Unclassified **ENV/WKP(2018)333**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

English - Or. English

ENVIRONMENT DIRECTORATE

ENV/WKP(2018)333
Unclassified

IMPACTS OF GREEN GROWTH POLICIES ON LABOUR MARKETS AND WAGE INCOME DISTRIBUTION: A GENERAL EQUILIBRIUM APPLICATION TO CLIMATE AND ENERGY POLICIES

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Keywords: Computable general equilibrium model, Energy efficiency, Climate change mitigation policies, Employment & Redistributive Effects, Labour markets by occupation

JEL codes: D58, Q43, Q54, Q52, J4

OECD Environment Working Papers are available at www.oecd.org/environment/workingpapers.htm

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ABSTRACT

Green growth policies aim at improving environmental quality and economic growth at the same time. A successful transition towards green growth can create new opportunities for workers, if the associated challenges are managed well. Job creation can be achieved in a number of economic sectors with low emission intensities, while job destruction occurs in emission-intensive sectors. The success of green growth policies depends on the capacity of the firms and workers to adapt to the changes in economic structures induced by the policies. These policy-induced structural changes can lead to distributional impacts that can undermine the political acceptability of a policy proposal, if these impacts are not properly considered.

This paper explores the consequences on the labour markets of structural changes induced by decarbonisation policies. These policies are likely going to have consequences on labour-income distribution given i) existing rigidities in the labour markets, and ii) their different impacts on sectors and on job categories. These policies are analysed in a general equilibrium modelling framework, which includes interlinkages between different sectors and regions as well as five different categories of workers. This simulation-based analysis helps identify which workers are most vulnerable to the implementation of climate and energy policies, given that workers are not perfectly interchangeable between different jobs. This first step is fundamental to adjust education and training policies, as well as redistributive schemes that will accommodate the green growth objectives.

The main conclusion of the paper is that, whatever the nature of the decarbonisation policy or the country considered, the low-skilled workers will generally be more sensitive to the impacts of the policies than the other categories of workers (in terms of job rotation or wage income outcome).

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RÉSUMÉ

Les politiques de croissance verte ont pour objet l'amélioration de la qualité de l'environnement tout en maintenant une croissance économique soutenue. Une transition réussie vers une croissance verte peut être créatrice de nouvelles opportunités pour les travailleurs dans la mesure où les défis associés à cette transition sont clairement identifiés. Des créations d'emploi dans les secteurs faiblement carbonés sont possibles, tandis qu'à l'opposé des destructions d'emploi dans les secteurs fortement générateurs d'émissions sont attendues. Le succès des politiques de croissance verte dépendent *in fine* des capacités d'adaptation, des entreprises et des travailleurs, aux changements des structures économiques résultants de la mise en place de ces politiques. Les impacts distributifs consécutifs à ces changements structurels peuvent avoir des impacts distributifs qui fragiliseront l'acceptabilité des réformes, si ces impacts ne sont pas correctement envisagés.

Ce papier analyse les conséquences sur les marchés du travail des changements structurels induits par les politiques de « décarbonisation de l'économie ». Par ricochet, ces politiques auront des conséquences sur la distribution des revenus du travail, dans la mesure où i) ils existent des rigidités sur les marchés du travail, ii) les secteurs économiques et les différentes catégories d'emploi ne seront pas tous touchés de la même façon. L'analyse des impacts des politiques est effectués dans le cadre d'une modélisation de type équilibre général, ce qui sous-entend des interactions étroites entre les changements des différents secteurs et des différentes régions, ainsi qu'entre les cinq catégories de travailleurs considérées. Une telle analyse numérique permet d'identifier quels type de travailleurs seront les plus vulnérables suite à la mise en place de politiques climatiques et énergétiques, sachant que les travailleurs ne sont pas parfaitement interchangeables pour occuper tous les types d'emploi. Cette première étape est fondamentale pour identifier comment ajuster les politiques d'éducation et de formation, mais aussi les politiques de redistribution, pour accompagner de façon souhaitable les mutations associées aux objectifs de croissance verte.

Le principal enseignement de de cette étude, quel que soit la nature des politiques de « décarbonisation » envisagées et quelle que soit le pays considérés, est que les catégories de travailleurs les moins qualifiés seront généralement plus sensibles aux impacts de ces politiques que les autres catégories de travailleurs (en termes de rotation de la main œuvre ou d'impact sur les revenus du travail).

***Codes JEL**:* D58, Q43, Q54, Q52, J4

***Mots-clés**:* Modèle d'équilibre général calculable, Efficacité énergétique, Politiques d'atténuation du changement climatique, Effets distributifs et sur l'Emploi, Marchés du travail par occupation

ACKNOWLEDGEMENTS

This report has been authored by Jean Chateau, Ruben Bibas and Elisa Lanzi of the OECD Environment Directorate. The authors are grateful to delegates to the Working Party on Integrating Environmental and Economic Policies for helpful comments on earlier drafts. The authors would like to thank the OECD colleagues Rob Dellink, Shardul Agrawala and Susan Stone, for multiple insights in previous versions of the paper, and Katjusha Boffa and Stéphanie Halimi, for their excellent editorial assistance. The paper has also benefited from useful comments from external experts on presentation of the results at the 2015 GTAP Conference and at a session of the “Conseil d'Orientation pour l'Emploi”, February 2018.

The authors are responsible for any remaining omissions or errors. Work on this paper was conducted under the overall supervision of Shardul Agrawala, Head of the Environment and Economy Integration Division, OECD Environment Directorate.

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EXECUTIVE SUMMARY

Green growth policies aim at achieving growth without harmful environmental outcomes. A successful transition towards green growth can create new opportunities for workers, if the associated challenges are managed well. Job creation can be achieved in a number of economic sectors, for example with low emission intensities, while job destruction occurs in emission-intensive sectors. The success of green growth policies depends on the capacity of the firms and workers to adapt to the changes in economic structures induced by the policies. These policies can lead to distributional impacts that can undermine the political acceptability of a policy proposal. Further knowledge of the job categories that are most vulnerable when implementing green growth policies is fundamental to adjust education and training policies, as well as redistributive schemes that will accommodate the green growth objectives.

The objective of this report is to understand the consequences on the labour market of the structural changes induced by decarbonisation policies, as examples of green growth policies. These policies are likely going to have consequences on labour-income distribution given i) existing rigidities in the labour markets, and ii) their different impacts on sectors and job categories. This simulation-based analysis helps identify which workers are most vulnerable to the implementation of certain types of climate and energy policies, given that workers are not perfectly interchangeable between different jobs.

Given the complexities in analysing the impacts of policies on the different sectors and on the labour force, the report adopts a quantitative modelling approach, which takes into account inter-sectoral and inter-regional interdependencies. The tool used for the analysis is the OECD global computable general equilibrium (CGE) model ENV-Linkages.

Previous modelling work assessed total and sectoral employment impacts of a carbon tax in OECD countries (OECD, 2011). It found limited aggregate impacts of a carbon tax on total employment but with significant differences among sectors. While this previous work considered unemployment as the only imperfection of labour market, the present paper considers that labour market is imperfect because mobility of workers across sectors is costly. It does so by distinguishing different job categories, which split workers into high-skilled workers ('Professionals' and 'Managers and officials'), intermediate-skilled workers ('Service and sales workers' and 'Clerical workers') and low-skilled workers ('Blue collar and farm workers') and limits the degree of substitutability between these categories. The analysis adopts a long term perspective and therefore abstracts from temporary adjustment costs.

The report focuses mainly on one decarbonisation scenario: the *central scenario*, in which a carbon tax of USD 50t/CO_2 is applied in all regions of the world. The report then considers a sensitivity analysis around the *central scenario*, which focuses on policy stringency and on the adopted revenue recycling scheme. Finally, it compares the *central scenario* to an alternative *mixed policy scenario* which includes efficiency measures as well as a USD 18t/CO_2 tax and is designed to achieve the same greenhouse gases (GHG) emission reductions as the *central scenario*.

The results from the *central scenario* show that the changes in level and composition of both employment and wage rates that follow the implementation of the tax can differ by region, because their initial economic structures differ and the carbon tax has asymmetric impacts on sectors. While sectoral output and employment changes can be substantial, they do not generate large job reallocations overall, as the policy is not very stringent and only affect a small part of the economy. However, countries where the economic structure is dominated by large fossil-fuel sectors can have larger job reallocations.

Energy supply sectors are the dominant source of job destructions for most countries, albeit with different impacts across regions, depending on the relative importance of the energy production sector. For all sectors with declining output, employment generally decreases. Results show that workers in energy supply sectors and energy-intensive industries are the most vulnerable. Conversely, workers in sectors that are stimulated as result of the policy, such as renewable energy, stand to gain most.

In most countries, job reduction in the *central scenario* will affect ‘Blue collar and farm workers’ most. This job category is largely employed in energy sectors and energy-intensive industries, which are the most impacted sectors. Workers generally benefit from the policy when the revenues from the carbon tax are used to lower income taxation. Workers in the categories ‘Service and sales’ and ‘Managers and officials’ generally benefit most in terms of wage income, since these job categories are more represented in sectors that are the less affected by the policy (such as non-energy related service sectors).

Distributive issues may be a rising concern with increasing levels of policy ambition. Indeed, while the established impacts are robust to carbon tax levels ranging from USD 5t/CO_2 to USD 100t/CO_2, the negative effect of the carbon tax outweighs the positive effect on net-wage incomes in the higher range of carbon taxes. Thus, for low carbon tax values, net wages increase with the increase in the tax level, but beyond some point further tax level increases lead to lower net wages. In addition, this analysis reinforces the result that low-skilled workers are the most vulnerable, with a decline in their net wage income for relatively low values of the carbon tax.

Wage income for all job categories (low-skilled workers in particular) is critically affected by the recycling schemes of carbon tax revenues. The *central scenario* considers that carbon revenues are recycled through reductions of the income tax rate where all household revenues are increased. Two alternative recycling schemes are also discussed as sensitivity analyses: the case of lump-sum transfer where households receive uniformly the revenues from the carbon tax, and the case where revenues are recycled through reductions of the wage income tax rate only. The lump-sum improves the situation of vulnerable categories of workers (as per person payments are not related to their wages), at the expense of employment. In contrast, the scheme with the reduction in wage income tax rates performs best for employment and overall wages, but may exacerbate changes in income distribution.

Comparing the *central scenario* to the *mixed policy scenario* shows that decarbonisation policies using different channels imply differences in terms of labour markets and redistributive impacts. In the *mixed policy scenario*, more sectors, like construction or business services, are also affected, leading to a higher number of job reallocations when compared to the *central scenario*. Since the energy efficiency measures included in this scenario are tailored to the characteristics of countries and sectors, the impact on job categories are sector- and country-specific, while the *central scenario* results are much more uniform across countries. As in the central scenario, low-skilled workers are the most vulnerable. Moreover, in OECD countries the large turnover of high-skilled workers makes them more exposed to the policy than average.

The impacts of the two policies on the labour market differ substantially as they imply different sectoral reallocations and macroeconomic consequences. The energy efficiency component of the *mixed policy scenario* acts by directly changing production modes and energy demand, thereby reducing costs, while the carbon tax affects production and demand through a price effect, which increases costs. The policies thus imply a more positive macroeconomic impact in the *mixed policy scenario*, which is more beneficial for households. However, the larger number of job reallocations (and therefore job destructions) implies that the distributional impacts of the *mixed policy scenario* are larger than that of the *central scenario*, which may lead to more vulnerable workers and in turn a lessened political acceptability of the policy. A redistributive policy is crucial in shaping the impacts for vulnerable sectors and job categories; and the *mixed policy scenario*, that present lower carbon taxes than the *central scenario*, has much less carbon revenues to leverage to that end. These contrasted results for the two policy scenarios are a clear illustration of the traditional equity-efficiency dilemma.

Even if labour markets and distributional aspects are not the core target of climate and energy policies, this report shows that they are key dimensions to understand the barriers to their implementation. Identifying the most vulnerable job categories is indeed crucial for a seamless implementation of the policies. In particular, paying attention to the job categories that may be confronted with income losses constitutes the first step to address the issue. One mechanism that can be implemented is the use of carbon tax revenues to correct undesirable distributional effects. The very complex dynamics at play need to be incorporated in providing policy designs tailored for specific countries.

1. INTRODUCTION

Green growth policies aim at decoupling economic growth from environmental pressures. This objective requires a transformation of the structure of production and consumption across the entire economy towards less-polluting and more resource-efficient economic activities. These changes in demand patterns and in production processes will therefore reshape labour markets. The structural changes will not affect all workers homogenously, since jobs are heterogeneous in terms of skill requirements and types of tasks to be performed. To adjust to the changes, workers can switch between jobs and sectors that require similar skills, but these shifts are constrained by rigidities in the labour market.

The objective of this paper is to identify the job categories that are most impacted from the structural changes induced by decarbonisation policies. The labour market is indeed divided into separate segments corresponding to different job categories (e.g. occupation) based on different sets of skills. By looking at the wage income of different types of workers, the analysis can also provide insights into the distributional consequences.

The paper focuses on long-run structural changes. In a long-run perspective, the scope is to study how the distribution of workers across different job categories responds to the structural changes induced by decarbonisation policies. These insights can be useful to identify strategies to adjust education, training and labour market policies. They can also help to identify undesirable income impacts on specific workers across sectors and job categories and thus the redistributive policies needed to contribute to a fair transition towards a low-carbon economy. While these topics are beyond the scope of this report, they are relevant policy issues that motivate this analysis of the long run impacts of green growth policies on the labour market.

Given the interactions between the impacts of these policies on the different economic sectors and on labour markets, it is best to adopt a modelling approach that can take into account sectoral, regional and international trade interdependences. This is for instance supported by Bowen (2014), who advocates for "more modelling of how environmental policies may affect wages relative to other factor returns and the relative pay associated with particular skills".[1]

Previous modelling work assessed total and sectoral employment impacts of a carbon tax in OECD countries (OECD, 2011).[2] It found limited aggregate impacts of a carbon tax on total employment but with significant differences among sectors. However, this previous work considered unemployment as the only mechanism limiting perfect labour adjustment. The modelling framework indeed assumed a perfect mobility of workers across sectors. Implicitly, this supposes an unrealistic world where all workers are uniform, in terms of productivity and inherent skills, and where all job categories are interchangeable. This paper focuses instead on a more realistic labour market representation, characterised by different job categories. In particular, it aims at shedding light on the differentiated impacts of decarbonisation policies

1 The term "skills" is often used in the literature to describe different job categories. Generally, skills are associated with educational attainment. However, especially for OECD countries which generally have high levels of tertiary education, it makes more sense to distinguish between the types of training rather than educational attainment. This report splits the labour market into five job categories (see Annex A) based on different types of training and occupations.

2 More details on this work are provided in Chapter 4 of the 2012 OECD Employment Outlook (OECD, 2012b), while the analytical modelling framework and the simulations analysis are described in Chateau and Saint-Martin (2014).

on job categories in different sectors. Segmenting the labour market in different job categories is a pre-requisite for assessing the impacts for those different job categories. In addition to the direct policy impacts, the asymmetric impacts on sectors could be exacerbated by the differences in the various segments of the labour market, since workers in different categories cannot be perfect substitutes for each other and since jobs reallocation across sector within a same category are costly.

The main tool for the analysis is the OECD's global Computable General Equilibrium (CGE) model: ENV-Linkages (Chateau et al., 2014b). Building on the empirical work on labour markets segments by ILO (2008), the ENV-Linkages Model has been enhanced to include five different jobs categories. This enhanced version of the model is used to perform a "comparative-static" analysis, which aims at assessing the structural change associated with policies and its labour market implications in a long-run perspective.

The paper shows that different policies to curb greenhouses gases may have very different implications for changes in the total level of employment, its sectoral composition and the distribution of workers between different job categories. Further, distributive issues may be a rising concern with increasing levels of policy ambition. The wage incomes for all workers are also critically affected by the recycling schemes of carbon tax revenues. Finally, changing the policy instrument from a carbon tax to a combination of carbon tax and energy efficiency measures shows that using different channels implies differences in terms of labour markets and redistributive impacts.

While the model used could simulate the short and medium run dynamics associated with decarbonisation policies, the paper will abstract from the study of short-term labour market effects. The first reason is a practical one; to study the dynamics of the transition to a long-run decarbonized economy it is necessary to rely on projections of labour supply by job category, but no such projections exist at global level and it is beyond the scope of the report to project these trends. Second, even if the ENV-Linkages Model could produce larger costs of adjustments in the short run for a given policy, these larger costs of adjustment only reflect that in the short run production structures are more rigid than in the long run. However, as indicated in OECD (2016), sluggish labour market conditions in the short run are essentially caused by intrinsic inefficiencies in the functioning of product and labour markets[3] that no CGE model is able to reproduce accurately.

The remainder of this paper is structured as follows. Section 2 reviews the main possible consequences of the implementation of green growth policies on the labour market and presents the modelling methodology used for the analysis of more specific decarbonisation policies. Sections 3 to 5 present the results from the modelling analysis. Section 3 starts with presenting the results of the main policy scenario: the *central scenario*. This section outlines the channels through which a tax on carbon dioxide (CO_2) emissions might affect the economy, with a focus on the labour consequences. Section 4 explores the importance of the carbon tax stringency and the impact of various carbon tax revenue recycling schemes. Section 5 examines how combining energy efficiency measures with a carbon tax to reach the same level of abatement-modifies the main results. Finally, Section 6 puts the results into context and provides possible ways to address the limitations of the analysis.

3 Entry barriers, inefficient price setting processes are examples of such inefficiencies in product market, while inefficient statutory dismissal protection, termination costs are examples labour market inefficiencies.

2. MODELLING LABOUR MARKET IMPACTS OF CLIMATE MITIGATION POLICIES

This section examines the channels through which policies that aim at curbing greenhouse gas (GHG) emissions change the structure of the economy and of the labour market. It first gives an overview of the relevant mechanisms in the broader perspective of green growth policies. Then, it presents evidence on the distribution of GHGs and energy intensities as well as job categories across different sectors. Finally, it details the modelling framework that will be used in this paper, with a focus on assumptions about the functioning of the labour market.

2.1 An overview of the mechanisms influencing the labour markets

A transition towards more environmentally friendly and resource-efficient economic growth implies permanent macroeconomic and sectoral structural changes. Table 1 illustrates the various channels through which some green growth policies may impact economic activity. For a clearer understanding, these impacts have been subjectively classified in four main categories:

- changes in production modes and technologies;
- changes in demand patterns;
- changes in aggregate income and other macroeconomic conditions;
- changes in international trade and competiveness.

Changes in production modes and technologies will be the most direct response of firms to green growth policies as firms aim to reduce the use of "dirty" inputs in production. The shift in production structure towards cleaner technologies and products will determine the change in production costs. Sectoral employment itself is not only determined by the level of activity of the industry but also by the substitution possibilities between labour and other inputs, that result from changes in their relative prices. The degree to which labour is used as a substitute or complement to other inputs determines the changes in labour demand. Such substitution effects in addition occur for each job category. Moreover, there can be substitution effects between different job categories.

Green growth policies also aim at obtaining *changes in demand patterns* (including both final and intermediate demands). These changes in composition of demand could be the result of policy-induced increases in the relative price of polluting goods. Changes in demand patterns also occur when agents react by investing or purchasing durable goods that reduce their own sources of pollution (e.g. investments in building isolation). As a consequence, job creation will occur in 'green' sectors that produce more environmentally friendly goods and services, while job destruction will occur in the 'brown' sectors that get replaced by the green activities.

As they boost (or reduce) overall economic activity, green growth policies also imply *changes in aggregate income or in other macroeconomic conditions*. For instance, changes in households' income imply changes in demand patterns,[4] but also modify their savings and labour supply.

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[4] This happens when the elasticity of demand to income differs across goods. Distributional impacts of green growth policies could also alter the macroeconomic situation in a way similar to aggregate income effects, because individuals generally differ in their "consumption" patterns (including their labour-leisure choices or consumption-saving choices). In a same spirit, one could add that if some individuals are facing some

Table 1. Selected impacts of green growth policies on sectoral activity and employment

	Impacts	Examples	Plausible labour impacts
Changes in production modes	Shift away from sources of environmental damages by using more resource-efficient capital	– Electric vehicles in transportation sector – Investments in buildings isolation	Changes in labour according to the degree of complementarity between capital and labour
Changes in demand patterns	Reduced demand for commodities that are sources of environmental impacts when consumed by firms or final consumers	– fossil-fuel demands	Decreased labour in sectors producing these commodities
	Reduced demand for commodities that are sources of environmental impacts during their production processes	– Extraction of fossil-fuel – Ferrous metal production – Chemicals production	Decreased labour in sectors producing these commodities
	Reduced demand for commodities that are used jointly with the sources of environmental impacts (complements)	– Motor vehicles manufacturing (combustion engine)	Decreased labour in sectors producing these commodities
	Increased demand for commodities that can be used instead of commodities that are sources of environmental impacts (substitutes)	– Renewable power generation	Increased labour in sectors producing these commodities
	Indirect change in demand for intermediate goods intensively used in sectors impacted or for stimulated investment commodities.	– Solar panels Energy-efficient appliances	Increased (decreased) labour in sectors producing these commodities
	Indirect change in final demand, through changes in prices	– Energy intensive sectors	Changes in labour in sectors producing these commodities
Changes in macroeconomic conditions	Multiplier on final demand associated with stimulus from broad policy packages	– Public investments in energy efficient infrastructures	Economy-wide positive impact on labour
	Crowding out of investments in other sectors	– Reduced resources for other investments	Decreased labour in sectors producing these commodities
	Decreased taxation (or increased other government expenditures) thanks to the extra revenues from environmental taxes or from phasing out fossil-fuel subsidies	– Feed in tariffs – Subsidies to R&D	Changes in labour in all affected sectors
	Increased taxation (or decreased other government expenditures) to finance extra public expenditures for investment	– Expenditures in subsidies to renewable energy	Decreased labour in all sectors affected by the increased tax or reduced government spending
	Changes in primary factor supply (capital, labour, land, etc.)	– Increase in employment, in reaction to higher wages from carbon revenues recycling	Overall change in labour supply of workers
Changes in international trade	Changes in exports and imports from changed relative competitive position vis-à-vis international competitors in a world of varying	– Reduced exports of energy-intensive trade-exposed commodities such as Iron & Steel	Decreased labour in sectors producing these commodities

specific constraints, and if a policy reinforced these constraints, the distributive impacts of the policy might, in turn, alter its economic efficiency.

	stringency of green growth policies		
	Changes in trade balances and in real exchange rates induced by changes in exports and imports (terms of trade effect)	– Reduction of oil export revenues in large energy exporting countries (e.g. Russia and Middle-East)	Changes in labour in all sectors

Consequently, there could be an overall positive (or negative) net impact on total employment. Strong demand multiplier effects have for instance been projected by Barker et al. (2015) for energy efficiency policies, while a previous analysis by the OECD for carbon taxes identified very limited possibilities of increasing employment if the labour market is characterised by rigidities (OECD, 2012a). These multiplier effects are not directly related to green growth policies *per se*, but to the government stimulus.

Macroeconomic effects of green growth policies also encompass government budget adjustments that result from implementation of these policies. Especially market-based instruments such as carbon or other environmental taxes have the capacity to generate revenues for the government. The policies can be coupled with compensating changes in the taxation system through a revenue-neutral environmental tax reform, or with changes in government expenses. But even when policies do not directly affect the government budget (as is the case for most regulations), they can lead to changes in the tax basis, hence in a possible budget imbalance. The government can then choose to accommodate this imbalance by modifying tax rates or expenditures, which can result in additional price and income effects. The literature highlights the possibility of a "double-dividend" phenomenon, showing that in some circumstances extra revenues from a carbon tax can lead to a GDP increase.[5]

Finally, green growth policies change the production structure and prices differently in different countries, leading to *international trade impacts* and changes in the relative competiveness of countries, especially in a world of varying policy stringency (see for instance Lanzi et al., 2013). Energy and *energy-intensive industries* in regions with strict policies can indeed suffer from a loss in competitiveness, hence a decreased labour demand in the concerned sectors, whereas clean production sectors may expand their exports and thus boost production and labour.

These effects of green growth policies suggest that economic activity levels as well as employment in each job category would be differently impacted across sectors. Relative shortage or excess of workers may translate into important changes in relative wages between workers in different job categories. The resulting increased wage inequality may lead to social tensions and thus limit the public acceptability of a policy proposal. Distributional impacts of green growth policies can also alter the macroeconomic situation, because individuals generally differ in their "consumption" patterns (including their labour-leisure choices or consumption-saving choices)".

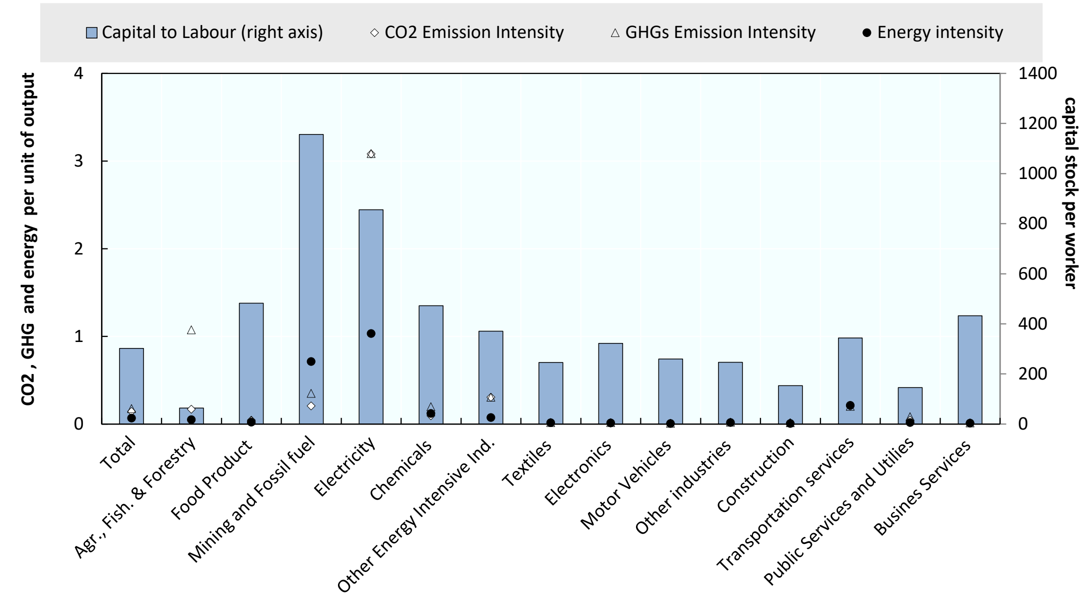
5 The double-dividend hypothesis supports the idea that the use of the revenues gained from environmental taxation can offer improvements in welfare thanks to the reduction in the distortions of the revenue-raising tax system. As such environmental taxation has two benefits (dividends): the environmental benefits and the welfare ones. See Chateau and Saint-Martin (2013) for an illustration of the concept with the same model.

