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Full Length Article

Distributional implications of carbon taxation policy in Indonesia

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ABSTRACT

We combine the Environmentally-Extended Multi-Regional Input-Output (EE MRIO) analysis with a micro-simulation analysis to estimate the distributional implications of carbon policy reform, a combination of carbon tax and revenue recycling initiatives, on households in Indonesia. We consider two relevant scenarios: an "economy-wide" carbon tax versus an "electricity-only" carbon tax. The impact of carbon policy reform is measured by the net impact of carbon tax and cash transfer relative to initial expenditure. Carbon policy reform in Indonesia tends to be progressive, meaning the relative net impact on households decreases as income increases. Carbon tax in Indonesia primarily affects households through the price increase in electricity and fuel products. The distributional impacts of a carbon policy reform are determined more by the percentage of tax revenue recycled and taxation scenario and less by the tax rate. In order to protect the poorest 40 % of Indonesian households from inflationary pressure, the Indonesian government needs to recycle 25 % of tax revenue.

1. Introduction

Indonesia faces the dual challenge of reducing carbon emissions while maintaining its development objective of improving the living standards of its people [1]; 9.5 % of the 277.5 million Indonesians lived below the national poverty line in 2022 [2]. During the past decades, the country has been highly reliant on fossil-based energy provisions to fuel its economic growth, making it one of the biggest carbon and greenhouse gas emitters in the world [3] [2] To minimize the future negative impacts inflicted by climate change and to halt the country's increasing reliance on fossil fuels, Indonesia has pledged to reduce carbon emissions and scheduled to implement various climate-related policy measures [4], including the initiative to experiment levying a $2 per tonne of CO_2 carbon tax on coal-fired power plants. Following this experimentation, Indonesia plans to gradually raise the carbon tax rate and widen the sectoral coverage [5]. However, the consequences of such a plan on households' budgets remain relatively unexplored. Understanding the distributional impacts of a carbon tax in Indonesia is instrumental; without a clear insight into how a carbon tax affects the expenditure of Indonesian households across income spectrum, there is a risk that the policy could place a disproportionate burden on lower-income households. This study investigates how alternative carbon tax designs would affect households across different income levels in Indonesia.

Two studies assessing the impacts of carbon taxation policy in Indonesia find that a carbon tax has similar effects on low- and high-income households. Yusuf and Resosudarmo [6], based on a Computable General Equilibrium (CGE) model calibrated with 2003 data, estimate the distributional impacts of a carbon tax on households. The authors estimate the percent change in households' expenditure and income and find that the relative impact of introducing a $30 carbon tax on fuel products (e.g. coal, gasoline, diesel, kerosene and natural gas) does not differ significantly for households across income levels. Steckel et al. [7], based on an input-output model calibrated with 2019 data, evaluate the short-run impacts of carbon taxes in several developing Asian countries, including Indonesia. They report that the relative impacts of a carbon tax in Indonesia on low-income households are not significantly different than that on the high-income households. However, In Steckel et al. [7], Indonesia stands out from other countries in developing Asia. Only in Indonesia is the carbon tax neutral in the sense that the relative impact (the additional tax burden in percent of

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[2] According to World Bank data, total greenhouse gas (GHG) emissions in Indonesia in 2019 were 1.24 Gt CO_2eq (measured in CO_2-equivalent), excluding GHG emissions from land-use, land-use changes and forestry. Roughly half of the country's GHG emissions consist of CO_2. Indonesia's CO_2 emissions in 2019 were 0.65 Gt CO_2; these carbon emissions are primarily due to the combustion of fossil fuels (including coal). Electricity generation and heat producers are responsible for circa 45 % of the CO_2 emissions in Indonesia.

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household income) is roughly the same for each income group. In the other countries studied, the carbon tax is regressive, meaning that the additional tax burden falls disproportionally on the poorer households. This result is striking and worth investigating further, for it may have to do with the input-output table and the household survey data of that particular year.

To this end, we offer a new analysis of the distributional impacts of carbon taxation in Indonesia. We focus on a single country and investigate the net impacts arising from alternative revenue recycling schemes; to the best of our knowledge, this has not been done for Indonesia before. We report novel estimates how much of the collected carbon tax revenue the Indonesian government would need to recycle to offset the negative effects of carbon taxation on Indonesia's poorest households. We consider two carbon taxation scenarios that directly speak to Indonesia's recent climate policy plan. The government plans to introduce a carbon tax in the electricity sector first before widening the tax base to the whole economy. In some of our simulations, the government prioritizes the bottom 40 % of households to receive the relief package while in other simulations all households receive transfers. In the past, the Indonesian government has used cash transfers to protect low-income households in various instances of economic shocks and natural disasters [8]. We analyze what percentage of the collected tax revenue would need to be recycled to the bottom 40 % of households until they become net beneficiaries of the carbon policy reform and can maintain their initial expenditure level. Compared to the earlier studies, our estimates of the (direct and indirect) carbon intensity of household consumption are more disaggregated, because we use more detailed input-output matrix. The EXIOBASE3, our main data source, offers finer sector detail than the Multi-Regional Input-Output (MRIO) tables used by the earlier studies, and this is a clear advantage because EXIOBASE3 disaggregates the electricity sector by energy source. The dis-aggregation is key to analyze the specific contribution of CO_2-intensive electricity sectors on carbon tax impacts.

Our methodological approach follows previous studies of carbon pricing impacts (for instance, [7]). We estimate, first, the relative impact of a carbon tax on Indonesian households by income decile. Second, we explore the consequences of different carbon tax rates and revenue recycling schemes. While households incur extra costs due to the carbon tax, they also receive extra benefits in the form of transfers. We use a multi-regional input-output model to estimate price increases by sector, assuming full cost pass-through (producers pass the tax cost through to output prices). We map the price increases by sector to the expenditure categories found in household expenditure surveys using the latest household expenditure survey.

Our analysis focuses on CO_2 emissions and excludes other GHG emissions for several reasons. CO_2 are emitted in significantly larger volumes and persist much longer in the atmosphere compared to other GHG emissions such as methane and nitrous oxide [9]. Although methane and nitrous oxide have higher warming potentials, their overall contributions to climate change are smaller due to their lower emission volumes and shorter lifetimes [9]. CO_2 emissions are also linked with key economic sectors that provide essential goods and services, such as energy production, transportation, and industry. Regulatory measures aimed at reducing CO_2 emissions could potentially impact households through these sectors. Understanding this impact is a key objective of our study.

This study is structured as follows. Section 2 discusses the related literature and important concepts related to carbon taxation. Section 3 discusses the model framework, the notation for the environmentally-extended MRIO (EE MRIO) model, and the integration between the MRIO model and the microsimulation model. Section 4 explains the use and the harmonization of the MRIO and household expenditure survey data. Section 5 discusses the results and Section 6 concludes this study. We find that carbon policy reform in Indonesia has a tendency to be progressive. A carbon tax in Indonesia mainly affects households through price increases in electricity and fuel for private vehicles and cooking activities. The distribution of relative net impacts of a carbon policy reform in Indonesia is determined by revenue recycling percentages and taxation scenario (e.g., to which sectors a carbon tax is levied). The Indonesian government would need to recycle at least 25 % of tax revenue to compensate the impacts of carbon tax on the poorest 40 % of Indonesian households.

2. Related literature and key concepts

A carbon tax is, in theory, an economically-efficient policy for reducing carbon emissions as it holds polluters accountable for the negative externalities of the emissions associated with their activities [10–12]. By assigning a price to carbon emissions, a carbon tax creates a financial incentive for both producers and consumers to reduce carbon emissions. A carbon tax encourages behavioral changes: as the cost of emitting carbon increases, producers and consumers are stimulated to either substitute emission-intensive for less-polluting energy sources or to increase the energy efficiency of their activities. Further, a carbon tax generates fiscal revenue, which can be recycled into various government programs for promoting sustainable development and facilitating the transition to a cleaner energy system. Compared to a cap-and-trade system, a carbon tax ensures greater transparency and predictability [13]. Getting the public to accept a new carbon tax can be challenging due to the short-run economic consequences [14,15]. A carbon tax raises the prices of fossil fuels and, through inter-industry linkages, the prices of other products. In Indonesia, the public has frequently opposed similar policies, as is shown by the mass protests that happened immediately after the government's decision to eliminate fossil fuel subsidies in 2008 [16,17], or in 2022 [18].

Wang et al. [19] and Ohlendorf et al. [20] document how the distributional implications of carbon pricing policy (e.g., carbon tax) vary across countries and by the modelling approach used in the analysis. The impacts of carbon tax are deemed 'regressive' when it disproportionately affects low-income households. The effects of carbon tax are deemed 'progressive' when higher-income classes are hurt more by it than lower-income classes. Studies using various methods find that carbon pricing policies tend to be regressive in many developed economies, for instance in the case of Canada [21], the US [22], The Netherlands [23], the UK [24], Sweden [25]. However, a few studies report neutral impacts (the impacts increase proportionally with the income level), e.g., in the case of Spain [26] and Australia Sajeewani et al. [27]. Results also vary among the developing economies (see Steckel et al. [7] for developing Asia and Vogt- Schilb et al. [28] for Latin America and the Caribbean countries). Carbon tax has been found to hurt higher income classes relatively more than lower income classes in the case of ASEAN countries such as Vietnam, Malaysia, the Philippines, and Thailand [29]. Yusuf and Resosudarmo [6] conclude that carbon pricing is not necessarily regressive for Indonesia. Similarly, Steckel et al. [7] find that, under certain pricing scenarios, the carbon pricing policy in Indonesia would have a relatively larger impact on high-income groups. Different studies for the same country obtain different results. Using different methods, Brenner et al. [30] find that the direct carbon tax has progressive results while Liang et al. [31] conclude that the carbon tax in China is regressive. In the case of Italy, Tiezzi [32] finds that the outcome of a carbon tax is progressive, whereas Symons et al. [33] conclude that the distributional impacts are rather 'neutral' for Italian households.

When evaluating the distributional effects of carbon pricing policy, three methods are popular. The **econometric** model is used to statistically estimate the effect of carbon pricing policy on related variables such as household expenditures and incomes (for instance, the study by Bureau [34] for France). The so-called **hybrid** model combines the EE MRIO analysis with the microsimulation analysis to assess the short-run implications of carbon pricing policy. The EE MRIO analysis accounts for the direct and indirect emissions embodied[3] in aggregate final demand while microsimulation analysis simulates the effects of levying an emission tax on micro (e.g. households) levels [35]. The existing studies implement the hybrid model while assuming no change in demand (see Dorband et al. [36], Vogt-Schilb et al. [28], Feindt et al. [37], and Steckel et al. [7]) or including demand-side response (see Burtraw et al. [38], Datta [39], and Douenne [40]). As a MRIO-based model, the hybrid model incorporates the cost-of production structure of dozens of industrial sectors; most econometric models do not have a similar degree of industry-level disaggregation and detail [19]. The **CGE** model takes into account both the income- and expenditure-side to assess the distributional implications of carbon pricing (for instance, Yusuf and Resosudarmo [6] in the case of Indonesia). However, the production cost structure of industries in CGE models tends to be less disaggregated and detailed than in hybrid models and as a result, the impacts of a carbon tax on costs and prices are less well captured in these models than in hybrid IO-micro simulation models. The strength of CGE models is their capacity to trace the indirect (general equilibrium) effects of a carbon tax, that mostly operate through relative price changes. We focus on the immediate real income impacts of a carbon tax on lower-income households, which are arguably the most significant effects, because the price elasticities of demand for energy are low.

Hence, using the hybrid model, our goal is to evaluate the first-order effects of a carbon tax on lower-income households in Indonesia. This is because lower-income households have limited resources to adapt to the immediate price increase, while in longer term they have more room to change behavior as a response to the price changes and subsidies [7,36, 41].

3. Methods

3.1. Model framework

Our model is a static model that simulates the short-run effects of implementing a carbon tax, assuming that the price elasticities of producer and consumer demand functions are zero. The assumption of zero price elasticities means that consumers do not change the scale and pattern of their consumption and producers do not change their production technology (intermediate input structure) in response to changing relative prices. We estimate not only the carbon tax burden due to embodied emissions but also the burden due to households' direct emissions from fuel combustion (private vehicle transport and cooking activities). We treat the total expenditure of each household as a proxy of its income [42,43] and then categorize households into ten income deciles based on their total expenditures.

