change" environmental indicator at the beginning of this section. The GHGs emissions related to primary metal production and construction and to non-metallic minerals sectors is projected to substantially diminish under the *material fiscal reform* scenario. Emissions of F-gases relative to primary material production in BRIICS countries are particularly affected, since PFCs and SF_6 gas emissions are strongly linked to the production of primary aluminium and magnesium.

However, the increase in the production of secondary metals is projected to drive a substantial increase in GHG emissions. Thus, the shift towards secondary metal use leads to an increase of CO_2, CH_4 and N_2O emissions, particularly in the *Rest of the world* region.

Overall, the Material fiscal reform scenario leads to a decrease in GHG emissions. The decrease in emissions related to primary metal, construction and non-metallic minerals production offsets the increase in emissions related to secondary metals production. Nevertheless, the trade-off in emissions from primary and secondary metals highlights the need to consider RE-CE policies in the wider context of different policy objectives, with a particular focus on those related to climate change mitigation (see Section 6).

Figure 6. Greenhouse gases emissions in metal production and construction sectors by aggregate region, *material fiscal reform* scenario

Changes w.r.t with the baseline in 2040 - Mt of CO_2-equivalents.



Source: OECD ENV-Linkages model.

5.2. Country-specific results

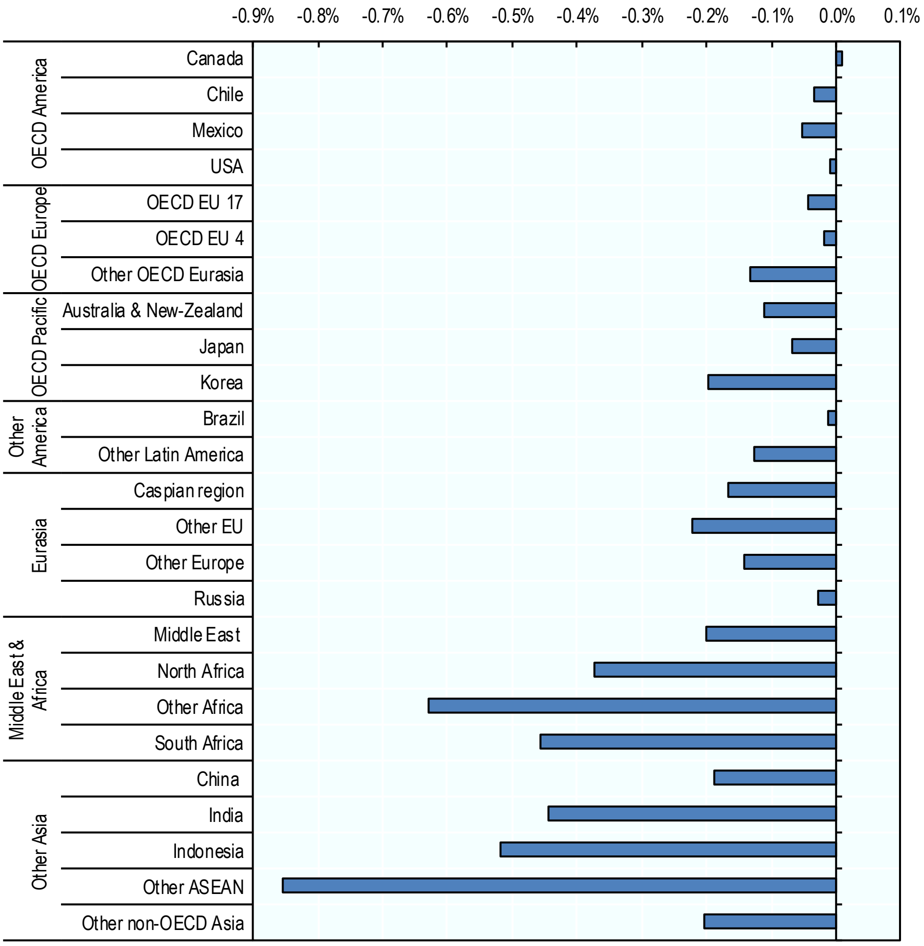
5.2.1. Vulnerability of countries to the policies

The implementation of the material fiscal reform scenario comes at small aggregate economic costs by 2040 at global level, but this hides some disparities across countries (Figure 7). The most affected regions – ASEAN countries (including Indonesia and Malaysia that are both major resources-exporters), or African countries – lose between 0.8% and 0.4% of GDP, but for other regions lost are less than 0.4% and almost 0% for OECD countries.

This limited cost is largely because, in most sectors, primary material costs amount to less than 10% of total input costs. In addition, the ambition of the material fiscal reform scenario remains limited and, since the reform is budget neutral, governments do have room for manoeuvre to reduce distortive factor income taxation. Furthermore, environmental benefits, such as reduced costs of environmental degradation, are not included in these GDP calculations.

Figure 7. GDP impacts by region, *material fiscal reform* scenario

Percent change of real GDP in 2040 w.r.t. baseline scenario.



Source: OECD ENV-Linkages model.

GDP impacts are however not symmetric among countries. Several factors come into play to explain the differences: the exposure of countries to the policies (i.e., how dependent their economy is on materials use), the additional weight of the taxes and subsidies (as the taxes were calibrated to take into account existing taxes), the trade links of the economy and the general structure of the economy.

A main factor explaining the difference in impacts between countries is the material intensity. As described in (OECD, 2019[1]), Other Asia has the highest material intensity (1.2 t/USD in 2017) and shows the highest costs. In contrast, OECD America and OECD Europe have a much lower material intensity (0.5 t/USD in 2017), which leads to much lower costs.

A second key indicator of the stringency of the policy is the additional burden of the material taxation. As shown in Table 4, India has initially no material taxation, while China has. The implication is that the material tax in the *Material tax reform* is larger in India than in China (two third higher for non-metallic minerals and 40% higher for metals). This is a large factor in explaining why the cost in India are twice higher than in China.

5.2.2. Partial geographical coverage

The extent to which the material fiscal reform is adopted across the globe creates leakage effects and competitiveness impacts through regional changes in terms of economic cost and material savings. This section examines the impacts of geographical coverage of the three sets of scenarios described in the previous sections: (i) a tax on metals, (ii) a tax on metals and minerals and (iii) the material fiscal reform. These three sets may cover only OECD countries, OECD and BRIICS countries or have global coverage (central case). Table 15 describes the results of these scenarios at the global level and for the three groups of countries.[14]

At the global level, the main insight is that increased policy coverage increases the reduction in materials use. If applied to BRIICS countries in particular, the reduction in materials use is high. This is expected since the largest increase of materials use in the baseline will occur in BRIICS countries (see Annex C). GDP costs, while modest, also affect most the BRIICS when policies are implemented in those countries.

Materials use generally increases in regions that are not implementing policies. This leakage effect indicates that non-acting countries increase their demand for primary materials when some acting countries implement policies, since the former benefit of lower international prices for these materials. These prices are decreasing because the demands of materials by acting countries are lower. The more the number of participating countries are, the more international prices of materials are falling and therefore the higher the rebound effect (non-acting countries benefit and increase their demand for material). For instance, the increase of materials shows for the "rest of the world" column in Table 15 when coverage goes from "OECD" only to "OECD + BRIICS".

The feedback effect on GDP from region acting to non-acting region is however not straightforward, it changes if the non-acting country is net exporter or net importer of raw materials. In details, the effect of taxing metals is either neutral (in BRIICS when OECD puts policies in place) or negative (in Rest of the world when OECD and BRIICS set policies). The same occurs when taxing both metals and minerals.

When only material taxes are implemented, OECD countries are less impacted by the policies when other countries are also acting than they are when they act alone. Materials use is less impacted in OECD countries (showing that their relative competitiveness is improved by other countries taxing materials). In contrast, when the *material fiscal* reform is considered, the gradual action of the other countries does not reduce GDP costs of the policy for OECD.

[14] (Dellink, 2020$_{[32]}$) further analyses the partial implementation of resource efficiency and circular economy policies, as well as their trade consequences.

Table 15. Impact of the geographical coverage of policies on materials use and GDP

Percent change in 2040 w.r.t. baseline scenario.

		World		OECD		BRIICS		Rest of the world	
Policy	**Coverage**	**Materials use**	**GDP**	**Materials use**	**GDP**	**Materials use**	**GDP**	**Materials use**	**GDP**
Tax on metals	OECD	-0.6%	0.0%	-3.1%	-0.1%	0.1%	0.0%	0.3%	-0.1%
	OECD + BRIICS	-2.7%	-0.1%	-2.9%	0.0%	-4.1%	-0.2%	0.3%	-0.1%
	Global	-3.2%	-0.2%	-2.7%	0.0%	-4.0%	-0.3%	-2.0%	-0.2%
Tax on metals and minerals	OECD	-1.1%	-0.1%	-5.3%	-0.1%	0.1%	0.0%	0.3%	-0.1%
	OECD + BRIICS	-6.1%	-0.3%	-5.2%	-0.1%	-9.8%	-0.6%	0.3%	-0.1%
	Global	-7.4%	-0.4%	-5.0%	-0.1%	-9.8%	-0.7%	-5.1%	-0.4%
Material fiscal reform	OECD	-1.1%	0.0%	-5.3%	0.0%	0.2%	0.0%	0.3%	0.0%
	OECD + BRIICS	-5.9%	-0.1%	-5.2%	0.0%	-9.5%	-0.3%	0.5%	0.0%
	Global	-7.2%	-0.2%	-5.0%	0.0%	-9.5%	-0.3%	-4.8%	-0.4%

Source: OECD ENV-Linkages model.

Policy cooperation is thus crucial to reduce material use. When more countries act, the global material reduction is higher. Furthermore, a wider coverage avoids leakages to other countries. The policy is also less costly for acting countries in the case when all countries act relative to the case where other countries do not act.

5.3. Sectoral impacts

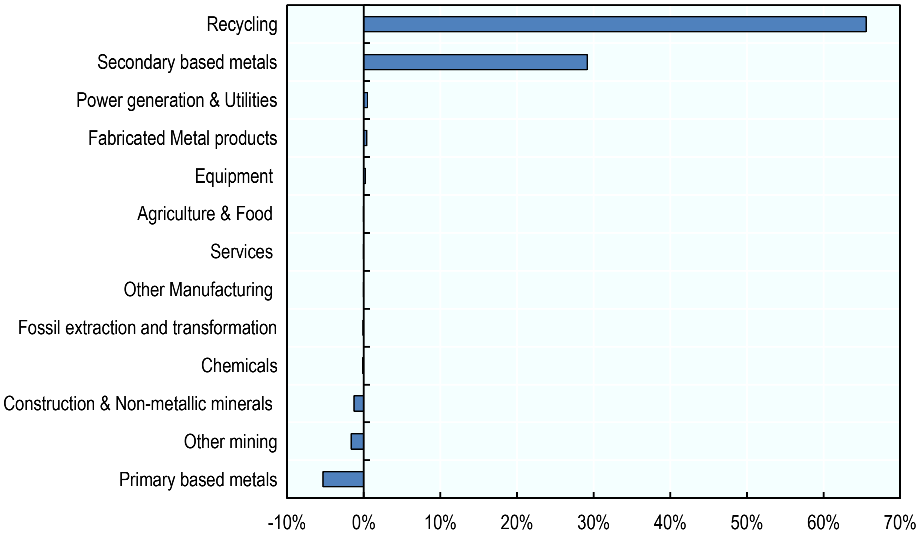
At the aggregate level, changes in real production, resulting from the implementation of the *material fiscal reform*, are modest: from -0.4% to +0.2% according to country or regions (details in Figure A D.1 in Annex D), but as shown in Figure 8, this hides larger sectoral impacts.

First, the material tax elements of the fiscal reform implies changes in production modes and demand patterns away from sectors that rely on intensive use of primary materials: Construction and non-metallic minerals production drop by 1% and primary-based productions of metal are decreasing by 5%, relative to baseline levels in 2040 (as showed on the left of Figure 8). Details of this category gives -7% for Iron and Steel, -6% for aluminium, while primary copper decreases by 3% and other nonferrous metals by only 2%. Non-metallic minerals decrease by 4%.

On the opposite side of the spectrum, sectors that provide substitutes for the commodities targeted by the *material fiscal reform* are stimulated (right of Figure 8) by the subsidy to production elements of the fiscal reform. This is the case for secondary-metal based technologies: that increase between +25% and +36% (relative to baseline levels in 2040). Those technologies are not only stimulated through the subsidies but also because the price of their direct competitors (i.e., primary-based metal production) are higher due to the metal taxes.

Figure 8. Change in sectoral composition of production, *material fiscal reform* scenario

Global real gross output, variation in 2040 w.r.t. baseline scenario.



Note: In this figure, for simplicity sectors have been aggregated to 13 sectors. The new aggregates include: Power generation & Utilities = Fossil Power + Renewable power + Utilities; Services = Transportation services, Other Services (Government), Other Services and Dwellings; Other Manufacturing = Electronic Equipment + Textiles + Lumber: Wood products + Other manufacturing: excludes recycling + Pulp, paper and publishing products; Equipment = Motor vehicles + Transport equipment n.e.s. + Machinery and equipment n.e.s; Agriculture & Food = Agriculture + Food products; Construction & Non-metallic minerals = Construction + Non-metallic minerals. The complete list of sectors in the model is reported in Table A.1 in Annex A.
Source: OECD ENV-Linkages model.