2.2 A double asymmetry in sectoral production structures: emission intensity and job type composition

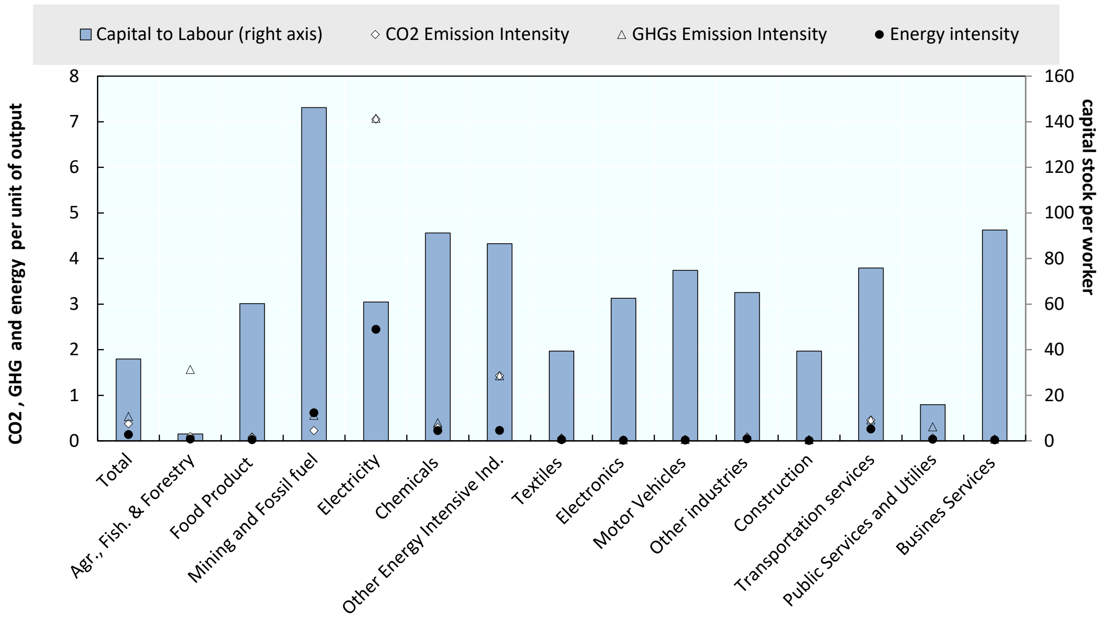
Sectoral GHG emission intensity can help to identify the most vulnerable sectors of the economy to climate policies. Workers in these sectors, which are likely to bear the largest costs of the policy, are thus the most exposed, especially when the sectors also rely relatively more on labour than on capital. Figure 2 reports carbon and energy intensities (left axis) as well as capital to labour ratios (right axis), by sector for OECD countries (Panel A) and non-OECD countries (Panel B).

Figure 1. Carbon and energy intensities, and capital to labour ratio, by sector

Panel A. OECD countries, 2011



Panel B. Non-OECD countries, 2011



Notes:

1. The capital to labour ratio (right axis) is measured as the total installed capital stock (in thousands of 2011 USD) divided by total employment (millions of persons).

2. Energy intensity is measured as total primary energy demand (in tons of oil equivalent) divided by output (in thousands of 2011 USD).
3. CO_2 emission intensity is measured as total emissions of CO_2 (tons of CO_2) divided by output (in thousands 2011 USD).
4. GHGs emission intensity is measured as total emissions of GHGs (tons of CO_2 equivalent) divided by output (in thousands of 2011 USD).
5. The scales for both axes differ between Panel A and B: capital to labour ratios is larger in OECD countries while emission and energy intensities are larger in Non-OECD countries.
6. Details about the aggregated sectors are provided in Table B.1 of Annex B.

Source: Authors calculations on the basis of the GTAP 9 database (Aguiar et al., 2016).

Workers in sectors characterised by high GHG emission and energy intensities are relatively more exposed to the effects of climate and/or energy policies. Those sectors (shown in Figure 1) include energy industries, which comprise 'Electricity' and 'Mining and fossil fuel supply', and those heavily relying on energy use, such as *energy intensive industries*[6] or 'Transportation services'. On average, energy intensity in OECD countries is lower than in Non-OECD countries. This is thanks to cleaner production processes as well as an economic structure that is more oriented towards services utilization and less oriented towards energy-intensive inputs. Moreover, CO_2 emission intensities are almost three times larger in non-OECD countries than in OECD countries.[7]

The extent to which sectors rely on labour force determines which sectors are most sensitive to changes in labour market conditions. The bars in Figure 1 represent the capital to labour ratio, which are highest in electricity and fossil-fuel sectors as well as in *energy intensive industries*. Thus, the impacts of climate and energy policies, which will be stronger on these capital-intensive sectors, would imply only a moderate effect on overall labour market. These same policies are also likely to induce a shift of labour from emission-intensive sectors towards cleaner and more-labour-intensive sectors. This holds particularly for OECD countries that, as indicated by the '*Total*' column in Figure 1, have a higher capital-to-labour ratio than Non-OECD countries.

Asymmetrical distribution of job categories across sectors

It is possible to go one step further and identify which kind of jobs are likely to be affected by climate and energy policies. Indeed, the second asymmetry across sectors is their specific labour composition across the different job categories. Based on the ILO (2008) database, and following the ILO ISCO-88 classification, this report examines five different job categories: (i) 'Professionals', (ii) 'Managers and officials', (iii) 'Service and sales workers', (iv) 'Clerical workers' and (iv) 'Blue collar and farm workers' (See Annex A for a more detailed description).[8]

The distribution of workers across the 5 job categories is presented in Figure 3. For each sector, Figure 3 reports the share of workers of each job category relative to total employment of the category. Under the heading "all workers", the figure also reports the share of workers in a given sector relative to total employment. If the share for a given job category is above the share of "*all workers*" in a given sector, then

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[6] Energy intensive industries include 'Chemicals' and 'Other energy intensive industries'. 'Other energy intensive industries' includes 'Iron and steel', 'Pulp and Paper' and 'Non-Metallic Minerals'. Further details about the composition of aggregated sectors are provided in Table B.1 of Annex B.

[7] The main reason that the carbon intensity gap between non-OECD countries and OECD is higher than the energy intensity gap is that energy systems in non-OECD countries are much more fossil-fuel based than in OECD (this is particularly the case in 'Electricity' production and in 'Energy intensive industries').

[8] This ILO dataset is also the basis of the labour data used in the current modelling analysis.

the corresponding job category is relatively more intensively used, in this sector, than the other job categories.

On average, energy and *energy intensive industries* account together for less than 6% of total employment for OECD countries, and less than 7.5% for non-OECD countries (detailed analysis will show that this share can reach up to 17% in transition economies and around 15% in Middle East countries). But while the highest share of employment in OECD countries is in the services sectors (68% on average), employment still remains high in 'Agriculture, fishing and fisheries' (50% on average) in non-OECD economies.

In the OECD, sectors with high emission intensities (e.g. 'Mining and fossil fuel', 'Electricity', 'Chemicals', 'Other energy intensive industries', 'Transportation services' and 'Agriculture, fishing and fisheries') account for only 30% of the total employment of the 'Blue collar and farm workers'. But in non-OECD economies theses same sectors account for more than 90% of low-skilled employment. Moreover, the job structure of these emission-intensive sectors, except for 'Chemicals' and 'Electricity', shows that the share of 'Blue collar and farm workers' exceeds the share of high-skilled workers (i.e. 'Managers and officials' and 'Professionals') in almost all countries.

The service sectors, such as 'Business services' and 'Public services and utilities' are more labour intensive, and thus present a lower capital-to-labour ratio in Figure 2, these sectors have also lower energy and emission intensities. Moreover, these sectors rely intensively on 'Service and sales workers', 'Professionals' and 'Managers and officials', while they have a low share of 'Blue collar and farm workers'. The implementation of climate and energy policies is thus expected to be less advantageous to this last job category, which is required more in sectors with higher emission intensity.

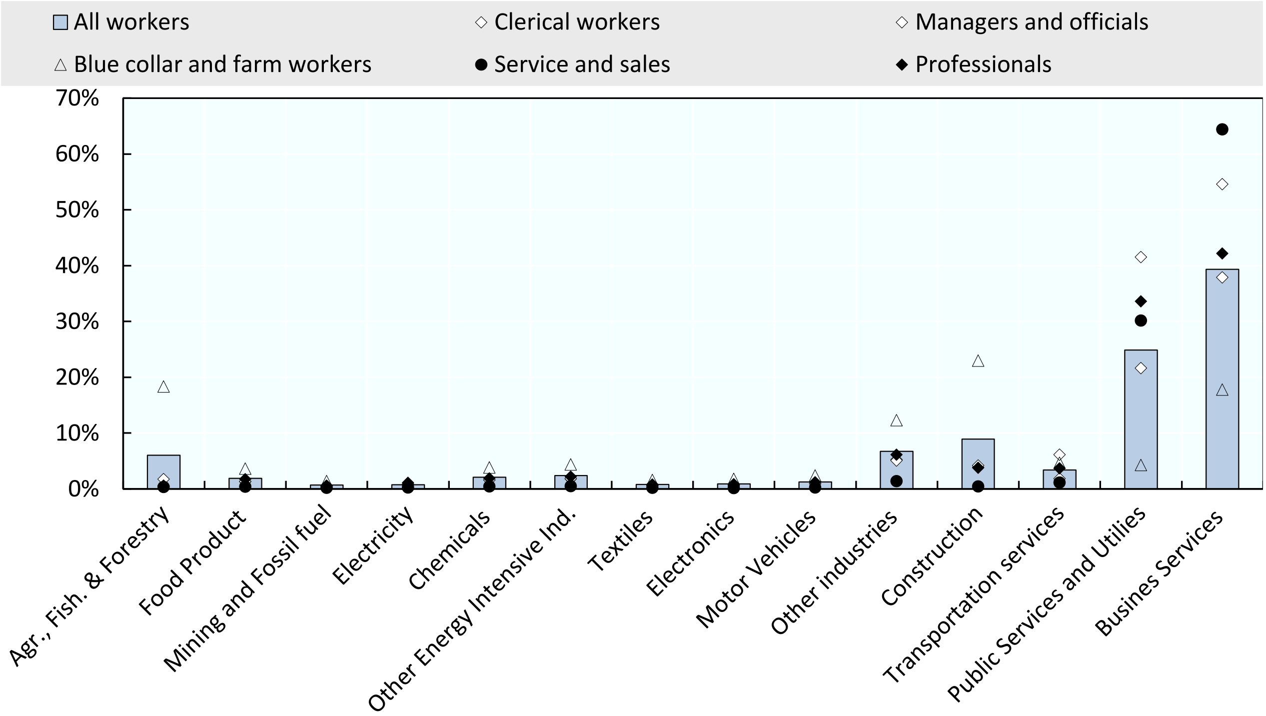
Other features of the distribution of job categories by sectors are worth mentioning to understand policy results discussed later in the report. A more detailed sectoral analysis (not presented here) reveals that, in certain countries, some energy producing sectors employ a relative higher share of 'Professionals' and 'Managers and officials' than the economy-wide average. This situation occurs in 'Electricity' generation and 'Mining and fossil fuel supply' as well as in some high energy-user sectors (such as 'Transportation services' and 'Chemicals'). However, overall, the share of high-skilled workers appears to be higher for the sectors with lower emission intensity. Further, a large share (more than 20%) of 'Blue collar and farm workers' is employed in the 'Construction' sector in OECD countries while the same share for non-OECD countries is only 5%.

The comparison of the structures of sectoral energy intensities and the sectoral composition of employment by job category (for the year 2011) illustrates that an energy efficiency or climate policy is likely to have asymmetrical impacts on sectoral production and employment. However, no definitive conclusions on economic and distributional impacts of these policies can be inferred from this pure graphical exposition. This kind of graphical analysis abstracts from economic mechanisms in action when policies are effectively implemented. General equilibrium modelling provides a powerful tool for analysing these mechanisms.

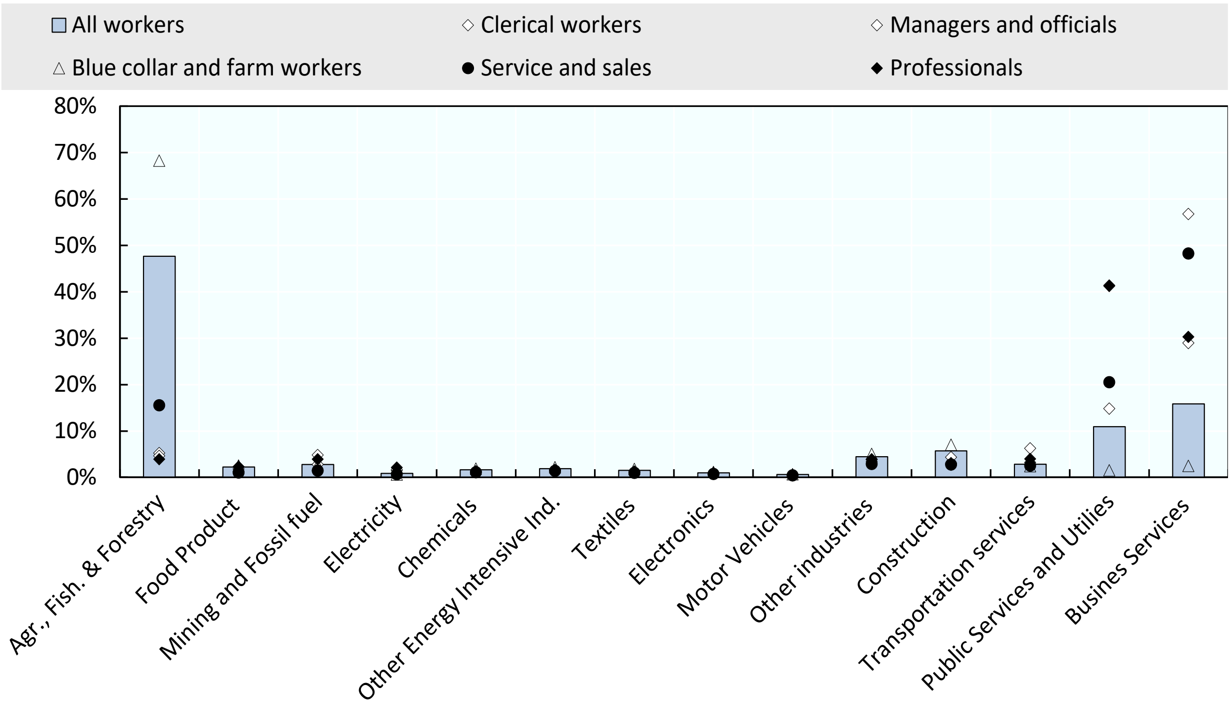
Figure 2. Employment shares by job category and sector

Employment share as percentage of total employment of the category, 2011

Panel A. OECD countries



Panel B. Non-OECD countries



Source: Authors calculations on the basis of GTAP 9 database (Aguiar et al., 2016) and Walmsey and Carrico (2013).

2.3 A general equilibrium perspective to assess the labour market impacts of climate and energy efficiency policies

The OECD ENV-Linkages Model is the tool used for the analysis of the impacts of energy and climate policies on labour market and income distribution across workers. ENV-Linkages is a global Computable General Equilibrium (CGE) model that describes how economic activities are linked to each other among sectors and across regions. The version used for the current analysis contains 35 economic sectors and 25 regions.[9] ENV-Linkages also links economic activity to environmental pressure, specifically to GHG emissions.

For this report, the ENV-Linkages Model has been enhanced to include the five classes of jobs presented in the previous section. The disaggregation of total labour for each sector and country into these five classes of jobs is described in Walmsley and Carrico (2013), based on the GTAP9 database (Aguiar et al., 2016), which constitutes the core social accounting matrix of the ENV-Linkages Model for the base year 2011.

The labour market functioning of the ENV-Linkages Model is also improved. In the standard version of the model, as used for example in OECD (2012b), the model assumed a fully flexible labour market: job reallocations across economic sectors, which results from the introduction of climate policies, was costless and occurred instantaneously. Box 1 provides explanations for the improvements in the model.

In the current version of the model, the labour market is assumed to be segmented into 5 job categories and workers cannot move from one category to another. This assumption allows for employment rates as well as wage rates that differ for each job category. Following Boeters and Savard (2013), labour supply for each job category is assumed to increase with the net of tax wage rates. Therefore, the net variations in employment are also differentiated by job category. Finally, firms can substitute workers from different job categories, which indirectly links the wage rates of different job categories.

Within a given job category, a worker can switch between sectors. This switch entails a cost, which prevents a complete flexibility from one sector to another. For example, ‘Professionals’ cannot decide to move from the ‘Public services and utilities’ sector to the ‘Chemicals’ sector (for instance so as to benefit from a higher relative net-of-tax wage in the ‘Chemicals’ sector) without suffering any cost. This implies that wages for the same job category are not identical across sectors. As a consequence, the job reallocation across economic sectors, which results from a policy, is lower than if all workers were assumed to be identical. For the sake of simplicity, the modelling framework also assumes that the costs of moving from one sector to another are the same, independently of the initial or final sectors that employ the worker. For instance, this implicitly means that the competencies of ‘Managers and officials’ are the same in all sectors. A final assumption is that the resulting change in relative employment between two sectors is strictly proportional to the changes in relative net wages.

The assumptions retained about technical combination possibilities in the production process across labour and capital, and across the different kinds of jobs also need further precision. The modelling framework assumes that each type of labour is equally substitutable to other inputs, and in particular to the physical capital stock. However, these substitution possibilities are different across sectors. Further, in a given sector, it is assumed that substitution possibilities between two job categories are identical, whatever the two job categories are (e.g. the elasticity of substitution between the 5 type of workers is the same). For simplicity, it is also assumed that the substitution possibilities among two job categories are identical across all sectors (e.g. the elasticity of substitution between workers is also the same across sectors). The

9 See respectively Tables B.1 and B.2 in Annex B for details about country and sectoral aggregations.

change in relative employment between different job categories is proportional to the changes in their relative gross wage rates.

For this report the ENV-Linkages Model is used in its static version[10] in order to perform a “comparative-statics” analysis. This type of analysis aims at assessing the structural changes associated with the policies in a long-run perspective where the levels of the potential physical capital stock and the potential number of workers in each job-category are given. In other words, dynamic behaviours (e.g. past saving to constitute capital stock, or past trainings, education and dynamics of the active population) do not play any role in this analysis. This type of analysis emphasises the long-run reallocation of resources across sectors that result from the implementation of a policy. While the total effective capital and employment are not flexible, the total capital stock and total employment by job category can be reallocated between economic sectors.

One motivation to run policy simulations in such a modelling framework is to identify any possible job-specific bottleneck that could limit the efficiency of the climate policies, in the absence of any changes in the economy-wide job-supply composition as resulting from education and training policies. This issue is critical for Cedefop and ILO (2011) that reports that “Many studies on green jobs highlight the risk that the large job creation potential of green industries might go unfulfilled because of prevalent skills shortages”. Beyond the accuracy of any shortages of labour for specific job,[11] the static analysis also helps to obtain information on which types of workers could benefit from the policy-induced structural changes and which would be affected through real income losses.

10 In previous work, the ENV-Linkages Model has mostly been used in its dynamic version to create economic projections, the relative emission pathways and to study both the economic consequences of environmental policies and the costs of inaction of environmental degradation.

11 OECD (2012a) stressed that “from the point of view of skill policy there appear to be relatively few unique green skills”.

Box 1. Net employment impacts of green growth policies

Climate and energy efficiency policies will likely reshape labour markets through the sectoral restructuring they imply. Green growth policies in principle do not modify labour market institutions (e.g. the functioning of the labour market itself) or the education system, but net employment impacts may still occur in two cases: first, if labour supply changes in response to the new economic structure and macroeconomic situation (like a change in aggregate wage); and secondly, if the economies in their initial situations are characterised by under employment in some part of the workforce. Insofar as activities expanding output are more labour-intensive than activities contracting output, a positive net impact on employment can be expected.

In this report, total employment for each job category is assumed to vary with the corresponding average net-of-taxes real wage, therefore the modelling framework can lead to positive (or negative) net-employment impact of the policies. This simplifying assumption about employment changes in response to wage aims at representing a realistic functioning of labour markets in the long run without an explicit characterisation of the underlying sources of under-employment. An additional difficulty is that regional labour market characteristics are often not transferable from one region to another: some developing countries are characterized by large local segmentation between rural and urban labour market (China), other regions show large informal labour market (India, Indonesia), while OECD countries are characterized by large disparities in across them in terms of unemployment, labour market participation by age, gender or average annual hours worked per worker.

The sources of unemployment are indeed numerous and difficult to characterise in a CGE context: (i) rigidities in wage setting adjustments that prevent wages to decrease to a level that implies full employment; (ii) temporary costs of adjusting labour to new market conditions; (iii) global demand imbalance; or (iv) from these sources together. Under-employment is a temporary phenomenon in this context and it is not taken into consideration since the report focuses on long-run impacts and not on short-term adjustment issues. In contrast, the so-called “long-run structural unemployment” is a phenomenon that largely depends on institutional rigidities on goods and labour markets (see Bassanini and Duval, 2007) and these are independent of the implementation of green growth policies, thus not relevant for this report.

Another reason why, in the long run, total employment could change in response to some policy is a change in the size of the labour force. The labour force could adjust to new conditions resulting from policy, if working-age population itself changes or through a change in labour force participation. Changes in working-age population do not usually take place in response to a green growth policy. The only change that could be expected is a change in the composition of labour by occupation of the working-age itself (e.g. stemming from education, training, migration). However, as already mentioned, such migrations from one job category to another are not taken into consideration in this analysis. Nevertheless, total employment could eventually change if labour force participation changes in reaction to the policy, which is implemented in this report (and tested in the sensitivity analysis).

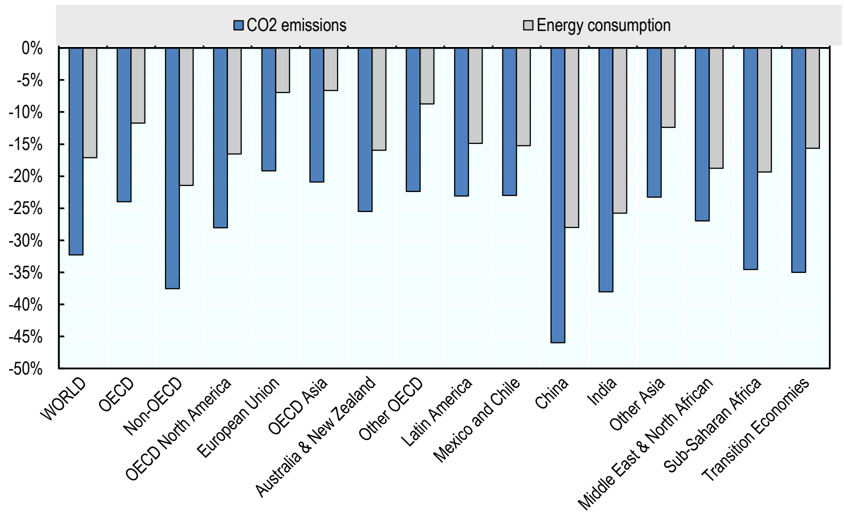
3. THE ECONOMIC AND EMPLOYMENT IMPACTS OF A CARBON TAX: THE CENTRAL SCENARIO

This section presents the labour market consequences of a *central scenario*. The *central scenario* implements a USD 50/tCO_2 uniform tax on CO_2 emissions resulting from economic activities – excluding emissions from land use, land-use change and forestry (LULUCF) – for all regions in the world.[12] The outputs of the policy simulation are compared to the reference equilibrium in which the carbon tax is not included. The implementation of any policy scenario implies changes in government budgets: the balancing rule assumed is that governments adjust income taxation rates (labour and non-labour alike) in order to restore the initial budgetary situation. In particular, this means that revenues from the carbon tax are generally used to decrease the households' income taxation rates, for a given income.

Agents react to the implementation of the *central scenario* by adapting their *production modes* and *consumption patterns*. The global CO_2 abatement induced by this USD 50/tCO_2 carbon tax, presented in Figure 3, equals -32% of CO_2 emissions globally (-27% when all GHGs emissions excluding LULUCF are considered). These emission reductions correspond to the global reductions needed to be in line with the 450 ppm target in 2035 (IEA, 2016).[13] Unsurprisingly given their low average emission-intensity of production, OECD countries decarbonize relatively less than Non-OECD countries (-24% and -37.5% respectively). Part of the emission reductions are accomplished through a reduction of energy use, which equals -18% globally (-14% for OECD countries and -20% for Non-OECD countries).

Figure 3. Change in CO_2 emissions and energy consumption by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011



Note: Excluding LULUCF emissions.
Source: OECD ENV-Linkages Model

12 While optimally a climate policy would also be applied to other GHGs, focusing on CO_2 only facilitates the comparison with the *mixed policy scenario* presented in Section 5, in which energy efficiency measures are also considered.

13 This target is very stringent in the second half of the century, while in 2035, the decarbonisation of the economy is not yet complete. This needs to be considered when interpreting the results, as the economic consequences of the *central scenario* are modest.

3.1 Consequences for the sectoral composition of production and employment

3.1.1 What are the effects on sectoral prices and output levels?

The main channel through which a carbon tax influences the economy is through increased energy costs for firms and households.[14] Due to carbon pricing, fossil fuels are more expensive, and so is electricity generation when it relies on them. Since energy inputs remain necessary in production and consumption, the energy bills increase for both firms and consumers.

As illustrated in the first column of There are opposing forces that drive sectoral output price changes in carbon-intensive sectors: the increase in energy costs from carbon taxes and the decreased demands for energy move prices in opposite directions. For instance, the 'Mining and fossil fuel supply' sectors are directly impacted through the reduced sales (demand for fuels) that follow the implementation of a carbon tax. The lower demand for the goods delivered by this sector puts negative pressure on the production price to ensure equilibrium between supply and demand. In other sectors characterized by a high share of energy expenditures, the higher production cost impact dominates; such that the demand for their output decreases while production prices increase. This is illustrated in **Error! Not a valid bookmark self-reference.** for sectors such as 'Fossil-fuel electricity' and "*energy-intensive industries"*, which have both lower production and increased production prices.

On the opposite side of the spectrum, sectors that provide substitutes for the taxed commodities are stimulated. This is the case for alternatives to electricity relying on fossil fuels (i.e. renewable and nuclear electricity generation, which are both included in 'Other electricity'), where both output levels and selling prices increase since demand for these goods is higher.

For this USD 50/tCO_2 carbon tax, sectors with low emission intensity are mostly affected through the negative macroeconomic *income effect* associated with lower disposable income, which drives down overall demand. This effect is however minor given the low impact on overall prices and outputs.

Finally, while the sectoral impacts of the carbon tax are similar across country groups, there are some differences between OECD and Non-OECD countries. For instance, as illustrated in Figure 4, the 'Fossil-fuel electricity' sector is more affected in Non-OECD countries (price increases by 33 %) than in OECD countries (price increases by 21 %). The negative impact on energy-intensive industries is also stronger in Non-OECD countries, since these industries represent a larger share of the economy and are more emission-intensive in Non-OECD than OECD countries.

Figure 4, the effect of the carbon tax on total economic output is quite modest. This is largely due to the fact that, in most sectors, energy costs amount to less than 5% of total input costs. Energy input costs indeed increase by 0.2% on average, while global output level and price do not vary significantly (-1% and -0.2% respectively).