Table 1

We use a hybrid approach that consists of two modules: the EE MRIO model and the microsimulation analysis. The EE MRIO analysis extends the traditional Input-Output (IO) analysis [44] and combines it with environmental impact variables. The EE MRIO model tracks the flow of goods and services through the economy and links final consumption expenditure to the associated environmental impacts [45,46]. The outcome of this model are carbon tax burdens by expenditure category, where tax burden refers to the additional expenditure required to maintain the same consumption level. The microsimulation analysis then permits the analysis of the distributional implications; it maps the carbon tax burden by expenditure category to the household level, using survey data on the scale and pattern of consumption, to estimate the carbon tax burden by household [19].

Table 1
Carbon tax reform scenarios.

Tax rate	Tax base	Size of cash transfer	Eligibility of cash transfer
$2	"Economy-wide"	$100 flat	All households
$40	"Electricity-only"	X % recycling	Bottom 40 %
$100	"Fuel-only"		
$120	"Economy-wide + BTA"		

Notes: BTA stands for Border Tax Adjustment.

We create carbon tax reform scenarios that combine carbon taxes with cash transfers to estimate net impacts at the household level. Our model uses annual IO data; the final demand, tax revenues, and cash transfers are annual flows. The cash transfers compensate households for the carbon tax burden; in some cases, the cash transfers are so high that households net gain from carbon tax reform. In general, the net impact depends on the size of the transfer, and the scale and pattern of consumption.

We explore the net impacts of alternative carbon tax reform scenarios. The scenarios differ in terms of the carbon tax rate, the tax base, the size of the cash transfer, and the eligibility criteria of the cash transfer. All scenarios reported in the main text are based on a tax rate of $40 per tonne of CO_2.[4] To explore the implications of different tax bases, the "Economy- wide" scenario places a carbon tax on all producing sectors in the Indonesian economy, while the "Electricity-only" scenario places a tax only on the electricity sector.[5]

The simplest cash transfer scheme is one that does not depend on the magnitude of carbon tax revenues; we explore the consequences of transferring $100 to each household. In alternative cash transfer schemes, we let the size of the cash transfer per household to depend on the carbon tax rate (which, together with the total number of households, determines the total carbon tax revenue) and the fraction of tax revenues recycled (e.g., 100 % revenue recycling means that 100 % of the carbon tax revenues are transferred to households in full).

We also explore a variation of the cash transfer eligibility criterion: instead of awarding the same cash transfer to every household, the "Bottom-40 % only" scheme simulates cash transfers to only the poorest 40 % of households.

The rationale for the different scenarios is as follows. Indonesia has tested the effects of the carbon cap-and-trade system as applied to the national coal-based electricity sector on the basis of the Presidential Regulation Number 98/2021 and ESDM Ministerial Regulation Number 16/2022 [5]. While the outcome of this test is yet to be made public, Indonesia plans to gradually introduce the carbon taxation system in the near future. A $2 per tonne CO_2 carbon tax will first be introduced to the coal-based electricity sector in the form of cap-and-tax system which combines the elements of cap-and-trade and tax. In this system, only the excess emissions beyond the regulated (or the capped) amount are subject to taxation, which makes it different from a straightforward taxation approach. The limited scope combined with the low tax rate ($2) means that the impacts on households' expenditures will be very

[3] We use the traditional nomenclature in the environmentally-extended multi-regional input-output (EE MRIO) study, the 'direct and indirect emissions' refer to the direct and indirect emissions – generated along the production chains – that are embodied in final demand. The direct and indirect emissions embodied in final demand exclude the direct households' emissions generated from fuel use.

[4] The Appendix explores alternative tax rates ($2, $40, $100 and $120 per tonne of CO_2.)

[5] In addition, the Appendix explores the "Economy-wide tax + BTA" scenario, which presumes that imported products are taxed in proportion to their total embodied carbon content. It also explores the "Fuel-only" scenario, which narrows the tax base to fuel products.

small. The government intends to broaden the tax base to cover the whole electricity sector, and later other sectors in the economy; moreover, it intends to include not only the excess quantity of carbon emissions, but all emissions. 80 % of Indonesia's electricity is produced from fossil-based energy sources [47].

Our main goal is to understand the impacts of an ambitious carbon tax scheme that might be implemented in the future. Our base tax rate is \$40 per tonne of CO_2 emissions, a rate regarded as the lower bound required to achieve the target of the Paris Agreement [48]. The implications of alternative tax rates are explored in the Appendix. Stern and Stiglitz [49] suggest a tax of \$100 per tonne of CO2. Different integrated assessment models yield different values for the social cost of carbon [50]. The IPCC Sixth Assessment Report suggests a carbon tax of \$115 per tonne of CO2 emissions (see World Bank [51] page 20, box 4). The \$120 reported in the Appendix is at the upper bound of carbon tax rates suggested by those studies.

Besides the "Electricity-only" and the "Economy-wide" scenarios reported in the main text, the appendix explores the "Fuel-only" scenario, which 1) taxes fuel producers based on the emissions from fuel production processes, and 2) taxes fuel suppliers based on the estimated emissions generated by the vehicles that are used in the transportation services, and on the estimated household's emissions from direct use of fuel for private vehicle and cooking activities. Indonesians are highly reliant on the use of private vehicle for mobility and liquified petroleum gas (LPG) stove for cooking activities, which in turn drives a heavy dependence on fossil-based fuels [52], which makes the "fuel-only" scenario worth investigating for it may directly impact households. The Appendix also reports the "Economy-wide tax + BTA" scenario, which simulates a border tax adjustment (BTA), whereby importers pay a tax proportional to the carbon emissions embodied in the imported products. We want to understand the effects of imposing a carbon tariff on imported products on households in Indonesia. The idea is that as a carbon tax is implemented on domestic products, the resulting price increases could render these products less competitive compared to imported ones that may not face similar charges. As a protective measure for domestic products, Indonesia may impose tariffs on imported products – with domestic carbon price as a reference – to maintain their competitiveness. Indonesia has implemented various protective measures for domestic industries by imposing tariff on imports [53]. For this reason, it is a worthwhile enterprise to explore this possible future scenario.

3.2. The input-output model and microsimulation module

In input-output (IO) analysis, the total output of the economy can be determined by the following system:

$$x = (I - A)^{-1} y \tag{1}$$

Where x is the total (gross) output vector, is identity matrix, A is technical coefficient matrix, and y is a vector of final demand. $(I - A)^{-1}$is known as the Leontief inverse matrix which captures the total inputs required by each sector to produce one unit of final demand. The embodied carbon tax in household h's consumption, can be determined by

$$\sum_{n,m} t^{emb}_{h,n,m} = \hat{\tau} q^T (I - A)^{-1} y_{h,n,m} \tag{2}$$

Where $t^{emb}_{h,n,m}$ denotes the vector of direct and indirect carbon tax embodied in household h's consumption, containing n sectors and m countries. $\hat{\tau}$ is the vector of carbon tax rates in dollar per tonne of CO_2 (the hat denotes diagonalization) and q^T is the vector of direct carbon emissions per unit of gross output, or simply emission intensities (the superscript T denotes the transposition of a vector). We assume that in a carbon taxation scenario, the carbon tax rate is always equal across sectors in the economy. $y_{h,n,m}$ denotes the column vector of household h's consumption, containing n sectors and m countries, which is constructed by first harmonizing the Indonesian household survey product classification into the EXIOBASE product classification, and then estimating[6] it using the share of household final demand from the EXIOBASE final demand data,

$$y_{h,n,m} = \frac{y_{n,m}}{\sum_m y_{n,m}} \cdot y_{h,n} \tag{3}$$

where $y_{n,m}$ denotes the column vector of household final demand (from the EXIOBASE) and $y_{h,n}$ denotes household h's consumption bundle containing n sectors (from the Indonesian household survey that has been mapped into EXIOBASE product classification).

The carbon tax associated with household h's direct emissions, t^{dir}_h, is calculated by multiplying the corresponding carbon tax rate with household h's direct emissions from fuel combustion h, $e_{h,fuel}$,

$$t^{dir}_h = \tau \cdot e_{h,fuel} \tag{4}$$

In EXIOBASE, direct household emissions are available as a single-entry aggregate and interpreted as "the aggregate households" direct emissions associated with fuel combustion from using private vehicles and cooking activities. Thus, we estimate the direct emissions of household h, $e_{h,fuel}$, by the share of its monetary expenditure for fuel in the total fuel monetary expenditures of all households and its household survey weight:

$$e_{h,fuel} = \frac{y_{h,fuel}}{\sum_h y_{h,fuel}} \cdot e^{dir}_{fuel} \cdot \frac{1}{\omega_h} \tag{5}$$

Where e^{dir}_{fuel} denotes the (aggregate) direct household emissions and ω_h denotes household h's survey weight (household survey weight determines the number of households in real life the corresponding household represents).

The total carbon tax of household h is the sum of the direct and the embodied carbon tax in its expenditure,

$$t_h = t^{dir}_h + \sum_{n,m} t^{emb}_{h,n,m} \tag{6}$$

To include only the relevant region or products to which a carbon tax is levied, the emission intensities of foreign countries or products are set to 0. The total carbon tax revenue T the government collects from the implementation of carbon tax is the sum of the additional cost of all households:

$$T = \sum_h t^{dir}_h + \sum_{h,n,m} t^{emb}_{h,n,m} \tag{7}$$

The relative net impact of a carbon tax on household h after a carbon tax and cash transfer program is the ratio between the absolute net impact of carbon tax and the initial expenditure,

$$I_h = \frac{-t_h + s_h}{\sum_{n,m} y_{h,n,m}} \tag{8}$$

I_h denotes the relative net impact of carbon tax on household h's expenditure. s_h denotes the cash household h receives from the corresponding cash transfer program, which is assumed to be consumed entirely in proportion to its initial consumption. Otherwise, s_h is 0 when the cash transfer is non-existent.

The relative net impact of the first income decile q_1 is then determined by,

[6] Indonesia household survey data does not differentiate between domestically-sourced and imported consumption items.

$$I_{q_1} = \sum_{h=1}^{q1} V_h \cdot I_h = \sum_{h=1}^{q1} V_h \cdot \frac{-\sum_n t_{h,n} + s_h}{\sum_{n,m} y_{h,n,m}} \tag{7a}$$

Where V_h denotes the share of household h's survey weight in total survey weight of households belonging in the first income decile,

$$V_h = \frac{\omega_h}{\sum_{h=1}^{q_1} \omega_h} \tag{4a}$$

4. Data

For the EE MRIO module, we use the monetary product-by-product EXIOBASE 3.8.2 MRIO tables [54]. The EXIOBASE 3.8.2 data are constructed on the basis of the existing macroeconomic data published by multiple official sources such as the UN Accounts Main Aggregate Database, the services trade data from the UN Service Trade Database, the Detailed Tables of the UN National Accounts Statistics and national statistical offices for product and industry output, goods and trade data from BACI [55], and the additional supply and use tables from national statistical offices. The EXIOBASE 3.8.2 consists of 44 countries (including Indonesia) and five ROW (rest of the world) aggregate regions, covering 200 product categories per country with electricity sector disaggregated on the basis of energy source. The EXIOBASE Supply-Use Table (SUT) disaggregates the electricity sector on the basis of the International Energy Agency (IEA) energy balance by taking into consideration the share of electricity that goes both to industry as well as residential use and the countries' energy mix [54]. The EXIOBASE 3.8.2 also provides detailed environmental satellite accounts, including the CO_2 emissions (kg) as the environmental stressor variable and the direct emissions from fuel combustion by households. We add the latter to the emissions embodied in motor gasoline product before calculating the emission intensity of household final demand. We use the EXIOBASE 3.8.2 2019 table instead of the latest available year to avoid any economic anomaly caused by the Global Pandemic.

For microsimulation, we use household expenditure survey data of Indonesia, documented in SUSENAS (The National Economic Survey) 2019 by Badan Pusat Statistik (The Indonesia Statistical Office) [56]. SUSENAS is a series of comprehensive surveys to record socioeconomic data at the household level. SUSENAS covers around 300.000 household samples across 34 provinces in Indonesia. The data document the amount (in Indonesian Rupiah) each household spends on 315 consumption items. Since we are the first to combine the EXIOBASE 3.8.2. with the Indonesia household survey data for 2019, we construct our own concordance table (or 'bridge matrix') to harmonize SUSENAS item classification to EXIOBASE 3.8.2 product classification. To do this, we take inspiration from the various concordance tables provided by the EXIOBASE and the study done by Steckel et al. [7] which also uses Indonesia household survey data. This concordance table is provided in the Appendix. We split electricity consumption for each household in the SUSENAS data into the EXIOBASE 12 electricity sub-products (coal, hydro, etc.) by using the final demand share of electricity sub-products in total electricity final demand by households.