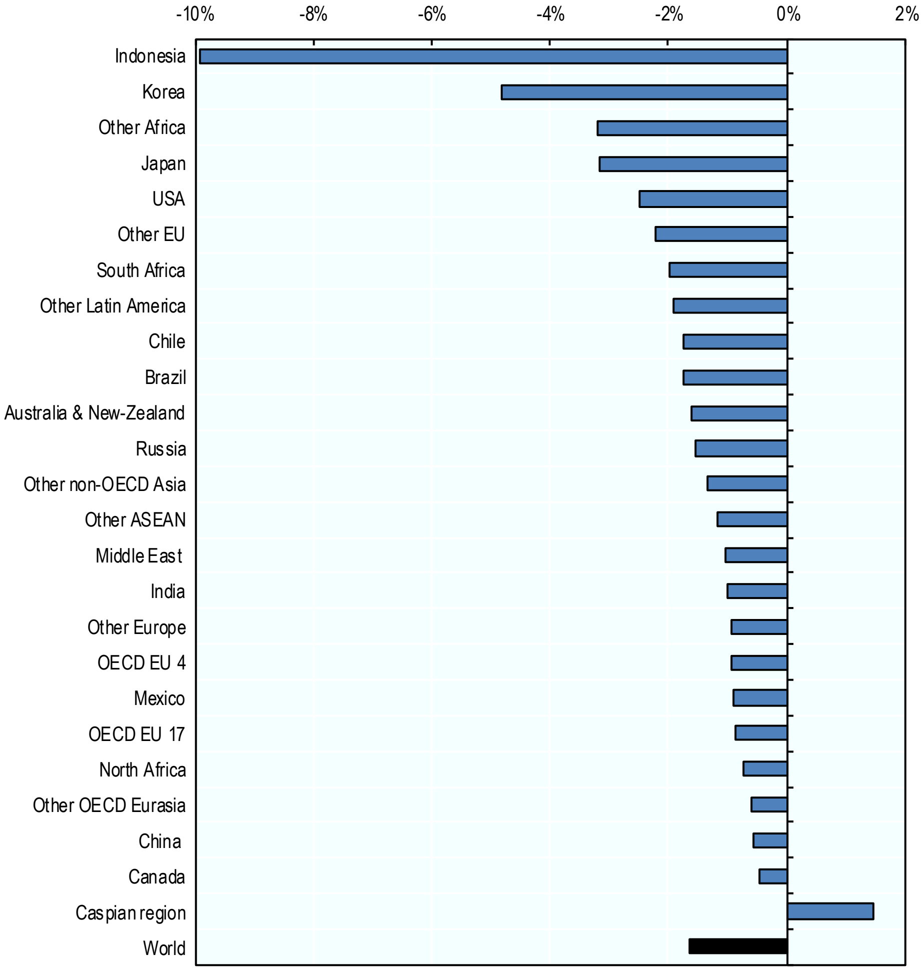
The third element of the reform aims, with dedicated subsidies, at stimulating the use of recycling as input in production processes. Thus, the recycling sector will increase by 66% at a global level (relative to baseline level in 2040). This is mainly the consequence of the increase of the subsidy to the use of recycling, but also to a lesser extent to the stimulus to secondary-metal technologies, that are using more intensively products from recycling than primary metals activities.

The other impacts on sectoral composition of production are indirect impacts. For instance, there are opposing forces that drive producer price in material-intensive sectors (including raw and refined materials): the price increase of the resources (directly from the material tax or from induced cost of production of refined materials) and the decreased demands for the same goods move prices in opposite directions.

The Other mining sector reflects this opposition (see Figure 9). For big producers (e.g. Indonesia, Africa), the effects on production are very negative, through the reduced sales. In contrast, other countries are affected more modestly, and are comparative winners (for instance, Canada shows very modest impacts on mining, and GDP gains following the implementation of the *material fiscal reform*). The Caspian region records positive production stimulated by the decrease of gross-of-tax world price of mining products and a comparatively low additional tax on mining products.

Figure 9. Change in mining output by region, *material fiscal reform* scenario

Changes in percentage of real gross output of the mining sector, in 2040 w.r.t. to baseline levels.



Source: OECD ENV-Linkages model.

The increased cost of production for material-based industries (primary metal productions, non-metallic minerals) will translate into increase of cost for the sectors that intensively use these products, such as construction and non-metallic minerals, equipment. Production of Other manufacturing goods are less impacted, mostly because they can substitute secondary metals input (with subsidised prices) to primary metals.

While the aggregate impacts of the policies contained in the *Material tax reform* are limited, a small set of sectors is heavily impacted. Thus, material intensive sectors (e.g. mining, metals and non-metallic minerals processing) are negatively impacted by the reform negatively, while sectors promoting circularity (e.g. secondary materials and recycling) gain from the reform. The success of green growth policies depends on the capacity of firms and workers to adapt to the changes in economic structures induced by the policies. These policies can lead to sectoral impacts that can undermine the political acceptability of a policy proposal. In order to promote a fair transition, accompanying measures to adjust education and training policies, as well as redistributive schemes to alleviate the adverse impacts, could help workers and firms of these sectors adapt to this transition.

6. The complementarities between the circular economy and the energy transition

Policies to promote resource efficiency and the transition to a circular economy need to be understood in the larger policy context, given their effects on several sectors and the environment. One important issue that will provide the context for policy design are climate change and energy policies, given that they affect energy intensive sectors, such as mining and metal processing. This section explores interactions between these two sets of policies. It compares the results of the *material fiscal reform* with those of the *combined energy and material transition* scenario, which corresponds to the *material fiscal reform* in a world where the energy transition occurs. Section 6.1 first examines the impacts on materials use in the *combined energy and material transition* scenarios. Then, Section 6.2 examines the macroeconomic impacts of the two scenarios. This means comparing the results of the *material fiscal reform* when setting it in a baseline with or without the energy transition. Finally, Section 6.3 investigates the country-level effects of these scenarios, while Section 6.4 assesses their sectoral impacts.

6.1. Materials use impacts

The *combined energy and material transition* scenario discussed in this section implements the *material fiscal reform*, within a baseline scenario including policies driving the energy transition.[15] Annex H describes the *energy transition* scenario which constitutes the benchmark against which the *combined energy and material transition* scenario is compared.

The material tax reform and the energy transition policies will both imply reductions in material use. Table 16 shows the contribution of each scenario: the *material fiscal reform* reduces materials use by 7%, relative to baseline. The *energy transition* scenario reduces materials use by 12%. These policies and trends are cumulated to examine a *combined energy and material transition* scenario where materials use decrease by 19%. This result provides evidence to a synergy between both transitions.

[15] For the energy transition of this scenario, the shift in electricity technologies and the increased demand for materials for renewable technologies is represented within the social accounting matrix, which describes 8 different electricity technologies. The demand for storage, batteries, or electric vehicles represented to some extent in the structural shift in sector. However, this representation is crude, as those technologies are not described in the initial social accounting matrix.

Table 16. Materials use by scenario and by aggregate region

Materials use in Gt and percentage changes to baseline scenario, 2040.

	OECD		BRIICS		Rest of the world		World	
	Gt	% change	Gt	% change	Gt	% change	Gt	% change
Baseline	31.0		65.0		33.1		129.1	
Material fiscal reform	29.4	-5%	58.8	-9%	31.5	-5%	119.8	-7%
Energy transition scenario	27.3	-12%	54.2	-17%	31.7	-4%	113.2	-12%
Combined energy and material transition	25.8	-17%	48.7	-25%	30.1	-9%	104.6	-19%

Note: In this table, all results are compared to the baseline (without the energy transition).
Source: OECD ENV-Linkages model.

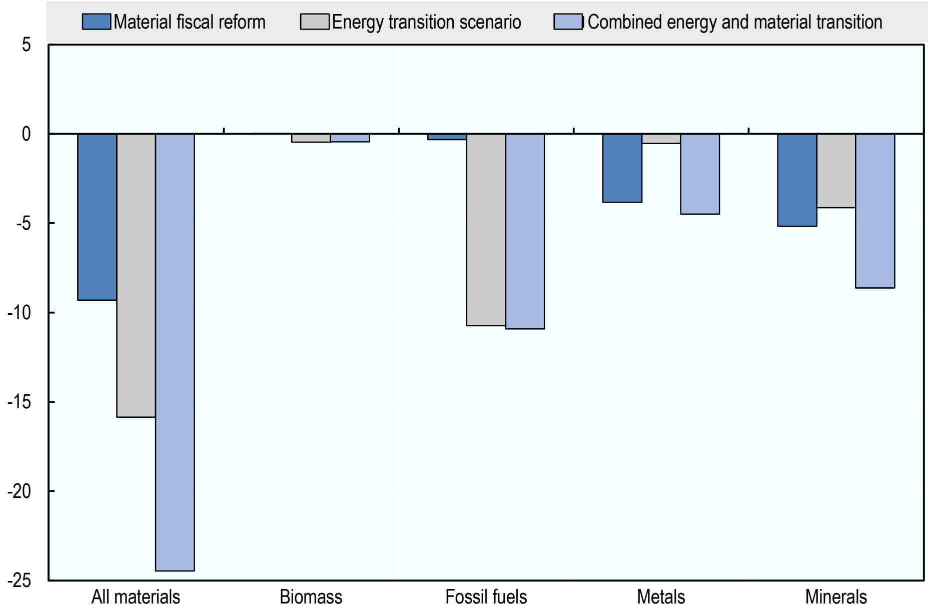
The comparison between these scenarios sheds light on the complementarity between the energy transition and the RE-CE transition regarding materials use. As the reductions in materials use seem to add, a further look allows to explain what material types are affected, as seen in Figure 10. Roughly, the *energy transition* targets fossil fuels, while the *material fiscal reform* targets metals and non-metallic minerals.

The material use reductions in the two policy packages are additive. For fossil fuels, the *energy transition* leads to a reduction by 11 Gt in 2040 relative to baseline. For Metals, the *material fiscal reform* brings about a reduction by 4 Gt in 2040 relative to baseline. For non-metallic minerals, both transition contribute to the material use reduction: a 5 Gt reduction in the *material fiscal reform* scenario and a 4 Gt reduction in the *energy transition* scenario. All these reductions are added up in the *combined energy and material transition* scenario, leading to a 24 Gt material reduction compared to baseline levels in 2040.

However, for more ambitious material policies, the interactions could be less straightforward, given that the energy transition will affect metal demand, taken into account through material needs for investments. The higher demand for electricity from secondary metal production could lead to higher investments and material demands, discussed in Section 6.4.

Figure 10. Materials use by scenario and by material category

Materials use reduction in Gt w.r.t. to baseline in 2040.



Notes: The interaction effect corresponds to the difference between the reduction in the *combined energy and material transition scenario* (where both transition are realized simultaneously) and the sum of reductions when both transition are implemented separately. It is shown on the right axis.
In this table, all results are compared to the baseline (without the energy transition).
Source: OECD ENV-Linkages model.

6.2. Macroeconomic impacts

The reduction of materials use goes along with a change in macroeconomic conditions. For comparability, the results of the *combined energy and material transition* scenario are assessed relative to the *energy transition* scenario (which is an alternative baseline). Table 17 describes the evolution of GDP, employment, gross and net-of-tax wage rate, and household consumption. In addition, Table 17 displays again the results of the *material fiscal reform* scenario from Table 12 for comparison purposes.

Table 17. Main aggregate indicators, *material fiscal reform* and *combined energy and material transition* scenarios

Percent change w.r.t. their respective baseline [a] in 2040.

	Material fiscal reform				Combined energy and material transition			
	OECD	BRIICS	Rest of the world	World	OECD	BRIICS	Rest of the world	World
GDP	0.0%	-0.3%	-0.4%	-0.2%	0.0%	-0.1%	-0.4%	-0.1%
Household consumption	0.0%	-0.1%	-0.3%	-0.1%	0.0%	0.0%	-0.2%	0.0%
Employment (prs)	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
Wage rate (real)	-0.1%	-0.2%	-0.3%	-0.2%	0.0%	-0.1%	-0.2%	-0.1%
Capital stock to GDP ratio	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%
All materials (volume)	-5.0%	-9.5%	-4.8%	-7.2%	-5.3%	-10.2%	-5.1%	-7.6%
Metals (volume)	-16.9%	-36.9%	-20.7%	-27.3%	-17.7%	-40.4%	-21.8%	-29.4%
Minerals (volume)	-4.4%	-10.4%	-6.3%	-8.0%	-4.2%	-9.6%	-6.3%	-7.5%

Note: [a] In this table, the *combined energy and material transition* scenario is compared to the *energy transition* scenario, while the *material fiscal reform* is compared to the baseline with no energy transition.
Source: OECD ENV-Linkages model.

Globally, GDP losses reach -0.1% at the global level in the *combined energy and material transition* scenario, slightly smaller than in the *material fiscal reform* scenario. However, household consumption is now almost unaffected in this new scenario. This change results from the shift in consumption and production structures already started in the *energy transition* scenario, which alleviates the transition to a circular economy brought about by the material fiscal reform. While employment change remains the same (slightly positive in both scenarios), the increase in wage rate decrease slightly but remains.

At the global level, the *material fiscal reform* is more effective when implemented within the context of the energy transition. For lower GDP costs, materials use decreases more with the same fiscal instruments, and that is due to metals decreasing more. Indeed, the energy transition already makes inputs to primary metals production more expensive (energy inputs), while the *material fiscal reform* makes mining inputs more expensive. Combining the two makes the fiscal reform more effective in reducing metals use.

The transition to a circular economy could be a component of an environmental tax reform, but its revenues seem too small to constitute its sole basis. Indeed, in the *combined energy and material transition* scenario, revenues in OECD countries are seven times higher for the carbon tax than they are for the materials tax (see Table 18). The carbon tax is indeed more pervasive and the ambition of the energy transition higher, leading to much higher revenues. The energy transition, with a strong carbon tax, could be the stepping-stone of an environmental tax reform (Chateau, Saint-Martin and Manfredi, 2011[28]; Chateau, Bibas and Lanzi, 2018[25]). Factoring in a Resource Efficiency and Circular Economy package could increase the scope and ambition of such an environmental tax reform.