This small effect at the aggregate level masks larger sectoral impacts. In fact, the main consequences of the increased energy costs caused by taxing carbon emissions are changes in *production modes* and *demand patterns*, which shift away from fossil-fuel use and, when possible, substitute fossil fuels with cleaner inputs. In particular, the more a sector is energy-intensive, the more its aggregate production cost will increase. The cost of fossil fuel electricity for instance increases, driving up the average selling price of

[14] Section 3.1 and Section 3.2 are kept concise since most of the discussion of general impacts have already been studied in previous work (Chateau and Saint-Martin, 2013).

electricity by 27%. Energy production and energy-intensive sectors are often forced to reduce output, thus decreasing the amount of carbon emitted through less energy input used.

There are opposing forces that drive sectoral output price changes in carbon-intensive sectors: the increase in energy costs from carbon taxes and the decreased demands for energy move prices in opposite directions. For instance, the ‘Mining and fossil fuel supply’ sectors are directly impacted through the reduced sales (demand for fuels) that follow the implementation of a carbon tax. The lower demand for the goods delivered by this sector puts negative pressure on the production price to ensure equilibrium between supply and demand. In other sectors characterized by a high share of energy expenditures, the higher production cost impact dominates; such that the demand for their output decreases while production prices increase. This is illustrated in **Error! Not a valid bookmark self-reference.** for sectors such as ‘Fossil-fuel electricity’ and “*energy-intensive industries”*, which have both lower production and increased production prices.

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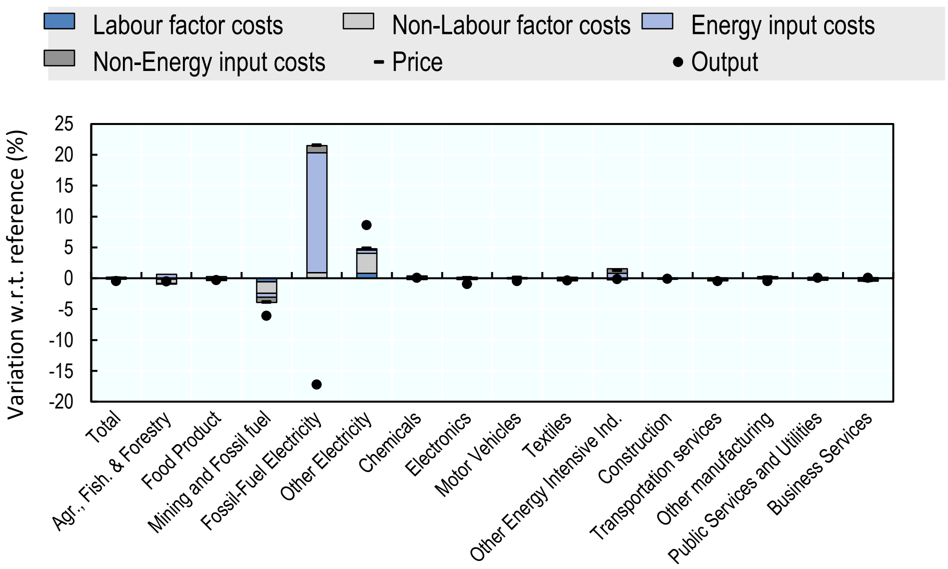
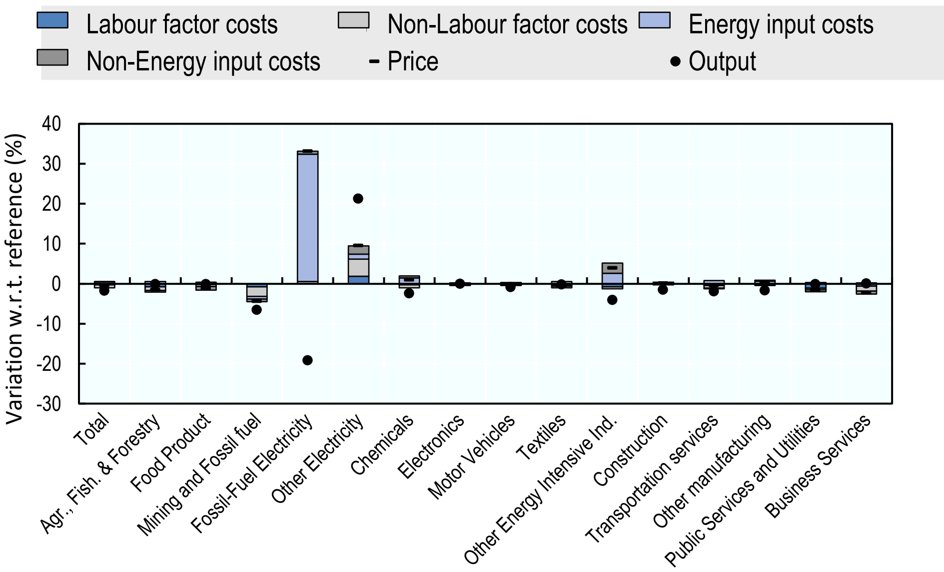
Figure 4. Change in output levels and price decomposition by sector, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011

Panel A. OECD Countries



Panel B. Non-OECD Countries



Note: Factor and input costs include taxes. The sum of factor and input costs give the overall price change, represented by the line marks while the dots show output levels.

Source: OECD ENV-Linkages Model

3.1.2 What are the implications for sectoral employment and wages?

Figure 5 reports, in addition to the changes in sectoral composition of output, the changes in sectoral composition of employment and gross wages which follow the implementation of the *central scenario*. Employment is substantially impacted in very few sectors only: ‘Mining and fossil fuel supply’, ‘Fossil-fuel electricity’ and ‘Other electricity’ sectors. Since those sectors are emission intensive and also not labour-intensive (cf. Figure 2), the aggregate impact on total employment is very small (less than 0.1%). But, this small aggregate effect hides disparities in sectors and job categories, which are analysed in the rest of Section 3.

Figure 6 suggests that employment largely follows output in heavily impacted sectors. For instance, employment in ‘Mining and fossil fuel supply’ decreases by 8% in OECD countries and 6% in Non-OECD countries. Conversely, employment increases in ‘Other electricity’ by 7% in OECD countries and 14% in Non-OECD countries.

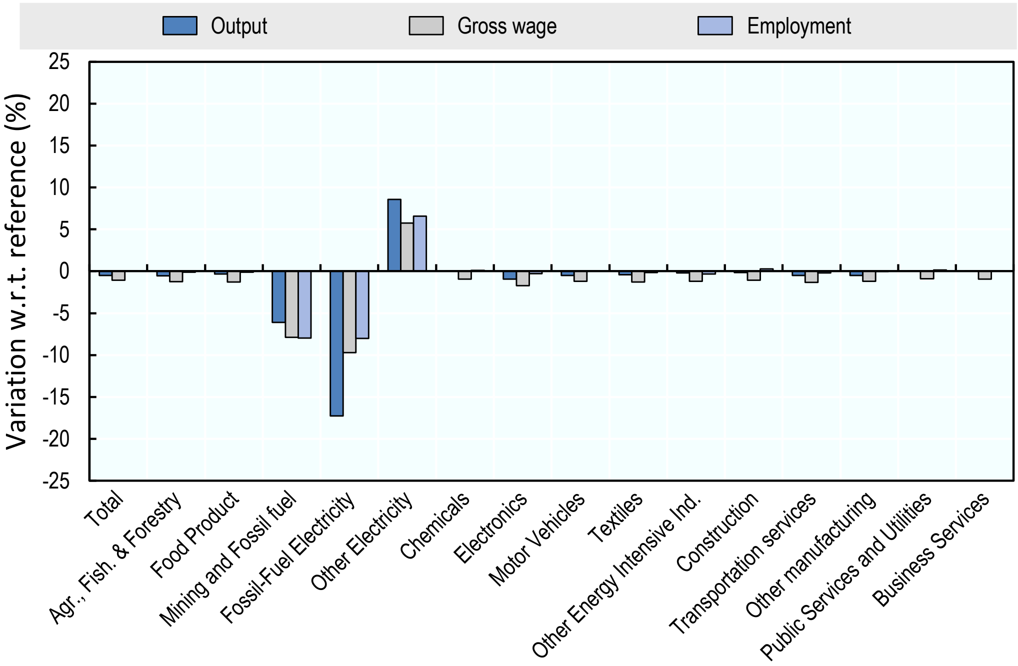
In some sectors, employment increase so as to substitute for energy inputs as they get more expensive with the carbon tax. This effect predominates in sectors with low emission intensity, mostly in Non-OECD countries. For instance, this substitution occurs in ‘Construction’ for OECD and Non-OECD countries, as well as in Non-OECD countries for ‘Electronics’, ‘Food products’, or ‘Motor vehicles’.

The overall impacts of the carbon tax on output, sectoral employment and gross wages are similar in OECD and Non-OECD countries. OECD countries have lower carbon intensity and are therefore less impacted (both for positive and negative variations) by the implementation of a carbon tax. Moreover, labour changes remain smaller than output changes; because sectoral reallocation of labour is costly and total labour supply by job category is fairly inelastic. As a consequence, wage rates absorb most of the economic shock.

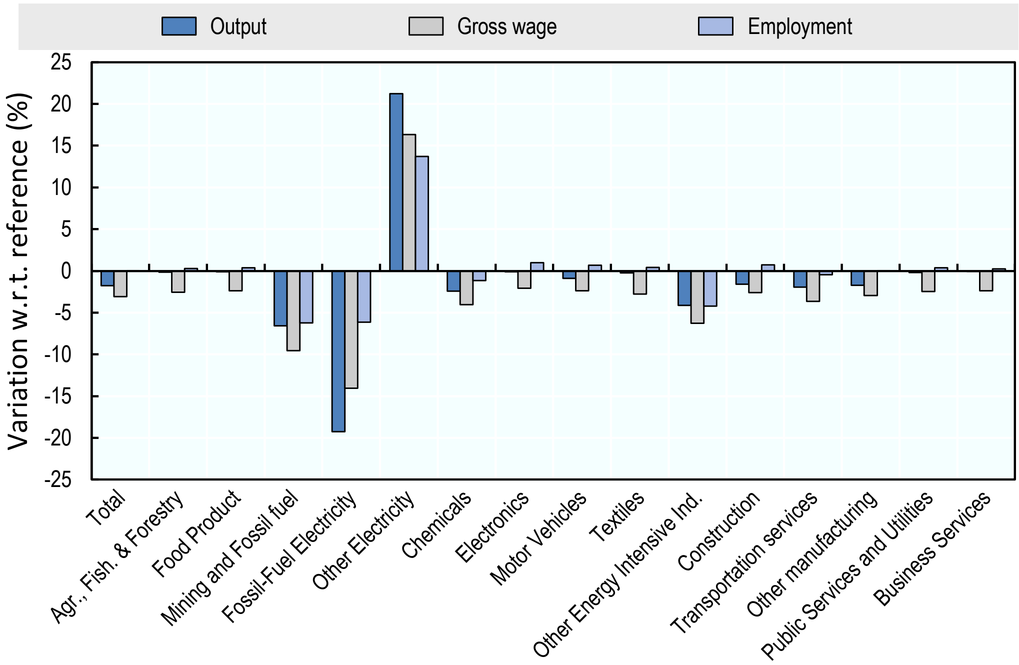
Figure 5. Change in output, employment and gross wage by sector, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011

Panel A – OECD Countries



Panel B – Non-OECD Countries



Source: OECD ENV-Linkages Model

3.2 Consequences for aggregate labour markets

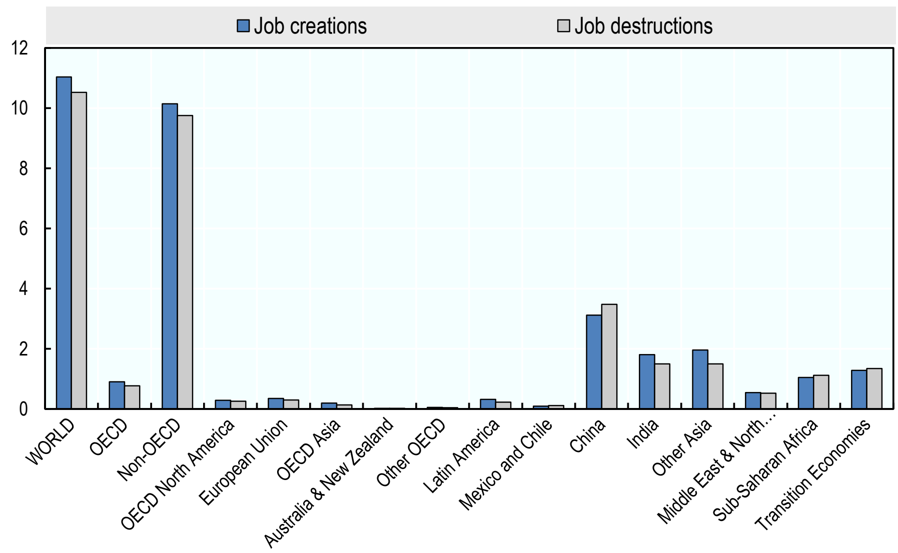
3.2.1 How are jobs reallocated at the regional level?

While the previous section showed that expansions and contractions, both of output and employment, can be large at the individual sectoral level, Figure 6 indicates that the overall reallocation of jobs (i.e. the sum of job creations and job destructions) is quite limited: lower than 2% of total employment in most regions of the world. An aggregate calculation indicates that the total job reallocation would only be 0.3% for OECD and 0.8% for Non-OECD countries, in the *central scenario*, corresponding to a rotation of 21 million jobs at the global level. The main explanation for the small number of job reallocations is that climate policies do not fundamentally reshape labour markets, as extensively discussed in OECD (2012a). Indeed, the heavily impacted sectors (mostly energy sectors) represent only a small share of total employment. A second explanation is that the responsiveness of labour supply, for each of the five job categories, is assumed to be only weakly affected by policies.

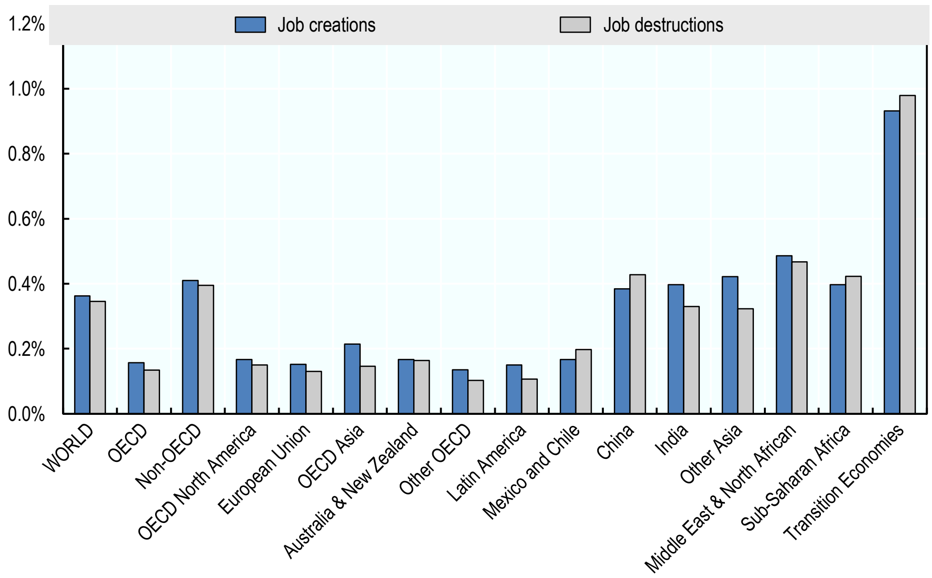
Facing identical tax rates of CO_2 emissions, Non-OECD countries present higher job reallocation rates, mostly because their production structure is more fossil-fuel dependent, both in terms of technologies and in the sectoral composition of GDP. Further, job reallocation rates are much higher in some specific countries. The total labour reallocation appears to be at least twice higher than the OECD average in countries where the economic structure is dominated by large fossil-fuel sectors (e.g., ‘Middle-East and North Africa’, ‘Transition economies’ or ‘Sub-Saharan Africa’).

Figure 6. Job reallocations by region, *central scenario*

Panel A. Absolute numbers (million jobs), 2011



Panel B. Percentage change w.r.t. reference equilibrium employment, 2011



Note: Job creations and the job destructions include those in all economic sectors, for all job categories taken together. Job reallocations constitute a measure of job rotation, adding up both job creations and destructions.

Source: OECD ENV-Linkages Model

3.2.2 What are the impacts on wages and expenses?

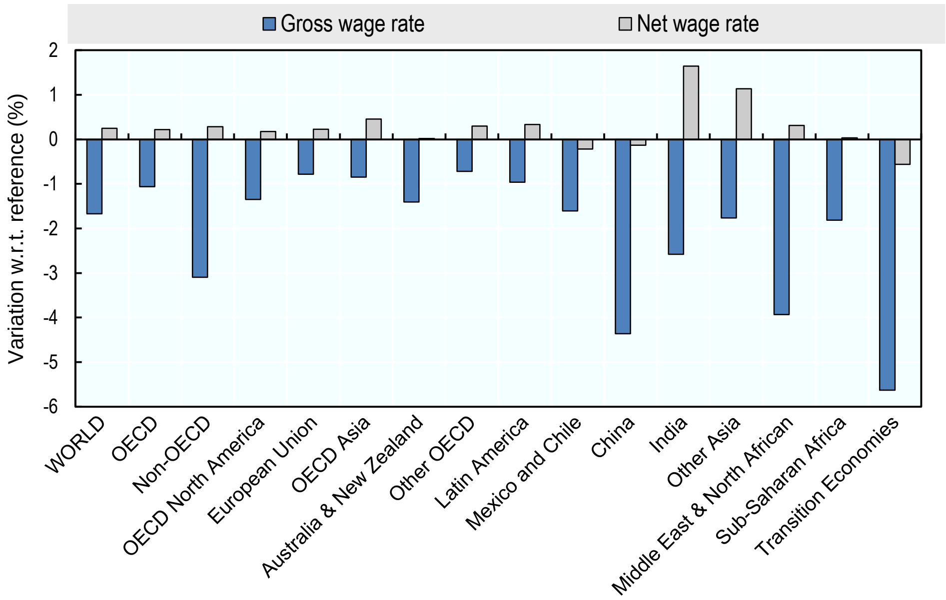
The overall direct impact of the implemented carbon tax is a recessive effect on activity, which in turn drives down gross wages, absorbing most of the economic shock. The carbon tax indeed adds an additional pressure on carbon emissions, which trickles down through the whole economy. But, the flipside is that there are extra fiscal revenues for the government. In the *central scenario*, the revenues from the carbon tax are uniformly used to decrease the household income tax rate (regardless of the origin of the revenue, whether it is labour, capital or others).

Figure 7 shows that for most countries real gross wages and real net wages (after payroll and income taxes) move in opposite directions, because the recycling scheme itself aims at offsetting the gross wage income losses.

This increase in net wage income allows for a limitation of the propagation of the increased energy prices (inclusive of carbon tax). As shown in Figure 8, the Consumer Price Index (CPI) indeed remains stable for most countries, ranging from -2% to 1%. This recycling scheme thus contains the negative impact to price to the consumer. In addition, energy expenses decrease in all regions, with changes from -4 to -17 %. Thus the carbon tax seems effective in reducing energy consumption. Despite increased energy prices, energy expenses indeed decrease through an energy consumption reduced by 6 to 30 % (see Figure 3).

Figure 7. Change in gross and net real wage rates by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011

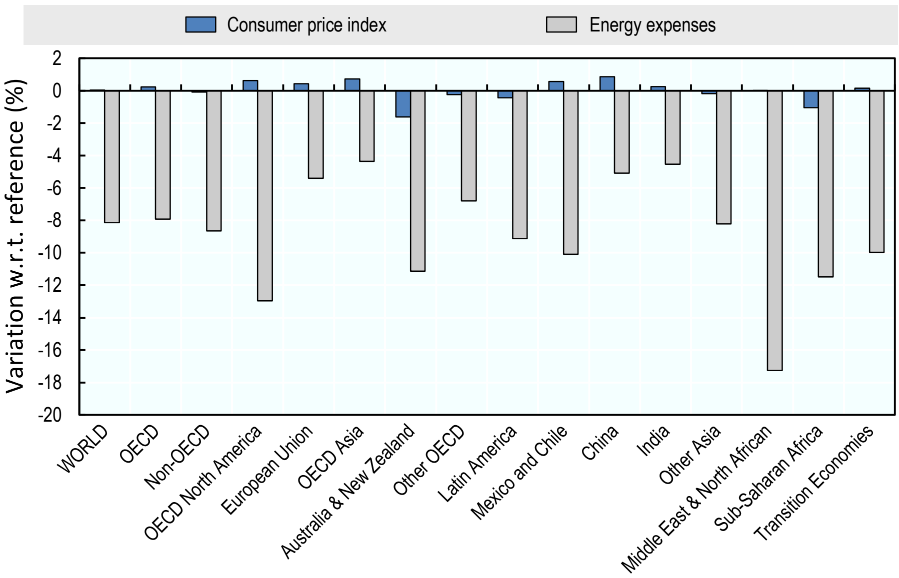


Note: Real gross wage refers to real wages (before payroll taxes are exacted paid by the employer or the employee), while real net wages refer to real wages, net of payroll taxes (paid both by employer and employee) as well as income taxes.

Source: OECD ENV-Linkages Model

Figure 8. Change in Consumer Price Index and households energy expenses by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011



Source: OECD ENV-Linkages Model

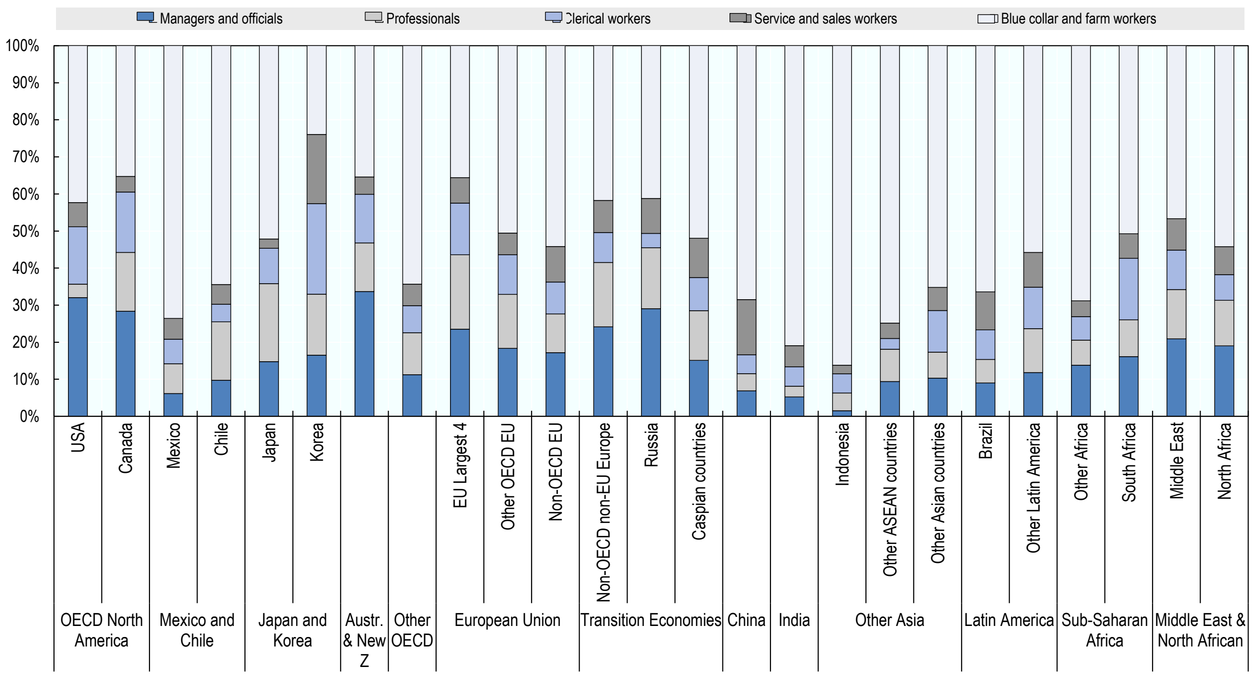
3.3 Consequences for the composition of labour

3.3.1 How are job categories affected by job reallocations?

At the aggregate level, the consequences of the implementation of the *central scenario* on both employment and aggregate (wage) income remain very limited. But, labour markets are segmented, because workers have different occupations. In this setting, three additional elements can explain changes in employment structure: the initial job structure of each sector by job category, the changes in the relative cost of labour for a given job category relative to the average cost of labour in a given sector, and the relative scarcity of workers in each category at the aggregate level. Therefore, studying the segmented labour markets helps understanding which job categories are more exposed to job reallocations and income losses.

As shown in Figure 9, the impact of the *central scenario* on the different segments of the labour market are not uniform. Indeed, low-skilled workers (i.e. 'Blue collar and farm workers') account for the large majority of total job reallocations, with on average 2/3 of total reallocations. For instance, job reallocations for low-skilled workers amount to 81% for India, 68% for the People's Republic of China (hereafter China), and 86% for Indonesia. In OECD countries, job reallocations for low-skilled workers are still large but smaller relative to other categories of workers, since the categories 'Managers and officials' or 'Professionals' contribute also to a large part of total job reallocations (21% and 12% respectively).

Figure 9. Job reallocation shares by job category and by region, *central scenario*



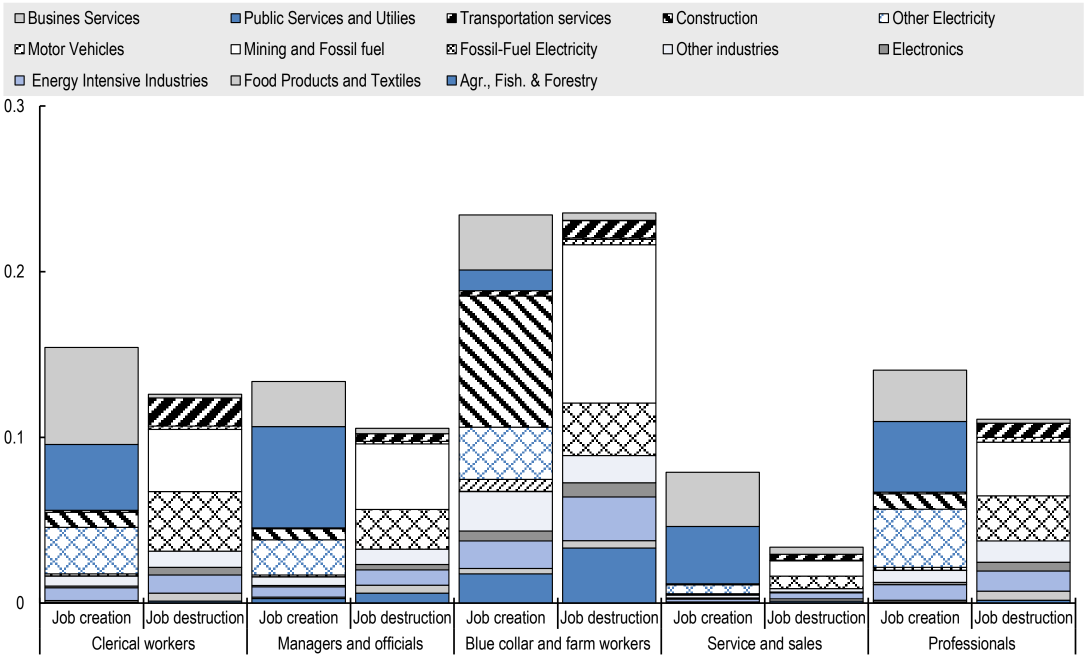
Note: The job reallocation shares are presented in percentage of total regional reallocations.