5. Results and discussion

5.1. Distributional implications of a carbon tax

To estimate the impacts of the carbon policy reform on Indonesian households, we simulate an economy-wide carbon tax of $40 per tonne of CO_2 under three recycling schemes: (1) A "No transfer"' scheme where there is no cash transfer program in place, hence the household impacts are asserted only by the carbon tax. (2) A "100 % recycling" scheme in which 100 % of the carbon tax revenues are transferred back to households, and every household receives the same amount. 3) A cash transfer of $100 to each household. Fig. 1 reports the net impacts by income decile.

Both the "100 % recycling" and the "$100 flat" scheme tend to be progressive: low-income households net gain (the relative net impact is positive) and high-income households net lose (the relative net impact is negative). However, without an accompanying cash transfer policy, a carbon tax per se is neither progressive nor regressive, as it would affect households almost equally in proportional terms. In the "100 %

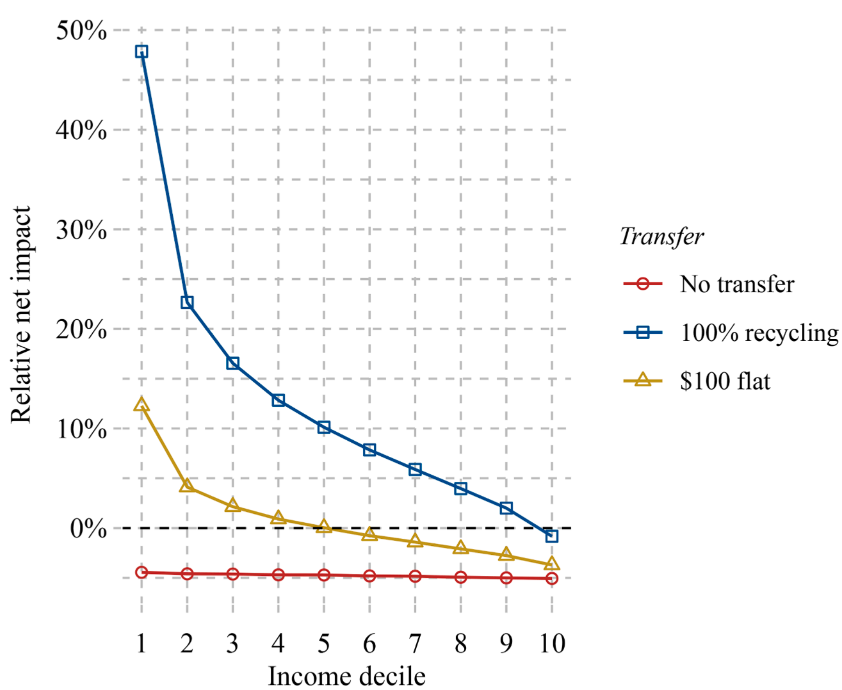

Fig. 1. Relative net impact of a $40 economy-wide carbon tax. Notes: Own calculations. The values represent the net impacts (in percent of initial expenditure) of a $40/tonne economy-wide carbon tax and three alternative cash transfer schemes. The "No transfer" scenario shows the impacts of the carbon tax only. The "100 % recycling" scheme assumes that 100 % of the carbon tax revenues are transferred back to households (every household receives the same amount). The "$100 flat" scheme transfers $100 to every household.

recycling'" scheme, the cash transfer per household amounts to $316. The bottom 90 % of households would net benefit from such a carbon tax reform. However, only the bottom 50 % of households would net benefit from the "$100 flat" scheme. If the carbon tax rate was set at $40 per tonne of CO_2, the "$100 flat" scheme would only require 32 % of the total carbon tax revenue collected. In the past, BLT cash transfer programs in Indonesia were not tied to the magnitude of particular tax revenues [5].

The average carbon tax burden of a $40 carbon tax is roughly 4.8 % across all income deciles. This (almost) uniform tax burden reflects the consumption patterns in Indonesia where all households, regardless of income, bear the tax proportionally to their expenditure on consumption goods. The distributional implications change with the introduction of a revenue recycling mechanism. In the "100 % recycling" scheme, for the poorest 10 % of households, the transfers received are far greater than the additional expenditure required to maintain the old consumption bundle. The net gain is substantial (the relative net impact is 48 %). For the richest 10 % of households, the relative net impact amounts to minus 0.8 %, meaning the "100 % recycling" does not fully offset the carbon tax impact on higher-income households. The relative net impact significantly decreases from the 1st to the 2nd decile; it then decreases gradually from the 2nd to the 10th decile. Cash transfers greatly benefit the poorest 10 % of households.

Which consumption categories contribute to the incidence of the carbon tax? We aggregate household consumption categories into four groups (electricity, fuel, food, and all other categories) and investigate

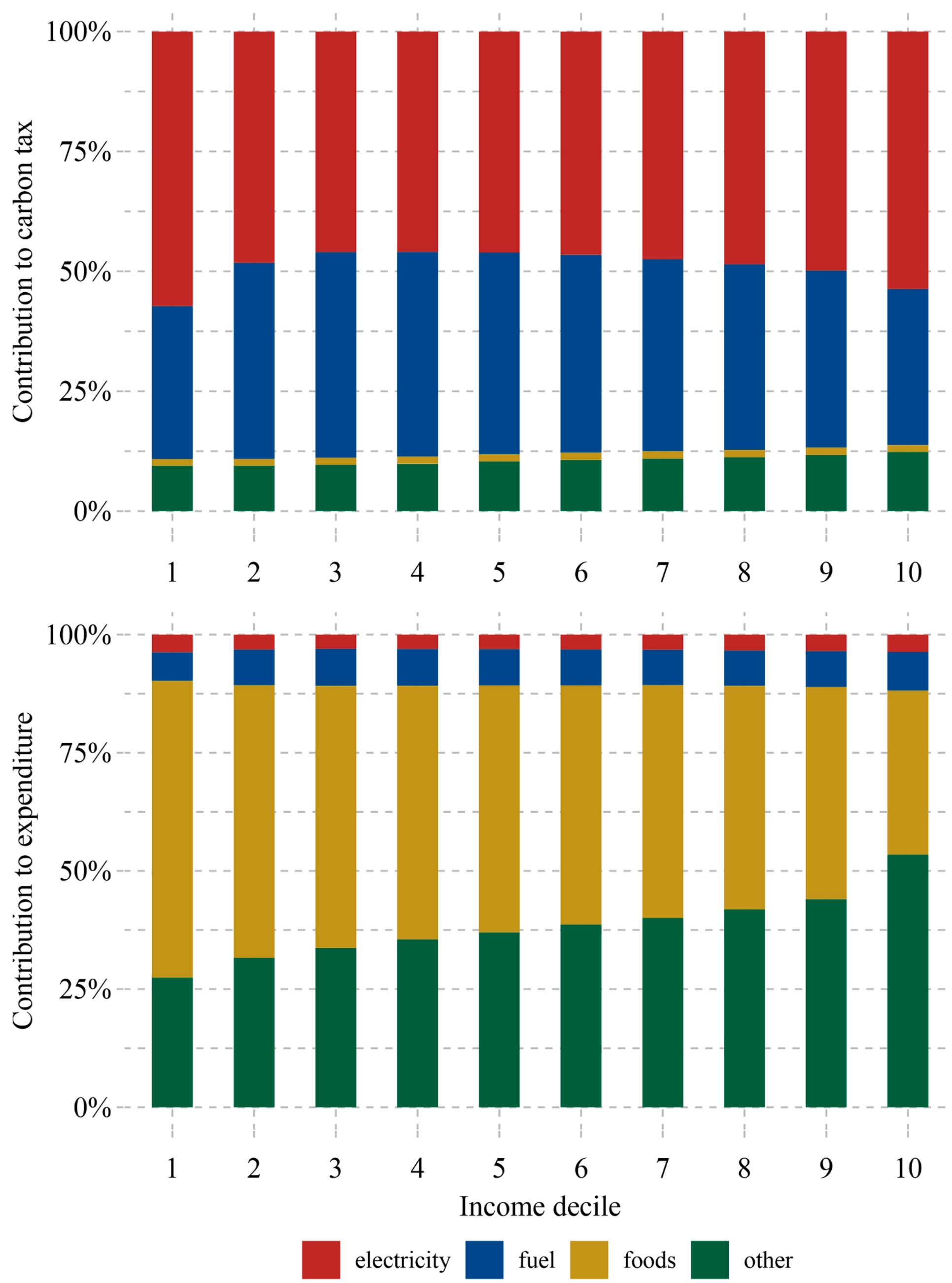

Fig. 2. Distribution of carbon tax burden and expenditure by consumption category and by income decile. Notes: Own calculations. The top chart displays the percentage contribution of electricity, fuel, foods, and other goods to the total carbon tax burden by income decile (see Table A.9 and Table A.10 in the Appendix). The bottom chart displays the corresponding expenditure distribution by income decile (see Table A.12 in the Appendix).

how these groups contribute to the total impacts (Fig. 2). Irrespective of the income group, the economy-wide implementation of a carbon tax primarily affects households through price increases in electricity and fuel, with electricity price increases having a greater impact than fuel price increases. For households in the lowest income decile, electricity consumption is responsible for more than half of the burden (57 %) and fuel use contributes 32 %. Together, these two sectors account for 89 % of the carbon tax burden for this income group. In contrast, food and other consumption items contribute much less, 1 % and 10 % respectively. The carbon tax significantly impacts the lowest income households through their expenditures on fuel and electricity. This pattern is consistent across the income spectrum, with fuel and electricity consumption contributing between 86 % and 89 % to the carbon tax for households in the middle- and high-income deciles as well.

While the carbon tax impacts all households mainly through price increases in electricity and fuel, both electricity and fuel constitute only a small portion of households' expenditures (Fig. 2). Most household expenditure is directed towards food and other consumption items.

For households in the lowest income decile, electricity and fuel account for only 10 % of their expenditure, while food and other consumption items account for 63 % and 27 %, respectively. The consumption pattern of the top 10 % households differs from that of the bottom 10 %. Food accounts for 35 % of their expenditure, while other consumption items contribute 53 % to the total. However, the top 10 % households only spend 12 % on electricity and fuel. Despite the higher absolute spending on electricity and fuel in dollar terms, the expenditure shares of these emission-intensive categories is comparable in magnitude to the bottom 10 % households. A similar expenditure pattern is observed for households between these two income groups, with the share of food in expenditure gradually decreases as income increases.

5.2. *Key takeaways of the appendix*

In the Appendix, we report results for four revenue recycling rates (0 %, 25 %, 75 %, and 100 %), four different tax rates ($2, $40, $100, and $120) and four tax bases (the "economy-wide", the "electricity-only", the "fuel-only", and the "economy-wide tax + BTA" scenario). The distributional implications of a carbon tax, with no transfers, do not depend on the tax rate. This is because the MRIO model is linear; therefore, changing tax rates will only change the overall magnitude of the impacts, but not their distribution. The choice of the tax base and recycling rate determine which income groups will net benefit from a carbon policy reform. For instance, when the carbon tax revenue is 100 % recycled, the top 20 % of households will experience a net loss when the tax base is confined to "electricity-only", whereas they will experience a net benefit under an "economy-wide" tax base (Appendix Table A.1).

Introducing a BTA mechanism on imports alongside an economy-wide carbon tax does not significantly affect the distribution of the relative net impacts. The BTA mechanism, which is designed to level the playing field between domestic products subject to carbon tax and imported goods, only marginally alters the relative net impacts by income decile. The distributional effects are broadly unchanged.

5.3. *What percentage of the carbon tax revenue would need to be recycled to protect the poor?*

What fraction of carbon tax revenue would have to be recycled in order to protect the poorest 40 % of households? Now we deviate from the previous cash transfer schemes, where all households received transfers, and presume that only the bottom 40 % receive cash transfers — a more targeted approach. Like before, we explore the consequences of a $40 per tonne of CO_2 carbon tax rate. The left panel of Fig. 3 reports the "economy-wide" reports the "economy-wide" tax base and the right panel reports the "electricity-only" tax base. Regardless of the tax base, we find that roughly a quarter of the expected tax revenue would have to be recycled in order to enable the poorest 40 % to maintain their expenditure levels.