Table 18. Changes in composition of government budgets, *combined energy and material transition* scenario

			Tax on labour income	Tax on primary metals	Tax on non-metallic minerals	Subsidy on recycling good use	Tax on primary metals production[a]	Subsidy on secondary metals production	Carbon Tax	Total Taxes
OECD	Bn USD	2040	6617	41	63	35	94	103	653	27114
	Pct of tax revenues	2017	25.0%	-	-	0.0%	0.4%	0.1%	0.3%	
		2040	24.4%	0.2%	0.2%	0.1%	0.3%	0.4%	2.4%	
BRIICS	Bn USD	2040	890	46	132	36	-67[b]	269	638	8866
	Pct of tax revenues	2017	12.4%	-	-	0.0%	-1.2% [b]	1.2%	0.3%	
		2040	10.0%	0.5%	1.5%	0.4%	-0.8% [b]	3.0%	7.2%	
Rest of the world	Bn USD	2040	934	23	49	12	54	131	9	5618
	Pct of tax revenues	2017	20.0%	-	-	0.0%	1.2%	1.0%	0.0%	
		2040	16.6%	0.4%	0.9%	0.2%	1.0%	2.3%	0.2%	
World	Bn USD	2040	8441	111	243	82	81	503	1301	41598
	Pct of tax revenues	2017	22.2%	-	-	0.0%	0.2%	0.4%	0.3%	
		2040	20.3%	0.3%	0.6%	0.2%	0.2%	1.2%	3.1%	

Notes:
a. Tax rates on primary metal production are fixed, in all scenarios, at their baseline levels.
b. Negative tax revenues on primary metals production in BRIICS reflect subsidies on production in China as recorded in the GTAP database.
Source: OECD ENV-Linkages model.

6.3. Country-specific results

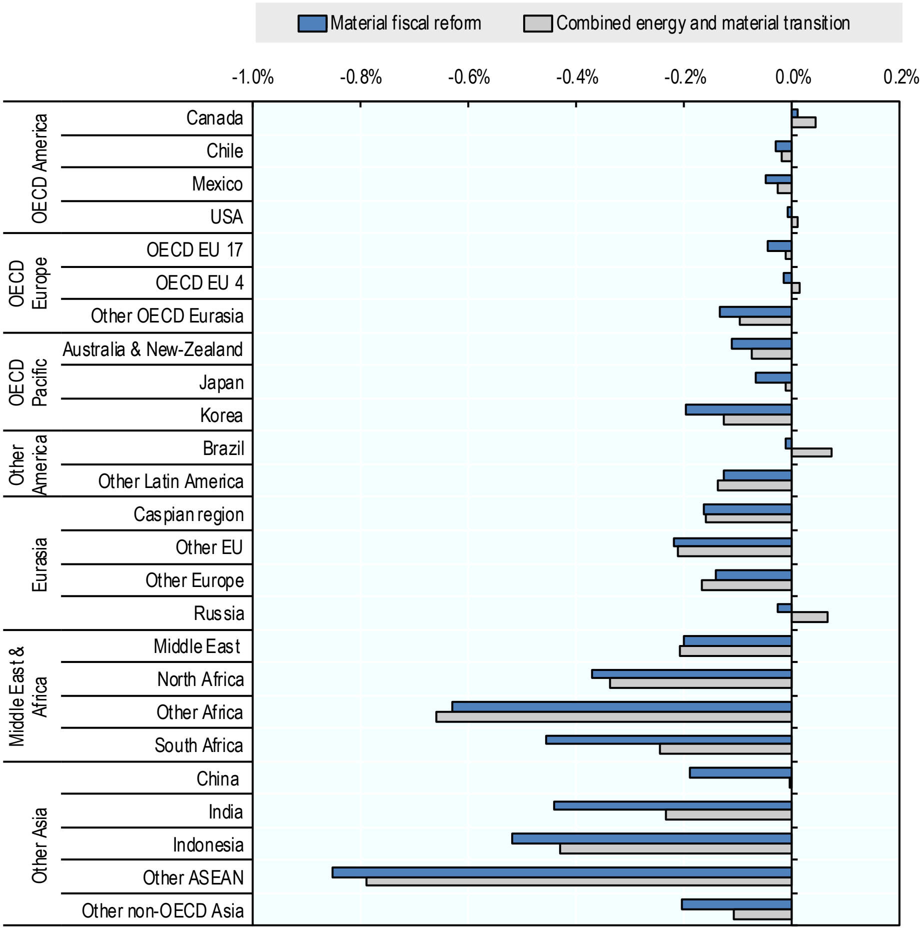
The *combined energy and material transition* scenario has similar results as the *material fiscal reform*, albeit with lower GDP costs. Figure 11 compares the results of the *Material fiscal reform* and the *combined energy and material transition* scenario. GDP costs are very limited, with projected country impacts ranging from -0.8% to +0.1% (-0.8% constitutes about a growth delay of a quarter). The range is thus slightly improved from the *Material fiscal reform* scenario alone (0% to -0.9%).

For most countries or regions, the cost of the *combined energy and material transition* scenario is lower than that of *Material fiscal reform* scenario alone. As with the *material fiscal reform*, Non-OECD countries are still more affected that OECD countries. However, country results vary between the two scenarios. Thus, for most countries the cost decrease (or even become small gains), but some regions show (marginal) increased costs (Other Latin America, Other Europe, Middle East and Other Africa).

Several mechanisms bring about this change. First, the *energy transition* scenario is very ambitious, targeting a limitation of global temperature increase to +1.5°C, which significantly affects input costs. Second, the disparities in material and fossil fuel extraction and use changes the potential impacts for many countries. Furthermore, the sectoral interactions (described in Section 6.4) imply more complex interactions between sectors, and therefore at the country level.

Figure 11. GDP impacts by region, *material fiscal reform* and *combined energy and material transition* scenarios

Percent change their respective baseline [a] in 2040.



Note: the *combined energy and material transition* scenario is compared to the *energy transition* scenario, while the *material fiscal reform* is compared to the baseline (with no energy transition).

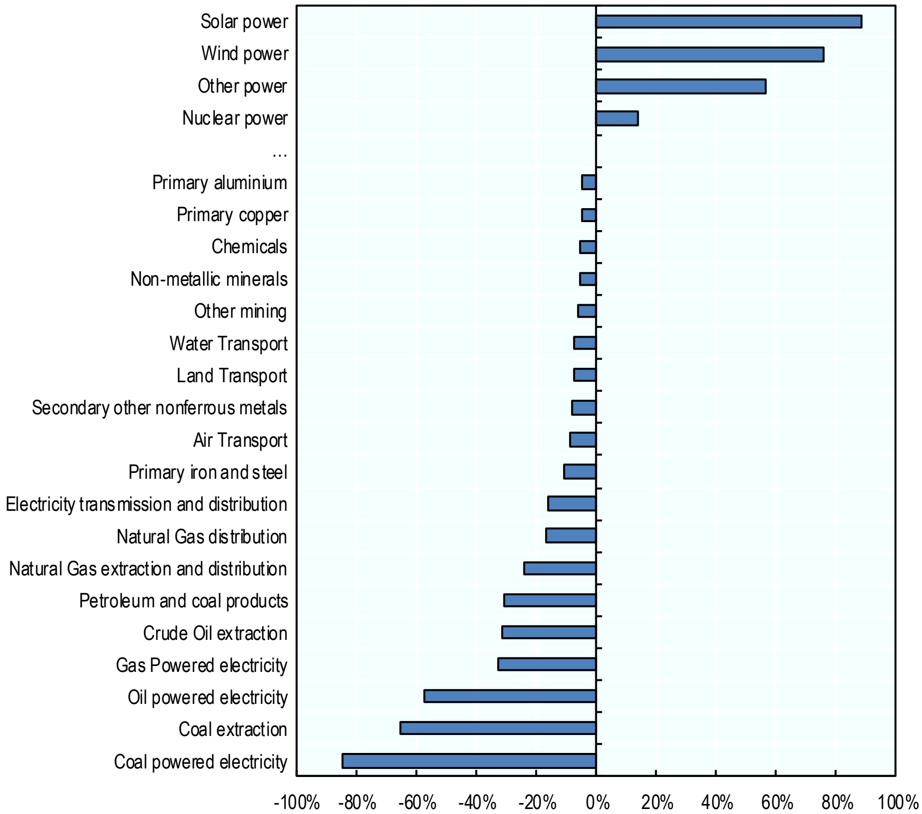
Source: OECD ENV-Linkages model.

6.4. Sectoral impacts

Figure 12 presents the development of various economic sectors at the global level, following the implementation of the *combined energy and material transition scenario*, compared to the *material tax reform*. In particular, the *Combined energy and material transition* scenario shows the higher share of renewable electricity, as well as secondary iron and steel production. Furthermore, the share in the economy of the sectors linked to fossil fuel extraction and use as well as primary steel sector decrease in the *Combined energy and material transition* compared to *the material fiscal reform* alone.

Figure 12. Change in sectoral composition of production, *combined energy and material transition* scenario

Global sector share, variation in 2040 w.r.t. *material tax reform*.



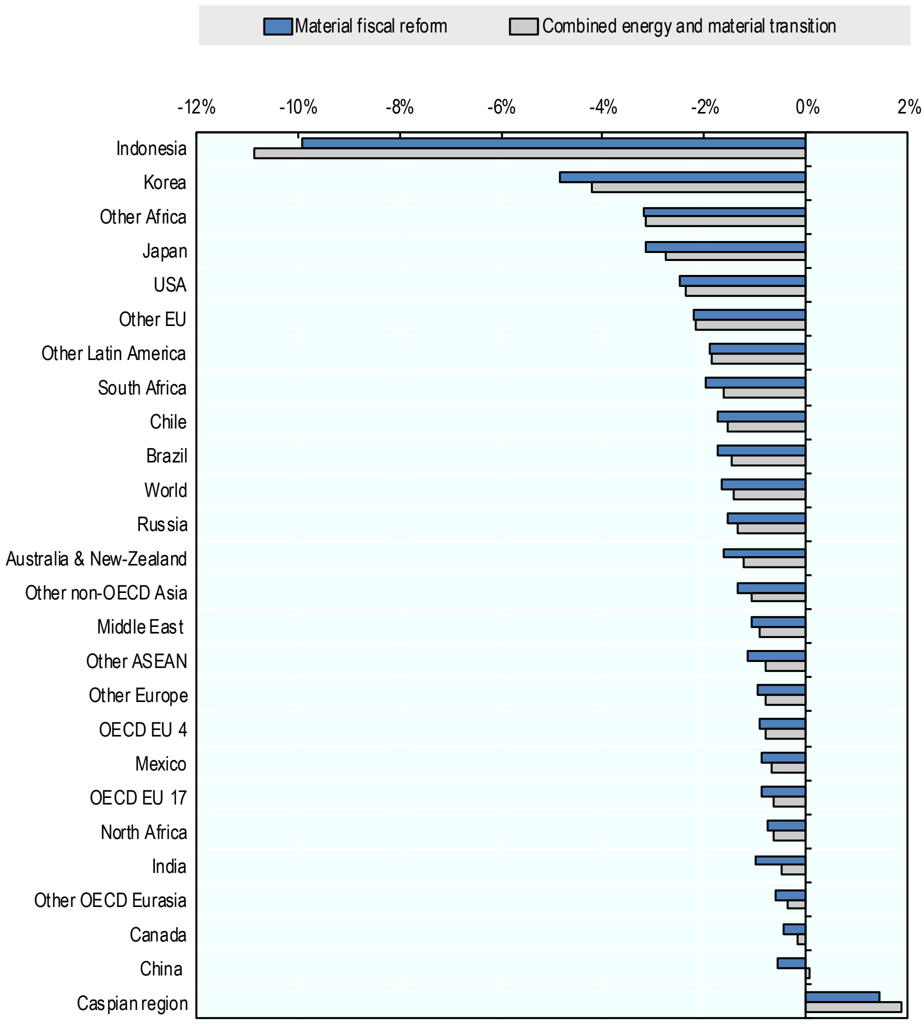
Note: Sectors with changes lower than 5% are not represented. The shares represent the output of the sector, compared to the total global economic output.
Source: OECD ENV-Linkages model.

The interactions between material tax reform policies and climate change and energy policies also appear in sectors that are affected by both policies. For instance, the impacts on the mining sector (excluding extraction of fossil fuels) are affected strongly. The patterns are similar to the *Material fiscal reform* scenario alone (see Figure 13).

In the *Material fiscal reform* (in blue and discussed in Section 5.3), mining outputs declines strongly for big producers while other countries benefit from this decline through a reduction in the gross-of-tax world price of mining products. However, the policies included in the *energy transition* scenario affect different sectors than the *material fiscal reform*, changing the countries' response to the *Material fiscal reform*. Therefore, in the context of the energy transition, the effects of the Material fiscal reform are amplified.

Figure 13. Change in mining output by region, *material fiscal reform* and *combined energy and material transition* scenarios

Variation of global real gross output of the mining sector, in 2040 w.r.t. to baseline.



Source: OECD ENV-Linkages model.