Source: OECD ENV-Linkages Model

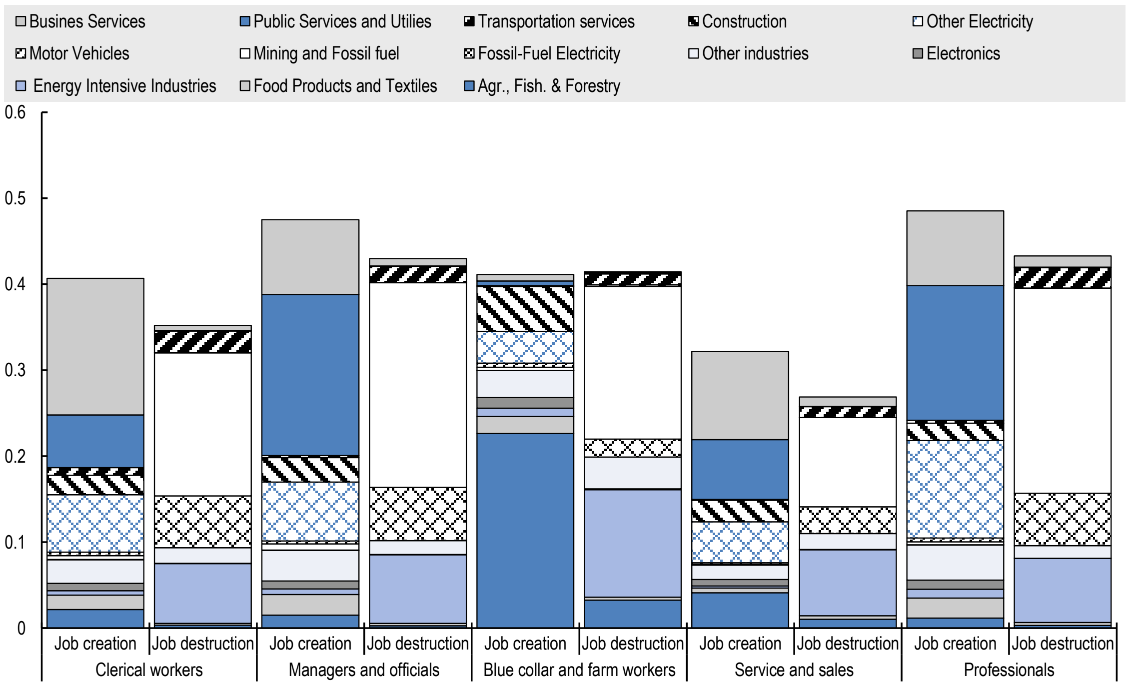
Figure 10. Change in sectoral composition of job creations and job destructions by job category and by aggregate sectors, *central scenario*

Percentage change in employment relative to total employment of the category in the reference equilibrium, 2011

Panel A. OECD countries



Panel B. Non-OECD countries



Note: 'Energy supply and mining' aggregates 'Mining and fossil fuel supply', 'Fossil-fuel electricity' and 'Other electricity'. For 'Mining and fossil fuel supply' and 'Fossil-fuel electricity' only job destructions occur, while all the job creations occur in 'Other electricity'.

Source: OECD ENV-Linkages Model

Figure 10 reports the sectoral composition of job destructions and creations for each job category (as a percentage of total employment in the category) in the *central scenario* both for OECD and Non-OECD countries. The figure shows that the declining energy sectors will systematically proceed to job destructions for all job categories. A deeper examination at a more disaggregated level would show that this is true for all regions and all individual declining energy sectors. Further, it could be shown that these job destructions in energy sectors are even the predominant source of job destructions in most countries. At the global level, job destructions in declining energy sectors account for around 53% of total job destructions, and 26% in declining energy intensive industries.

However, the share of job destructions in energy sectors out of total job destructions varies across regions, following the relative importance of these sectors in each region. In OECD countries, job destructions in the energy sector account for 56% in the *central scenario*, while for Non-OECD countries they attain 53%. In parallel, the job destruction in energy-intensive sectors reach 10% in OECD countries and 27% in Non-OECD countries.

These job destructions in energy sectors explains why Figure 10 stressed that the majority of job destructions will hit ‘Blue collar and farm workers’ in most countries. Since half (or more) of the total labour costs in the energy sectors is composed of the labour cost of this job category, then energy sector accounts generally for most of low-skilled workers job destructions. A second explanation why job destructions for ‘Blue collar and farm workers’ are relatively more important is that *energy intensive industries* also employ many workers in this category and are also relatively more impacted than other sectors by the carbon tax.

As a consequence, in both regional areas, the ‘Blue collar and farm workers’ category is subject to the highest degree of job rotation. A regional analysis could show that in a few regions the job reallocations could be higher in the ‘Professionals’ category (‘Other Asian’ and ‘Other sub-Saharan African’ countries) or in the ‘Clerical workers’ category (Brazil, India and Indonesia) than in the ‘Blue collar and farm workers’ category. However, this last category still shows a higher degree of job rotation than the average across all job categories.

As already stated, in most OECD countries high-level workers (i.e. ‘Managers and officials’ and ‘Professionals’) are also characterised by large turnovers. This reflects, first, the lower share of energy sectors in these economies when a large part of job reallocations occur out of these sectors towards cleaner sectors (e.g. ‘Services’ and ‘Other Industries’). Second, energy sectors (and to a lesser extent energy intensive industries) are characterized by a skill-structure of labour that relies more on high-skilled workers than in Non-OECD countries.[15]

Another general characteristic, indicated in Figure 9 and Figure 10, is that the *central scenario* the category of ‘Service and sales workers’ is the one where the turnover is the lowest, both in relative to the average and in absolute number.

Besides these general features, other common characteristics are also shared by most countries, but cannot be generalized at the global level. Generally, energy-intensive sectors (e.g. ‘Transportation services’ and

15 A more detailed sectoral analysis (not presented here) reveals that, in certain OECD countries, some energy producing sectors employ a relative higher share of ‘Professionals’ and ‘Managers and officials’ than the economy-wide average. This situation occurs in electricity generation and oil and gas extraction as well as some specific energy intensive industries (such as air transport and chemicals). Pollin et al. (2009) insist on that for the US the proportion of high skilled workers in traditional fossil-fuel sectors is larger than in energy efficient building construction sector, which is something confirmed in the database used for this analysis.

energy intensive industries) record total net job destructions, since their demand is negatively impacted by the higher energy input costs. Since in general these sectors rely more intensively on ‘Blue collar and farm workers’ than the average of the economy, they will destroy more jobs for low-skilled workers in absolute value than any other type of job.

The ‘Business services’ and ‘Government services’ sectors generally contribute to job creations, since they are relatively more labour-intensive and less energy-intensive than the rest of the economy. Thus, these sectors are less impacted by the increase in energy prices while labour demand will benefit from lower economy-wide wage rates. Moreover, the corresponding job creations in the services sectors are generally symmetrical across all types of jobs (in absolute value, they account for more ‘Managers and officials’ job creations, as illustrated in Figure 10).

3.3.2 How are labour wages affected for different job categories?

The success of the policies depends on the capacity of the workforce to adapt to structural changes implied by the policies. In the current modelling framework this adaptation process of the workforce remains limited: workers cannot switch job categories and total employment does not fluctuate significantly. Thus, the total number of workers in each job category does not vary substantially in response to policies. As a consequence, most of the adaptation happens for workers moving across sectors. This particular context could help to identify sectors where possible “shortages” of certain job category could appear or, on the contrary, sectors that are in “excess” of certain job categories.

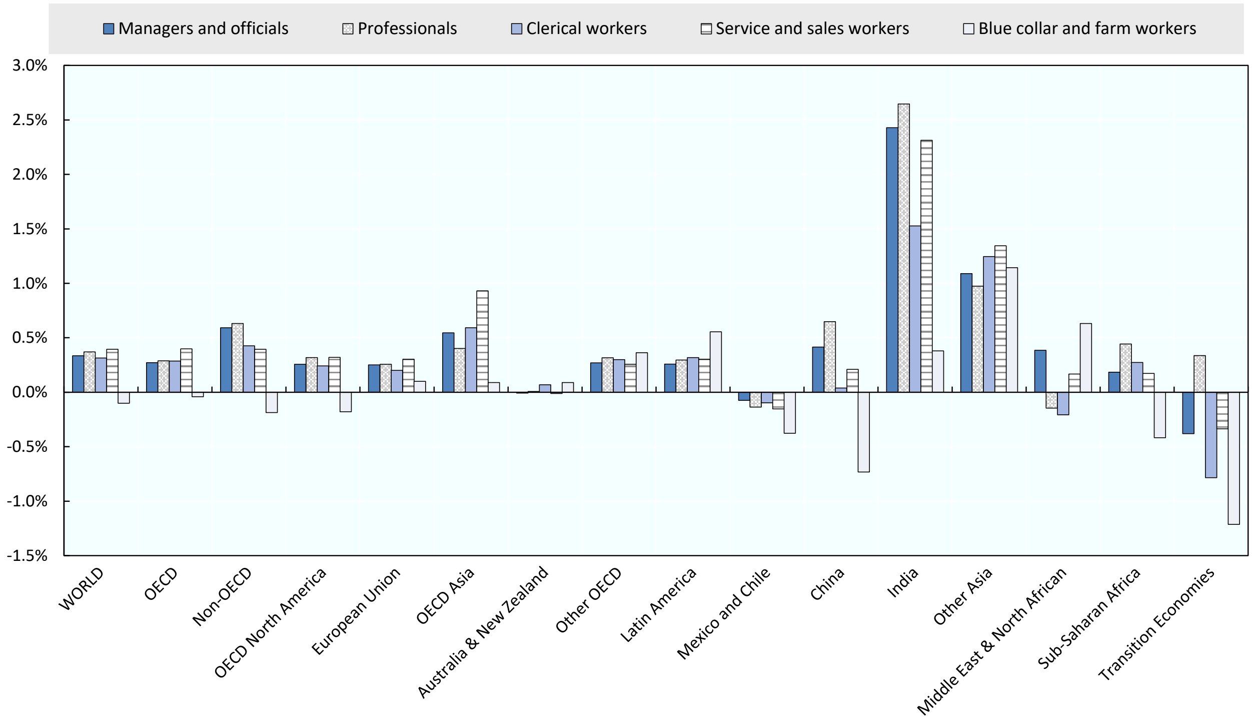
An easy way to deal indirectly with this issue is to look at the changes in wage rates by job category as reported in Figure 11.[16] Therefore identifying wages for specific job categories that “overreact” relative to the average wage will help to identify the possible shortages (excess) of labour for a given category if the changes in the relative wage is significantly positive (negative).[17]

16 The changes in wage structure are very different across countries. Thus, only some general features could be provided at global level in this section. Nevertheless, all region-specific characteristics as well as their explanation are entirely reported in Annex D.

17 Given the actual assumptions about the functioning of the labour market, in the model, the real gross-of-tax-wage rates are the variables that adjust in order to clear the different segments of the labour market. Two main assumptions explain that wage rates absorb most of the labour impacts of the policy: the fixed total labour supply by job category, that will prevent the simulations to give results about net job creations or job destructions, at the macroeconomic level; and the extent to which some extent workers in a given job category could still move from one sector to another, with some costs and rigidities of course but still they could move, while in reality some skills are really sector specific in such a way temporary job shortages and unemployment should exist for such specific jobs: in other words an engineer in oil prospection could no become in one day a nuclear engineer, or a steelworker to become a farmer.

Figure 11. Change in the distribution of net real wage rates by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011



Source: OECD ENV-Linkages Model

In the *central scenario,* no specific jobs types (outside energy sectors) seem to be situations of either "excess" or "shortages" of jobs in any specific sector. As a general rule, sectors that are more intensive in labour and less intensive in energy will generally improve wages relative to energy intensive sectors but this does not really help to reach a conclusion on the specific jobs.

The broad picture is that, given the recycling scheme that lowers income tax rates, all categories are gaining in all countries, with a few exceptions. All economies indeed have a net gain, except 'Mexico and Chile' and 'Transition Economies'. 'Mexico and Chile' lose overall because the extra revenues from the carbon tax that are used to decrease income taxes are not sufficient to offset the negative effects of the carbon tax. 'Transition Economies' suffer from large losses in fossil fuel exports.

As "Blue collar and farm workers" are the most concerned by the job rotation, they are the category that loses most or gains less everywhere. This is particularly true in Asia, including China and India. Results for the 'Middle East and North Africa' also differ from other regions, as 'Clerical workers' lose when other categories gain. This effect might stem from the particular job structure in those countries, which are strongly affected by the carbon tax.

Notwithstanding these differences, a number of general conclusions can be drawn. Specifically, this analysis stresses the need to address the situation of workers in polluting energy sectors concerning the implementation of the carbon tax, while low-skilled workers seem slightly more affected than the average worker, their relative situation changes are not marked enough to stress this as a risk.

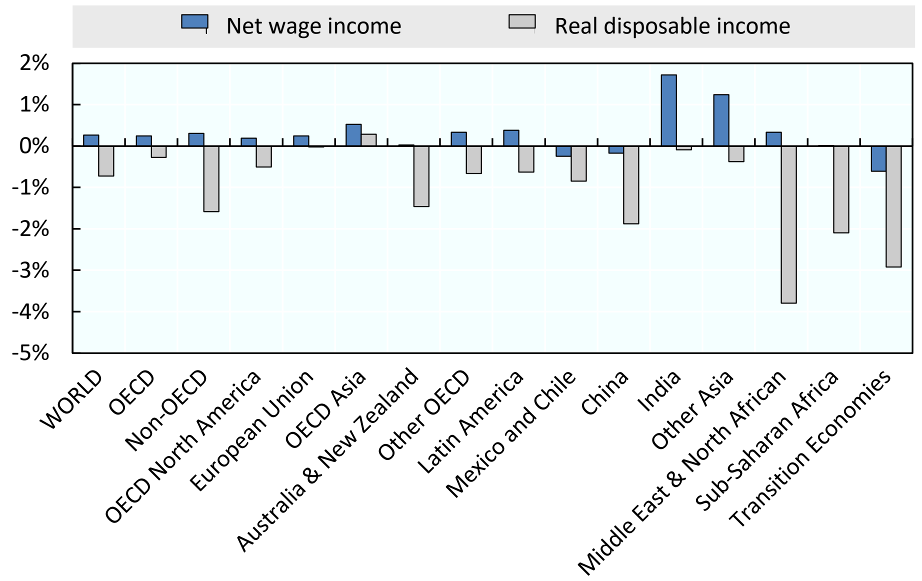
3.4 Distributional impacts on income

3.4.1 How is income affected at the aggregate regional level?

From the reconfiguration of labour markets that results from the structural changes induced by the carbon tax, it is possible to identify the potential "winners" and "losers" among workers of the different job categories. These distributional consequences occur because workers are not entirely interchangeable.[18]

Figure 12. Change in household real disposable income by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011



Notes:

The "net real wage income" is defined as: the real gross wage income received, net of income taxation (paid by the household) and of any factor income taxation/subsidy (paid by firms). The average is calculated across all workers in the economy.

The real disposable income is the sum of all incomes received by households from their labour and from their capital, land and natural-resources ownership (net of any income taxation and factor taxation or subsidy) deflated by the CPI.

Source: OECD ENV-Linkages Model

Thus, the carbon tax will affect differently income between labour and non-labour income sources. As indicated in Figure 12, which reports the changes in wage and total real incomes, the carbon tax favours wage earners over capital and natural-resources owners in all countries (and to a larger extent in fossil-fuel producer countries). Indeed, when taxes (or subsidies) resulting from policies are taken into account in calculating workers' average net-of-tax real wage income, this income increases slightly in most countries. However, to obtain an overall impact, all income sources should be considered. But if all income sources were taken together (e.g. changes in total real income), most countries experience a moderate total income loss. In general, fossil fuel exporters will observe the largest income loss, through reduced revenues from

[18] In this paper the focus on real incomes instead of a welfare indicator)result from the assumption of one "representative" household that could be seen as perceiving incomes from various sources, including various labour categories. In this context only income sources differ across workers, not utility or capital income.

exports, while some regions, such as 'OECD Asia' and some European countries, will experience net income gains.

3.4.2 How is income affected for different job categories?

Another key result is that policies will change the allocation of the total wage income across the different job categories. Figure 13 presents the distribution of the impacts of the carbon tax on the distribution of net-of-tax real wage income across labour income for each job categories. The figure reveals differences in impacts between job categories. Labour income impacts on the different kinds of workers are variable across countries and across the different job categories.

Beyond these absolute changes, the examination of the categories of the workers that gain or lose relatively to the other categories give an indication of the distributive impact of the policy considered. The first remarkable feature is that generally the category of 'Blue collar and farm workers' is polarized in terms of changes in the distribution of net wage income: it is either the category that benefits most from the policy or the one that is most affected, depending on the region considered. 'Blue collar and farm workers' are likely to be "winners" in regions such as 'Australia and New Zealand', 'Other OECD', 'Latin America' and 'Middle East and North Africa'. In contrast, they appear to lose compared to other job categories in other regions, as in India and 'Mexico and Chile'. Moreover, in regions such as 'Mexico and Chile', all other job categories see their relative wage income reduced relative to the average among all categories while the contrary happens in India (all categories win relative to 'Blue collar and farm workers'). The biggest tensions are likely to occur in countries where they are absolute losers like the US, Canada or China.

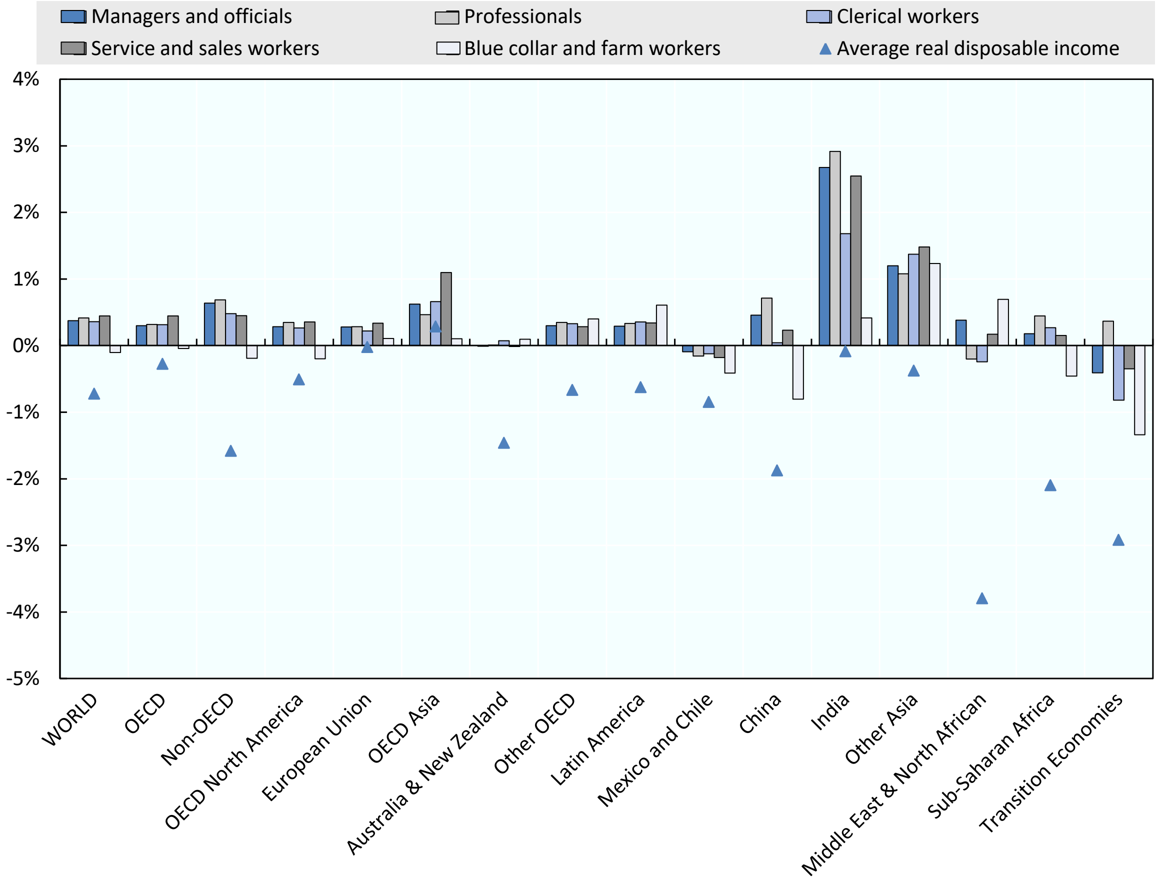
Under the *central scenario*, workers in the categories 'Service and sales workers', 'Professionals' and 'Managers and officials' generally benefit more from the policy than the other job categories.[19] This is not surprising since these types of jobs are more represented in the sectors that are the less affected by the policy (like services sectors). On the contrary, low-skilled workers are generally less well-off with the carbon tax than the other types of workers (except in some fossil-fuel producer countries).

This section showed that the distributional impacts (measured by differences in labour income of the different individuals) resulting from implementation of a carbon tax, can create categories of population at risk. Further, the effects of policies on the different job categories would differ across regions. These distributive impacts however, are likely to change if the policies are accompanied with alternative redistribution scheme options that offset the negative impacts for the losers of the policy (like different income taxation rate or labour support to sectors that massively employ these workers).

[19] One exception is 'Managers and officials' in 'Middle East and North Africa' since a large part of them are employed in declining fossil-fuel sectors.

Figure 13. Change in the distribution of income by region, *central scenario*

Percentage change w.r.t. reference equilibrium, 2011



Note: Bars correspond to net wage income while triangles refer to real disposable income.

Source: OECD ENV-Linkages Model

4. THE IMPORTANCE OF THE POLICY STRINGENCY AND REVENUE RECYCLING: SENSITIVITY ANALYSIS ON THE *CENTRAL SCENARIO*

The results presented in Section 3 depend on the way the policy simulations are set up in the modelling framework. This section explores the robustness of the results to two key modelling assumptions: the level of the carbon tax and the scheme used to recycle the revenues from carbon taxation. The stringency of the climate policy (e.g. the level of the carbon tax) can influence the results as the reactions to the policy shocks are non-linear. The revenue recycling scheme used can also significantly affect the economic consequences of the carbon tax as the distributional impacts of various recycling instruments will be different.

4.1 The impact of carbon tax stringency

For labour markets, the evolution of wages plays a central role. Section 3 found that in the *central scenario* gross wages decrease because the implementation of the carbon tax reduces overall economic activity. As a result, firms react by adjusting their production to lower levels, implying reductions in both capital rental and wage rate paid by firms. In contrast, net wages (net of income tax) increase slightly thanks to the recycling of carbon tax revenues that reduce income taxes. This section assesses the sensitivity of these results to a range of carbon taxes from USD 5/tCO_2 to USD 100/tCO_2. The objective is to identify the level from which workers lose out and thus the vulnerabilities in different world regions and across job categories.

4.1.1 What are the impacts of different carbon tax levels on the aggregate labour market?

Figure 14 reports changes in gross and net wage rates for a range of carbon taxes from USD 5/tCO_2 to USD 100 /tCO_2. It clearly shows the increasing wedge between gross and net wages. The effects of the carbon tax on gross wages are straightforward: gross wages decrease with increasing levels of carbon taxes. As was seen previously, OECD countries are less impacted than Non-OECD countries: the reduction of gross wages is about three times higher in Non-OECD countries than in OECD countries.[20]

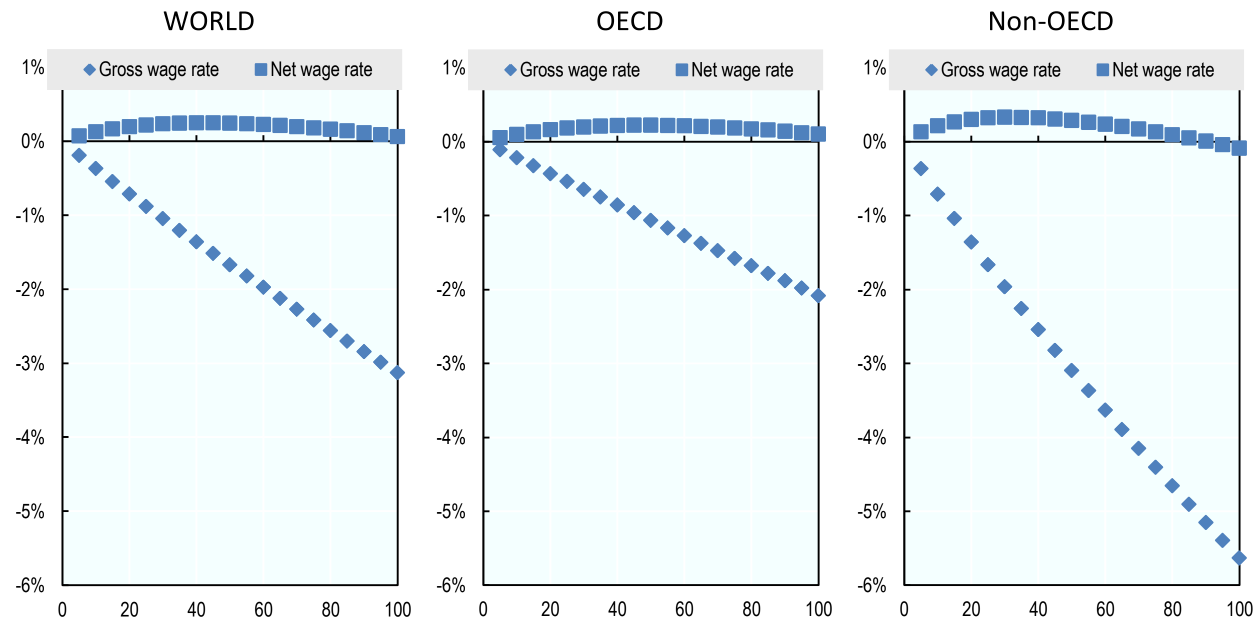
Net wages (net of income tax) in

[20] This holds for a uniform global carbon tax, which triggers much higher carbon abatement in Non-OECD countries. There obviously is room to improve the implementation of the carbon tax policy with the integration of the specificities of each country.

Figure 14 show an inversed U-shaped curve: net wages increase for low levels of the carbon tax, but decrease for higher taxes. This behaviour is similar to that of a "Laffer curve": there is a trade-off between the increasing cost of the carbon tax and the increase in labour supply, which suggests the existence of a value for the carbon tax that maximises net wages. The tipping point for OECD countries is roughly USD 50/tCO2, while for Non-OECD countries, it is close to USD 25/tCO_2. This gap hinges on the difference in the economic and fiscal structure of the two sets of countries, and seems to indicate that OECD countries can more easily absorb higher levels of carbon taxes. This could be an argument to advocate for a differentiated regime of carbon tax, adapted to the specificities of countries, potentially with different sets of objectives (e.g. growth, employment, government debt reduction…).

Figure 14. Change in wage rates for various levels of carbon tax

Percentage change w.r.t. reference equilibrium, 2011



Source: OECD ENV-Linkages Model

For higher levels of carbon taxes (for instance, higher than USD 90/tCO2 for Non-OECD countries), the positive result of lower labour taxes from the recycling mechanism for net wages gets outweighed by the negative impact on total output, and net wages actually decrease below reference levels.