6. Conclusion and policy implications

This study combines the Environmentally-Extended Multi-Regional Input-Output (EE MRIO) model with microsimulation to measure the direct and indirect impacts of carbon policy reform (a carbon tax and revenue recycling program) on households across different income levels in Indonesia. The impact of the carbon policy reform on households is measured by the relative net impact, that is, the net effect of the carbon tax (negative) and accompanying cash transfer (positive) relative to initial household expenditure. In general, carbon policy reform in Indonesia has a progressive tendency: the relative net impact of carbon policy reform becomes smaller and eventually turns negative as household income increases. A carbon policy reform would need to be evaluated not only by its progressiveness (or regressiveness) but also by considering whether low-income households recover from the carbon

Fig. 3. Relative net impact (expressed in % of initial expenditure) of a $40 "economy-wide" carbon tax (left) and a $40 electricity-only'' carbon tax (right) on the poorest 40 % of households.

policy reform. A compensation scheme, at least for the poorest households, is necessary to increase the public's acceptability of the carbon policy reform [57–59]. The Indonesian government would need to recycle at least 25 % of the carbon tax revenue to the bottom 40 % households in order for them to maintain their initial consumption levels.

The tax on carbon emissions in Indonesia mainly affects households through the price increases of electricity and fuel for private vehicles and cooking activities. Electricity contributes more to the total price increase than fuel. These two products, however, only make up a fraction of the total annual expenditure of households, regardless of income level. Most of the households' annual expenditure consists of spending on food products and other consumption items. A carbon tax only on electricity and fuel products will involve lower administrative cost compared to an economy-wide national carbon tax, while being almost as effective.

The distribution of relative net impacts across households by income deciles is determined primarily by the revenue recycling percentages and the carbon tax scenario. The rate of the carbon tax only influences the magnitude of the relative net impact, but not the distribution of impacts. The low-income households can be restored to their pre-tax consumption levels when enough tax revenue is redistributed to those households. This analysis has shown that this can already be done by recycling 25 % of the carbon tax revenue to support the poorest 40 % of Indonesian households. However, in practice, a carbon tax may be administratively complex to implement and the Indonesian state may not be able to collect the carbon tax revenue in its entirety. The Indonesian government has pledged to gradually widen the base of the carbon tax. If we assume that the carbon tax revenue cannot be fully collected and redistributed, the Indonesian government should prioritize the poorest households. This can be done by a targeted cash transfer program exclusively for low-income households.

We note that funding a cash transfer program by means of the revenues from carbon taxation could turn out to be problematic over time. As carbon emissions decline in response to the tax, the tax base shrinks, which may reduce government revenue depending on the sensitivity of emissions to the tax rate. While this funding problem may arise, it is not likely to happen soon, primarily because the price-elasticity of the demand for carbon-intensive goods and services is relatively low and also because carbon tax rates will most likely be ramped up more slowly than in some of our experiments. In addition, if the supply of renewable energy at lower cost is scaled up, households will reduce their consumption of carbon-intensive goods and services in favour of low- or zero-carbon goods and services. This will, in turn, reduce the need for the cash compensation for the real income losses due to carbon taxation.

This study uses a static model to measure the impacts of carbon tax and revenue recycling policy, under the assumption that the price elasticities of producer and consumer of demand functions are zero. This represents a limitation to this study. In reality, households are likely to adjust their behavior in response to the economy-wide price increase induced by carbon tax. For instance, households may shift their expenditure from products with high relative price increases to those with lower relative price increases. Future research could explore more comprehensive models that incorporate behavioral responses of households and producers. This could be done by 'closing` the input-output model (i.e., by endogenizing part of demand as a function of income) and by incorporating the responses of consumers and producers to the changes in relative prices. Additionally, future research could also explore more dynamic modeling approaches by capturing the effects of carbon taxation on technological progress, industrial restructuring, and capital accumulation over time.

While this study focuses on Indonesia, the methodology and findings could be extended to evaluate similar impacts in other developing countries with comparable socioeconomic and energy profiles. This would provide insights into how carbon taxation and revenue recycling schemes can be designed to fit into different national contexts to achieve both environmental and social objectives.

Code availability

For transparency and reproducibility, the code written for this study is made available here: https://github.com/gustinara/IDNCarbonTax.

Data availability

Global and country-specific Input-Output data are available free of charge from EXIOBASE (https://zenodo.org/records/5589597). Household survey data are available on request from the Indonesian statistical office (Badan Pusat Statistik), in which restrictions and fees apply to utilize the data (https://www.bps.go.id/en). Authors have been granted permission to use the Indonesian household survey data for research purposes.

CRediT authorship contribution statement

Aldy Darwili: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Servaas Storm:** Writing – review & editing, Validation, Supervision. **Enno Schröder:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.egycc.2025.100186.

Appendix

Fig A.1, Fig. A2, Fig. A3, Fig. A4, Fig. A5, Fig. A6, Fig. A7, Fig. A8, Table A.1, Table A.2, Table A.3, Table A.4, Table A.5, Table A.6, Table A.7, Table A.8, Table A.9, Table A.10, Table A.11, Table A.12, Table A.13, Table A.14, Table A.15, Table A.16, Table A.17, Table A.18

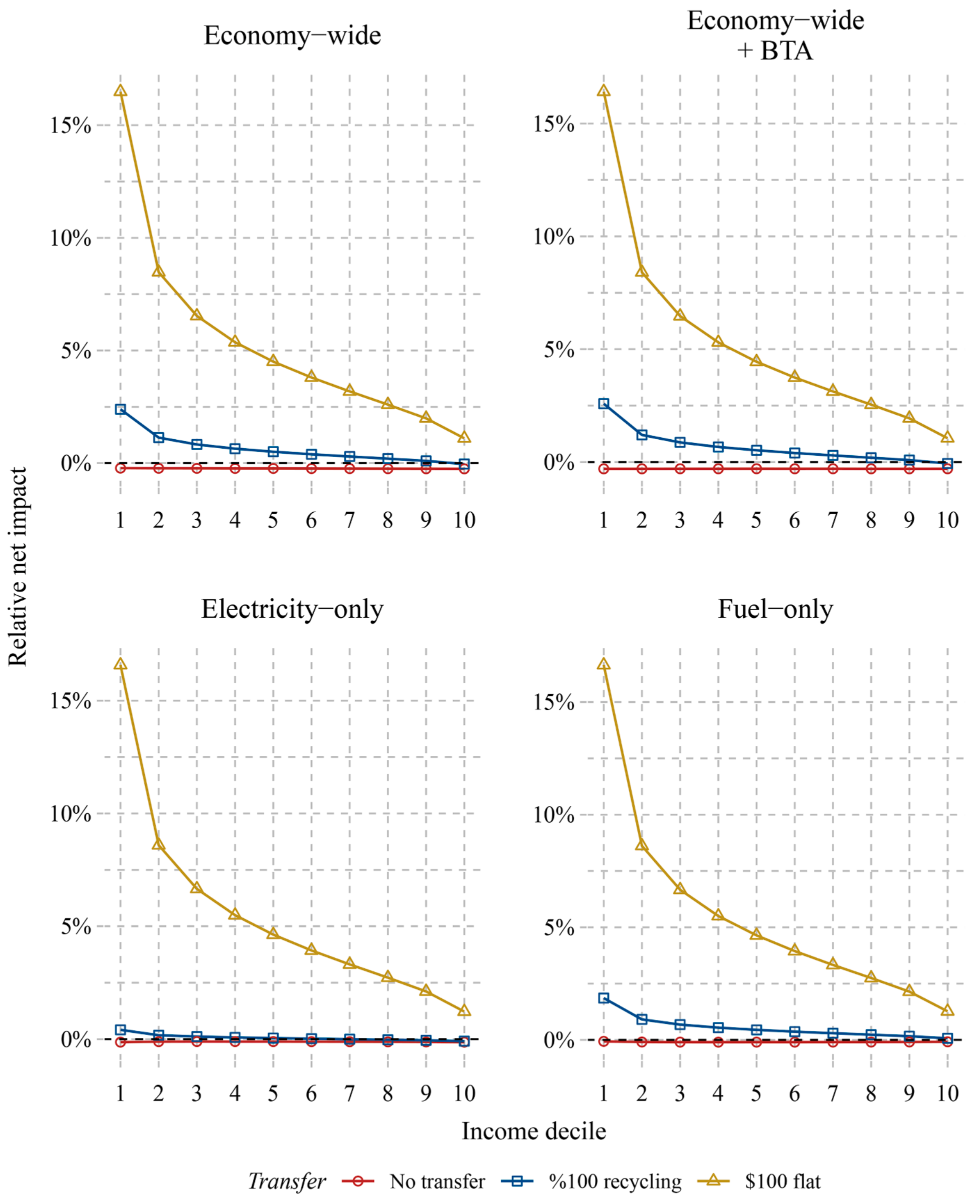

Fig. A.1. Relative net impact of a $2/tonne carbon tax in various tax bases.

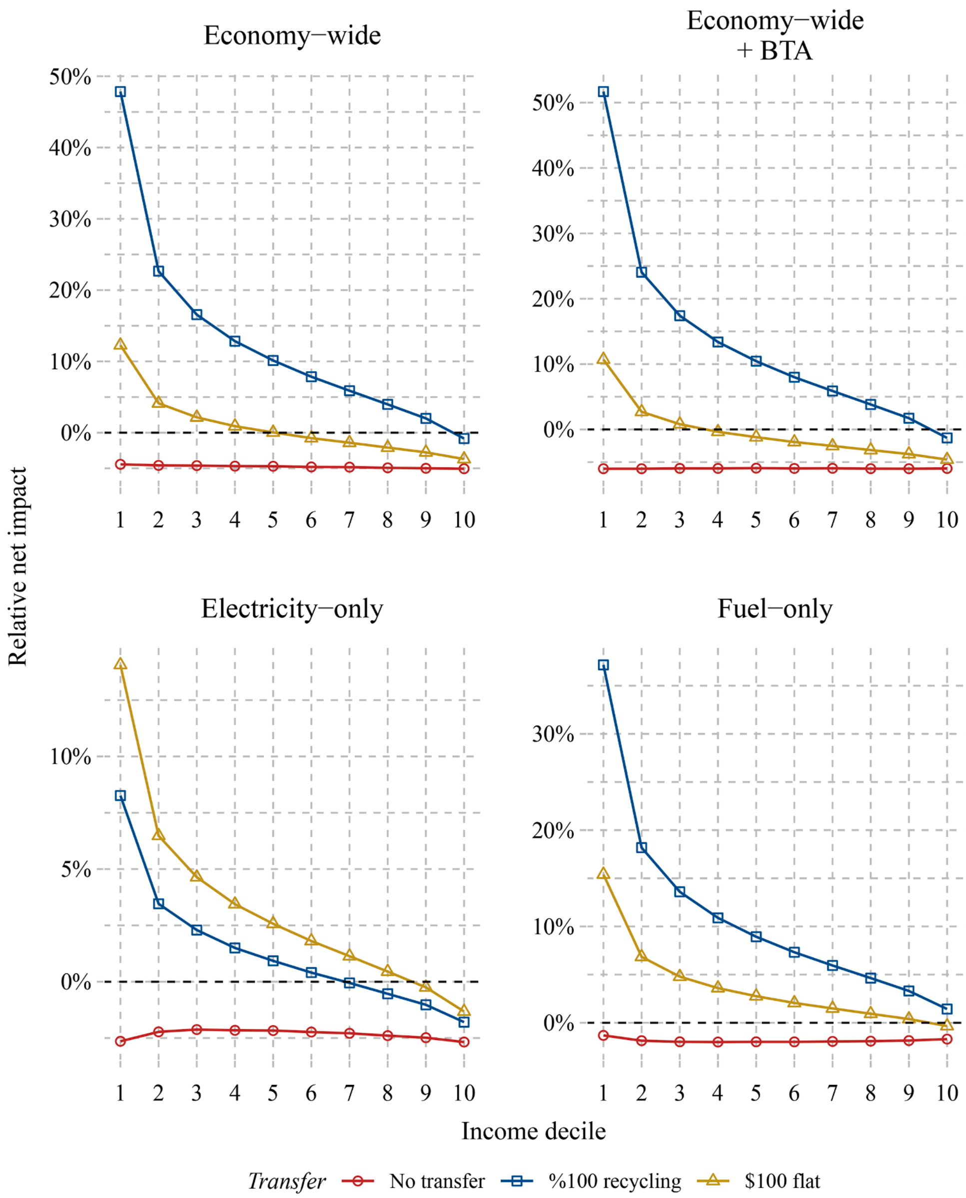

Fig. A.2. Relative net impact of a $40/tonne carbon tax in various tax bases.