7. Discussion

The results from the modelling analysis outlined in this report show that policy action can substantially reduce global materials use, with significant environmental benefits, while hardly affecting economic growth overall. There are certain limitations to the current modelling analysis. One important caveat is the lack of a full stock accounting of material flows, due to limited data availability. Furthermore, the simulations are based on limited information on the substitutability of secondary and primary materials. Some characteristics of materials use and management, such as the potential lack of recyclable material to produce the secondary materials could not be taken into consideration. Furthermore, the fact that some materials are downcycled rather than recycled, and thus cannot be reused as perfect substitute to primary materials, is not captured fully. Indeed, the substitutability remains imperfect but is high. Finally, there is also a strong need to assess the regional environmental impacts of materials extraction, processing and use, beyond greenhouse gases and air pollutants.

The RE-CE policy package considered in this analysis is based on a material tax reform that aims at shifting consumption away from primary material use towards secondary materials and recyclables. Therefore, it does not take into consideration a wider set of policies and societal changes that can contribute to the RE-CE transition. As governments and companies move towards circularity, more information will become available on other policies. For instance, policies such as information campaigns, labelling, R&D investments in resource efficiency, eco-design requirements, extended producer responsibility or green public procurement are not included in the analysis. Such policies can significantly alter consumption modes.

With more empirical information, further modelling scenarios could be developed to include a wider set of resource efficiency and circular economy policies. Energy efficiency has been studied for decades and estimates exist for the rates of efficiency improvements and the links to the investments needed. However, such estimates are not yet available for material resource efficiency, rendering the modelling of resource efficiency improvement a risky endeavour. Moreover, the scenario abstracts from the additional changes on production modes due to policies such as extended producer responsibility and green public procurement, as well as the effect of new business models such as the sharing economy, increased digitalisation and R&D investments in resource efficiency.

These limitations notwithstanding, this report highlights the prospects of policies to address the different objectives that governments have regarding the transition to a more resource efficient and circular economy and that progress towards a more circular economy can be made without harming economic growth.

References

Arnberg, S. and T. Bjørner (2007), "Substitution between energy, capital and labour within industrial companies: A micro panel data analysis", *Resource and Energy Economics*, Vol. 29/2, pp. 122-136, http://dx.doi.org/10.1016/j.reseneeco.2006.01.001. [29]

Atkinson, A. and J. Stiglitz (1980), *Lecture on Public economics*, Mc Graw Hill. [20]

Brodway, R. and F. Flatters (1993), *The taxation of natural resources: principles and policy issues*, World Bank. [21]

Cambridge Econometrics (2014), *Study on modelling of the economic and environmental impacts of raw material consumption*, European Commission Technical Report, http://dx.doi.org/10.2779/74169. [6]

Chateau, J., R. Bibas and E. Lanzi (2018), "Impacts of Green Growth Policies on Labour Markets and Wage Income Distribution: A General Equilibrium Application to Climate and Energy Policies", *OECD Environment Working Papers*, No. 137, OECD Publishing, https://doi.org/10.1787/19970900. [25]

Chateau, J., R. Dellink and E. Lanzi (2014), "An Overview of the OECD ENV-Linkages Model: Version 3", *OECD Environment Working Papers*, No. 65, OECD Publishing, Paris, https://dx.doi.org/10.1787/5jz2qck2b2vd-en. [13]

Chateau, J., A. Saint-Martin and T. Manfredi (2011), "Employment Impacts of Climate Change Mitigation Policies in OECD: A General-Equilibrium Perspective", *OECD Environment Working Papers*, No. 32, OECD Publishing, Paris, https://dx.doi.org/10.1787/5kg0ps847h8q-en. [28]

Dellink, R. (2020), "The Consequences of a more resource efficient and circular economy for international trade patterns: A modelling assessment", *OECD Environment Working Papers*, No. 165, OECD Publishing, Paris, https://dx.doi.org/10.1787/fa01b672-en. [32]

Distelkamp, M. and M. Meyer (2019), "Pathways to a Resource-Efficient and Low-Carbon Europe", *Ecological Economics*, Vol. 155, pp. 88-104. [8]

EEA (2016), *More from less — material resource efficiency in Europe — European Environment Agency*, https://www.eea.europa.eu/publications/more-from-less (accessed on 23 April 2018). [4]

Giljum, S., M. Bruckner and A. Martinez (2014), "Material Footprint Assessment in a Global Input-Output Framework", *Journal of Industrial Ecology*, Vol. 19/5, pp. 792-804, http://dx.doi.org/10.1111/jiec.12214. [31]

Government of the Netherlands (2016), *A circular economy in the Netherlands by 2050*, https://www.government.nl/documents/leaflets/2016/09/22/a-circular-economy-in-the-netherlands-by-2050 (accessed on 23 April 2018). [17]

Hatfield-Dodds, S. et al. (2017), "Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies", *Journal of Cleaner Production*, Vol. 144, pp. 403-414, http://dx.doi.org/10.1016/j.jclepro.2016.12.170. [12]

Hu, J., S. Moghayer and F. Reynès (2015), *Report about integrated scenario interpretation EXIOMOD/LPJmL results*, POLFREE Deliverable D3.7B., http://www.polfree.eu/publications/publications-2014/report-d37b. [7]

IEA (2018), *World Energy Outlook 2018*, International Energy Agency, Paris, https://dx.doi.org/10.1787/weo-2018-en. [24]

Lutter, S., S. Giljum and M. Bruckner (2016), "A review and comparative assessment of existing approaches to calculate material footprints", *Ecological Economics*, Vol. 127, pp. 1-10, http://dx.doi.org/10.1016/j.ecolecon.2016.03.012. [30]

Marten, M. and K. van Dender (2019), "The use of revenues from carbon pricing", *OECD Taxation Working Papers*, No. 43, OECD Publishing, Paris, https://dx.doi.org/10.1787/3cb265e4-en. [34]

Mavroeidi, E. and J. Chateau (2020), *The jobs potential of a transition towards a resource efficient and circular economy*, OECD Publishing, https://doi.org/10.1787/19970900. [33]

McCarthy, A. and P. Börkey (2018), "Mapping support for primary and secondary metal production", *OECD Environment Working Papers*, No. 135, OECD Publishing, Paris, https://dx.doi.org/10.1787/4eaa61d4-en. [23]

McCarthy, A., R. Dellink and R. Bibas (2018), *The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches*, OECD Publishing, http://dx.doi.org/10.1787/af983f9a-en (accessed on 15 November 2017). [16]

MoE Japan (2013), "Fundamental Plan for Establishing a Sound Material-Cycle Society", http://www.env.go.jp/en/recycle/smcs/3rd-f_plan.pdf (accessed on 23 April 2018). [18]

OECD (2020), *Environment at a Glance 2020*, OECD Publishing, Paris, https://dx.doi.org/10.1787/4ea7d35f-en. [15]

OECD (2019), *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264307452-en. [1]

OECD (2017), "Towards a G7 target to phase out environmentally harmful subsidies", http://www.minambiente.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/background_paper_4_G7_env_OECD_Towards_G7_target_to_phase_out_EHSs.pdf (accessed on 23 April 2018). [22]

OECD (2016), *The Economic Consequences of Outdoor Air Pollution*, https://dx.doi.org/10.1787/9789264257474-en. [27]

OECD (2014), *Innovative economic instruments for sustainable materials management*, https://one.oecd.org/document/ENV/EPOC/WPRPW(2014)8/en/pdf. [19]

OECD (2012), “Sustainable Materials Management MAKING BETTER USE OF RESOURCES”, https://www.oecd-ilibrary.org/docserver/9789264174269-en.pdf?expires=1524478063&id=id&accname=ocid84004878&checksum=949A3E10A630BF1D8594982EADF2797F (accessed on 23 April 2018). [3]

OECD (2009), “REPORT OF THE 2ND SURVEY ON SMM-RELATED ACTIVITIES IN OECD COUNTRIES”, https://one.oecd.org/document/ENV/EPOC/WGWPR(2008)3/FINAL/en/pdf (accessed on 23 April 2018). [2]

OECD (2005), “ANALYTICAL FRAMEWORK FOR EVALUATING THE COSTS AND BENEFITS OF EXTENDED PRODUCER RESPONSIBILITY PROGRAMMES”, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/epoc/wgwpr(2005)6/final (accessed on 23 April 2018). [14]

Schandl, H. et al. (2016), “Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions”, *Journal of Cleaner Production*, Vol. 132, pp. 45-56, http://dx.doi.org/10.1016/j.jclepro.2015.06.100. [11]

UNEP (2019), *Global Resources Outlook 2019: Natural Resources for the Future We Want.*, United Nations Environment Programme. Nairobi, Kenya., http://www.resourcepanel.org/reports/global-resources-outlook. [9]

UNEP (2017), *Resource Efficiency: Potential and Economic Implications. A report of the International Resource Panel.*, Ekins, P., Hughes, N., et al. [10]

WHO (2018), *Ambient and Household Air Pollution and Health*, The World Health Organisation, Geneva, https://www.who.int/airpollution/data/en/ (accessed on 9 May 2019). [26]

Winning, M. et al. (2017), “Towards a circular economy: insights based on the development of the global ENGAGE-materials model and evidence for the iron and steel industry”, *International Economics and Economic Policy*, Vol. 14/3, pp. 383-407, http://dx.doi.org/10.1007/s10368-017-0385-3. [5]

Annex A. A brief overview of the methodology

Multi-sectoral Computable General Equilibrium (CGE) models are the appropriate tool for quantifying the macroeconomic consequences of the transformation of the economy needed to improve resource efficiency and transition to a circular economy. CGE models can take into consideration both direct and indirect effects of the policies (e.g. through changes in trade and production structure), and thus quantify the overall economy-wide consequences of the policies.

The OECD's in-house CGE model, ENV-Linkages has been used extensively in the past to assess the consequences of environmental policies. One of the key advantages of the ENV-Linkages model is that it encompasses all major economies in the world, as well as several regional groups that allows for a global analysis.[16] This ensures that all quantitative analyses will be directly relevant for both OECD countries and key emerging economies, including China, India, Indonesia, South Africa and Brazil. The multi-sectoral nature of the model also allows for detailed insights into the consequences of policy reform on the mining and industrial activities, and thus provides key indicators of the consequences for main policy objectives such as material intensity and sectoral performance. In this report, 60 materials linked to 55 sectors and 43 commodities are considered.

In order to provide in-depth analysis of the macroeconomic consequences of circular economy enabling policies, these modelling tools have been enhanced by linking physical material flows to specific economic activities and integrating essential elements of a circular economy, not least an explicit representation of the use of secondary inputs as substitutes for primary resource use (OECD, 2019). This provides internally consistent and globally connected policy scenarios for primary and secondary materials use and their economic drivers as they evolve over time, and the main sectors and materials where resource efficiency and circularity policies have an impact.

[16] The regional aggregation for the model is as follows. Canada, Chile, Mexico, the USA, Japan, Korea, China, Russia, Brazil, India, Indonesia, and South Africa are individually modelled. Results for the EU are presented for the subset of OECD member states and member states that are not part of OECD. Other countries are aggregated in larger regions on a geographical basis, e.g., the group of all Sub-Saharan African countries excluding South Africa.

Table A A.1. Sectoral aggregation of ENV-Linkages

Agriculture, Fisheries and Forestry	Manufacturing
Paddy Rice	Food Products
Wheat and Meslin	Textiles
Other Grains	Wood products
Vegetables and Fruits	Chemicals
Oil Seeds	Pulp, Paper and Publishing products
Sugar Cane and Sugar Beet	Non-metallic Minerals
Fibres Plant	Fabricated Metal products
Other Crops	Electronics
Cattle and Raw Milk	Motor Vehicles
Other Animal products	Other Transport Equipment
Fisheries	Other Machinery and Equipment
Forestry	Recycling
Non-manufacturing Industries	Iron and Steel - Primary
Coal extraction	Iron and Steel – Secondary
Crude Oil extraction	Aluminium – Primary
Natural Gas extraction	Aluminium – Secondary
Other Mining	Copper – Primary
Petroleum and Coal products	Copper – Secondary
Gas distribution	Other Non-ferrous Metals – Primary
Water Collection and Distribution	Other Non-Ferrous metals – Secondary
Construction	Other Manufacturing
Electricity Transmission and Distribution	**Services**
Electricity Generation (8 technologies)	Land Transport
Electricity generation: Nuclear Electricity; Hydro (and Geothermal); Solar; Wind; Coal-powered electricity; Gas-powered electricity; Oil-powered electricity; Other (combustible renewable, waste, etc).	Air Transport
	Water Transport
	Business Services
	Other Services (incl. Government)

Table A A.2. ENV-Linkages model regions

Macro regions		ENV-Linkages countries and regions	Most important comprising countries and territories
OECD	OECD America	Canada	Canada
		Chile	Chile
		Mexico	Mexico
		USA	United States of America
	OECD Europe	OECD EU 17	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden
		OECD EU 4	France, Germany, Italy, United Kingdom
		Other OECD Eurasia	Iceland, Israel[1], Norway, Switzerland, Turkey
	OECD Pacific	Australia and New-Zealand	Australia, New-Zealand
		Japan	Japan
		Korea	Korea
Non OECD	Other America	Brazil	Brazil
		Other Latin America	Other non-OECD Latin American and Caribbean countries
	Eurasia	Caspian region	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
		Other EU	Bulgaria, Croatia, Cyprus[2], Latvia, Lithuania[3], Malta, Romania
		Other Europe	Albania, Andorra, Belarus, Bosnia and Herzegovina, Gibraltar, Former Yugoslav Rep. of Macedonia, Rep. of Moldova, Montenegro, San Marino, Serbia, Ukraine
		Russia	Russian Federation
	Middle East and Africa	Middle East	Bahrain, Iraq, Islamic Rep. of Iran, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, United Arab Emirates, Syrian Arab Rep., Yemen
		North Africa	Algeria, Egypt, Libya, Morocco, Tunisia, Western Sahara
		Other Africa	Sub-Saharan Africa excl. South Africa
		South Africa	South Africa
	Other Asia	China	People's Rep. of China, Hong Kong (China)
		India	India
		Indonesia	Indonesia
		Other ASEAN	Brunei Darussalam, Cambodia, Lao People's Dem. Rep., Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam
		Other non-OECD Asia	Other non-OECD Asian and Pacific countries

Material flows are linked to the economic flows at the detailed sectoral level. The dataset on physical material flows from the International Resource Panel (UNEP, 2018) is used as the basis for the projection of primary material extraction. The basic principle for linking is that physical flows (materials use in tonnes) for each of the 60 materials is attached to the corresponding economic flow (materials demand in USD). A coefficient of physical use per USD of demand is calculated and used to project materials use to 2060.