Unsurprisingly, net job creations (illustrated in Figure 15) follow a similar pattern: net job creations increase for low levels of carbon taxes, up to a tipping point where job destructions outweigh job creations. These tipping points occur at the same values of carbon taxes as the net wages. The qualitatively different result is that for Non-OECD countries, net job destructions occur for levels of carbon tax that are not high (lower than USD 75/tCO_2). This result pushes global net job destructions for taxes higher than USD 75/tCO_2.

Figure 15. Net job creations for various levels of carbon tax

Percentage change w.r.t. reference equilibrium, 2011

Source: OECD ENV-Linkages Model

4.1.2 What are the distributional impacts of different carbon tax levels?

Figure 16 presents the evolution of net wage incomes by job category: it illustrates clearly that different job categories have different levels of vulnerability towards the carbon tax (as measured by the level of carbon tax from which they start to lose wage income). The profile is similar to that of net wage rates and job creations presented in Section 3. The tipping point is around USD 12-20/tCO2 across all countries, with net losses of income for carbon taxes lower than USD 40/tCO_2, even for OECD countries.

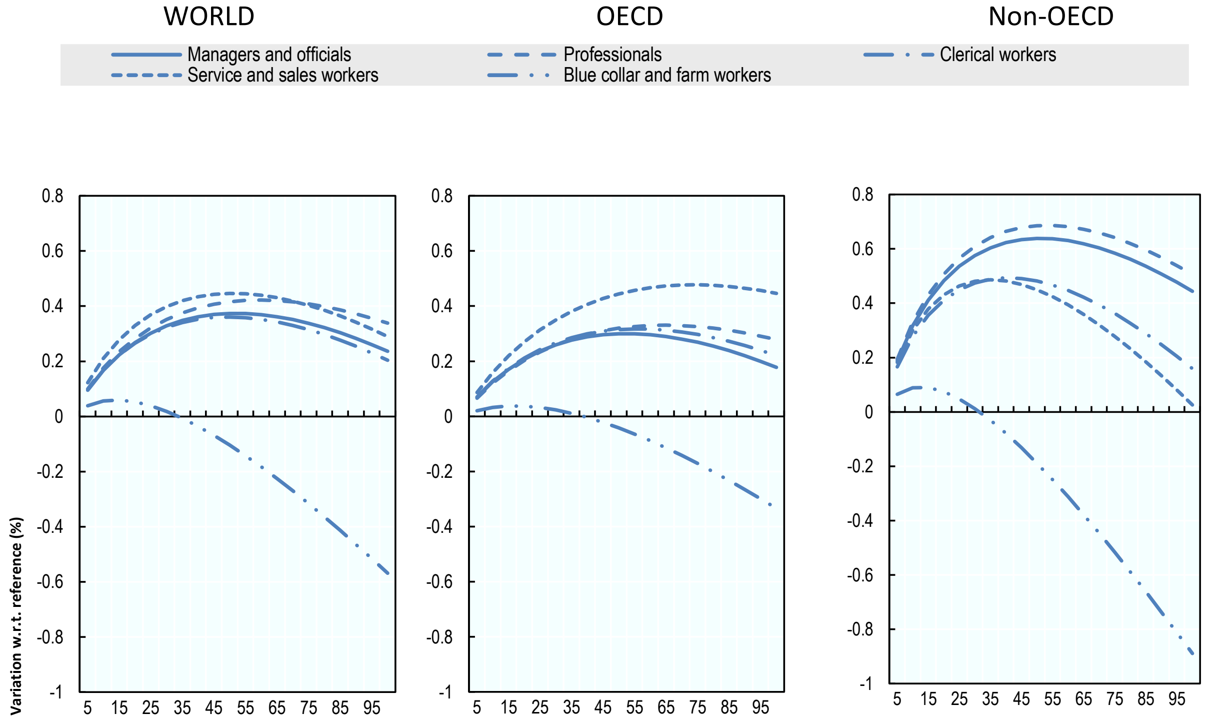
Moreover, Figure 16 shows much more substantial income losses (up to 1%) for ‘ Agriculture and Production workers’ than for the others. The net gain in wage income for this job category is only visible for very low levels of carbon taxes. As explained in Section 3, the ‘Agriculture and Production workers’ are indeed the most affected category.

In OECD countries, for taxes below USD 100/tCO_2, all other job categories show net gains, with the highest increase for ‘Service and sales workers’ (up to 0.5% of net labour income). For Non-OECD countries, two different classes emerge. First, ‘Managers and officials’ and ‘Professionals’ clearly show net gains (over 0.5%) over all the range. In contrast, ‘Service and sales workers’ and ‘Clerical workers’ show a very early tipping point (about USD 30/tCO_2), with no net gains at taxes around USD 100/tCO_2.

Overall, this sensitivity analysis shows that the identified mechanisms are robust to varying the degree of stringency of the carbon tax. However, the negative effect of the carbon tax outweighs the positive effect on net wages identified in the central scenario in the higher range of carbon taxes. Furthermore, this analysis clearly reinforces the result that the workers that are the most vulnerable of having a decline in their net wages are ‘Agriculture and Production workers’. In addition, ‘Service and sales workers’ and ‘Clerical workers’ are at risk when increasing the carbon tax in Non-OECD countries.

Figure 16. Change in wage income by skill for various levels of the carbon tax

Percentage change w.r.t. reference equilibrium, 2011



Source: OECD ENV-Linkages Model

4.2 The effects of different carbon revenues recycling on wage income distribution across workers

A central assumption on the results of the *central scenario* is the way the revenues from the carbon tax are spent by the government. The intensity of the labour supply reaction to net wage changes constitutes a key assumption as well. It links the amount of workers that join (leave) the labour force with salary increases (decreases). Three alternative schemes are tested in this section: (i) a reduction of the income tax (*central case*) where all household revenues are decreased, (ii) a lump-sum transfer where households receive uniformly the revenues from the carbon tax (regardless of their wage income), and (iii) a reduction in wage income tax rates.

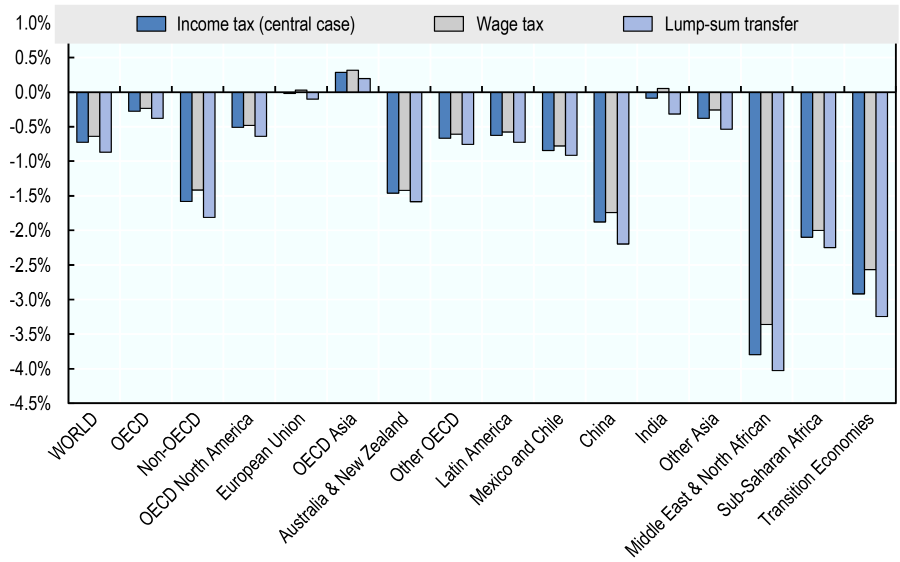
4.2.1 How does the use of carbon tax revenues influence the results?

Figure 17, Panel A shows that changes in real disposable income are not very sensitive to the nature of the recycling scheme. The variations are lower than 0.7% between recycling schemes, for a variation in real disposable income of [-4% – 0.5%]. As expected, recycling carbon tax revenues with a uniform transfer will reduce income as it does not stimulate labour supply. The alternative recycling with wage income taxation would, on the contrary, have a positive impact on income compared to the two other recycling schemes since it would directly target labour supply

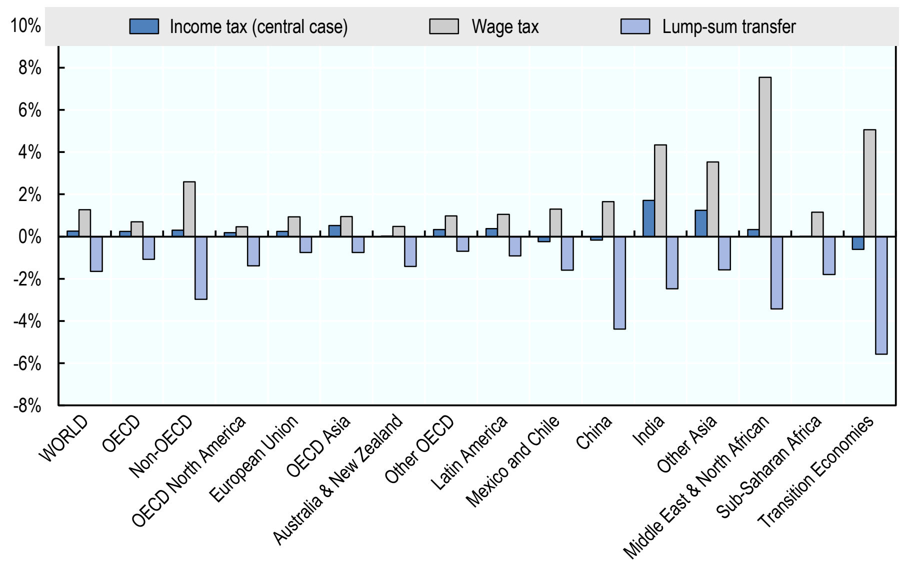
Figure 17. Change in income for alternative recycling schemes by region for a USD 50/tCO_2 carbon tax

Percentage change w.r.t. reference equilibrium, 2011

Panel A. Real disposable income



Panel B. Net wage income



Source: OECD ENV-Linkages Model

Figure 17, Panel B shows that net wage income is much more impacted. The variations can be as high as 11% between recycling schemes, for a variation of net wage income between -6% and 8%. Not only is the amplitude much higher for net wage income, the overall impact of the recycling scheme can be either negative or positive and change between recycling schemes. While recycling carbon tax revenues into reducing wage income tax (at the level of the country) unsurprisingly allows for an increase in net wage rates (0.5% to 8%), recycling them in a lump-sum transfer to households is accompanied by a decrease in net wage rates (-1% to -6%). The central case (i.e. a recycling through a reduction in total income tax) gives a result between those two polar cases.

The differences in results between the three recycling schemes considered are larger for higher values of the elasticity of employment to net wage rate. Depending on the degree of sensitivity of labour supply to wage changes, the adjustment of labour markets to the carbon tax can rely more on adjustments of employment or on adjustments of net wage rates. Table 2 shows the extreme cases: when the elasticity is 0, employment is fixed and the pressure from the carbon tax is absorbed through a change in wage rates. At the other extreme, when the elasticity is infinite (*inf*), the pressure is absorbed through a change in employment.

While impacts are larger for Non-OECD countries, Table 2 shows similar results for OECD and Non-OECD countries. In addition, employment changes – both reallocations and net creations – are larger for higher elasticities (for instance, the range of total job reallocation is [0.3-1.2] for OECD and [0.8-3.25] for non-OCDE). Conversely, wage rates are less impacted when labour supply is more flexible. A consequence is that for reasonable labour supply response (elasticity between 0 and 2) net wage income changes are relatively stable.

Table 2. Interaction between labour supply reaction and alternative recycling schemes

	OECD					Non-OECD				
Elasticityof Employment to net of tax wage rate	Net wage income	Real disposal income	Real net wage	Net job creations	Job reallocations	Net wage income	Real disposal income	Real net wage	Net job creations	Job reallocations
Recycling Policy: Income Tax										
0	0.24	-0.30	0.24	0.00	0.28	0.30	-1.60	0.30	0.00	0.79
0.1	**0.24**	**-0.28**	**0.22**	**0.02**	**0.29**	**0.30**	**-1.58**	**0.29**	**0.02**	**0.81**
1	0.27	-0.18	0.13	0.14	0.39	0.32	-1.51	0.21	0.11	0.94
inf	0.31	-0.04	0.01	0.30	0.55	0.33	-1.41	0.09	0.24	1.22
Recycling Policy: Lump-sum Transfer										
0	-1.07	-0.30	-1.07	0.00	0.28	-3.01	-1.60	-3.01	0.00	0.79
0.1	-1.08	-0.38	-0.99	-0.10	0.27	-2.97	-1.81	-2.68	-0.30	0.70
1	-1.16	-0.78	-0.63	-0.53	0.60	-2.84	-2.71	-1.32	-1.54	1.70
inf	-1.33	-1.37	-0.22	-1.12	1.17	-2.73	-3.69	0.13	-2.85	2.97
Recycling Policy: Wage Income Tax										
0	0.69	-0.30	0.69	0.00	0.28	2.56	-1.60	2.56	0.00	0.79
0.1	0.70	-0.24	0.62	0.08	0.33	2.59	-1.41	2.36	0.22	0.94
1	0.76	0.04	0.31	0.45	0.64	2.74	-0.54	1.40	1.32	1.86
inf	0.85	0.44	-0.10	0.96	1.12	2.95	0.62	0.12	2.83	3.24

Notes:

- These numbers are percentage deviation from reference.
- The *central scenario* results are in bold.

Source: OECD ENV-Linkages Model.

4.2.2 How do distributional impacts change with different recycling schemes?

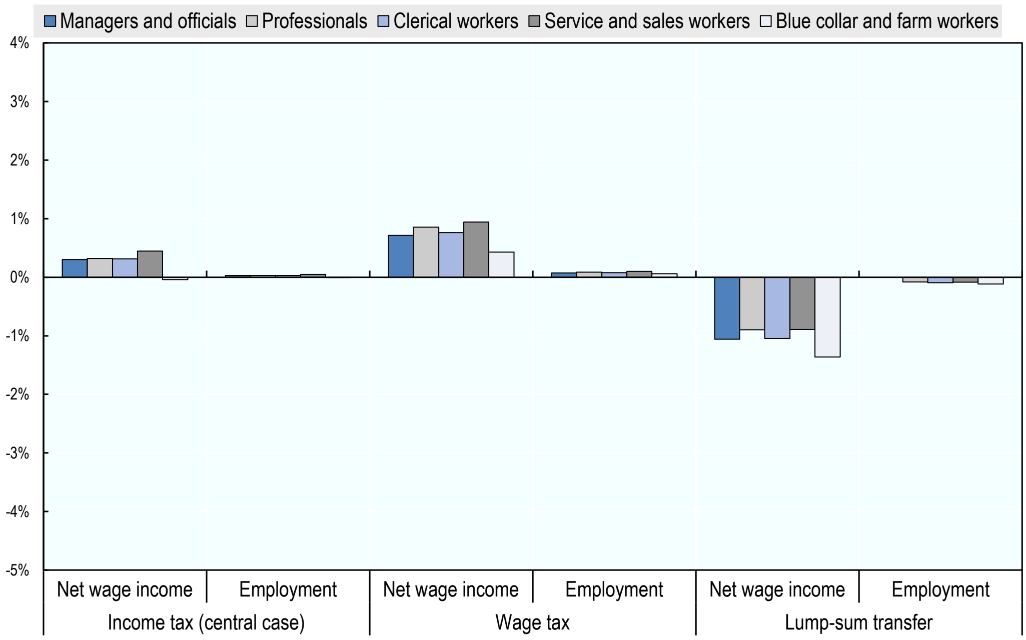
When workers differ by their job categories, the way carbon revenues are recycled could also be designed as a form of redistribution mechanism. Figure 18 shows the differentiated impacts of the recycling scheme on the job categories. The recycling scheme affects net total employment according to the effect on labour income taxation. Thus, a lump-sum transfer policy will redistribute towards workers whose income is the lower, while a reduction in wage income taxation reduction will smooth differences in wage income changes across job categories.

Figure 18 indicates that wage income for ‘Agriculture and production workers’ is critically affected by the recycling scheme retained. As illustrated in Section 3, their net wage income is the only one negatively affected (up to -0.2% in Non-OECD countries), while other job categories have an increased net wage income. In OECD countries, any of the three recycling schemes leave the difference unchanged (about 0.5 percentage points) between ‘Blue collar and farm workers’ and other job categories (but may allow at least for a net gain for ‘Blue collar and farm workers’). In non-OECD countries, however, even though the results are roughly similar, the lump-sum transfer increases the gap between ‘blue collar and farm workers’ and other job categories (from 0.9 percentage points to 1.3 percentage points).

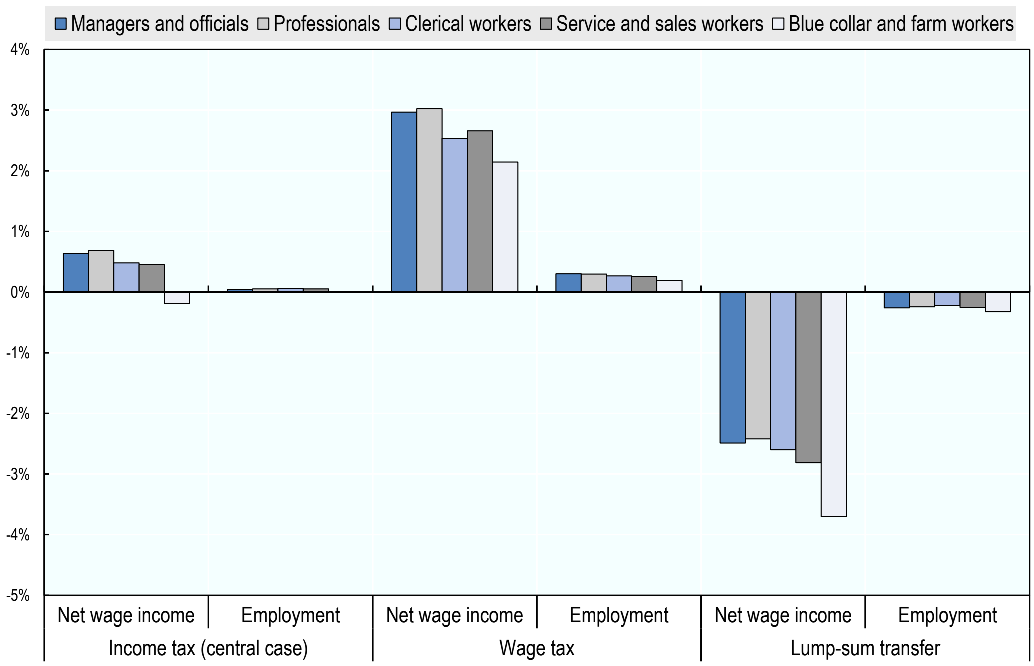
Figure 18. Change in income and employment for alternative recycling schemes by job category

Percentage change w.r.t. reference equilibrium, 2011

Panel A. OECD countries



Panel B. Non-OECD countries



Source: OECD ENV-Linkages Model

5. THE IMPORTANCE OF POLICY DESIGN: COMBINING ENERGY EFFICIENCY MEASURES WITH CARBON TAXES IN THE *MIXED POLICY SCENARIO*

Carbon taxation is not the only way to curb greenhouse gas emissions. Promoting clean energy through targeted supports or acting towards more energy efficiency could contribute to mitigation efforts. This section presents an alternative policy scenario: the *mixed policy scenario*, which complements a global carbon tax on CO_2 emissions with policies promoting energy efficiency. This scenario thus includes a package of "economically viable" energy efficiency measures[21] for households and firms, that are similar to those of the *Efficient World Scenario* (EWS) described in the "2012 World Energy Outlook" (IEA, 2012).[22] To ensure comparability, the *mixed policy scenario* is designed to achieve the same level of abatement of global GHG emissions than in the *central scenario.* The global carbon tax level in the *mixed policy scenario* is therefore adjusted to USD 18/tCO_2.[23] The results show that using different channels to reduce emissions implies non negligible differences in terms of labour markets and redistributive impacts.

In the *mixed policy scenario*, increasing the energy efficiency comes at the expense of capital investment paid by firms and households. The implementation of these additional investment expenditures in the modelling framework assumes complete crowding out[24] with other kinds of investment, as described in Annex C. Finally, while the carbon tax revenues follow a similar recycling scheme as that of the *central scenario*, the magnitude of the revenues recycled will be significantly smaller as the carbon tax is only USD 18 t/CO_2, and the energy efficiency package does not yield revenues to recycle and may even imply extra government expenditures.

1. The energy efficiency package is characterised by various changes in the policy instruments of the model: i) regulation constraints and subsidies on household consumption of semi-durables good, which are implemented in ENV-Linkages so as to match the IEA's estimates of the extra expenses on these goods, and the changes in household demand for energy that they imply; and ii) additional capital stock in energy efficient investment by firms and the corresponding volume of the energy savings they imply;

5.1 Overview of the economic impacts of the *mixed policy scenario*

2. While the two policy scenarios lead to the same benefit in terms of GHG mitigation, the economic mechanisms followed to achieve the emission reductions are different. Thus, the two policies have different effects on the sectoral structure of the economies. The energy efficiency measures change *production modes* by promoting substitution of energy with capital, in many sectors which implement new energy-saving technologies (e.g. industries and services sectors). Similarly, the direct effect on households

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21 See Appendix for more details about the set of energy efficiency policies and their implementation in the model.

22 The examination of the macroeconomic consequences of the *EWS scenario* simulated with the ENV-Linkages model has been analysed in detail in Chateau et al. (2014a).

23 This is the level of carbon tax that results from equating the emission reductions between scenarios. The energy efficiency measures are assumed to be sufficiently incentivised by this lower carbon tax, which is not unrealistic given that these measures are in themselves cost-effective, and the carbon price is only needed to overcome political economy concerns. See IEA (2011) for more details about this issue of complementarity between both instruments and more precisely about how carbon pricing will address some of energy efficiency market failures such as externalities.

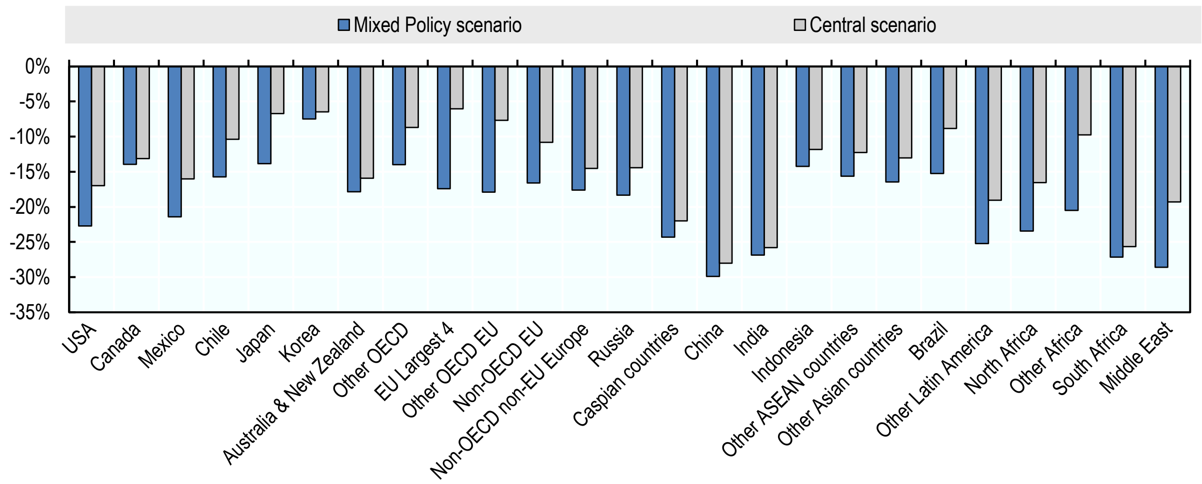
24 The complete crowding out excludes any potential increased (respectively decreased) investment through increased (respectively decreased) capital availability following higher (respectively lower) growth.

would imply a change in their *demand patterns*: households buy energy-efficient semi-durable goods to reduce their energy demand. The resulting decrease in energy demand in turn leads to a reduction in energy prices faced by consumers, despite the increasing impact of carbon taxation on fossil-fuel prices.

Figure 19 shows that total primary energy demand declines for both scenarios, in all regions. However, the *mixed policy scenario* results in higher reductions for all regions compared to the *central scenario*. Thus, part of the decarbonisation is achieved in the *mixed policy scenario* through energy efficiency rather than energy decarbonisation.