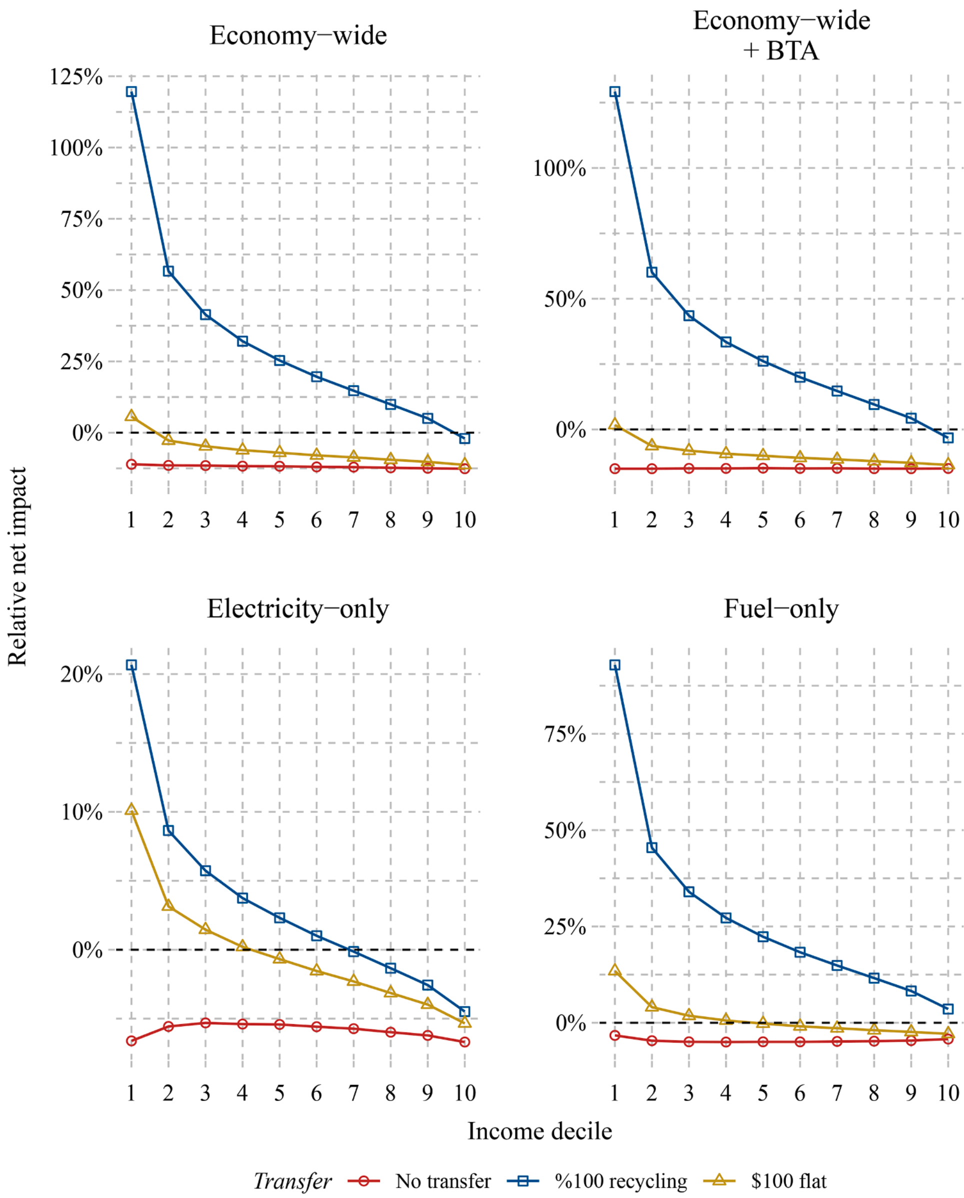

Fig. A.3. Relative net impact of a $100/tonne carbon tax in various tax bases.

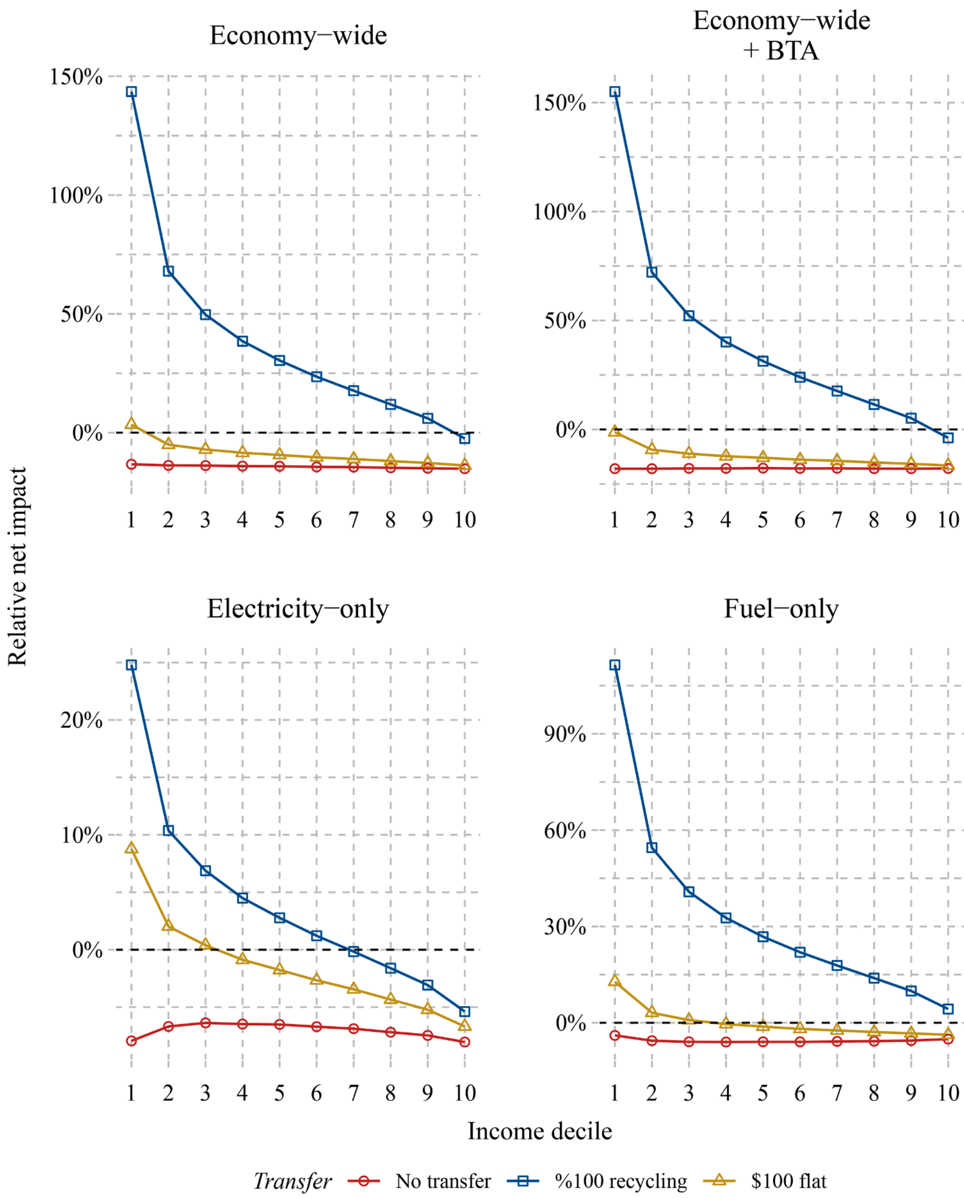

Fig. A.4. Relative net impact of a $120/tonne carbon tax in various tax bases.

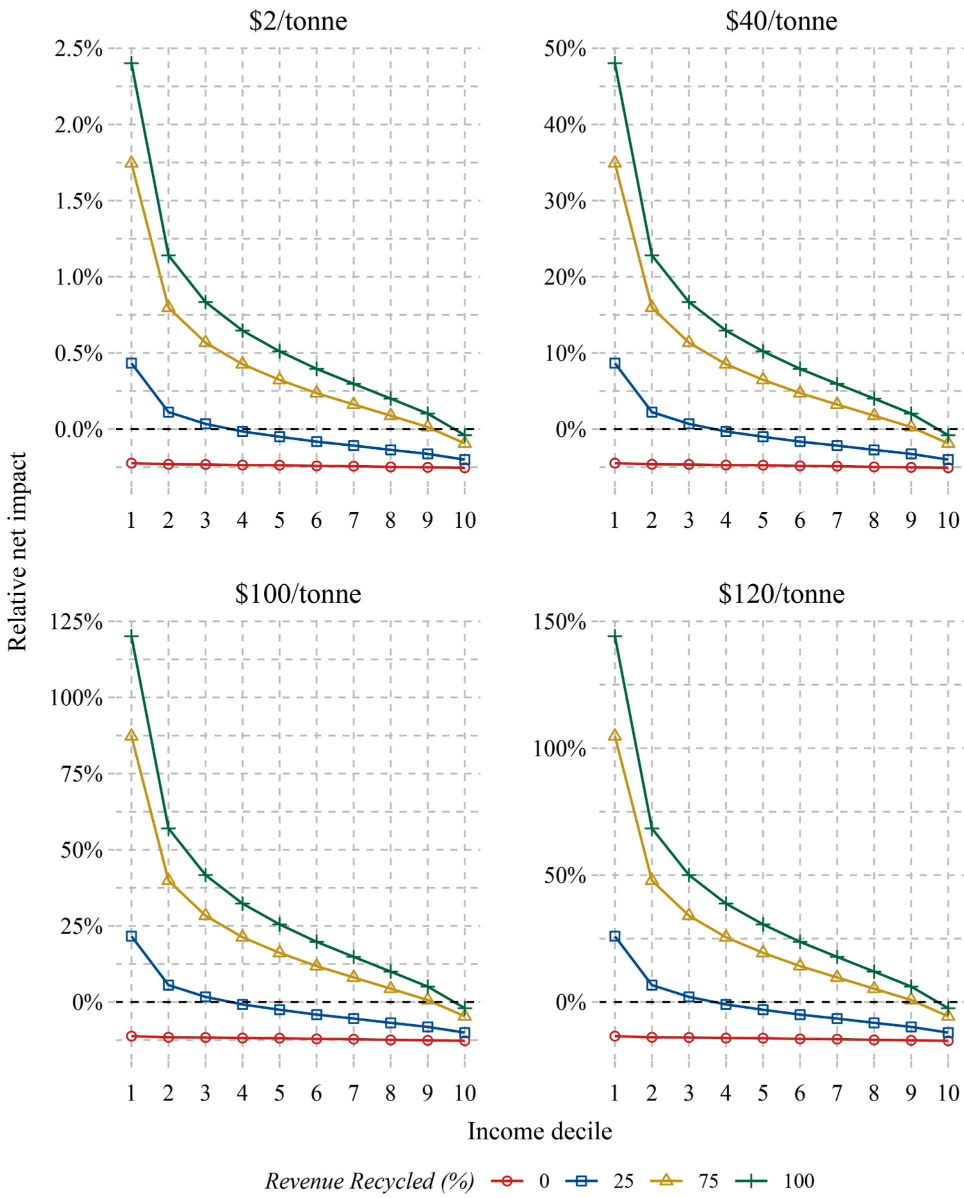

Fig. A.5. Relative net impact of various rates of “Economy-wide” carbon tax under “100 % recycling” scenario.