Annex B. Key parameters

As described in Chateau, Dellink and Lanzi (2014[13]), firms in all sectors minimise the cost of producing the goods and services that are demanded by consumers and other producers (domestic and foreign). Production is represented by constant returns to scale technology. Figure A B.1 illustrates the typical nesting of the model's sectors. Note that some sectors, like agriculture, have a slightly different nesting to reflect peculiarities of these sectors (e.g. fertiliser use in crop production).

In Figure A B.1, each node represents a constant elasticity of substitution (CES) production function. This gives marginal costs and represents the different substitution (and complementarity) relations across the various inputs in each sector. Each sector uses intermediate inputs – including energy inputs – and primary factors (labour and capital). Agricultural sectors also needs land input while in some sectors, primary factors also include a sector-specific natural resource factor, e.g. trees in forestry.

The top-level production nest considers final output as a composite commodity combining process emissions of CO2 and non-CO2 GHG emissions and the production of the sector net of these emissions. In sectors that do not emit such gases, the corresponding emission rate is set equal to zero. For the purpose of calibration, these gases are valuated using an arbitrary very low carbon price. The following non-CO2 emission sources are considered: i) methane from rice cultivation, livestock production (enteric fermentation and manure management), coal mining, crude oil extraction, natural gas and services (landfills); ii) nitrous oxide from crops (nitrogenous 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), aluminum, magnesium and semi-conductors production. The values of the substitution elasticities are calibrated such as to fit to marginal abatement curves available in the literature on alternative technology options.

The second-level nest considers the gross output of each sector (net of GHGs) as a combination of aggregate intermediate demands and a value-added bundle, including energy. For each good or service, output is produced by different production streams, differentiated by capital vintage (old and new). Capital that is implemented contemporaneously is new – thus investment has an effect on current-period capital, but then becomes old capital (added to the existing stock) in the subsequent period. Each production stream has an identical production structure, but with different technological parameters and substitution elasticities. In order to determine the industry-wide cost that includes both capital vintages, there is an averaging (weighted) of variable costs across the two vintages.

The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. While new capital is fully malleable across sectors, and derived from an economy-wide investment function, old capital is assumed to be only partially mobile across sectors, reflecting differences in the marketability of capital goods across sectors. There is also homogeneity in the use of old and new capital.

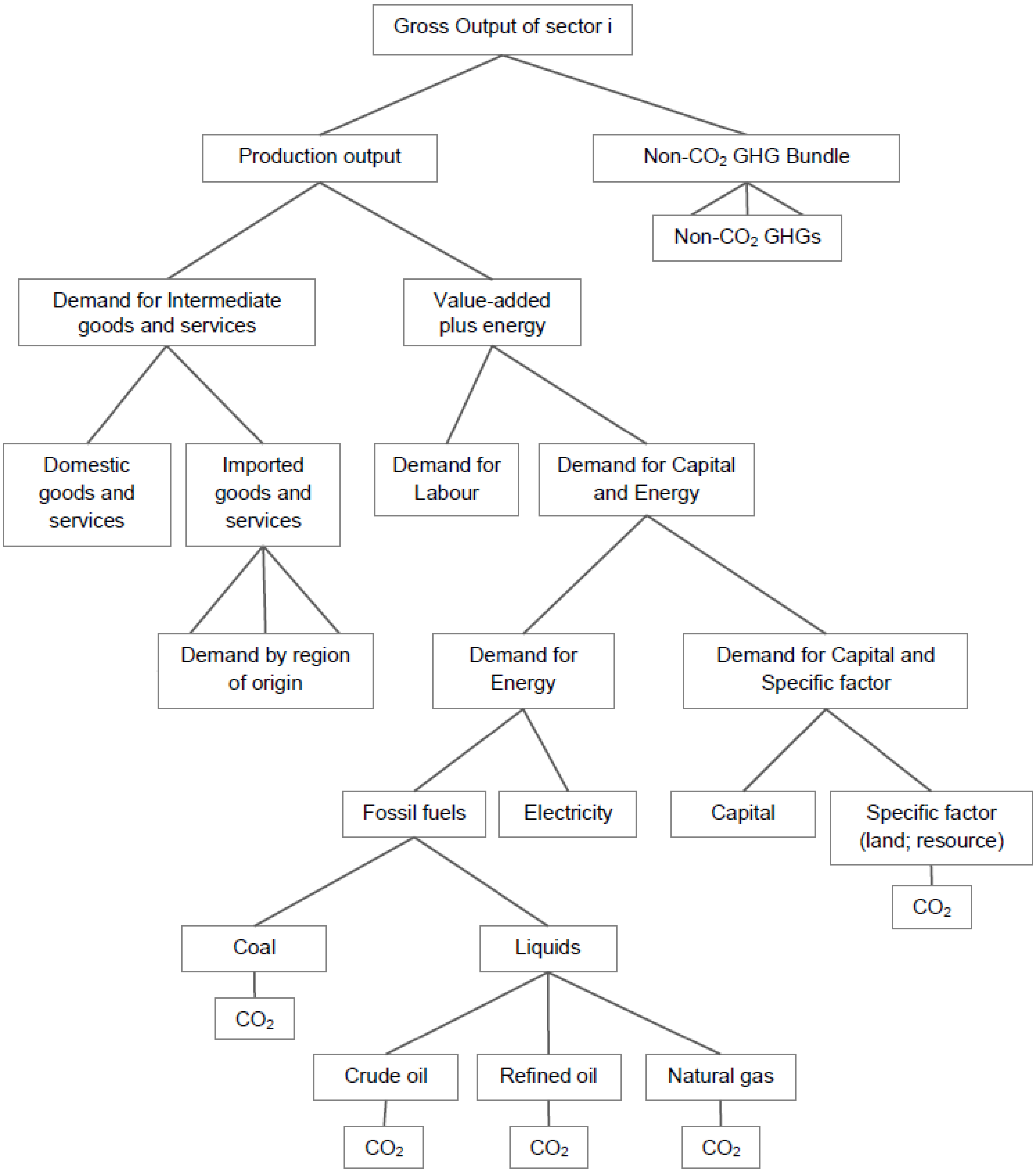
On the right-hand side of the tree in Figure A B.1, value-added is shown as being composed of a labour input, along with a composite capital-energy bundle. The value-added bundle is a sub-component of the top level node that produces sectoral net-of-GHGs output. Similar sub-components also exist in formulating the capital and energy bundles. As shown in Figure A B.1, the capital is bundled with a sector-specific production factor when one exists and energy is itself a bundle of different energy inputs.

The energy bundle is of particular interest for analysis of climate change issues. Energy, as reported in Figure A B.1, is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and a bundle of the “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 based on existing literature and calibrated to imply a higher degree of substitution among the other fuels than with electricity and coal.

According to the vintage-structure of technologies, the fuel mix in energy production is more flexible when associated with new capital. For old capital vintage production technology the substitution possibilities between fuels are very limited. This difference between the short and long run substitution possibilities of energy is consistent with empirical findings by (Arnberg and Bjørner, 2007[29]), who look at plant-level changes in energy intensity. However, since ENV-Linkages includes the possibility of changes in industry composition, the overall responsiveness to energy price changes will be higher than what these researchers found at plant level.

Once a sector’s optimal combination of inputs is determined from relative prices, sectoral output (included GHGs) prices are calculated assuming competitive supply (zero-profit) conditions.

Figure A B.1. Generic structure of production in ENV-Linkages



Note: See Table A B.1 for parameter values.
Source: OECD ENV-Linkages model.

Many key parameters are set on the basis of information drawn from various empirical studies and data sources (elasticities of substitution, income elasticities of demand, supply elasticities of natural resources, etc). Table A B.1 reports some key elasticities used in the current version of the model. Income elasticities of household demand as well as Armington elasticities are taken from the GTAP database (version 9).

Table A B.1. Key parameter values in ENV-Linkages

Parameter		Value
Substitution between	GHGs bundle and Net-of-GHGs output	0.05 for agricultural sectors; 0.15 to 0.3 for some industrial emissions
	material inputs and VA plus energy	0.1 for new capital in services and manufacturing; 0 for other sectors
	material inputs	0.1 for services and manufacturing sectors; 0 for other sectors
	VA and energy	0.04-0.27 for old capital vintages 0.3-2.0 for new vintages
	inputs feedstocks and land	0.5
	capital and energy	0 for old capital vintages, 0.1-0.95 for new vintages
	capital and specific factor	0.2 to 0.35
Elasticity of substitution between	electricity and non-electricity energy inputs	0.03 for old capital and 0.25 for new in electricity sector; 0.025 for old capital and 0.22 for new for fossil fuels; 0.125 and 1 in other sectors.
	coal and liquids bundle	0.06 for old capital and 0.55 except fossil fuels where equals to 0.
	energy inputs in liquids bundle	0.125 for old capital vintage, 1 for new vintages, but always 0 in the energy sectors, except for electricity (0.06 and 0.51 respectively)
	all energy goods in extraction sectors	0, except 0.25 for gas production
	of sector-specific factor in non-fossil electricity	0.2 to 0.4 depending on the sector
	between Nuclear, Hydro, Fossil power bundle and renewable bundle	1.5
	Between fossil power	0.25
	Between Renewables power	2
	between primary and secondary metal technologies	2
	between food in the feed bundle	0.75
	between GHGs in the GHGs bundle	0 to 0.05
Armington elasticity	domestic versus imports	0.9 to 5 depending on sector
	import sources	0.9 to 5 depending on sector
	intermediate goods imports	0.9 to 5 depending on sector
	energy imports	0.9 to 5 depending on sector
Elasticity of supply	of sector-specific factor	0 to 10 depending on the sector

Source: OECD ENV-Linkages model.

Annex C. Detailed baseline projections

Economic projections

In recent decades, global growth of GDP has been largely driven by fast-growing emerging economies like China and India. The coming decades are expected to bring further shifts in the geographical balance of the global economy.

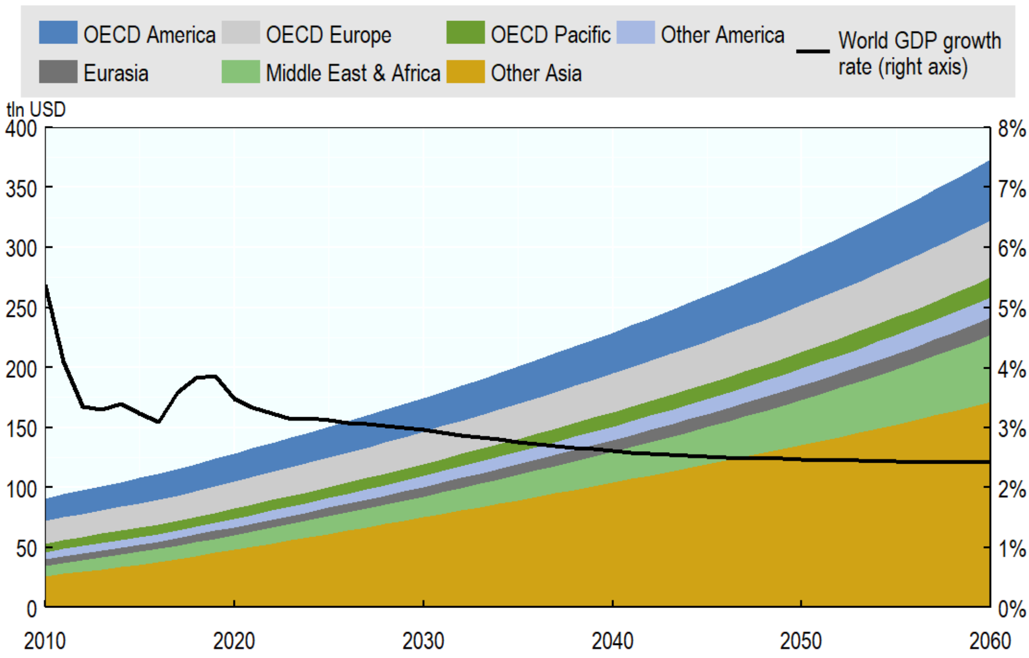
Global population growth is projected to slow down, but nonetheless, another 3 billion people are projected to be added to the current total of 7 billion by 2060. At the same time, living standards are gradually converging across economies: per capita growth rates are higher in emerging and developing economies than in the OECD region. By 2060, the global average Gross Domestic Product (GDP) per capita is projected to reach the current level of the OECD. Population growth and income convergence together drive growth of the global economy (Figure A C.1). The projected increase in population and tripling of global per capita income levels combine to a quadrupling of global GDP. Large populations and rapid catching up of living standards in the People's Republic of China (hereafter China), and to a lesser extent in India and the rest of Southeast Asia, will drive global growth the most.

But global growth is projected to be lower than in the past. The annual global GDP growth rate is projected to stabilise below 2.5% per year, a full percent-point below the average at the turn of the century. A key driver of this is the decline in the growth rate of China, which is only partially offset by strong growth in other emerging economies such as India, followed by high growth in large parts of Sub-Saharan Africa.