Figure 19. Change in primary energy demand by region, *mixed policy and central scenarios*

Percentage change w.r.t the reference equilibrium, 2011



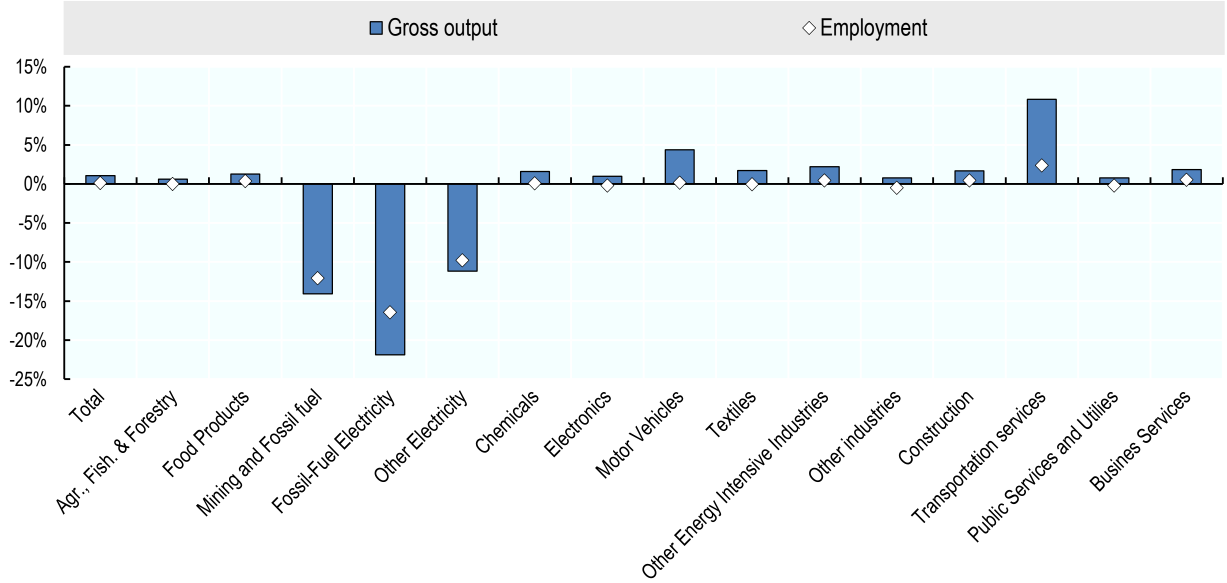
Source: OECD ENV-Linkages Model

As reported in Figure 20, the *mixed policy scenario* implies a slight increase in total output (i.e., 'Total') relative to the *central scenario*. But the main outcome is that the *mixed policy scenario* implies much more important changes in the sectoral composition of output than the *central scenario* (Figure 5, Section 3). Following production and demand changes, the sectoral composition of employment is also more affected than in the *central scenario.*

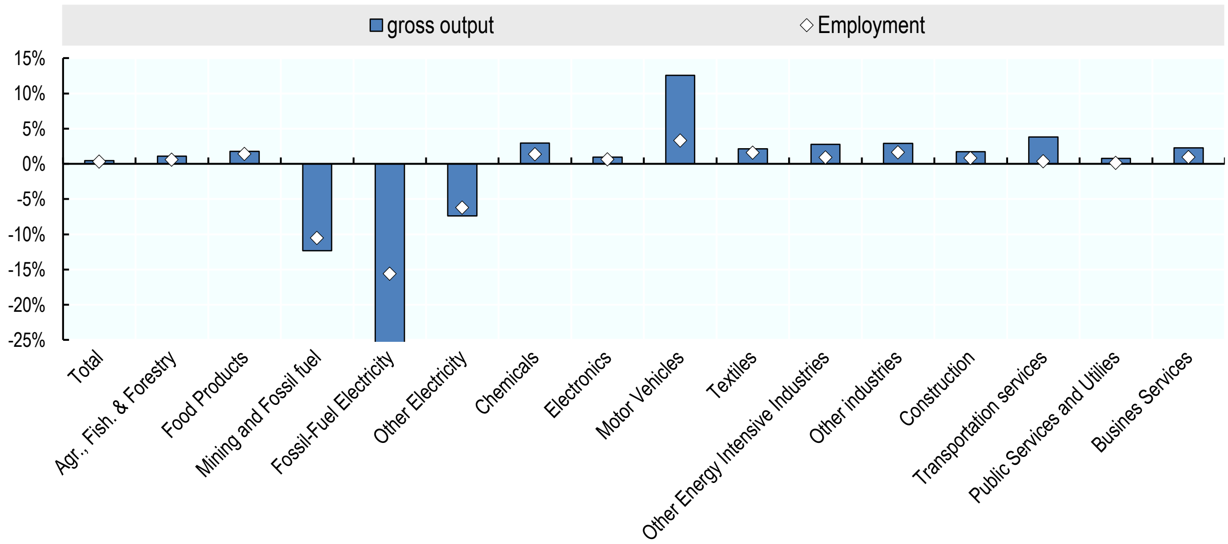
Figure 20. Change in the sectoral composition of output and employment by aggregate sector, *mixed policy scenario*

Percentage change w.r.t the reference equilibrium, 2011

Panel A. OECD countries



Panel B. Non-OECD countries



Source: OECD ENV-Linkages Model

While the *mixed policy scenario* implies a higher level of activity (output) in general, a deeper look at the results shows some reduction in activity in fossil fuel exporting countries. In any case, for all countries, total output is higher than in the *central scenario*. In other words, positive impacts of the policy on the economy – namely energy efficiency gains, increases in expenses in durable goods to build energy saving equipment, and positive labour supply in reaction to the recycling policy – are dominating the negative impacts (associated to the carbon tax implementation, the regulations toward energy efficiency investment, or the trade income losses from fossil fuel exports).

Figure 20 indicates that the *mixed policy scenario* affects many sectors, while the *central scenario* impacted only few sectors. This difference reflects the design of the two policies: under the *mixed policy scenario* numerous industrial and services sectors substitute capital with energy through investments in energy efficiency, while the *central scenario* only has substantial impacts on the sectors that are producing or intensively using fossil fuels. Despite this difference in design, the *mixed policy* scenario also features a large decrease of the production of fossil-fuel-based energy sectors. But since energy efficiency affects all energy, the 'Other electricity' sectors are also affected by the fall in energy demand.

Beyond these impacts on energy sectors, the *mixed policy scenario* implies more substantial changes on other sectors' output than the *central scenario* because the energy efficiency measures imply two additional effects. First, the direct changes in consumption and production modes (towards less energy demand) in the *mixed policy scenario* imply a reduction in energy prices for consumers and most firms. This is the opposite of what occurs in the *central scenario* in which the higher energy prices resulting from the carbon tax triggered a decrease in energy demands for all sectors. For 'Transportation services' or 'Chemicals', the reduction in the energy bill leads to lower selling prices for these goods and thus to important increases in their production, while their production decreased in the *central scenario*. Second, the energy efficiency package of the *mixed policy scenario* directly boosts demand for the production of the sectors that provide energy-saving equipment such as 'Motor-vehicles' or 'Electronics', as well as the sectors that support building isolation, like 'Construction' and 'Non-metallic minerals'.

Moreover, some sectors that either do not adopt energy efficient production modes (like 'Agriculture, fisheries and forestry') or benefit only modestly of lower energy costs (like 'Food product' and 'Textiles') are stimulated but through the macroeconomic income effect (e.g., changes in real income). These sectors record output increases, that could be shown to be close to the average increase in the economy-wide real income, and this despite not being affected by direct or indirect stimulus linked to any of the policy tools implemented in this scenario.

Finally, Figure 20 shows that the *mixed policy scenario* is characterized by contrasted changes in sectoral structure of output and employment between OECD and non-OECD regions, while the *central scenario* showed rather uniform changes across countries. This is explained mainly by the nature of energy efficient investments: in Non-OECD countries energy efficiency improvements are mostly in energy intensive industries, while in OECD countries investments industry is already energy-efficient, and new investments are more in transportation improvements and building isolation.

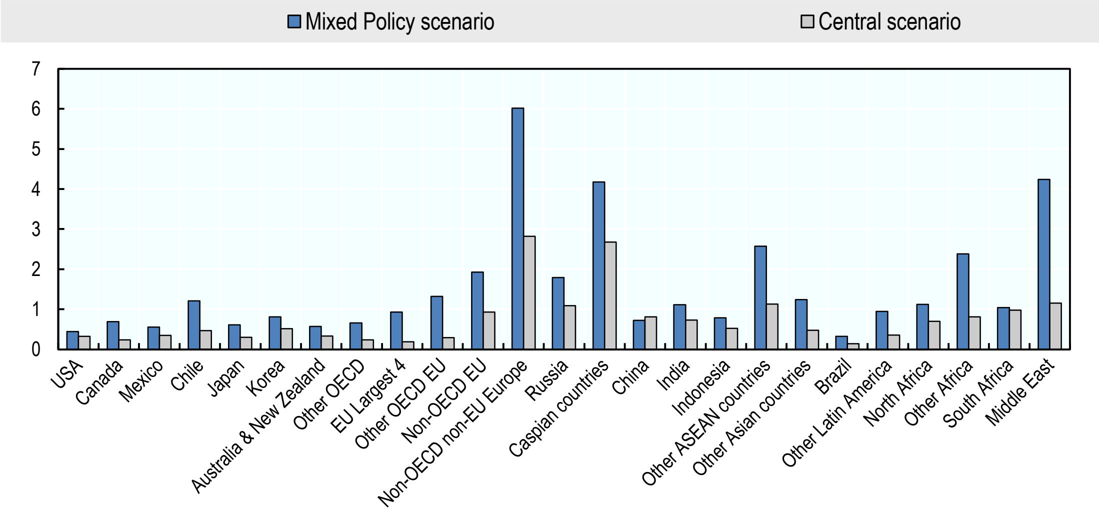
5.2 The sectoral reallocation of employment by job-categories in the *mixed policy scenario*

Figure 21 shows that job reallocations in the *mixed policy scenario* are limited even if the expansions and contractions of employment and output, as discussed in Section 3, can be large at the individual sectoral level. Nevertheless, Figure 21 shows that the resulting job reallocations are still limited, but logically larger than in the case of the *central scenario,*[25] since the mixed scenario imply deeper changes in the composition of employment.

[25] Additional details about job reallocations in the *mixed policy scenario* are reported in figures of Annex D.

Figure 21. Total job reallocation, *mixed policy and central scenarios*

Deviation from the reference equilibrium, % of total employment, 2011



Note: Total job reallocation is measured by the sum of the job creations and the job destructions, for all job-categories and in all economic sectors.

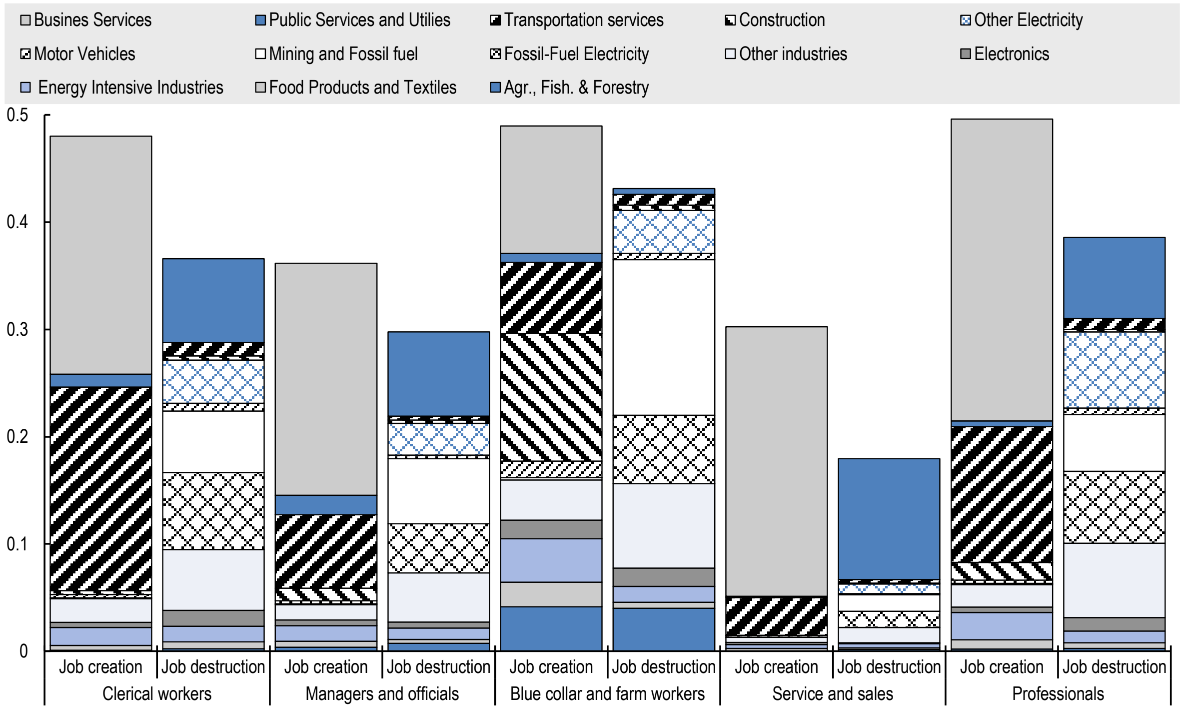
Source: OECD ENV-Linkages Model

Figure 22 details the nature of the job reallocations: it reports the rates of job creation and job destruction by sector for all job categories, for OECD and Non-OECD countries. Again the declining energy sectors will systematically proceed to job destructions for all job categories. A deeper examination would show that this holds true for all the 25 regions of the model and all energy sectors. Further, it could be shown that these job destructions in declining energy sectors are the predominant source of job destructions in most countries. Job destructions in declining energy sectors account for 73% of total world job destructions in the *mixed policy scenario* (55% for OECD countries). As in the *central scenario*, these job destructions in energy sectors also explain why a majority of job destructions will hit ‘Blue collar and farm workers’ in most countries.

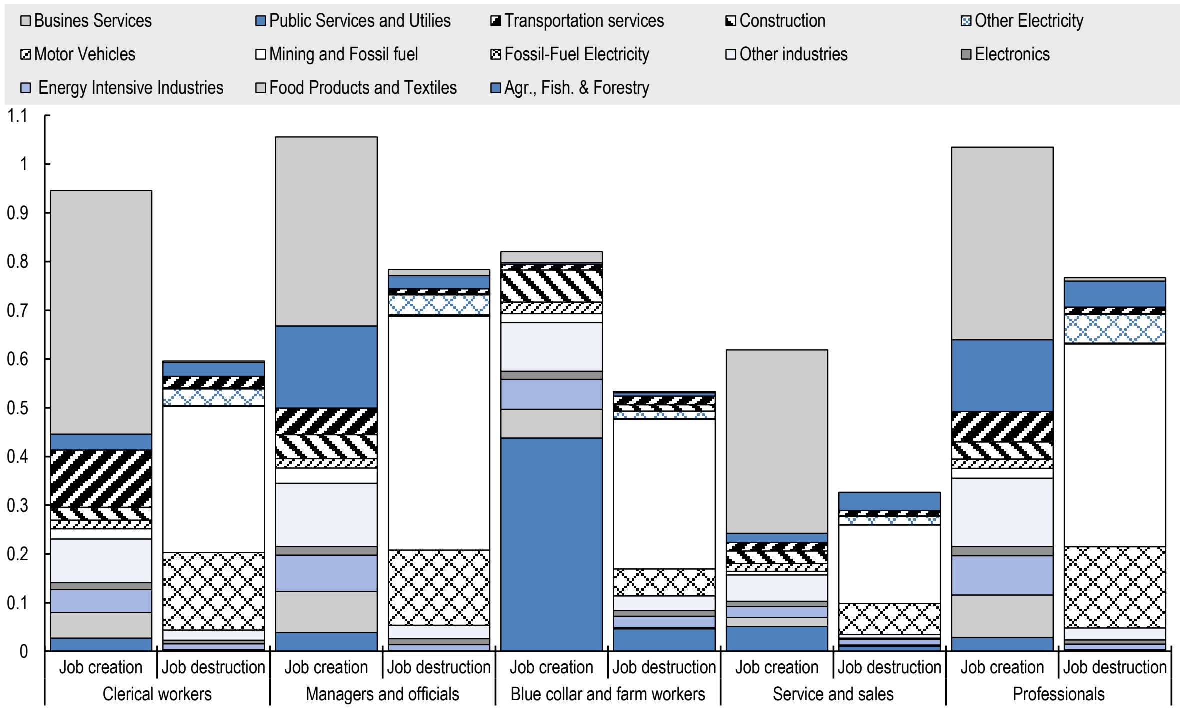
Figure 22. Change in sectoral composition of job creations and job destructions, by job category, *mixed policy scenario*

Percentage change in employment relative to total employment of the category in the reference equilibrium, 2011

Panel A. OECD



Panel B. Non-OECD



Source: OECD ENV-Linkages Model

In the *mixed policy scenario*, a non-negligible part of sectoral job reallocation will take place outside the most impacted sectors: for instance, job destructions in 'Government services' sectors or on the opposite job creations in the 'business services' sectors. An important difference with the *central scenario* is that in the *mixed policy scenario* the 'Transportation services' and 'Construction' sectors also create substantial employment in most OECD countries (around 25% and 10% of total creation respectively). Moreover, around 45% of total job creations in the 'Blue collar and farm workers' category could be found in 'Transportation services' and 'Construction' sectors in OECD countries on average.

Figure 22 also shows that high-skilled workers (e.g. 'Managers and officials' and 'Professionals') are also characterised by large turnovers in OECD countries. This reflects that energy sectors have a lower share in these economies, so that a larger part of job reallocations occurs out of these sectors (i.e. services sectors or 'Other industries'). Further, it reflects that energy sectors (and to a lesser extent energy intensive industries) are characterized by a skill-structure of labour that relies more on high-skilled labour than in non-OECD countries. In the case of *mixed policy scenario*, as already mentioned, 'Business services' and 'Public services and utilities' sectors are relatively more impacted in OECD countries, and these services sectors are relatively more intensive in high-level workers.

This analysis suggests that climate policies and the implementation of energy efficiency measures, which have limited scope, are unlikely to create structural adjustment pressures on labour that are quantitatively large compared with historical evidences (Handel, 2012), at least when the degree of transition to low energy economy remains limited to a reduction of 15% of total energy use as implied by the scenarios analysed in this paper.[26]

5.3 Distributional impacts of the *mixed policy scenario*

In the *mixed policy scenario,* the changes in the net wage income across the different job categories, reported by the bars in Figure 23, are more pronounced than in the *central scenario*. This again is a consequence of a more affected structure of employment in the *mixed policy scenario* because the energy efficiency measures have important employment consequences in many sectors, and not only on energy-related sectors as in the *central scenario.* The impacts on the income distribution is also larger because the recycling policy is less active than in the *central scenario*, since the extra revenue from the carbon tax are much lower, and therefore its redistribution-smoothing impact is more limited. But this second explanation remains marginal.[27]

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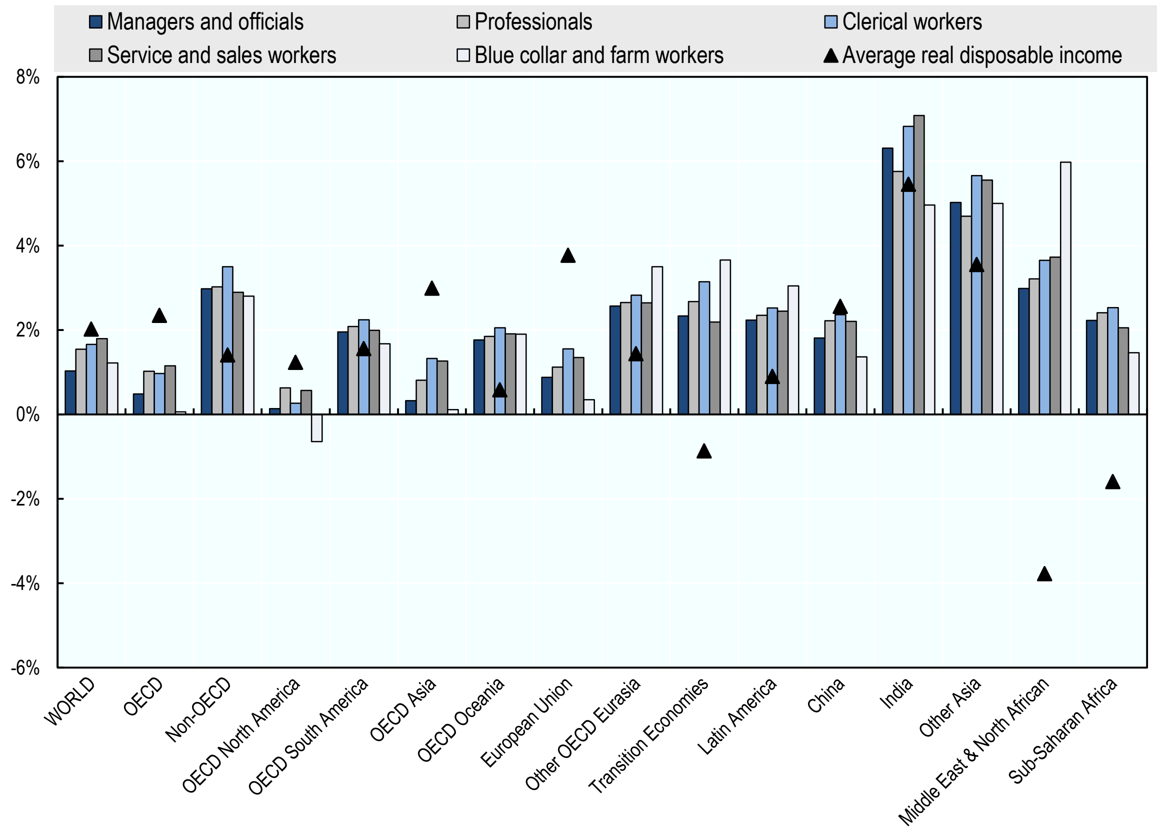
[26] This conclusion is subject to caveats relative to the level of detail of sector used here, and more important to the fact that sectoral reallocation within sectors accounted for (see OECD, 2012b).

[27] Figure C.8 in Annex C shows the same information as Figure 23 for an *energy efficiency scenario* where there is no carbon taxation. The similarities between the two figures indicate that the deformation of wage income distribution under the mixed policy scenario is mostly driven by the energy efficiency measures.

Figure 23. Impacts on the distribution of net-of-tax real wage income by job category and on total real disposable income, *mixed policy scenario*

Percentage change w.r.t the reference equilibrium, 2011



Note: Bars correspond to the net-of-tax real wage income while triangles refer to real disposable income.

Source: OECD ENV-Linkages Model

Under the *mixed policy scenario*, the category of 'Blue collar and farm workers' is polarized in terms of changes in the distribution of net wage income: it is either the category that benefits most from the policy or the one that is most affected, depending on the region considered. 'Blue collar and farm workers' are likely to be "winners" in regions such as "OECD Oceania", "Transition economies", "Latin America or 'Middle East and North Africa'. Conversely, they appear to lose compared to other categories of workers in other regions, such as the all OECD regions (but Oceania), India or China. Moreover, in regions such as 'Middle East and North Africa' or 'Transition economies', all other categories of workers see their relative wage income reduced relative to the average while the contrary occurs in the EU where all categories win relative to 'Blue collar and farm workers'.

Figure 23 also shows the changes in total real income, which can be lower than changes in wage income in some countries (of any job categories), while for other countries the opposite stands. It means that, in contrast with the *central scenario*, the policy is beneficial for capital earners in countries where "primary" sectors represent a low share of the total economy (e.g. US, China, Japan, Korea and many OECD EU countries). For countries that are either highly dependent on primary sectors activities, capital earners lose much more than under the *central scenario* (fossil-fuel producing countries but also Latin America and Asian countries, except China and India).

Besides the general remark that the *mixed policy scenario* embeds more disruptive forces acting on the distribution of wages than the carbon tax, the general appreciation of distributive impacts of both policies should be taken with care. The redistribution scheme chosen in the two policy scenario about the extra government revenues influences the results. The more pronounced asymmetrical impact of the *mixed policy scenario* relative to the *central scenario* on labour income distribution (across different types of workers) together with a better economic efficiency (e.g. higher total real disposable income) illustrates the traditional equity-efficiency dilemma.

6. DISCUSSION

This paper explores the consequences on the labour markets of structural changes induced by decarbonisation policies. A key insight resides in identifying the vulnerable job categories, when workers are not perfectly interchangeable because they are trained for different jobs. These policies are analysed in a general equilibrium modelling framework, which includes interlinkages between different sectors and regions as well as five different categories of workers. While necessarily stylised, the economic modelling framework is well suited to explain asymmetric structural effects of climate and energy efficiency policies on sectors, regions and workers, and thus to identify the wage-income distribution impacts of these policies. To reinforce the scope of the results obtained in this analysis, future work could focus on identifying possible bottlenecks on specific jobs, by augmenting the number of job categories. Unfortunately lack of detailed data on job categories at global level means that increasing the number of categories could only be done reducing the number of countries analysed to only OECD countries and a few emerging economies.

The sensitivity analyses presented in this paper underlines the importance of the design of the policy chosen to insure a fair and efficient transition to a decarbonized economy. However, other sources of uncertainty would be worth analysing in future work to enhance the scope of the analysis. For instance, there is a great level of uncertainty about the possibility to move workers in different job categories in the production of each type of goods and services. There is also some uncertainty about the possibility that climate and energy efficiency policies will be biased towards specific job categories because these may be associated with the new technologies.

As the paper adopts a long run perspective, it abstracts from short-run adjustment costs that follow the implementation of any green growth policies. Workers with specific jobs that are mostly employed in the declining sectors could have difficulties in finding a new job during the transition process because of the existing labour and product markets inefficiencies. On the other hand, workers with jobs that are more essential to expanding sectors could be difficult or costly to hire for the firms. In both cases, short-run transition costs can limit the efficiency of green growth policies. Future work that aims at analysing the full transition process form short to long run, could be based on a dynamic setting so as to evaluate short-run adjustment costs on labour markets, which could be amplified by considering also some short-run rigidities of labour markets. An extension of the current modelling framework to a dynamic setting is not easy as there are no labour projections by job category at the global level.

Improving the dynamic representation of the working population is also an imperative if one wants to consider more complex recycling policies relying on changes in government expenditures and other measures to correct some negative impacts of decarbonisation policies. A foremost example of these measures is the adaptation of training and education policies to correct the anticipated impacts on job structure of the economy, across skills and sectors. As education policies, financed or not by carbon taxation, would take time to show their effects, insights about the dynamics of the transition process are necessary for the success of environmental reforms and to correct some of their undesired distributive impacts.

Finally, the distributive impacts of the policies provided here mostly focus on the wage income distribution. However, for a broader perspective, households heterogeneity could be extended beyond wage income and the analysis could be expanded to multiple household groups. The composition of income of each type of workers should also take into account their difference in terms of capital and other non-wage income sources. Further, it would be useful to characterize specific consumption patterns of each worker as well as their saving behaviour. These two elements would not only help to enhance the scope of a study of the distributional impacts but also to assess how changes in distribution will have feedback on the efficiency of the climate and energy-saving policies.

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ANNEX A: JOB CATEGORIES INCLUDED IN THE ANALYSIS

There are different ways to categorise jobs and different data on which to base the categorisation. Based on the ILO (2008) database, this paper relies on 5 different job categories, as described below. Similar categorisations have been used in previous OECD work (see e.g. Handel, 2012). The ILO (2008) database describe the following categories:

Professionals, technical workers, and associate professionals. This is a wide category, which includes highly qualified workers in different sectors. This category includes professionals and technicians in science, engineering, physical and earth science, life science, mining, manufacturing and construction mathematicians, actuaries, statisticians, architects, planners, surveyors, designers, and ship and aircraft controllers and technicians. It also includes highly qualified workers in the health sectors (e.g. doctors, paramedics, nurses, medical assistants and veterinarians), in teaching (e.g. teachers at university and higher education, early childhood, primary and secondary school teachers), in business, finance, administration, and sales. Finally, it includes professionals and technicians working in information and communications technologies (including software and applications developers and analysts, database and network professionals, telecommunications and broadcasting technicians), legal, administrative and regulatory services, cultural services (including librarians, archivists and curators, authors, journalists, linguists, creative and performing artists, artistic, cultural and culinary associate professionals), social and religious professionals, and sports and fitness workers. As listed, this category includes various types of workers, ranging from technical workers to associate professionals, semi-professionals and para-professionals, at the cost of greater within-group heterogeneity.

Managers and officials. This category includes different types of jobs that are categorized as managers and related workers. These include, chief executives, senior officials and legislators, managing directors, as well as managers in administrative and commercial services, business and administration services, sales, marketing, production (including in agriculture, forestry and fisheries), manufacturing, mining, construction, and distribution sectors, information and communications technology services, professional services, hospitality, retail, hotels and restaurants, retail and wholesale trade services, and other services.

Service and sales workers. This category includes less qualified workers in different sectors. The types of jobs include personal service workers, travel attendants, conductors and guides, cooks, waiters, bartenders, hairdressers, beauticians, building and housekeeping supervisors, sales workers, cashiers and ticket clerks, personal care workers, child care workers and teachers' aides, personal care workers in health services, and protective services workers.

Clerical workers. This category also includes less qualified workers in different sectors. The types of jobs include general and keyboard clerks, general office clerks, secretaries, keyboard operators, customer services clerks, tellers, money collectors, client information workers, numerical and material recording clerks (including numerical clerks, material-recording and transport clerks), and other clerical support workers.

'Blue collar and farm workers'. This is a wide category which includes various low-skilled workers in different sectors. There is a great deal of variation in the assignment of workers to the major groups corresponding to craft, semi-skilled, and unskilled or elementary workers in manufacturing or similar blue-collar settings. In this report, following Handel (2012), the different broad job categories are included in a single group. More specifically, this category includes agricultural, forestry and fishery workers (market-oriented skilled agricultural workers, forestry, fishery and hunting workers, subsistence farmers, fishers, hunters and gatherers), craft and related trade workers (in buildings, metals, machineries, handicrafts and printing, electricity and electronics, food processing, wood working, and garment), plant and machine operators and assemblers (including stationary plant and machine operators, drivers and mobile plant operators, elementary jobs (including cleaners and helpers, labourers in mining, construction, manufacturing and transport, street and related sales and service workers, and refuse workers), and armed forces jobs, such as commissioned and non-commissioned armed forces officers.