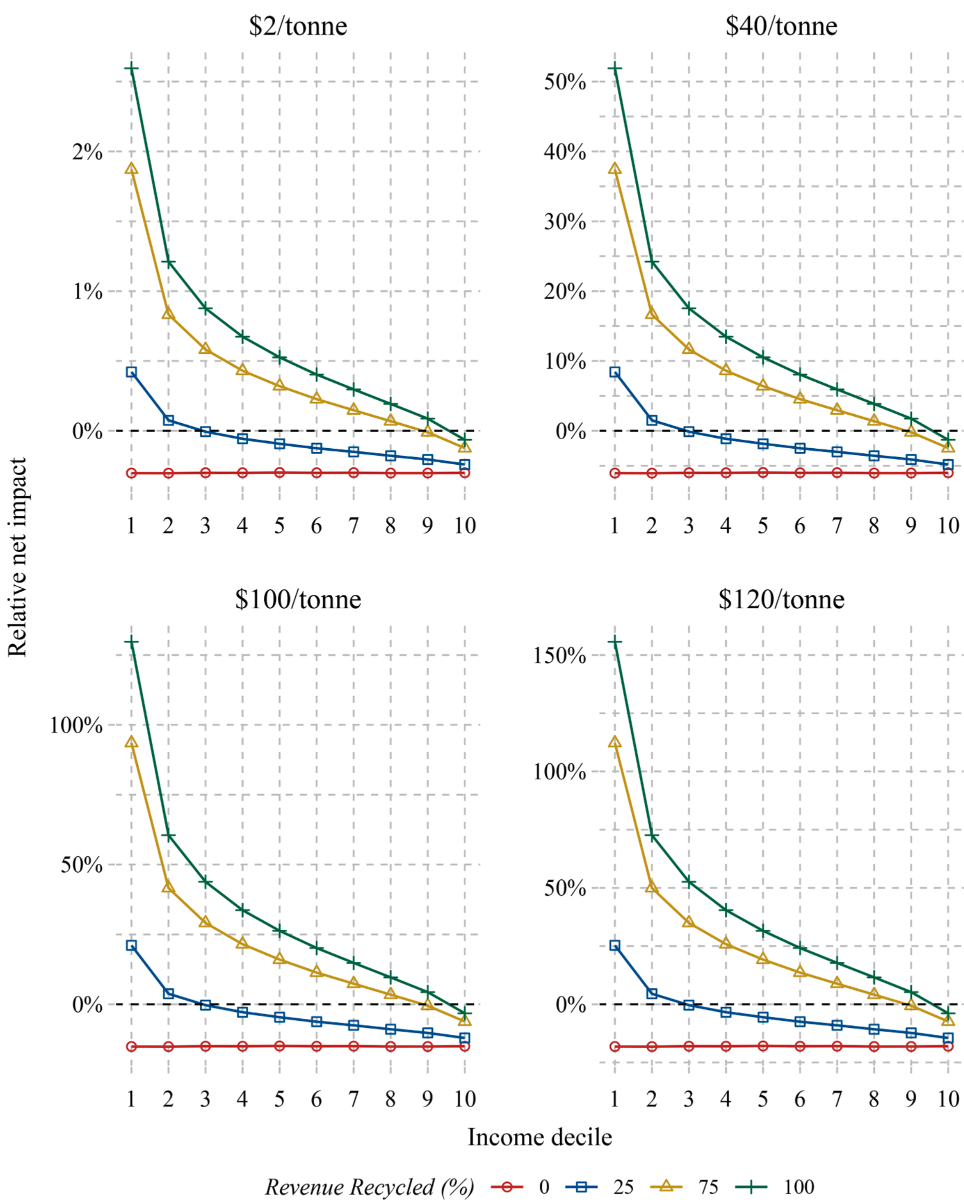

Fig. A.6. Relative net impact of various rates of “Economy-wide + BTA” carbon tax under “100 % recycling” scenario.

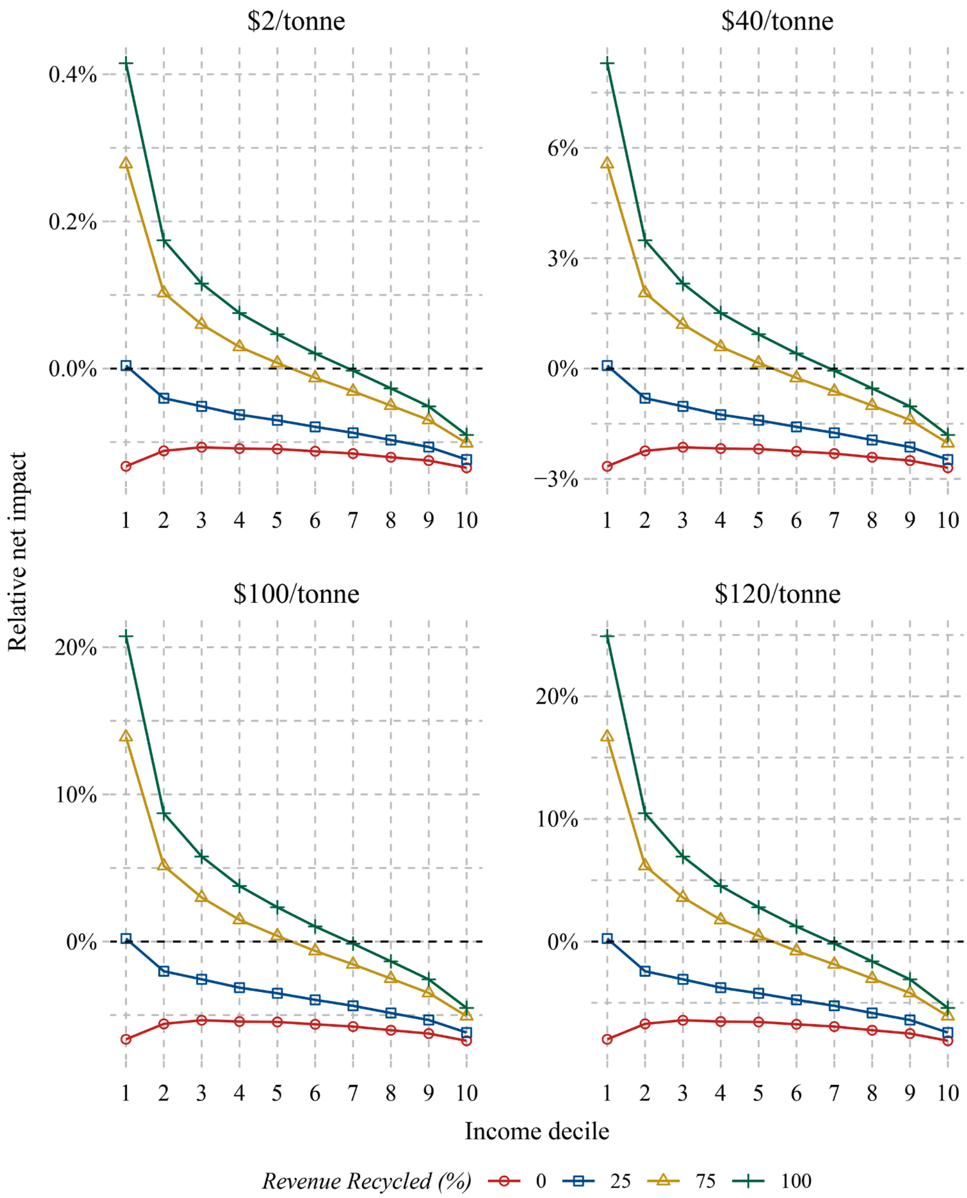

Fig. A.7. Relative net impact of various rates of “Electricity-only” carbon tax under “100 % recycling” scenario.

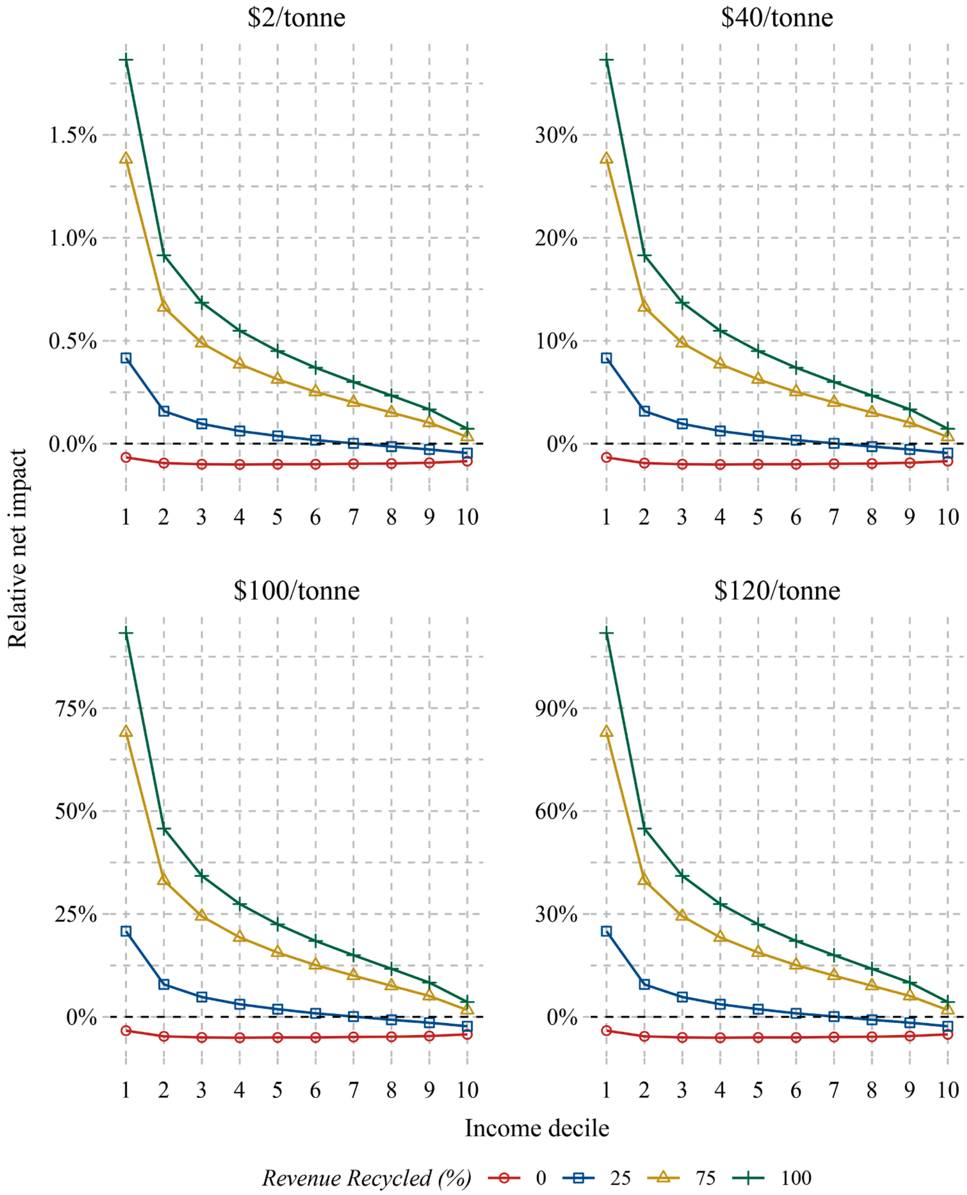

Fig. A.8. Relative net impact of various rates of “Fuel-only” carbon tax under “100 % recycling” scenario.

Table A.1
Summary of net impacts (expressed in %) of various taxation bases, rates, and recycling.

Tax Scenario	Tax Rate	Recycling (%)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Economy-wide	$2	0	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2	−0.3
Economy-wide	$2	25	0.4	0.1	0.0	0.0	0.0	−0.1	−0.1	−0.1	−0.2	−0.2
Economy-wide	$2	75	1.7	0.8	0.6	0.4	0.3	0.2	0.2	0.1	0.0	−0.1
Economy-wide	$2	100	2.4	1.1	0.8	0.6	0.5	0.4	0.3	0.2	0.1	0.0
Economy-wide	$40	0	−4.4	−4.6	−4.6	−4.7	−4.7	−4.8	−4.8	−4.9	−5.0	−5.1
Economy-wide	$40	25	8.6	2.2	0.7	−0.3	−1.0	−1.6	−2.2	−2.7	−3.2	−4.0
Economy-wide	$40	75	34.8	15.8	11.3	8.5	6.4	4.7	3.2	1.7	0.3	−1.9
Economy-wide	$40	100	47.9	22.7	16.6	12.8	10.1	7.8	5.9	4.0	2.0	−0.8
Economy-wide	$100	0	−11.1	−11.5	−11.5	−11.7	−11.8	−12.0	−12.1	−12.3	−12.5	−12.6
Economy-wide	$100	25	21.6	5.6	1.7	−0.8	−2.5	−4.1	−5.4	−6.8	−8.1	−10.0
Economy-wide	$100	75	87.0	39.6	28.2	21.1	16.0	11.7	8.0	4.4	0.6	−4.7
Economy-wide	$100	100	119.6	56.6	41.4	32.1	25.3	19.6	14.7	9.9	5.0	−2.0
Economy-wide	$120	0	−13.3	−13.8	−13.8	−14.1	−14.1	−14.4	−14.5	−14.8	−15.0	−15.2
Economy-wide	$120	25	25.9	6.7	2.0	−0.9	−3.0	−4.9	−6.5	−8.1	−9.7	−12.0
Economy-wide	$120	75	104.3	47.5	33.8	25.4	19.3	14.1	9.6	5.2	0.8	−5.6
Economy-wide	$120	100	143.6	68.0	49.7	38.5	30.4	23.5	17.7	11.9	6.0	−2.5
Electricity-only	$2	0	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1

(*continued on next page*)

Table A.1 (*continued*)