The economic projections are also characterised by changes in the structure of the economy. The main change is the shift of demand from manufacturing and agricultural goods towards services. At the global level, the share of services is projected to increase from 50% to 54%. This is driven by income growth, digitalisation, and ageing. This servitisation trend holds for both industrial and final demand.

Figure A C.1. Projections for GDP and global economic growth

GDP trillion USD (2011 PPP)



Source: Global Material Resources Outlook to 2060 (OECD, 2019[1]).

Materials use projections

Strong links between economic growth – and especially convergence in income levels across countries, investment, infrastructure and construction drive a solid increase in global materials use. As the economies of fast-growing countries mature and develop infrastructure, their use of non-metallic minerals and metals increases strongly. This has been occurring in China in the past two decades, and is projected to happen for many Asian and African countries in the coming decades. As China's construction boom gradually comes to an end, its demand for construction materials will stabilise below 25 Gt per year after 2025.

The demand for services by firms, government and households, which is projected to increase faster than the demand for agricultural or industrial goods – leads to structural change in the economy. As the services sectors have lower material intensity (materials use per unit of output) than agriculture and industry, the global material intensity of the economy is likely to decrease by 2060. Motor vehicles and electronics have low total materials intensities, but are relatively large users of metals, and therefore drive the fast increase in metals use.

Technology improvements slow the growth in future materials use despite production growth. These reductions in material intensity are projected to occur in all major sectors of the economy, albeit at widely varying rates. Together, income convergence, structural change and technology developments are projected to lead to a relative decoupling of primary materials use globally.

Global primary materials use, and thus global primary materials extraction, is projected to double in the coming decades in the central baseline scenario (from 79 Gt in 2011 to 167 Gt in 2060). But there are large variations across materials and across regions (Figure A C.2).

Metals are projected to grow the fastest. Over the period to 2060, metals are projected to increase from 7 Gt to 19 Gt per year. The rapid increase holds for both primary and secondary (recycled) metals, and for the Brazil, Russia, India, Indonesia, China, South Africa (hereafter BRIICS), as well as for developing countries.

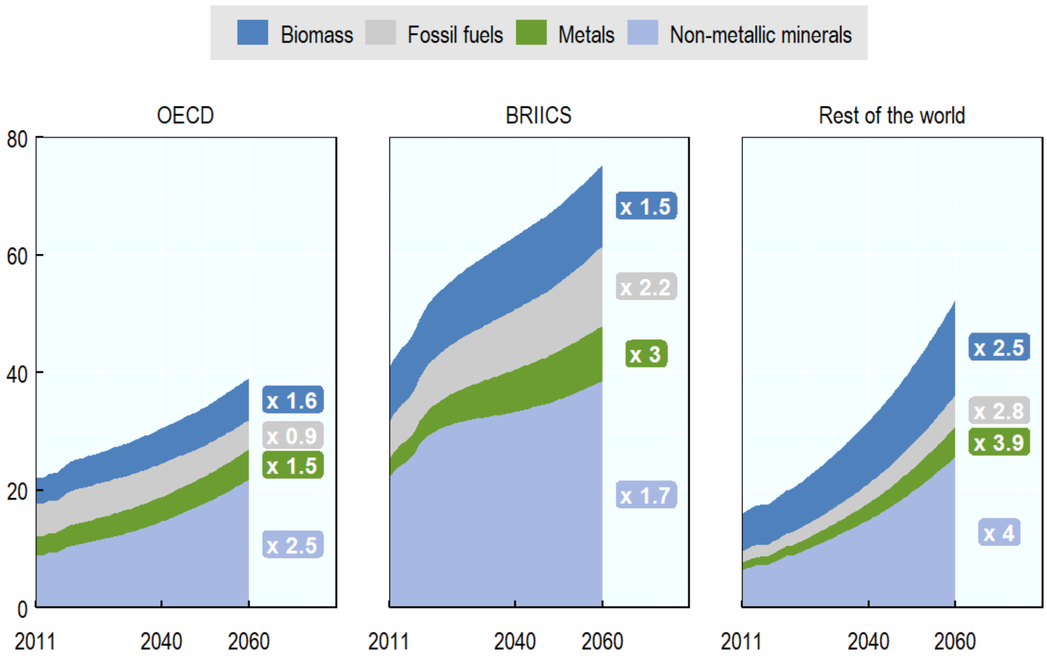
Non-metallic minerals such as construction materials are projected to grow rapidly from 35 Gt in 2011 to 82 Gt in 2060. Their use will grow especially rapidly in the short run, given their strong links to investment and construction needs and a lack of recycling. The strongest rise is projected for developing countries, while China faces a saturation in construction materials demand. In OECD countries, growth of non-metallic minerals is also likely to be stronger than for other materials groups.

Global extraction (and thus use) of biomass resources is projected to not quite double over the period, i.e. will remain well below the average economic growth rate, reflecting the low income elasticity of food demand.

Fossil fuel use follows projected trends in energy efficiency and will almost double by 2060.

Figure A C.2. Growth in materials use by region and material group

Materials use in Gt



Source: Global Material Resources Outlook to 2060 (OECD, 2019[1]).

In parallel to the growth in materials use, material intensity is projected to gradually decrease over time. While global GDP is projected to grow on average by 2.8% annually between 2011 and 2060, global primary materials use is projected to grow by 1.5% per year. The material intensity of the global economy is thus projected to decrease by 1.3% per year on average, with improvements occurring mostly after 2025 as the economy orients towards more services globally and the construction boom in emerging economies (especially China) is projected to slow down.

Recycling will gradually become more competitive than mining of minerals thanks to projected technological developments and changes in relative prices of production inputs. This leads to growth in the recycling sector outpacing growth in mining, as well as growth in GDP, albeit less strongly.

Nonetheless, the central baseline scenario projects a mild decrease by 2060 in the share of secondary nonferrous metals. A key driver for this is that the increase in total demand for materials can only be easily met through increasing both primary and secondary materials use. The relatively high labour costs for secondary production methods also hampers further penetration of secondary nonferrous metals in the central baseline projection.

The strongest growth in materials use is projected to be in emerging and developing economies that are likely to ramp up their economic growth rates in the coming decades. The trends in the OECD region are fairly stable in comparison: relatively slow population and income growth and a continued trend of relative decoupling lead an increase in materials use levels from 22 Gt in 2011 to 39 Gt in 2060.

Material intensity is projected to decline most in China and India, where the infrastructure boom is coming to an end. Even so, as economic activity levels remain high, materials use levels in 2060 are projected to rise to 38 Gt in China and 23 Gt in India, from 2011 levels of 27 Gt and 6 Gt, respectively.

The projected trend in the developing countries is much more one of acceleration of both economic activity and materials use, with less room for decoupling. Overall, non-OECD countries, excluding China and India, are projected to increase their materials use from 24 Gt in 2011 to 67 in 2060.

Environmental projections

The economic activities that drive materials use have a range of environmental consequences. These stem from obtaining the materials (e.g. greenhouse gas (GHG) emissions from extracting and processing primary materials), from using them (e.g. air pollution caused by burning fossil fuels), and from disposing of them (e.g. pollution of air, land and water from landfilling waste). They also have implications for achieving the Sustainable Development Goals.

A large share of GHG emissions is directly or indirectly linked to materials management. These come from the combustion of fossil fuels for energy, from agriculture, from manufacturing and from construction. The increased extraction and use of materials contributes to a global increase in GHG emissions, even if their contribution to overall emissions is projected to decrease relative to emissions not related to material management. Total emissions are projected to reach 75 Gt CO_2-eq. by 2060 of which materials management would constitute approximately 50 Gt CO_2-eq. The ambitions of the Paris Accord, including the Nationally Determined Contributions (NDC) and the "well below two degrees" objective, would not be met in the central baseline scenario. Additional policy efforts are required to meet these goals, such as including policies aimed at reducing emissions of GHGs in a comprehensive resource management policy package.

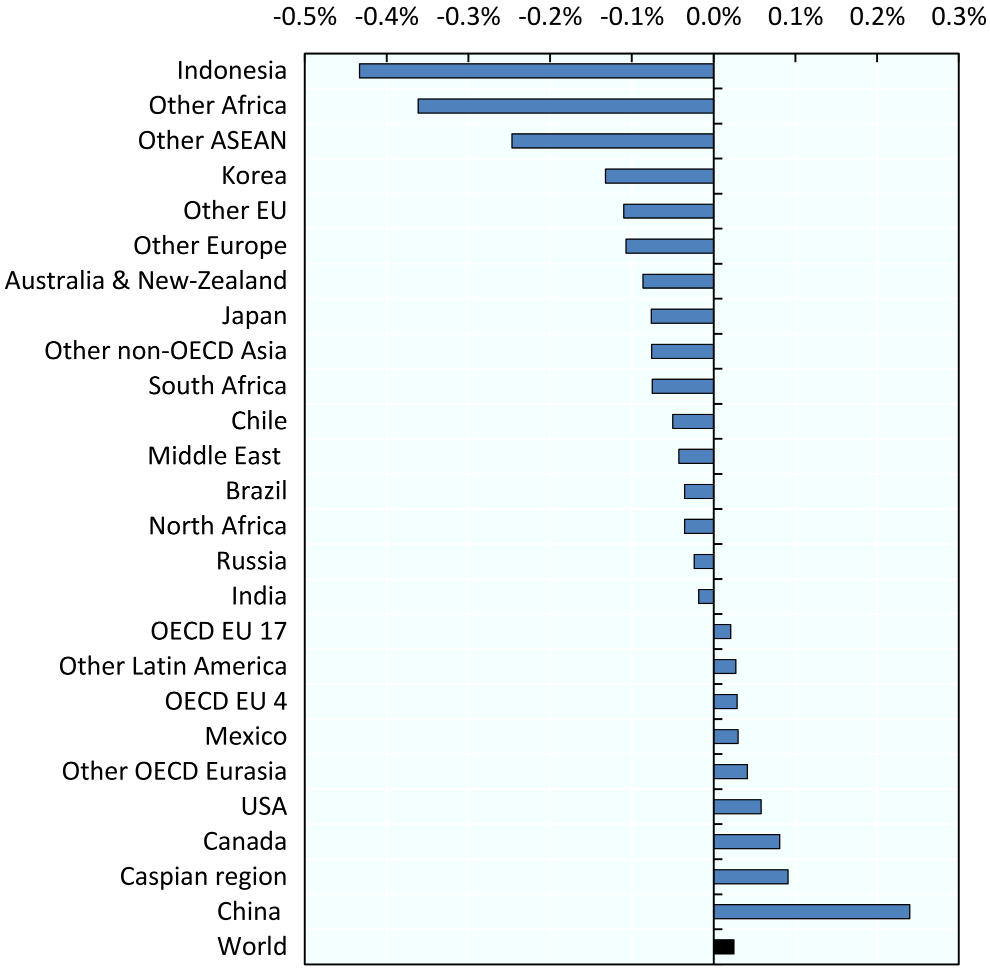
Life-cycle analysis of global extraction and production of seven metals (iron, aluminium, copper, zinc, lead, nickel and manganese) and concrete shows a wide range of environmental consequences linked to materials use, including significant impacts on acidification, climate change, cumulative energy demand, eutrophication, human toxicity, land use, ozone layer depletion, photochemical oxidation, and aquatic and terrestrial ecotoxicity. Despite ongoing efficiency improvements that reduce environmental impacts per unit of production, the global environmental impacts of using these metals are projected to more than double and in some cases even quadruple by 2060. This analysis excludes the impacts during the use phase, as these are highly product-specific. In general, copper and nickel tend to have the greatest per-kilo environmental impacts, while iron and steel have the highest absolute environmental impacts due to the large volumes used. Regional differences however can be large.

While secondary metals also have environmental impacts, these are generally one order of magnitude lower than primary production. In comparison to metals, concrete, sand and gravel have much smaller impacts per kilo, but their volume of use is huge. These materials are especially associated with climate change impacts (for concrete), and photochemical oxidation, which has severe health impacts. The seven metals and concrete together represent almost a quarter of all GHG emissions and one-sixth of cumulative energy demand.

Annex D. Detailed results

Figure A D.1. Evolution of output by region in the *material fiscal reform* scenario

Total real production in 2040, w.r.t. the baseline scenario



Source: OECD ENV-Linkages.

Annex E. Single metal simulations

This annex presents simulation where the *material fiscal reform* is implemented only on one sector at a time to understand the effects of the policy. Thus, the taxes and subsidies are implemented on one of those sectors: iron and steel production, aluminium production, copper production or other nonferrous metals production. The annex describes the difference in per kg environmental impacts for the metals, then the impact of the policies on the prices and production levels and finally the overall environmental impacts of the policy, explaining the contribution of both primary and secondary metals.

The production of primary materials is more polluting than that of secondary materials

According to the analysis in the Global Material Resources Outlook to 2060 (OECD, 2019[1]), primary copper and nickel production are the ones with the highest impacts per kilogramme of produced metals, for the selected environmental impacts. The per kg environmental impact values for 2015 are summarised in Figure A E.1. They are expressed as an index: for each environmental indicator, the metal whose production has the largest impact gets a value of 1.

It is possible that extraction and processing of specific metals not investigated in this report (e.g. rare earth elements) are more polluting than the metals presented here. Due to a lack of robust data, the global environmental consequences of production of other metals cannot be assessed. Hence, the term “most polluting” should be interpreted with care, as it is only in relative terms, i.e. in comparison to the other investigated materials.

Primary nickel production has the highest per kg values for 5 of the 10 indicators (acidification, climate change, cumulative energy demand, photochemical oxidation, terrestrial ecotoxicity), and also high values for land use. A driving factor for these impacts is that its production requires a large amount of energy, with consequences for e.g. GHG emissions.