Classifying jobs into only 5 categories limits the level of detail achieved in the analysis. The broader the aggregation (into job-groups), the less differentiation between jobs there is, hence some important unique characteristics of specific jobs may be missed, especially in specific sectors (e.g. for smart-grid electricity engineers). However, the labour and wage data from ILO for these 5 categories is the only one available that has sufficient sectoral and regional information. It covers more than 20 economic sectors and 95 regions. While, the job differentiation lacks details, a broad coverage on countries and sectors is available. One very important point this report wants to highlight is that similar policies may have very different impacts in different countries because the sectoral job structure and the sectoral composition of these economies are very different. Considering a broader coverage of economies and sectors over more job categories is therefore the best choice for this analysis.

ANNEX B: A SNAPSHOT OF THE ENV-LINKAGES (VERSION.3) MODEL

The OECD's in-house dynamic CGE model – ENV-Linkages – is used as the basis for the assessment of the economic consequences of climate impacts. ENV-Linkages is a multi-sectoral, multi-regional model that links economic activities to energy and environmental issues. The ENV-Linkages Model is the successor to the OECD GREEN model for environmental studies (Burniaux, et al. 1992). A more comprehensive model description is given in Chateau et al. (2014).

Production in ENV-Linkages is assumed to operate under cost minimisation with perfect markets and constant return to scale technology. The production technology is specified as nested constant elasticity of substitution (CES) production functions in a branching hierarchy. This structure is replicated for each output, while the parameterisation of the CES functions may differ across sectors. The nesting of the production function for the agricultural sectors is further re-arranged to reflect substitution between intensification (e.g. more fertiliser use) and extensification (more land use) of crop production; or between intensive and extensive livestock production. The structure of electricity production assumes that a representative electricity producer maximizes its profit by using the different available technologies to generate electricity using a CES specification with a large degree of substitution. The structure of non-fossil electricity technologies is similar to that of other sectors, except for a top nest combining a sector-specific resource with a sub-nest of all other inputs. This specification acts as a capacity constraint on the supply of the electricity technologies.

The energy bundle is of particular interest for analysis of climate change issues. Energy 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 values of the substitution elasticities are chosen as to imply a higher degree of substitution among the other fuels than with electricity and coal.

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

International trade is based on a set of regional bilateral flows. The model adopts the Armington specification, assuming that domestic and imported products are not perfectly substitutable. Moreover, total imports are also imperfectly substitutable between regions of origin. Allocation of trade between partners then responds to relative prices at the equilibrium.

Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated between the demands (both final and intermediary) addressed to domestic producers and the import demand.

CO_2 emissions from combustion of energy are directly linked to the use of different fuels in production. Other GHG emissions are linked to output in a way similar to Hyman et al. (2002). The following non-CO_2 emission sources are considered: i) methane from rice cultivation, livestock production (enteric fermentation and manure management), fugitive methane emissions from coal mining, crude oil extraction, natural gas and services (landfills and water sewage); ii) nitrous oxide from crops (nitrogenous fertilizers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); iii) industrial gases (SF_6, PFCs and HFCs) from chemicals industry (foams, adipic acid, solvents), aluminium, magnesium and semi-conductors production. Over time, there is, however, some relative decoupling of emissions from the underlying economic activity through autonomous technical progress, implying that emissions grow less rapidly than economic activity.

Emissions can be abated through three channels: (i) reductions in emission intensity of economic activity; (ii) changes in structure of the associated sectors away from the “dirty” input to cleaner inputs, and (iii) changes in economic structure away from relatively emission-intensive sectors to cleaner sectors. The first channel, which is not available for emissions from combustion of fossil fuels, entails end-of-pipe measures that reduce emissions per unit of the relevant input. The second channel includes for instance substitution from fossil fuels to renewable in electricity production, or investing in more energy efficient machinery (which is represented through higher capital inputs but lower energy inputs in production). An example of the third channel is a substitution from consumption of energy intensive industrial goods to services. In the model, the choice between these three channels is endogenous and driven by the price on emissions.

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

The sectoral and regional aggregation of the model, as used in the analysis for this report, are given in Tables B.1 and B.2, respectively.

The differentiation of the different types of occupations used in the model is described in Table A.3. This report distinguishes among five different skills classed by occupation, based on ILO (2008) data, following the ILO ISCO-88 classification. The disaggregation of labour payments, for each sector and country, into these five classes of skills has been done by Walmsley and Carrico (2013) for the economic GTAP8 database (Narayanan et al. 2012). Since the GTAP database constitutes the core social matrices on which the ENV-Linkages Model are built-on, it is straightforward to consider the examination of this 5-skills splitting as a point of departure of the current work.

Table B.1. Sectoral aggregation of ENV-Linkages

Aggregate sectors regions	ENV-Linkages sectors
Food Products	Food Products
Textiles	Textiles
Chemicals	Chemicals
Other Energy Intensive Industries	Non-metallic minerals Pulp, Paper and publishing products Fabricated metal products
Other industries	Metals n.e.s. Other manufacturing Electronic Equipment
Electronics	Iron and Steel
Motor Vehicles	Motor Vehicles
Construction	Construction
Public Services and Utilities	Water services Government Services
Business Services	Other private services
Transportation services	Air Transport Land Transport Water Transport
Agriculture, Fisheries and Forestry	Sugar crops Other Grains Other Crops Oil Seeds Paddy Rice Fibers Plant Vegetables and fruits Wheat and meslin Livestock Forestry Fisheries
Mining and Fossil fuel supply	Coal Gas Crude Oil Refined petroleum Other mining
Fossil-Fuel Electricity	Fossil-Fuel Electricity
Other Electricity Generation	Other renewables Electricity Hydro Electricity Nuclear Electricity Solar and Wind Electricity

Source: ENV-Linkages Model.

Table B.2. Regional aggregation of ENV-Linkages

Macro regions	ENV-Linkages countries and regions
US	US
China	People's Republic of China
India	India
Canada	Canada
Mexico and Chile	Mexico Chile
Latin America	Brazil Other Latin-American countries
OECD Asia	Japan Korea
Other Asia	Indonesia ASEAN9 (other ASEAN countries) Other Asia (other developing Asian countries)
Australia & New Zealand	Australia & New Zealand
Other OECD	Other OECD (Iceland, Norway, Switzerland, Turkey, Israel)
European Union	EU large 4 (France, Germany, Italy, United Kingdom) Other OECD EU (other OECD EU countries) Non-OECD EU (non-OECD EU countries)
Middle East & North Africa	Middle-East North Africa
Sub-Saharan Africa	South Africa Other Africa (other sub-Saharan African countries)
Transition economies	Russian Federation Caspian region Other Europe (non-OECD, non-EU European countries)

Source: ENV-Linkages Model.

Table B.3. Five individual categories of workers and aggregate categories at the ISCO-88 first level

ISCO-88 Major Group	Labels	Description
1,2	Managers and officials	Legislators, senior officials and managers (Major Groups 1), and professionals (Major Group 2)
3	Professionals	Technicians and associate professionals
4	Clerical workers	Clerical workers
5	Service and sales	Service workers and shop and market sales workers
6,7,8,9	Blue collar and farm workers	Skilled agricultural and fishery workers (Major Group 6), craft and related trade workers (Major Group 7), plant and machine operators and assemblers (Major Group 8), and elementary occupations (Major Group 9)

Source: Walmsey and Carrico (2013).

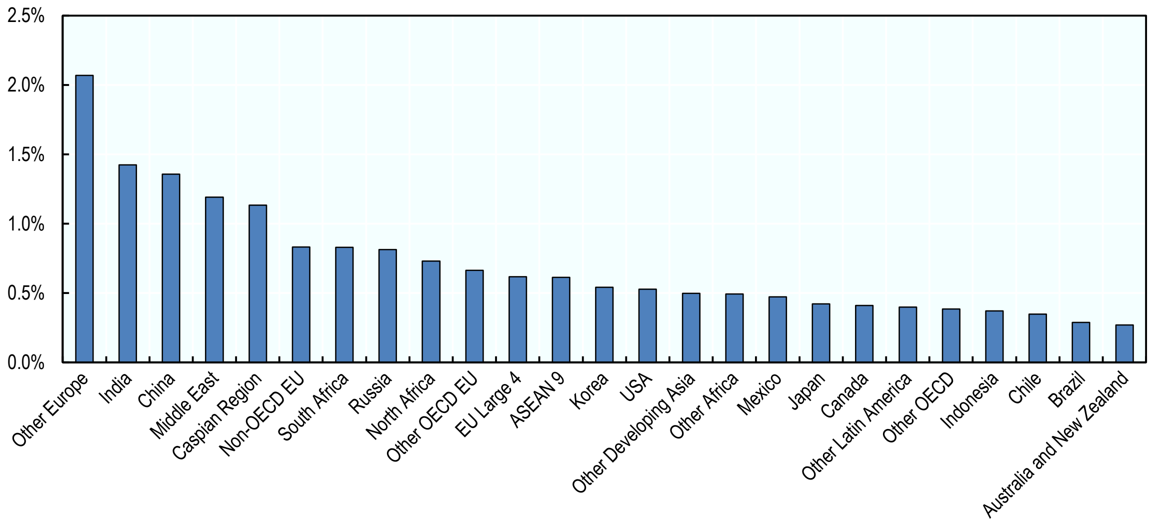
ANNEX C: MODELLING THE ENERGY EFFICIENCY PACKAGE

C.1 Description of the energy efficiency packages

The IEA Efficiency World Scenario was constructed for the report “World Energy Outlook 2012” (IEA, 2012) to assess the implications on energy markets, energy prices, investment and emissions of implementing economically viable energy efficiency measures. Measures were applied at a very detailed technical level and the indicator chosen to assess economic viability was the acceptable payback period for each class of investment for the technologies in the power, industry, transport, and building sectors.

Figure C.1. Energy efficiency investments by region

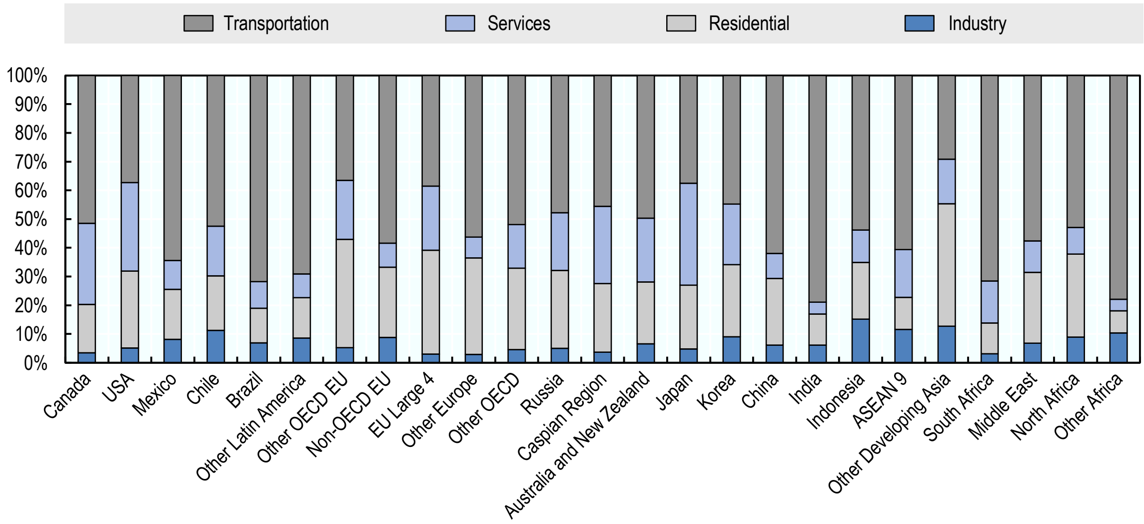
Yearly average over the period 2011-2035 as percentage GDP/1000, 2011 USD



Source: Authors’ calculations, based on WEO (IEA, 2012).

The energy efficiency measures consist in flows of firm’s investments and household’s expenses on semi-durable goods dedicated to technologies that imply reductions in both energy demands and energy expenses. The energy efficiency investments considered for this scenario correspond to the cumulative flows of investments for the period 2011-2035 calculated by the IEA for the *Efficiency World Scenario* (IEA, 2012) but they are implemented in a static setting. Hence, the long-term effects of the investments on the economy, on the different sectors and on the job market are analysed. Figure B.1 presents the energy efficiency investments (in value) for all regions in the model. The highest levels of investment, considered as a share of GDP, are undertaken in the “Other Europe” region, India, China, Middle East and in the “Caspian countries” region. The smallest levels take place in regions such as Chile, Brazil and Australia and New Zealand. The levels of investment depend on reference levels of energy efficiency but also on the economic viability of the best available technologies that can improve energy efficiency.

Figure C.2. Energy efficiency investments by sector



Source: Authors' calculations, based on WEO (IEA, 2012).

There are also large differences amongst countries and regions on the sectoral distribution of the investments, as illustrated in Figure C.2. Transport accounts for the largest share in most countries. In some regions, and specifically in Canada, the US and Japan, investments in the services sectors correspond to a large share of overall investment. Investments in the residential sectors are highest in European regions. Energy efficiency investments in industry correspond to the smallest share in all regions.[28]

C.2 Implementation of the energy efficiency package in the ENV-Linkages Model

The energy efficiency measures can be implemented in the ENV-Linkages Model since it has the same representation of the most relevant sectoral economic activities (especially energy and industrial sectors) as the IEA World Energy Model (WEM) used for the quantitative analysis in the WEO. The scenario makes no bold assumptions about technical breakthroughs, but instead shows the extent of benefits that could be achieved if known best technologies and practices to improve energy efficiency were systematically adopted.

In the ENV-Linkages Model, the Energy efficiency scenario mixes various policy instruments: 1) regulation constraints and subsidies on household consumption of semi-durables good, which are implemented in ENV-Linkages so as to match the IEA's estimates of the extra expenses on these goods; 2) additional capital stock in energy efficient investment and the corresponding volume of the energy savings they imply; 3) increased households savings to finance both the new investment needs by firms and the household investment in construction/building isolation; 4) changes in corresponding households

28 Because of some inconsistency in the data it is assumed that in the *Energy efficiency scenario* the 'Iron and steel' sector does not proceed to energy-efficient investment. Note also that even if most sectors, except agriculture sectors, are implementing this kind of energy efficiency investments, these represent substantial expenses only in very few sectors, and not in all regions: like in road transportation services, public and private services, and energy intensives industries. In the other sectors investments are marginal. Regardless, by design both scenarios would affect climate damages in the same way so this omission does not affect the comparative exercise of this report.

demand for energy. These measures are implemented in order to reproduce both the energy efficient investment expenses by type of good (Figure B.3) and the resulting energy savings calculated by the IEA.[29]

The *mixed policy scenario* discussed in this report only incorporates the energy efficiency measures characterised in the EWS of the WEO (2012) and do not take into account the other policies included in the IEA scenario, such as, energy subsidy reforms, regulatory policies and incentives for the transformation of the power sector.

As shown in the next section, implementing alone the energy efficiency packages without any carbon price will only imply a reduction of total GHG around 12.5% (relative to the reference equilibrium), this curb in emissions in far away from the ambition of keeping the world on the 450ppm pathway as described in "2016 World Energy Outlook" (IEA, 2016) at the horizon 2035, so only a carbon tax could help to reach such a target an additional carbon tax (of 18 USD/tCO_2). Indeed, any additional efficiency measures that would try to reduce energy demand will more than the energy efficiency packages calculated from Efficiency World Scenario (IEA, 2012) will imply net costs that will probably overweighs those associated to the 18 USD/tCO_2.

The levels of investment depend on reference levels of energy efficiency but also on the economic viability of the best available technologies that can improve energy efficiency. This investment in energy efficiency is completely integrated into the capital invested into by economic sector. The consequence is therefore a crowding out of this investment in such a way that the only variation in the economy-wide capital stock relative to its reference level is resulting from changes in the variation of macro-economic activity.

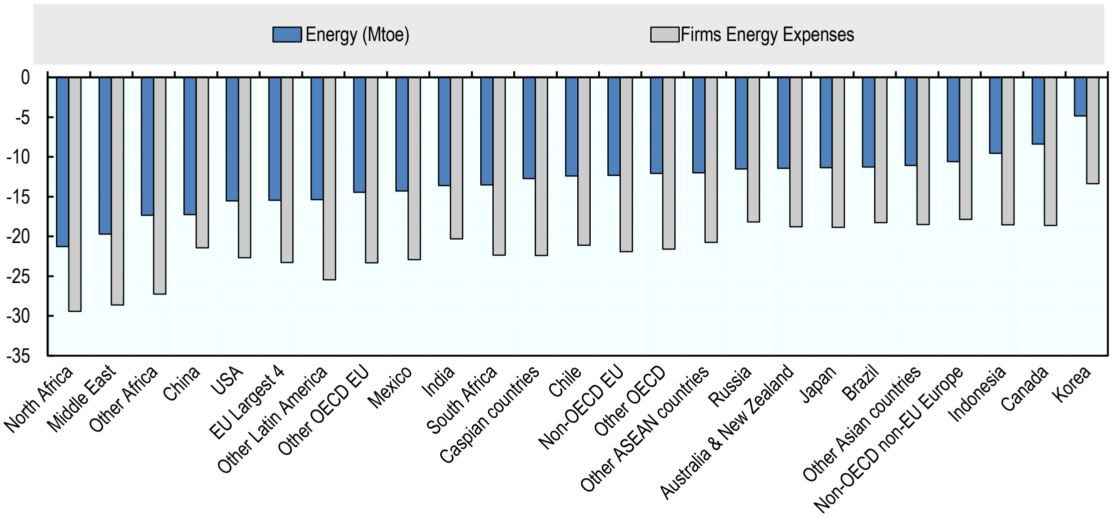
C.3 Illustrative simulation of the energy efficiency package alone: **energy efficiency** ***scenario***

In the core report the *mixed policy scenario* is a combination a carbon tax of 18 USD/tCO_2 and the energy efficiency packages described. For sake of clarification this section briefly presents the effect of implementing this energy efficiency packages without any additional carbon tax: *energy efficiency* scenario.

29 Two more technical points should be mentioned. Firstly, the energy-efficiency plans have been calculated by the IEA on the basis of given economic conditions. To be consistent with this, the energy-efficiency/ energy-saving plans have been calibrated in ENV-linkages, country by country, in order to stay in context of a given set of international prices for energy. Thus, for the e*nergy efficiency scenario*, country-specific plans have been applied everywhere in a multilateral way, where all countries and markets interact. As a consequence effective energy efficient investments and energy savings are different from what they would be if the countries were acting unilaterally. Second, in this setting, energy efficiency investments are assumed to be additional to reference investment levels, in such a way that the total capital stock is necessarily higher than in the reference equilibrium. However, this does not imply that total capital stock in the energy efficient scenario is equal to the stock in the reference equilibrium plus all the extra energy efficient investment, because the endogenous mechanisms of the model will imply a partial crowding out of investment in other activities.

Figure C.3. Change in energy demand and firm energy expenses by region, *energy efficiency scenario*

Percentage change w.r.t. the reference equilibrium, 2011

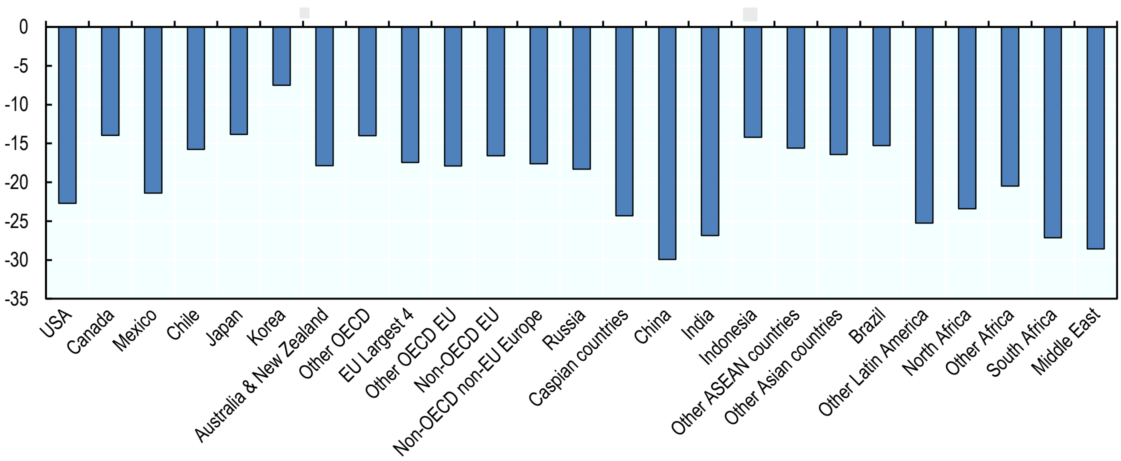


Source: OECD ENV-Linkages Model.

With energy demand decreasing in most sectors (from 5% to 20% across countries as shown in Figure C.4), including non-fossil fuel energy use, the energy efficiency policy will imply substantial reduction of GHG emissions. At the global level the Energy efficiency policy leads to a reduction of primary energy demands by 14.7%, which can be shown to translate into a reduction of total GHGs emissions of 12.6%. This total reduction in energy demand is slightly higher than the 14% reduction reported in the Table 10.1 of the World Energy Outlook 2012 (IEA, 2012). The main reason for this difference is that the scenario presented here is compared with a no-policy reference case, contrarily to the figures presented in the WEO. This in turn will lead to a reduction in energy prices for consumers. The effect of the policy is then reversed to those of the *central scenario* but for a same outcome on CO_2 emissions.

Figure C.4. Change in primary energy demand by region, *energy efficiency scenario*

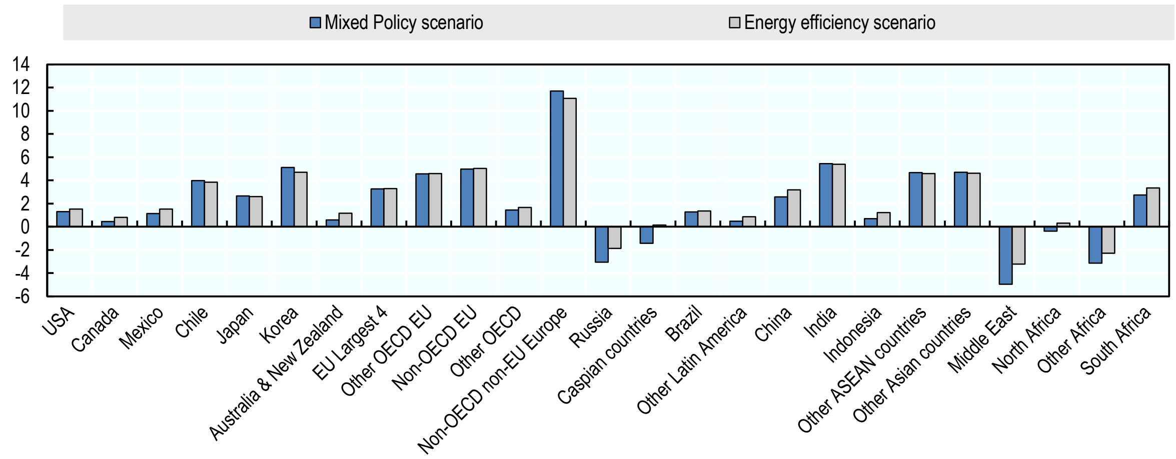
Percentage change w.r.t. the reference equilibrium, 2011



Source: OECD ENV-Linkages Model.

Figure C.5. Change in real disposable income by region, energy efficiency and mixed policy scenarios

Percentage change w.r.t. the reference equilibrium, 2011

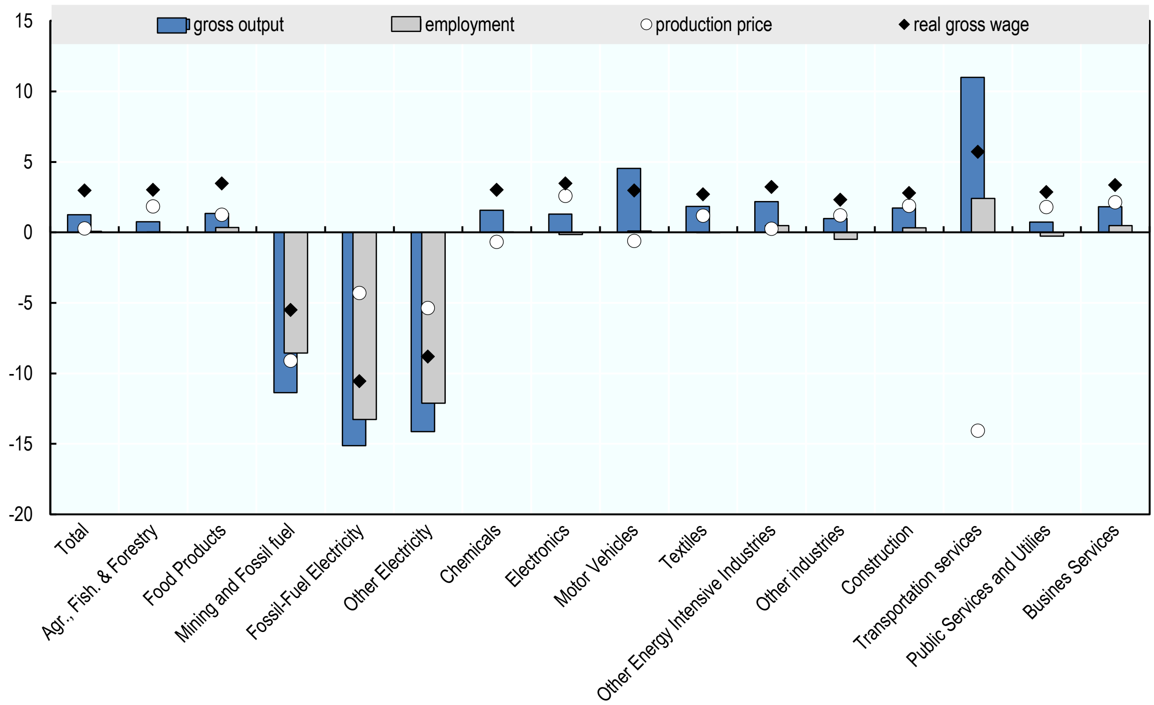


Note: The real disposable income is the sum of all nominal incomes received by households from their labour and from their capital, land and natural-resources ownership (net of any taxation and subsidy adjustments) deflated by the consumer price index (CPI).

Source: OECD ENV-Linkages Model.