Tax Scenario	Tax Rate	Recycling (%)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity-only	$2	25	0.0	0.0	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1
Electricity-only	$2	75	0.3	0.1	0.1	0.0	0.0	0.0	0.0	−0.1	−0.1	−0.1
Electricity-only	$2	100	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	−0.1	−0.1
Electricity-only	$40	0	−2.6	−2.2	−2.1	−2.2	−2.2	−2.2	−2.3	−2.4	−2.5	−2.7
Electricity-only	$40	25	0.1	−0.8	−1.0	−1.2	−1.4	−1.6	−1.7	−1.9	−2.1	−2.5
Electricity-only	$40	75	5.5	2.0	1.2	0.6	0.2	−0.3	−0.6	−1.0	−1.4	−2.0
Electricity-only	$40	100	8.3	3.5	2.3	1.5	0.9	0.4	−0.1	−0.5	−1.0	−1.8
Electricity-only	$100	0	−6.6	−5.6	−5.3	−5.4	−5.4	−5.6	−5.7	−6.0	−6.2	−6.7
Electricity-only	$100	25	0.2	−2.0	−2.6	−3.1	−3.5	−3.9	−4.3	−4.8	−5.3	−6.1
Electricity-only	$100	75	13.8	5.1	3.0	1.5	0.4	−0.6	−1.5	−2.5	−3.5	−5.0
Electricity-only	$100	100	20.7	8.6	5.7	3.7	2.3	1.0	−0.1	−1.3	−2.6	−4.5
Electricity-only	$120	0	−7.9	−6.7	−6.4	−6.5	−6.5	−6.7	−6.9	−7.2	−7.5	−8.0
Electricity-only	$120	25	0.2	−2.4	−3.1	−3.7	−4.2	−4.7	−5.2	−5.8	−6.4	−7.4
Electricity-only	$120	75	16.6	6.1	3.6	1.8	0.5	−0.8	−1.8	−3.0	−4.2	−6.0
Electricity-only	$120	100	24.8	10.4	6.9	4.5	2.8	1.2	−0.2	−1.6	−3.1	−5.4
Fuel-only	$2	0	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1	−0.1
Fuel-only	$2	25	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fuel-only	$2	75	1.4	0.7	0.5	0.4	0.3	0.2	0.2	0.2	0.1	0.0
Fuel-only	$2	100	1.9	0.9	0.7	0.5	0.4	0.4	0.3	0.2	0.2	0.1
Fuel-only	$40	0	−1.3	−1.9	−2.0	−2.0	−2.0	−2.0	−1.9	−1.9	−1.8	−1.7
Fuel-only	$40	25	8.3	3.2	1.9	1.2	0.8	0.3	0.0	−0.3	−0.6	−0.9
Fuel-only	$40	75	27.5	13.2	9.7	7.7	6.2	5.0	4.0	3.0	2.0	0.6
Fuel-only	$40	100	37.2	18.2	13.6	10.9	8.9	7.3	6.0	4.6	3.3	1.4
Fuel-only	$100	0	−3.3	−4.6	−4.9	−5.0	−4.9	−5.0	−4.8	−4.8	−4.6	−4.2
Fuel-only	$100	25	20.8	7.9	4.8	3.1	1.9	0.9	0.1	−0.7	−1.4	−2.3
Fuel-only	$100	75	68.9	32.9	24.3	19.2	15.5	12.5	9.9	7.5	5.0	1.6
Fuel-only	$100	100	92.9	45.5	34.0	27.2	22.3	18.3	14.9	11.6	8.3	3.6
Fuel-only	$120	0	−3.9	−5.6	−5.9	−6.0	−5.9	−5.9	−5.8	−5.7	−5.5	−5.1
Fuel-only	$120	25	24.9	9.5	5.8	3.7	2.3	1.0	0.1	−0.8	−1.7	−2.7
Fuel-only	$120	75	82.6	39.5	29.1	23.0	18.6	15.0	11.9	9.0	6.0	1.9
Fuel-only	$120	100	111.5	54.6	40.8	32.7	26.8	22.0	17.9	13.9	9.9	4.3
Economy-wide + BTA	$2	0	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3
Economy-wide + BTA	$2	25	0.4	0.1	0.0	−0.1	−0.1	−0.1	−0.1	−0.2	−0.2	−0.2
Economy-wide + BTA	$2	75	1.9	0.8	0.6	0.4	0.3	0.2	0.1	0.1	0.0	−0.1
Economy-wide + BTA	$2	100	2.6	1.2	0.9	0.7	0.5	0.4	0.3	0.2	0.1	−0.1
Economy-wide + BTA	$40	0	−6.0	−6.0	−6.0	−6.0	−5.9	−6.0	−5.9	−6.0	−6.0	−6.0
Economy-wide + BTA	$40	25	8.4	1.5	−0.1	−1.1	−1.8	−2.5	−3.0	−3.5	−4.1	−4.8
Economy-wide + BTA	$40	75	37.3	16.5	11.6	8.5	6.4	4.5	2.9	1.4	−0.2	−2.5
Economy-wide + BTA	$40	100	51.7	24.1	17.4	13.4	10.4	8.0	5.9	3.8	1.7	−1.3
Economy-wide + BTA	$100	0	−15.0	−15.0	−14.9	−14.9	−14.8	−14.9	−14.9	−15.0	−15.0	−14.9
Economy-wide + BTA	$100	25	21.0	3.8	−0.3	−2.8	−4.6	−6.2	−7.5	−8.9	−10.2	−12.0
Economy-wide + BTA	$100	75	93.2	41.4	28.9	21.4	15.9	11.3	7.3	3.4	−0.5	−6.2
Economy-wide + BTA	$100	100	129.2	60.1	43.5	33.4	26.1	20.0	14.7	9.6	4.3	−3.2
Economy-wide + BTA	$120	0	−18.0	−18.0	−17.9	−17.9	−17.8	−17.9	−17.8	−18.0	−18.0	−17.9
Economy-wide + BTA	$120	25	25.3	4.5	−0.4	−3.4	−5.5	−7.4	−9.0	−10.6	−12.2	−14.4
Economy-wide + BTA	$120	75	111.8	49.6	34.7	25.6	19.1	13.5	8.8	4.1	−0.6	−7.4
Economy-wide + BTA	$120	100	155.1	72.2	52.2	40.1	31.3	24.0	17.6	11.5	5.2	−3.9

Table A.2
The amount of “100 % recycling” cash transfer received by each household in various carbon tax rates and scenarios in Indonesia.

Carbon tax rate	Scenario			
	Economy-wide	Electricity-only	Fuel-only	Economy-wide + BTA
$2	$16	$3	$12	$17
$40	$316	$66	$232	$349
$100	$790	$165	$581	$871
$120	$948	$198	$697	$1046

Table A.3
Percentage of carbon tax revenue used for the “$100 flat” cash transfer program in various carbon tax rates and scenarios in Indonesia.

Carbon tax rate	Scenario			
	Economy-wide	Electricity-only	Fuel-only	Economy-wide + BTA
$2	100 %	100 %	100 %	100 %
$40	32 %	100 %	43 %	29 %
$100	13 %	61 %	17 %	11 %
$120	11 %	51 %	14 %	10 %

Table A.4
Relative net impact of a $2/tonne carbon tax in various pricing and cash transfer options (%).

Income decile	Economy-wide			Electricity-only			Fuel-only			Economy-wide + BTA		
	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat
1	−0.224	2.402	16.558	−0.133	0.415	16.649	−0.067	1.865	16.715	−0.303	2.595	16.479
2	−0.231	1.14	8.537	−0.112	0.174	8.656	−0.094	0.915	8.674	−0.303	1.211	8.465
3	−0.233	0.834	6.584	−0.107	0.116	6.709	−0.1	0.685	6.717	−0.3	0.877	6.516
4	−0.237	0.646	5.406	−0.109	0.075	5.534	−0.101	0.549	5.542	−0.301	0.674	5.342
5	−0.237	0.51	4.539	−0.109	0.047	4.667	−0.1	0.45	4.676	−0.299	0.526	4.477
6	−0.242	0.395	3.831	−0.113	0.02	3.96	−0.1	0.369	3.973	−0.3	0.403	3.772
7	−0.244	0.297	3.209	−0.116	−0.003	3.337	−0.098	0.3	3.355	−0.3	0.296	3.153
8	−0.249	0.2	2.618	−0.121	−0.027	2.746	−0.096	0.234	2.77	−0.302	0.193	2.564
9	−0.251	0.102	2.004	−0.125	−0.051	2.13	−0.093	0.167	2.162	−0.302	0.087	1.953
10	−0.254	−0.04	1.111	−0.135	−0.09	1.23	−0.085	0.072	1.281	−0.3	−0.064	1.065

Notes: Own calculations. NT stands for no transfer where there is no accompanying cash transfer policy.

Table A.5
Relative net impact of a $40/tonne carbon tax in various pricing and cash transfer options (%).

Income decile	Economy-wide			Electricity-only			Fuel-only			Economy-wide + BTA		
	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat
1	−4.48	48.04	12.31	−2.66	8.30	14.12	−1.33	37.30	15.45	−6.05	51.90	10.73
2	−4.63	22.81	4.14	−2.24	3.49	6.53	−1.89	18.30	6.88	−6.06	24.22	2.71
3	−4.65	16.68	2.16	−2.14	2.31	4.68	−1.99	13.70	4.82	−6.01	17.53	0.81
4	−4.73	12.93	0.91	−2.17	1.51	3.47	−2.02	10.97	3.62	−6.01	13.47	−0.37
5	−4.75	10.20	0.03	−2.19	0.93	2.59	−2.00	9.00	2.78	−5.97	10.52	−1.20
6	−4.84	7.91	−0.76	−2.25	0.41	1.82	−2.00	7.38	2.08	−6.01	8.05	−1.94
7	−4.87	5.93	−1.42	−2.31	−0.06	1.14	−1.95	6.00	1.50	−5.99	5.93	−2.54
8	−4.97	4.00	−2.11	−2.41	−0.54	0.46	−1.93	4.67	0.94	−6.05	3.85	−3.18
9	−5.03	2.03	−2.77	−2.50	−1.03	−0.25	−1.86	3.33	0.40	−6.05	1.74	−3.79
10	−5.08	−0.81	−3.72	−2.70	−1.81	−1.33	−1.69	1.45	−0.33	−6.00	−1.29	−4.64

Notes: Own calculations. NT stands for no transfer where there is no accompanying cash transfer policy.

Table A.6
Relative net impact of a $100/tonne carbon tax in various pricing and cash transfer options (%).

Income decile	Economy-wide			Electricity-only			Fuel-only			Economy-wide + BTA		
	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat
1	−11.19	120.10	5.59	−6.65	20.75	10.14	−3.33	93.25	13.45	−15.13	129.75	1.65
2	−11.57	57.02	−2.81	−5.60	8.72	3.17	−4.72	45.74	4.05	−15.15	60.54	−6.38
3	−11.63	41.69	−4.81	−5.35	5.78	1.47	−4.98	34.24	1.83	−15.01	43.83	−8.20
4	−11.83	32.32	−6.18	−5.44	3.77	0.21	−5.04	27.43	0.60	−15.03	33.68	−9.39
5	−11.86	25.50	−7.09	−5.47	2.33	−0.69	−4.99	22.49	−0.22	−14.93	26.30	−10.15
6	−12.09	19.77	−8.02	−5.63	1.02	−1.55	−4.99	18.45	−0.92	−15.02	20.14	−10.95
7	−12.18	14.83	−8.73	−5.78	−0.14	−2.33	−4.88	14.99	−1.43	−14.99	14.82	−11.53
8	−12.43	9.99	−9.56	−6.03	−1.35	−3.16	−4.82	11.68	−1.95	−15.12	9.63	−12.25
9	−12.57	5.08	−10.31	−6.26	−2.57	−4.00	−4.65	8.33	−2.39	−15.12	4.35	−12.86
10	−12.71	−2.02	−11.34	−6.74	−4.52	−5.38	−4.23	3.62	−2.87	−15.01	−3.22	−13.65

Notes: Own calculations. NT stands for no transfer where there is no accompanying cash transfer policy.

Table A.7
Relative net impact of a $120/tonne carbon tax in various pricing and cash transfer options (%).