Primary copper production has the highest per kg impact for the other 4 impacts (eutrophication, freshwater aquatic ecotoxicity, human toxicity and land use). It is the only metal in this list whose production has significant impacts on freshwater aquatic ecotoxicity. For eutrophication and freshwater aquatic ecotoxicity, primary nickel production is also relatively polluting, while the per kg environmental impacts of production of other metals are much less.

Aluminium production, while generally not as polluting as copper or nickel production, shows high impacts stemming from its extraction and processing on many indicators. Especially its impact on photochemical oxidation is close to that of nickel. Its impact on climate change and cumulative energy demand is also higher than half that of nickel (which is the highest in terms of per kg impacts).

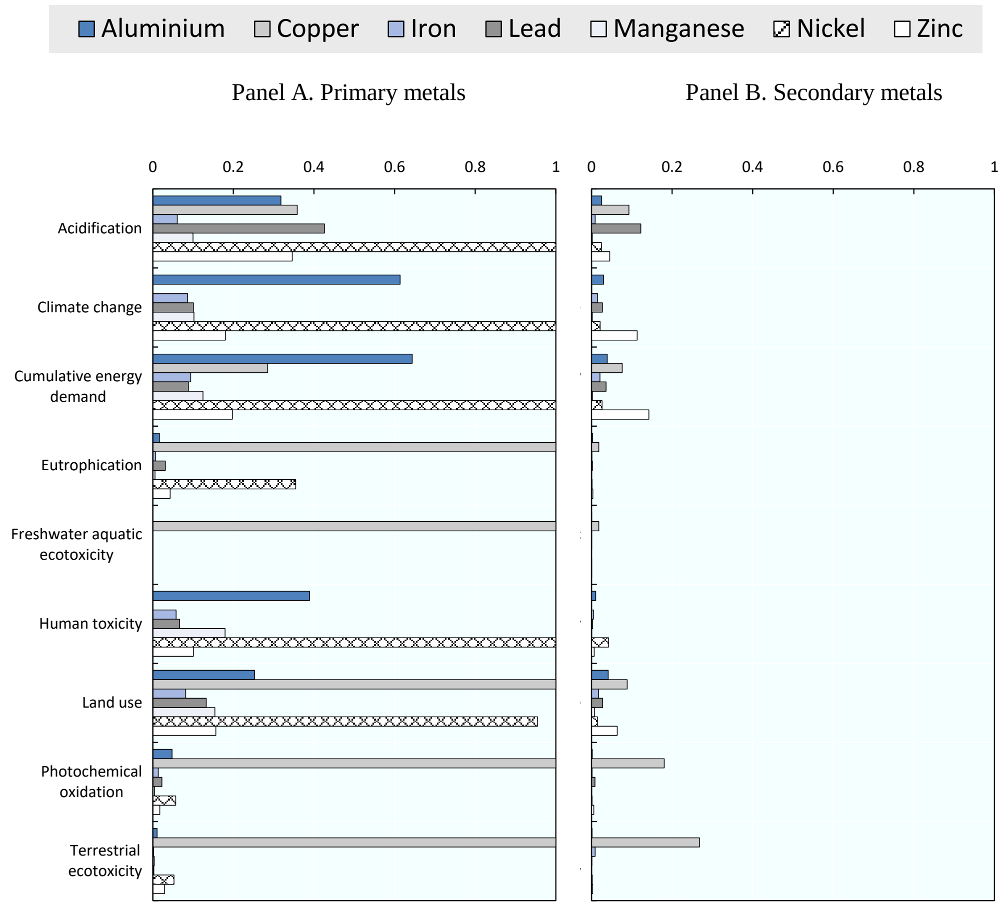
For some environmental impacts, some metals are much less polluting than others. For example, the water pollution related impacts (freshwater ecotoxicity and eutrophication) are much more significant for production of nickel and copper than for the production of other metals. The impacts directly or indirectly related to energy use are, however, more evenly spread and significant for all metals.

The environmental impact assessment also assesses the per kg environmental impacts associated with secondary materials production (panel B in Figure A E.1). This figure shows that the impacts tend to be an order of magnitude lower than those for primary-based production. The impacts of secondary copper production are smaller by a factor 4-60 when compared to primary, and the impacts of secondary nickel production are 25-300 times smaller than primary.

Nonetheless, some of the impacts from secondary production are not negligible compared to primary. Secondary zinc production has relatively high impacts on energy demand and thus climate change: the values for secondary are more than half those of primary. The photochemical oxidation impacts of secondary production for lead and zinc are also relatively high, amounting to roughly one-third of the value for primary production. In one case secondary production is even more polluting than primary: the terrestrial ecotoxicity impact of secondary iron is almost 5 times higher that of primary iron, albeit still much lower than that of nickel.

Figure A E.1. Per kg environmental impacts for primary and secondary metals

Normalised index value (highest impact normalised to 1) of different environmental impacts for 2015.



Source: (OECD, 2019[1]).

Impact of the policies on the price and production of metals

The overall impact of the policy is to reduce primary production and boost secondary production. Table A E.1 provides the example of the iron and steel production sectors. For most countries, the primary production is reduced, while secondary production is boosted.

The *material fiscal reform* impacts the prices of primary metals mostly, which are increased by the additional taxes. The impact on the prices of secondary metals is much more modest. In some countries, the prices are reduced due to the subsidies, while in other countries, the increase in demand counterbalances this effect and the price increase.

Table A E.1. Regional dynamics for iron and steel production and prices

Variation w.r.t. baseline scenario in 2040.

		Production		Prices	
		Primary	Secondary	Primary	Secondary
OECD America	Canada	-1%	1%	0.8%	0.0%
	Chile	-1%	1%	0.9%	0.0%
	Mexico	-1%	0%	0.6%	0.1%
	USA	-1%	1%	0.9%	0.0%
OECD Europe	OECD EU 17	0%	2%	1.0%	0.1%
	OECD EU 4	-1%	2%	1.0%	-0.1%
	Other OECD Eurasia	0%	1%	0.8%	0.0%
OECD Pacific	Australia & New-Zealand	-13%	16%	17.5%	1.6%
	Japan	-2%	1%	2.0%	0.8%
	Korea	-4%	2%	4.4%	1.6%
Other America	Brazil	-4%	5%	4.5%	-0.1%
	Other Latin America	-1%	1%	1.0%	0.1%
Eurasia	Caspian region	-2%	2%	1.9%	-0.1%
	Other EU	1%	2%	0.4%	0.0%
	Other Europe	-1%	1%	1.2%	0.0%
	Russia	-2%	1%	1.5%	0.0%
Middle East & Africa	Middle East	-1%	0%	1.0%	0.1%
	North Africa	-1%	1%	0.8%	0.0%
	Other Africa	-4%	6%	5.3%	0.0%
	South Africa	0%	0%	0.0%	-0.1%
Other Asia	China	-1%	1%	1.5%	0.3%
	India	-6%	5%	5.8%	0.3%
	Indonesia	-1%	1%	0.7%	0.0%
	Other ASEAN	-2%	2%	1.9%	0.1%
	Other non-OECD Asia	-3%	3%	3.8%	0.7%

Source: OECD ENV-Linkages model.

Negative externalities, compare primary to secondary

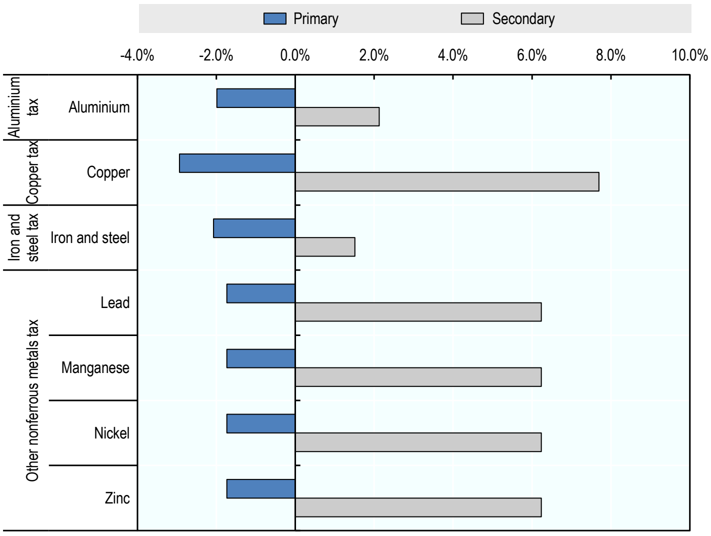
The environmental impacts follow the changes in production (decreased primary levels and increased secondary levels). As seen in Figure A E.2 Panel A, for each of the scenario, the policy decreases the total impacts of the primary metals, and increases the impacts of the secondary metals. The relative decrease for the primary metals is larger than the relative increase for the secondary metals.

The total environmental impacts decrease for most indicators. The reason is that the impacts of secondary metals are in general much lower (as seen above), so the decrease in the environmental impacts of primary metals contributes more.

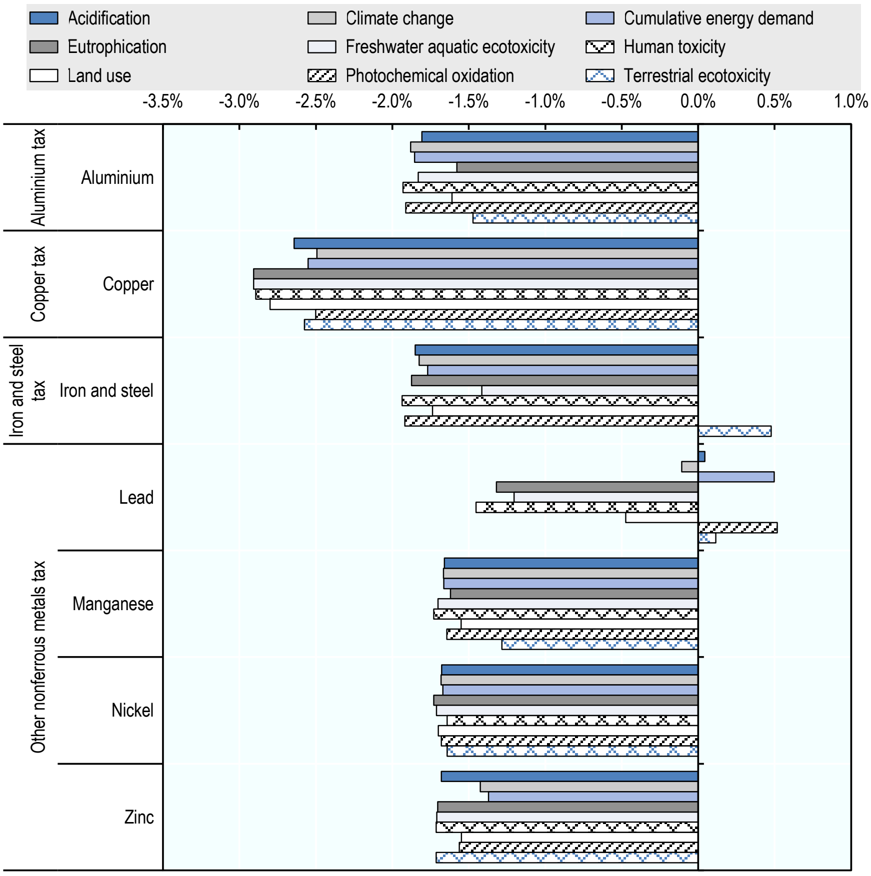
For a few indicators, the policy results in an increase. That is the case for Terrestrial ecotoxicity for Iron and Steel, as the secondary metals have a higher per kg impacts than the primary. However, all the other indicators decrease. The case of lead is also complex, as some of the environmental impacts associated with lead increase, as the growth of secondary lead use doubles, overcompensating the small decrease in primary lead use. However, these impacts are the lowest of all seven metals studied.

Figure A E.2. Impacts of single sector policies on environmental impacts

Panel A. Change in primary and secondary metal production



Panel B. Change in environmental indicators



Note: The graphs show 4 different scenarios: material fiscal reform scenarios applied to a single sector (aluminium production, copper production, iron and steel production and other nonferrous metal production).
Source: OECD ENV-Linkages model.

Annex F. Uniform vs. differentiated taxes

The main scenario in this report was adapted to adapt the taxes rates to take into account the pre-existing taxes on metals and non-metallic minerals. This annex presents a comparison of the scenario with differentiated taxes with a scenario with uniform taxes (presented in Table A F.1).

The main insight from this table is that the changes in GDP and material use for the Material fiscal reform are very similar in both cases. This justifies that taking the adapted scenario does not change significantly the performance of the reform on both the economic and environmental aspects. At the global level, both scenario achieve a similar level of material use reduction of 7% compared to baseline. The costs are quite small, with the uniform scenario being slightly more costly (0.3% of GDP) with respect to the differentiated taxes scenario (0.2% of GDP).

The main advantage of the differentiated Material fiscal reform is that it reduces the cost for most countries, with a similar efficiency of the policy package (even though some of the material reduction shifts from metal use to non-metallic minerals). For some countries, the material use reduction is however slightly larger, and accompanied by a similar or slightly higher cost.

Table A F.1. Comparison of uniform and differentiated taxes for the Material fiscal reform

Change with regards to baseline in 2040.