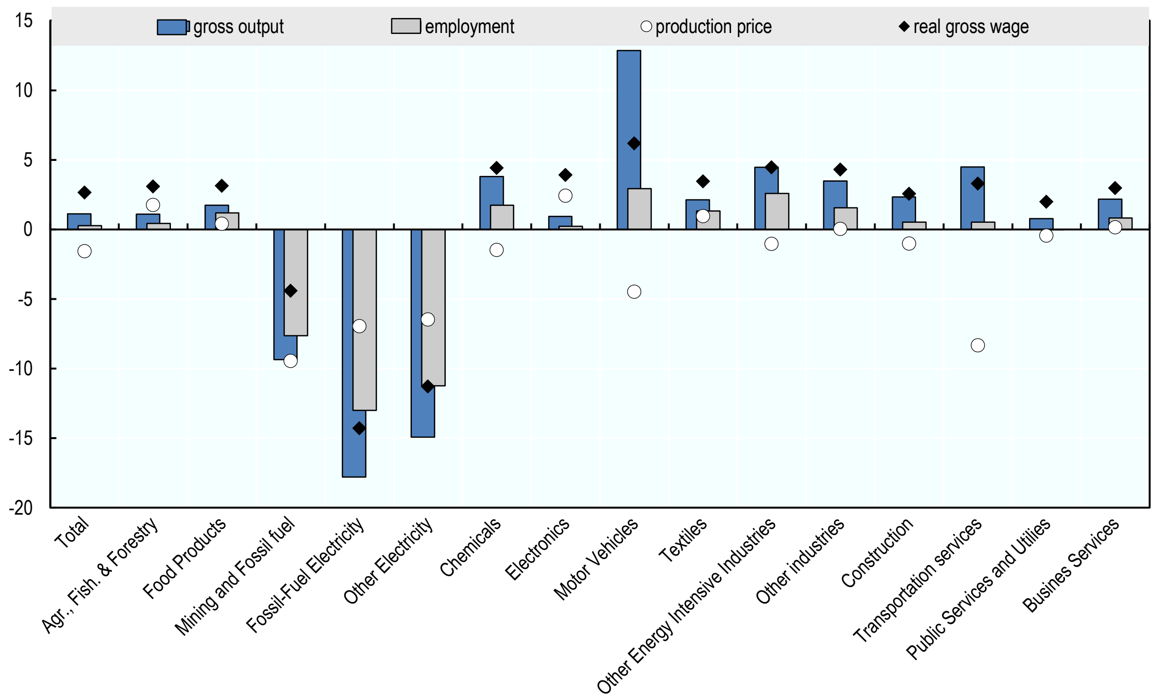
Figure C.6. Sectoral composition of output, employment and prices, *energy efficiency scenario*

Panel A. OECD



Source: OECD ENV-Linkages Model.

Panel B. Non-OECD



Source: OECD ENV-Linkages Model

As indicated by the changes in household real income reported in Figure C.5, energy efficiency measures stimulate the economy as a whole, in all countries except energy exporters, with or without the carbon tax added to the energy efficiency packages.

In general, fossil fuel exporters will observe income losses, through reduced revenues from exports, while some countries, such as Korea, India and "Other ASEAN countries" and many European countries, will have the highest income gains. For countries where the income effect remains limited most of the impacts on sectoral composition of output and employment are driven by the reallocation of resources across sectors resulting from the implementation of policies. In other countries the large induced income effects are an important channel of transmission of the policy.

The direct effect of investments in energy efficiency is to change the *production modes,* by an active substitution from energy to capital that reduces the demand for energy, in sectors that implement these new energy-saving technologies (e.g. industrial and services sectors). In a similar spirit, the direct effect on households would imply a change in *demand patterns*: households buy semi-durable goods and can thus reduce their energy demand. These two direct impacts together will change aggregate demand by shifting away from energy to expenditures in capital and semi-durable goods. Consequently, the composition of gross-output (production) will change, as illustrated in Figure B.6, which also reports changes in production prices.

All energy producers' sectors, are affected by the reduction in energy demand. Consequently, as shown in Figure B.6, their selling (production) prices decrease with their gross output. 'Mining and fossil fuel supply' is the most affected sector as it cannot easily offset the reduction in the selling price by changing the production technology. Although the energy efficient technologies reduce at least as much electricity needs as fossil fuel use, according to the results of the simulations, electricity generation sectors are less affected than extraction sectors because fossil-fuel energy costs in electricity generation sectors are now lower, and for non-fossil fuel based electricity generation changes in input structure help to reduce production costs.

Figure C.6 shows that for some sector both output and production price are increasing under the energy efficiency scenario: these are sectors that are directly stimulated through increased demands for their output. These economic sectors produce energy efficient goods/capital. In particular, the “Construction” sector is stimulated through the demand for building insulation while the “Electronics” and “Other industries” sectors are stimulated by the adoption of new energy efficient appliances. The increased demand for goods produced by these sectors will mechanically increase the selling price offered by firms. “Motor vehicles” manufacturing is also stimulated; both directly through purchases of cleaner vehicles and indirectly through lower fuel prices in general.

The policy also leads to changes in production prices as an indirect effect. The reductions in energy demand and costs feed-back in lower production prices that in turn stimulate demand for their output. This is because the energy saving bill is higher than the increasing capital cost. Figure C.6 reports those sectors where output is stimulated through a reduction of production prices, “Transportation services” and “chemicals” are typical in this sense: the reduction in the production costs are stronger in the sectors that implement energy efficiency investments than in other sectors and boost their activity. One could also noticed that some sectors that are energy-intensive but do not implemented energy efficient investments themselves could anyway benefit of the overall decrease in energy prices (this is for example the price for Iron and Steel or Fisheries, that are not reported in details in the figure). Non- OECD countries invest relatively more than OECD countries in energy intensive industries, while investment in transportation improvements and building isolation by the services sectors are relatively larger in OECD countries than in non-OECD countries.

Finally, some sectors are mostly stimulated (or depressed) through the macroeconomic income impacts (and some time through some trade effects). For example “Agriculture, fisheries and forestry” sectors, or “Food product” and “Textiles” record output/demand increases that are close to the average increase of the economy-wide real income. For these sectors, the production price increase is in line with the change in demand for their output.

The services sectors in general (excluded “Transportation services”) are generally much less affected by the policy than other sectors. Direct effects on change in production modes are limited because their cost structure is less sensitive to energy and capital costs than manufacturing sectors. Indirect effects are also limited as these sectors are only affected to a small extent by the new more efficient technologies. Nevertheless in OECD countries, where manufacturing sectors are already more efficient, the new gains in energy efficiency take place in the services sectors (“Public services and utilities” and “Business services”). Hence, these sectors are relatively more stimulated than in non-OECD countries. In the latter, large efficiency gains are found in manufacturing sectors

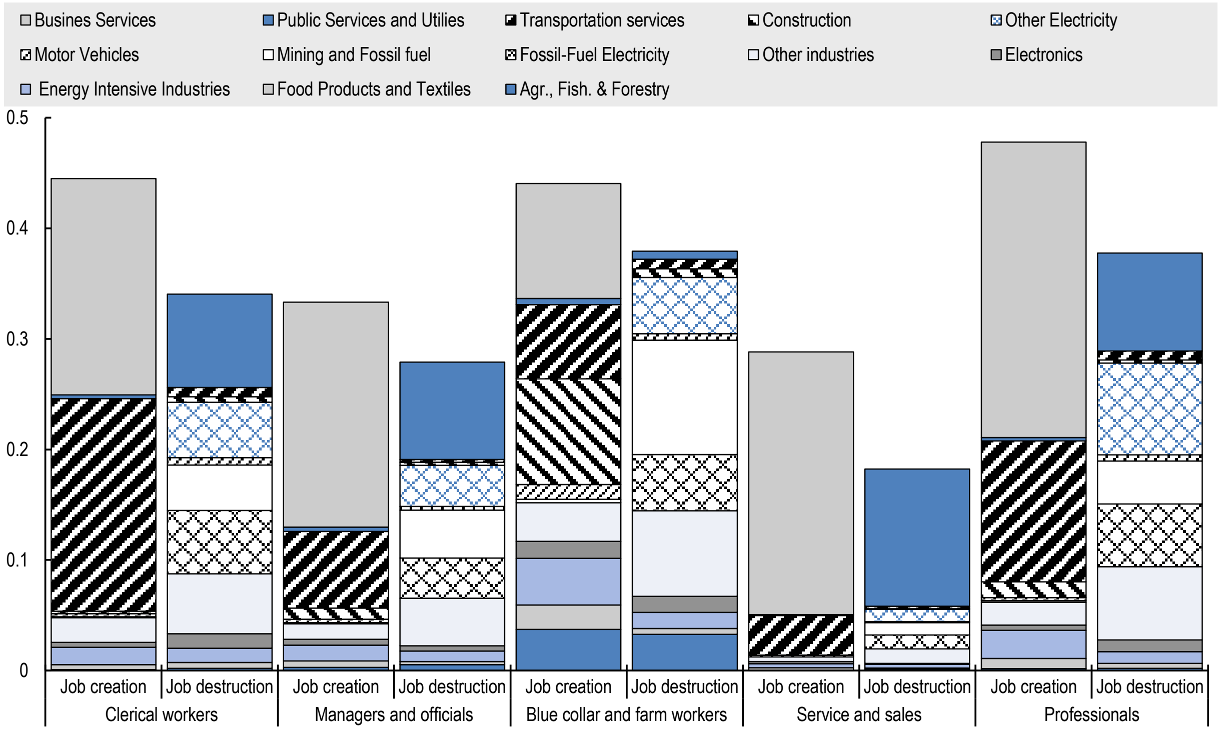
C.4 Labour market consequences of the **energy efficiency** *scenario*

The Figure C.7 also shows that under the *Energy efficiency scenario*, the real gross wage of the economy is increasing (while not reported here it could be shown that this is the case in all individual regions not only). Beyond these overall effects on aggregate wage, three other effects explain the changes in the sectoral mix of total employment. These three impacts are the changes in output level of the sector discussed previously; the changes in the relative costs of labour to capital (and energy) within a sector; and the changes in the relative wage received by a worker in a given sector with respect to the wage that could be earned in another sector (this information could be inferred from Figure B.7 by comparing sectoral wage to the “total” or average economy wage).

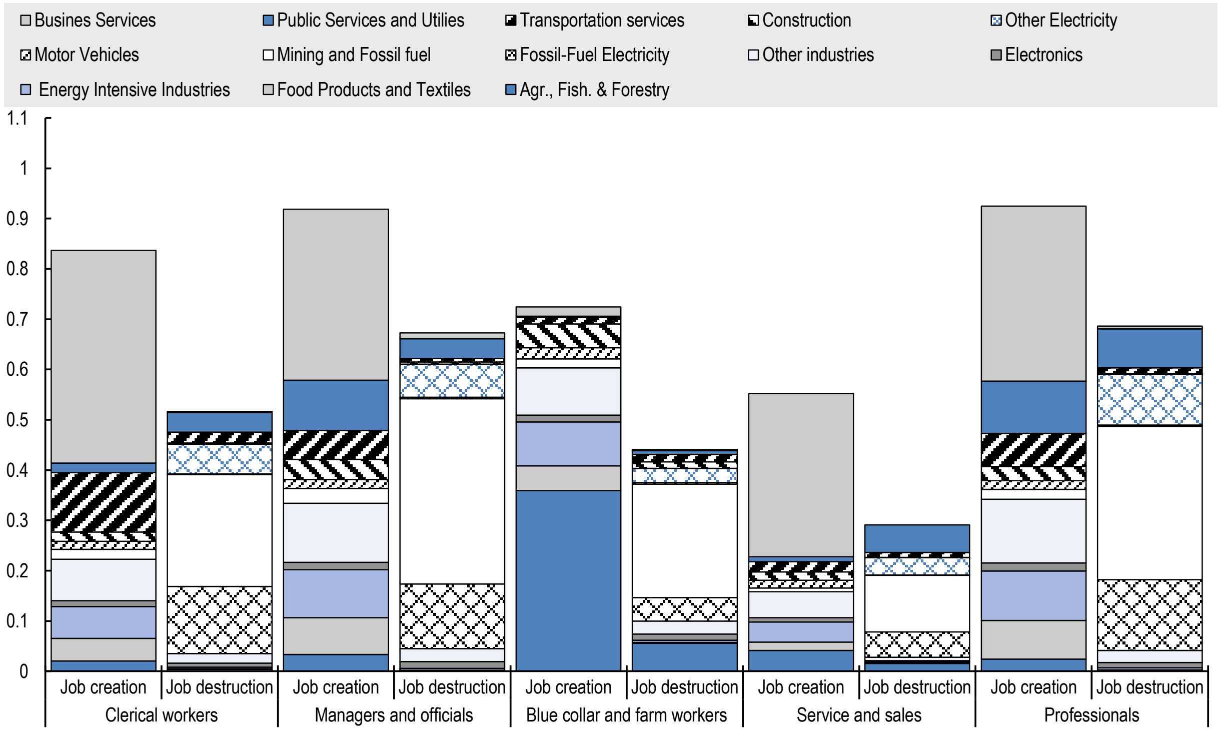
Figure C.7. Change in sectoral composition of job creations and job destructions, by job category: *energy efficiency scenario*

Deviation from the reference equilibrium, % of total employment of different job categories, 2011

Panel A. OECD countries



Panel B Non-OECD countries



Source: ENV-Linkages Model

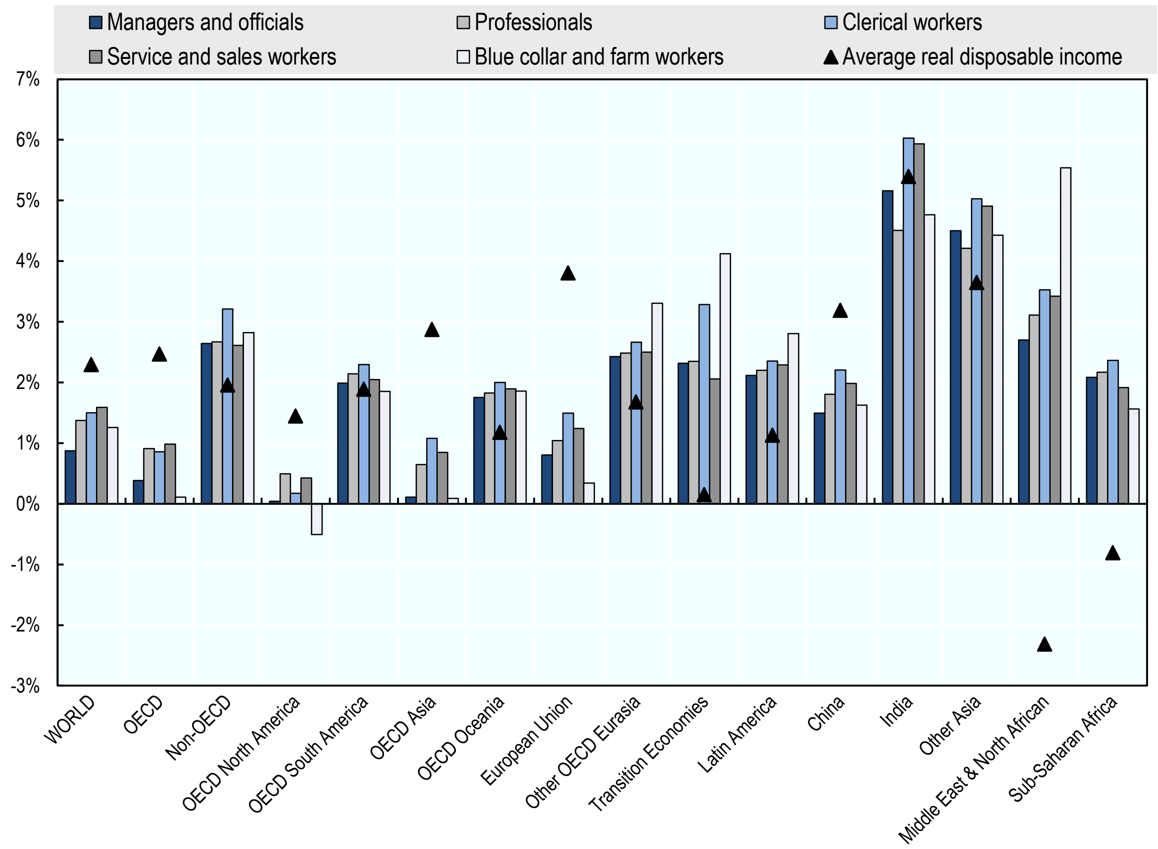
A common general feature is that changes in sectoral wage rates are always larger than changes in the corresponding employment, partly expressing that at aggregate level total employment is not very elastic, and partly reflecting that production structures are not fully flexible so prices always adjust more that quantities. Moreover, changes in sectoral real wages are also generally larger than changes in the corresponding gross output, for all sectors, and this because capital and labour are not close substitutes. Besides these general features, the changes in composition of employment and wage structures can differ largely across countries and this is another important difference with the *central scenario*: in Figure B.7 for example one could see that impacts on employment in "Transportation services" or "Motor vehicle" have very different magnitude in OECD and non-OECD countries. The initial structure of economy is not the only reason why economy react differently, the main other reason that is a specific characteristic of the energy efficiency scenario relative to the *central scenario* is that the "energy efficiency packages" themselves differ a lot across countries.

C.5 Distributional impacts of the energy efficiency scenario

In the *Energy efficiency scenario* the government expenses are generally higher than in the reference equilibrium, since the policy relies partly on some fiscal incentives and since some resources are displaced following the changes in tax-basis themselves (e.g. income, demands, factor remunerations). Hence, ultimately households need to pay extra wage income taxes to balance the budget, at least in OECD and non-OECD EU countries or in Brazil and China. In the other emerging countries and in transition economies countries, the adjustment in wage income taxation is negative or close to zero. It is important to bear in mind that labour income is not the only income that is impacted by the two policies; incomes from capital, land and natural resources are also paid back to households. However, since there is not enough information on the allocation of non-labor income sources across the different categories of workers, these income sources are not considered when comparing individual income.

Figure C.8. Impacts on the distribution of net-of-tax real wage income by job category and on total real disposable income, *energy efficiency scenario*

Percentage change w.r.t. the reference equilibrium, 2011



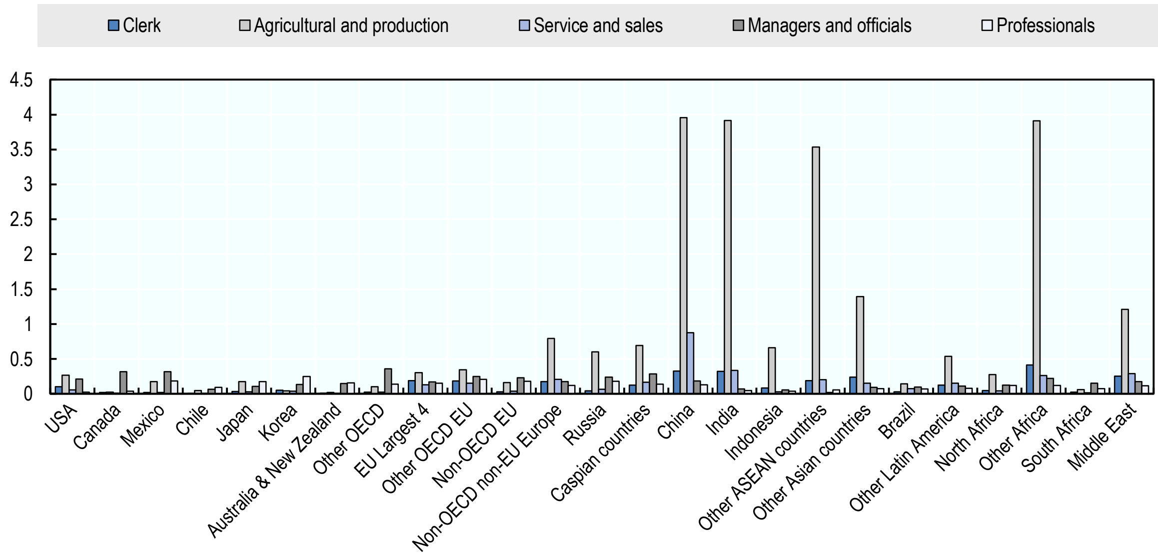
Note: Bars correspond to the net-of-tax real wage income while triangles refer to real disposable income.

Source: OECD ENV-Linkages Model

ANNEX D: ADDITIONAL RESULTS FOR THE MIXED POLICY SCENARIO

Figure D.1. Total job reallocation by region and job category, *mixed policy scenario*

Deviation from the reference equilibrium, Millions of persons, 2011



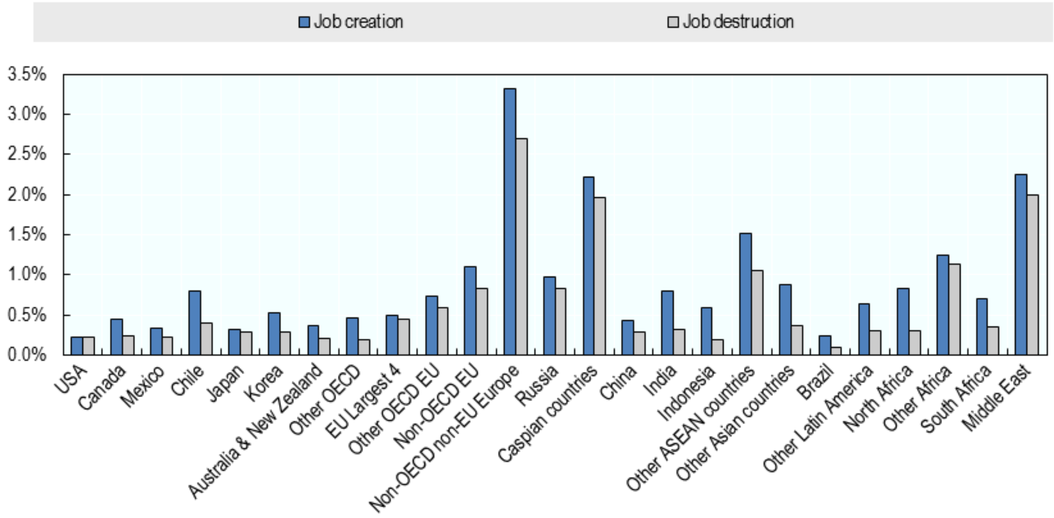
Source: OECD ENV-Linkages Model

An aggregate calculation indicates that the total job reallocation would affect less than 0.6% of total employment in OECD countries and around 1.1% at world level in the mixed policy. While limited these job reallocations are shown to be slightly higher than in the *central scenario*. The first explanation of this limited job reallocation is that the heavily impacted industries (mostly energy sectors) represent only a small share of total employment. The second explanation is that the level of total employment, for each of the five job categories, is assumed to be fixed and thus unaffected by any policies. Note that this assumption of fixed supply of labour implies that the total number of job destructions induced by a policy scenario is equal to the total number of job creations, for each of the five job categories.

Figure D.1 indicates that actually the job reallocations could sometimes appear to be much higher in some specific countries. Under both scenarios the total labour reallocation (in percentage of total employment) appears to be, at least, twice higher than the world average in countries where the economic structure is dominated by large fossil-fuel sectors ('Middle-East and North Africa', Russia, 'Caspian' countries or 'Other Africa').

Figure D.2. Job destruction rates and job creation rates by region for all workers, *mixed policy scenario*

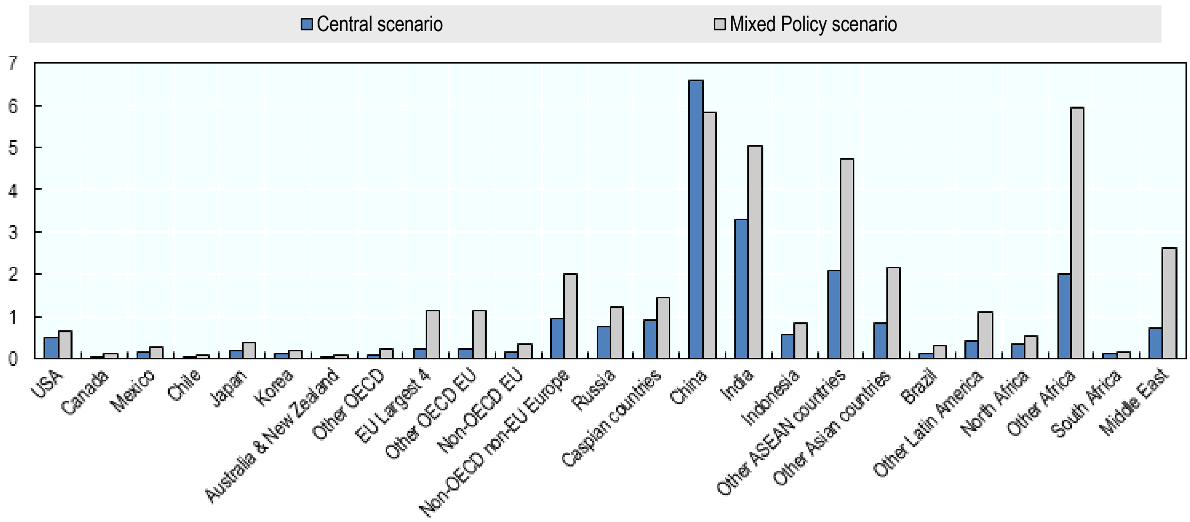
Changes in employment relative to total employment in the reference equilibrium, 2011



Source: OECD ENV-Linkages Model

Figure D.3. Total Job reallocations by region, *central and mixed policy scenarios*

Deviation in employment relative to the reference equilibrium, millions of persons



Note: Total job reallocation is measured by the sum of the job creations and the job destructions in all economic sectors, for all job categories taken together.

Source: OECD ENV-Linkages Model

ANNEX E: SENSITIVITY ANALYSIS OF THE *CENTRAL SCENARIO* TO PARAMETER CHANGES

The Table E.1 below reports change in selected impacts of the central when one consider change in the environment (e.g. change in the elasticities of the model). By sake of simplicity the table only report, changes in average real net wage income, average real disposable income, average real net wage rate, total employment, job reallocation rates, and the relative wage income of low-skilled workers.

Table E.1 Sensitivity analysis to changes in parameter values, *central scenario*

Percentage change w.r.t. the reference equilibrium, OECD average, 2011

		Net wage income	Real disposal income	Real net wage	Employment	Job reallocation	Relative low-skilled net wage income[#]
	Central case	**0.245**	**-0.276**	**0.222**	**0.023**	**0.291**	**-0.287**
possibility of substitution across workers for firms[1]	Not	0.224	-0.283	0.203	0.022	0.278	-0.671
	Full	0.250	-0.274	0.226	0.024	0.296	-0.171
Possibility of workers reallocation across sectors[2]	None	0.285	-0.200	0.257	0.029	0.051	-0.382
	Perfect	0.211	-0.161	0.188	0.024	0.583	-0.328
Capital to Labour substitution[3]	Low	-0.052	-0.293	-0.047	-0.005	0.321	-0.342
	High	0.465	-0.261	0.421	0.044	0.253	-0.186
Possibility of capital reallocation across sectors[4]	None	0.400	-0.086	0.359	0.041	0.257	-0.290
	Perfect	0.226	-0.297	0.205	0.021	0.297	-0.286

Notes:
Change in net wage income of low-skilled workers relative to average net wage income across all workers.

1) The second and third rows reports values of elasticities of substitution for workers by categories for firms, values are respectively 0 and infinity.
2) The fourth and fifth rows reports values of elasticities of transformation between sectors for worker in a given job-category, values are respectively 0 and infinity.
3) The sixth and seventh rows reports values of elasticities of substitution between capital and bundle of workers, values are respectively half and the double of the value in reference case.
4) The eighth and ninth rows reports values of elasticities of transformation between sectors for capital, values are respectively 0 and infinity.