		GDP		Material use		Metal use		Non-metallic minerals use	
		Uniform	Diff.	Uniform	Diff.	Uniform	Diff.	Uniform	Diff.
	World	**-0.3%**	**-0.2%**	**-7%**	**-7%**	**-32%**	**-27%**	**-7%**	**-8%**
OECD America	Canada	0.0%	0.0%	-3%	-2%	-8%	-5%	-3%	-2%
	Chile	-0.5%	0.0%	-55%	-27%	-80%	-39%	-3%	0%
	Mexico	-0.2%	-0.1%	-7%	-5%	-28%	-18%	-4%	-2%
	USA	0.0%	0.0%	-3%	-4%	-18%	-23%	-4%	-5%
OECD Europe	OECD EU 17	-0.1%	0.0%	-2%	-2%	-2%	-2%	-4%	-3%
	OECD EU 4	0.0%	0.0%	-2%	-2%	-1%	-1%	-3%	-4%
	Other OECD Eurasia	-0.2%	-0.1%	-6%	-6%	-1%	-1%	-9%	-8%
OECD Pacific	Australia & New-Zealand	-0.2%	-0.1%	-21%	-18%	-33%	-27%	-2%	-2%
	Japan	-0.1%	-0.1%	-2%	-2%	-3%	-4%	-2%	-2%
	Korea	-0.1%	-0.2%	-2%	-4%	-4%	-6%	-3%	-5%
Other America	Brazil	-0.1%	0.0%	-4%	-3%	-19%	-14%	-3%	-2%
	Other Latin America	-0.2%	-0.1%	-10%	-7%	-42%	-33%	-4%	-3%
Eurasia	Caspian region	-3.3%	-0.2%	-9%	-1%	-30%	-3%	-8%	-1%
	Other EU	-0.2%	-0.2%	-2%	-2%	-3%	-5%	-4%	-5%
	Other Europe	-0.3%	-0.1%	-3%	-2%	-11%	-8%	-7%	-5%
	Russia	0.0%	0.0%	-3%	-4%	-8%	-13%	-3%	-4%
Middle East & Africa	Middle East	-0.2%	-0.2%	-4%	-4%	-28%	-29%	-4%	-5%
	North Africa	-0.7%	-0.4%	-4%	-3%	-16%	-11%	-6%	-4%
	Other Africa	-0.8%	-0.6%	-8%	-7%	-31%	-28%	-13%	-11%
	South Africa	-10.2%	-0.5%	-5%	0%	8%	3%	-17%	-2%
Other Asia	China	-0.2%	-0.2%	-6%	-6%	-4%	-4%	-9%	-9%
	India	-0.2%	-0.4%	-6%	-10%	-13%	-19%	-11%	-16%
	Indonesia	-0.9%	-0.5%	-43%	-39%	-86%	-78%	-3%	-2%
	Other ASEAN	-0.8%	-0.9%	-5%	-6%	-6%	-9%	-7%	-9%
	Other non-OECD Asia	-0.2%	-0.2%	-3%	-3%	-21%	-22%	-6%	-6%

Note: Uniform taxes apply the level of tax presented in Table 3, but not adapted for country pre-existing taxes, while the differentiated (diff.) scenario presents the main Material fiscal reform scenario discussed in Section 4.3.
Source: OECD ENV-Linkages model.

Annex G. Sensitivity analysis to material tax stringency

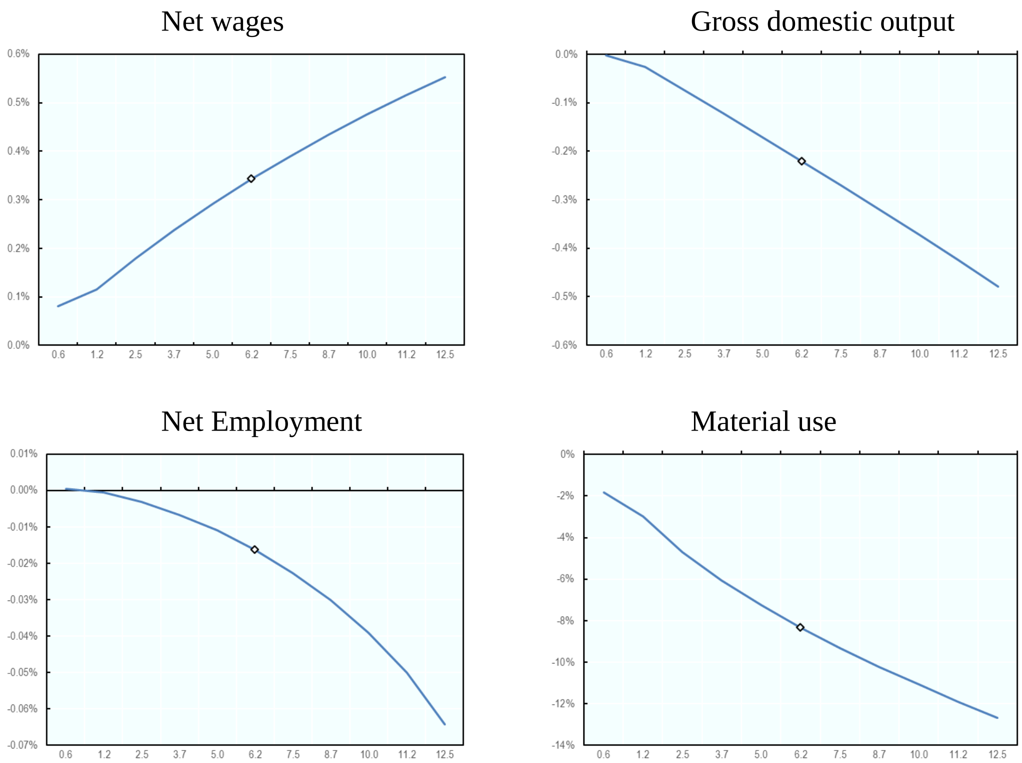
This section explores the effect of the level of material taxes on key macroeconomic variables under the assumption that the tax revenues from the material tax are used to decrease labour taxation.

As material taxes increase, material use drops linearly as a result of the direct price effect. At the same time, the gross domestic product decreases marginally due to the rising production costs. The employment impact remains neutral for low levels of material tax (below 1.2 USD/tonne) but decreases for higher taxes. Moreover, the more tax revenues rise due to material taxes increases, the more labour taxes decrease and thus net-wages rise. However, the positive effect on net wages is outweighed by the negative effect on total output and employment decreases below the reference levels. Thus, there is a trade-off between increasing the cost of labour tax and the increase in labour supply, suggesting the existence of a value for material tax that maximises net employment.

The current choice of material tax level has been chosen to minimise the level of tax within current policies while maximising the environmental benefits (in this case the reduction in material use).

Figure G.1. Macroeconomic impacts for various levels of material taxes, material tax only scenario

Percentage change w.r.t baseline, 2040 (y-axis), average global material tax level in USD/tonne (x-axis).



Note: The average material tax is increased by a factor ranging from 0.1 to 2. Diamonds indicate the central simulation.
Source: OECD ENV-Linkages Model.

Annex H. The energy transition scenario

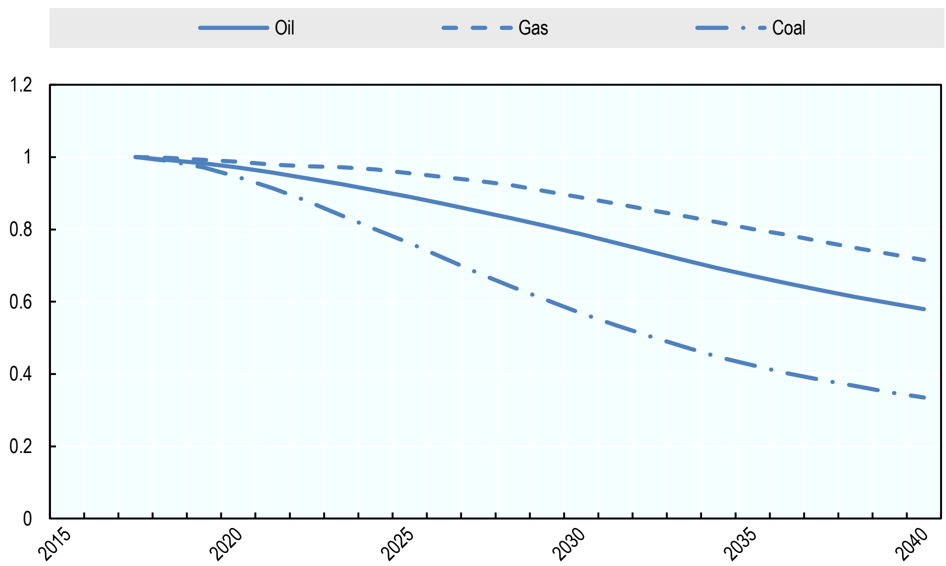
The *energy transition* scenario represents a scenario in which climate and energy policies as well as by technological improvements transform the energy system. In this report, it is used as an alternative baseline in which the *material fiscal reform* can be implemented.

The *energy transition* scenario is calibrated on the Sustainable Development Scenario (SDS) developed by the International Energy Agency (IEA) for the 2018 World Energy Outlook report (IEA, 2018[24]). To do so, the policy tools of the SDS were implemented in the OECD ENV-Linkages model. Box 3 lists the policy tools implemented to elaborate the *energy transition* scenario.

The global energy mix undergoes a deep transformation in the *energy transition* scenario (see Figure A H.1). Coal supply decreases strongly to less than half its size today (the equivalent of 1975 level). Oil demand shows a peak and starts a slow decline, reaching a 30% decrease in 2040. Natural gas consumption remains quite steady, given its versatility and lower environmental advantages relative to coal and oil. As a result, the *energy transition* scenario leads to a radical change in the energy system: the share of fossil fuels in the primary energy mix drops to 60% by 2040 and the GHG emissions drop by half in 2040 compared to 2017.

Figure A H.1. Evolution of global energy supply in the *energy transition* scenario

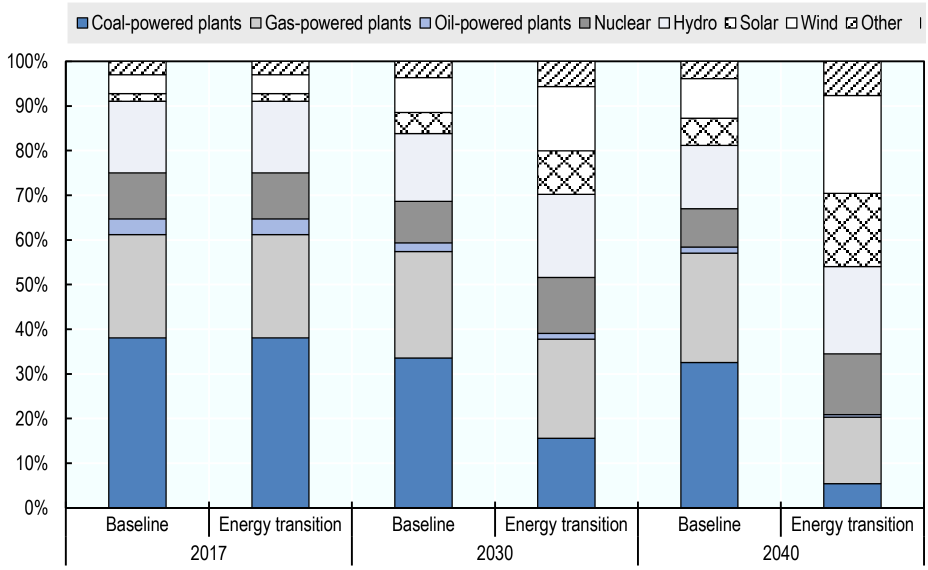
Change in energy supply by carrier w.r.t. baseline scenario (index 1 in 2017).



Source: adapted from the 2018 World Energy Outlook report (IEA, 2018[24]).

The electricity mix reconfigures to make a greater place to non-fossil power plants (see Figure A H.2). The share of electricity produced by power plants using fossil fuels drops to about a third, from around two-thirds today. The share of coal declines from around 40% today to less than 10% in 2040, while that of renewables grows from a quarter to 60%, becoming the major power source at the 2040 horizon. Gas remains an important player (from 23% to 15% over the same period).

Figure A H.2. Global power generation shares, baseline and *energy transition* scenarios



Source: adapted from the 2018 World Energy Outlook report (IEA, 2018[24]).

The implementation of the SDS scenario in the ENV-Linkages model gives rise to macroeconomic impacts (see Table A H.1). The *energy transition* scenario is on a trajectory with a lower GDP, given the costs and constraints of the transition, which reduces GHG emissions by a third by 2040. The global GDP is lower by 3.7%. Household consumption is lower by 3.1%. The impacts on employment are lower, but still negative (-1.3%), but the real wage rate is affected (-3.5%). Given the investments needed, the capital stock to GDP ratio increases by 2.1%.

Materials use in the *energy transition* scenario decreases by 12%, as described in Section 6.1. Most of the decrease is related to fossil fuels. However, since the *energy transition* affect energy prices, minerals use decrease. Metals use decrease by 3.8% while minerals use decrease by 6.4%.

Table A H.1. Aggregate indicators by aggregate region, *energy transition* scenario

Percent change in 2040 w.r.t. baseline scenario.

	OECD	BRIICS	Rest of the world	World
GHG emissions	-34.6%	-39.5%	-22.9%	-33.3%
GDP (constant PPP)	-3.1%	-4.8%	-2.5%	-3.7%
Household consumption	-2.5%	-6.8%	-0.4%	-3.1%
Employment (prs)	-1.2%	-2.0%	-0.8%	-1.3%
Wage rate (real)	-1.5%	-6.0%	-1.0%	-3.5%
Capital stock to GDP ratio	2.9%	0.6%	4.2%	2.1%
All materials (volume)	-12.1%	-16.6%	-4.1%	-12.3%
Metals (volume)	-5.3%	-5.0%	1.0%	-3.8%
Minerals (volume)	-3.1%	-11.1%	0.6%	-6.4%

Source: OECD ENV-Linkages model.