Income decile	Economy-wide			Electricity-only			Fuel-only			Economy-wide + BTA		
	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat	NT	100 % recycling	$100 flat
1	−13.43	144.12	3.35	−7.97	24.90	8.81	−4.00	111.90	12.78	−18.15	155.70	−1.37
2	−13.89	68.42	−5.12	−6.72	10.46	2.05	−5.66	54.89	3.11	−18.18	72.65	−9.42
3	−13.96	50.03	−7.14	−6.42	6.93	0.40	−5.98	41.09	0.84	−18.02	52.60	−11.20
4	−14.19	38.78	−8.55	−6.52	4.53	−0.88	−6.05	32.91	−0.41	−18.03	40.42	−12.39
5	−14.24	30.60	−9.46	−6.56	2.79	−1.78	−5.99	26.99	−1.21	−17.91	31.56	−13.14
6	−14.51	23.72	−10.44	−6.75	1.23	−2.68	−5.99	22.14	−1.92	−18.03	24.16	−13.96
7	−14.61	17.80	−11.16	−6.93	−0.17	−3.48	−5.86	17.99	−2.40	−17.98	17.78	−14.53
8	−14.92	11.99	−12.05	−7.23	−1.62	−4.37	−5.78	14.01	−2.92	−18.14	11.55	−15.28
9	−15.08	6.09	−12.83	−7.51	−3.09	−5.25	−5.57	10.00	−3.32	−18.14	5.23	−15.88
10	−15.25	−2.43	−13.88	−8.09	−5.42	−6.73	−5.08	4.35	−3.72	−18.01	−3.87	−16.65

Notes: Own calculations. NT stands for no transfer where there is no accompanying cash transfer policy.

Table A.8
Carbon tax relative to expenditure (%).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Relative carbon tax (%)	**4.48**	**4.63**	**4.65**	**4.73**	**4.75**	**4.84**	**4.87**	**4.97**	**5.03**	**5.08**
Electricity	2.66	2.24	2.14	2.17	2.19	2.25	2.31	2.41	2.5	2.7
Motor Gasoline*	1.25	1.8	1.9	1.92	1.89	1.89	1.84	1.81	1.73	1.55
Collected and purified water, distribution services of water (41)	0.18	0.16	0.16	0.16	0.17	0.19	0.19	0.21	0.23	0.24
Financial intermediation services, except insurance and pension funding services (65)	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Wearing apparel; furs (18)	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06
Sea and coastal water transportation services	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Post and telecommunication services (64)	0.03	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.08
Beverages	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Inland water transportation services	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Air transport services (62)	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.05

Note: Own calculations. The table shows the average carbon tax relative to total expenditure on product level, calculated based on $40 “Economy-wide” carbon tax. The table shows only the top 10 products.

Table A.9
Carbon tax embodied in consumption products ($).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity	17.7	25.9	31.8	39	46.3	55.9	67.8	85.3	113	226
Motor Gasoline	9.3	20.9	28.2	34.4	40	46.8	53.8	63.9	78.2	123.6
Collected and purified water, distribution services of water (41)	1.2	1.9	2.3	2.9	3.7	4.7	5.7	7.4	10.2	19.4
Financial intermediation services, except insurance and pension funding services (65)	0.3	0.6	0.7	0.9	1.1	1.4	1.6	2	2.6	5.2
Wearing apparel; furs (18)	0.3	0.5	0.7	0.8	1	1.3	1.5	1.9	2.5	4.8
Post and telecommunication services (64)	0.2	0.5	0.8	1	1.2	1.5	1.9	2.5	3.3	6.3
Sea and coastal water transportation services	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.6	2	3.8
Beverages	0.2	0.3	0.4	0.6	0.7	0.8	1	1.2	1.6	2.7
Inland water transportation services	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.1	1.5	3.1
Air transport services (62)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	1	1.4	5.1

Note: Own calculations. The table shows the average carbon tax embodied in consumption products, calculated based on $40 “Economy-wide” carbon tax and only shows the top 10 products.

Table A.10
Contribution of consumption products to carbon tax (%).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity	57.2	48.2	46.0	46.0	46.1	46.5	47.5	48.5	49.8	53.7
Motor Gasoline	30.1	38.9	40.8	40.5	39.8	39.0	37.7	36.4	34.4	29.4
Collected and purified water, distribution services of water (41)	4.0	3.5	3.4	3.4	3.7	3.9	4.0	4.2	4.5	4.6
Financial intermediation services, except insurance and pension funding services (65)	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.1	1.2	1.2
Wearing apparel; furs (18)	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1
Post and telecommunication services (64)	0.7	1.0	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.5
Sea and coastal water transportation services	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Beverages	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6
Inland water transportation services	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7
Air transport services (62)	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	1.2

Note: Own calculations. The table shows the contribution of consumption products to carbon tax, calculated based on $40 “Economy-wide” carbon tax and only shows the top 10 products.

Table A.11
Contribution of electricity sub-sectors to carbon tax (%).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity total	**57.2**	**48.2**	**46**	**46**	**46.1**	**46.5**	**47.5**	**48.5**	**49.8**	**53.7**
Electricity by gas	38.8	32.3	30.6	30.6	30.6	30.9	31.5	32.2	33.1	35.6
Electricity by petroleum and other oil derivatives	15.5	12.9	12.2	12.2	12.2	12.3	12.5	12.8	13.2	14.2
Electricity by coal	2.9	3	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.9
Electricity by Geothermal	0	0	0	0	0	0	0	0	0	0
Electricity by biomass and waste	0	0	0	0	0	0	0	0	0	0
Electricity by hydro	0	0	0	0	0	0	0	0	0	0
Electricity by nuclear	0	0	0	0	0	0	0	0	0	0
Electricity by wind	0	0	0	0	0	0	0	0	0	0
Electricity by solar photovoltaic	0	0	0	0	0	0	0	0	0	0
Electricity by solar thermal	0	0	0	0	0	0	0	0	0	0
Electricity by tide, wave, ocean	0	0	0	0	0	0	0	0	0	0
Electricity nec	0	0	0	0	0	0	0	0	0	0

Note: Own calculations. The table shows the average carbon tax relative to total expenditure of the electricity sub-products, calculated based on $40 “Economy-wide” carbon tax.

Table A.12
Expenditure of households across income deciles ($).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Food products nec	127.1	209.8	271.3	333.4	396.4	469.3	556.5	659.4	831.2	1284.2
Processed rice	100.5	146.6	166.9	178	188.9	197	206.5	216.9	228.8	240.7
Vegetables, fruit, nuts	98.3	140	167.5	191.5	216.6	240.5	270.6	311.5	364.4	499.1
Fish and other fishing products; services incidental of fishing (05)	36.9	58.1	73.6	89.8	106.5	124.7	145.2	173.6	213.1	307.9
Motor Gasoline	34	75.9	102.4	121.8	140.3	160.2	182.6	217.8	272.6	506.8
Tobacco products (16)	33.2	85.9	124.3	157.6	188.8	221.1	256.2	303.2	348	382
Beverages	32.8	63.9	87.4	108.9	132.8	159.8	194.1	236	310.2	522.5
Chemicals nec	31.1	48.1	60.3	73	87	104.1	123.4	149	190.2	341.3
Electricity	25.5	36.6	44.4	54.4	64.4	77.6	94	118.5	156.9	313.1
Wearing apparel; furs (18)	17.9	31.3	42.1	52.8	65.1	79.6	96.5	119.9	159	302.6
Insurance and pension funding services, except compulsory social security services (66)	14.2	22.2	27.1	32.2	39	45.1	54.2	65.2	90.3	207.8
Health and social work services (85)	12.5	21.7	27.2	34.7	42	53.3	66.2	87	121.6	283.3
Products of meat poultry	9.8	19.4	26.3	33.3	41.2	48.1	57.7	68.2	83.7	120.5
Post and telecommunication services (64)	9.7	24.5	35.9	46.8	59	73.8	92.3	119.9	160.5	298.4
Other services (93)	6.7	15	23.4	33.4	44.6	55.4	70.7	86.4	119	223.9
Education services (80)	6.1	19.8	30.2	40.3	50.9	64.8	79.6	103.9	143.2	371.6
Other land transportation services	5.7	8.8	10.7	13.5	16.6	20.2	24.9	30.9	41.8	78.5
Recreational, cultural and sporting services (92)	5.3	8.8	11.6	16.1	20.5	30.1	41.8	56.3	100.8	450.6
Motor vehicles, trailers and semi-trailers (34)	0.3	1.4	2.7	5.5	9.4	17.3	31.9	61.5	102.3	664.1
Private households with employed persons (95)	0.2	0.3	0.6	1	2.1	2.9	5.4	9.7	26.4	248.2

Note: Own calculations. The value shows the average expenditure on product level and only shows the top 20 products.

Table A.13
Expenditure of households in 4 sectors economy ($).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity	25.8	37	45	55	65.1	78.5	95.1	119.9	158.9	317
Fuel	42	88.7	118.3	141.8	165.6	191.8	222	268	346.2	706.7
Foods	435.9	677.6	834	973.3	1119.5	1271.8	1461	1690.4	2049.8	2996.6
Other	190.3	371.4	507.2	645.3	793.7	972	1189	1498.6	2007.8	4618.5

Note: Own calculations. The value shows the average expenditure aggregated into 4 sectors.

Table A.14
The share of expenditure in 4 sectors economy (%).

Product	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Electricity	3.1	3.2	3.0	3.0	3.0	3.1	3.2	3.4	3.5	3.7
Fuel	6.1	7.6	7.9	7.8	7.7	7.6	7.5	7.5	7.6	8.2
Foods	62.8	57.7	55.4	53.6	52.2	50.6	49.2	47.3	44.9	34.7
Other	27.4	31.6	33.7	35.5	37.0	38.7	40.1	41.9	44.0	53.5

Note: Own calculations. The value shows the average expenditure aggregated into 4 sectors.

Table A.15
Relative net impact of various rates of "Economy-wide" carbon tax and percentage of revenue recycling under 100 % revenue recycling (%).

Income decile	$2				$40				$100				$120			
	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %
1	−0.22	1.42	4.70	6.34	−4.48	28.35	93.99	126.81	−11.19	70.86	234.97	317.03	−13.43	85.04	281.97	380.44
2	−0.23	0.63	2.34	3.20	−4.63	12.52	46.82	63.96	−11.57	31.30	117.04	159.91	−13.89	37.56	140.45	191.89
3	−0.23	0.43	1.77	2.43	−4.65	8.68	35.34	48.67	−11.63	21.70	88.35	121.68	−13.96	26.04	106.02	146.02
4	−0.24	0.32	1.42	1.97	−4.73	6.31	28.38	39.41	−11.83	15.76	70.94	98.53	−14.19	18.92	85.13	118.24
5	−0.24	−0.24	−0.24	−0.24	−4.75	−4.75	−4.75	−4.75	−11.86	−11.86	−11.86	−11.86	−14.24	−14.24	−14.24	−14.24
6	−0.24	−0.24	−0.24	−0.24	−4.84	−4.84	−4.84	−4.84	−12.09	−12.09	−12.09	−12.09	−14.51	−14.51	−14.51	−14.51
7	−0.24	−0.24	−0.24	−0.24	−4.87	−4.87	−4.87	−4.87	−12.18	−12.18	−12.18	−12.18	−14.61	−14.61	−14.61	−14.61
8	−0.25	−0.25	−0.25	−0.25	−4.97	−4.97	−4.97	−4.97	−12.43	−12.43	−12.43	−12.43	−14.92	−14.92	−14.92	−14.92
9	−0.25	−0.25	−0.25	−0.25	−5.03	−5.03	−5.03	−5.03	−12.57	−12.57	−12.57	−12.57	−15.08	−15.08	−15.08	−15.08
10	−0.25	−0.25	−0.25	−0.25	−5.08	−5.08	−5.08	−5.08	−12.71	−12.71	−12.71	−12.71	−15.25	−15.25	−15.25	−15.25

Table A.16
Relative net impact of various rates of “Electricity-only” and percentage of revenue recycling under 100 % revenue recycling (\ %).

Income decile	$2				$40				$100				$120			
	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %
1	−0.13	0.00	0.28	0.41	−2.66	0.08	5.56	8.30	−6.65	0.20	13.90	20.75	−7.97	0.24	16.68	24.90
2	−0.11	−0.04	0.10	0.17	−2.24	−0.81	2.06	3.49	−5.60	−2.02	5.14	8.72	−6.72	−2.42	6.17	10.46
3	−0.11	−0.05	0.06	0.12	−2.14	−1.03	1.20	2.31	−5.35	−2.57	2.99	5.78	−6.42	−3.08	3.59	6.93
4	−0.11	−0.06	0.03	0.08	−2.17	−1.25	0.59	1.51	−5.44	−3.13	1.47	3.77	−6.52	−3.76	1.77	4.53
5	−0.11	−0.07	0.01	0.05	−2.19	−1.41	0.15	0.93	−5.47	−3.52	0.38	2.33	−6.56	−4.22	0.46	2.79
6	−0.11	−0.08	−0.01	0.02	−2.25	−1.59	−0.26	0.41	−5.63	−3.96	−0.64	1.02	−6.75	−4.76	−0.77	1.23
7	−0.12	−0.09	−0.03	0.00	−2.31	−1.75	−0.62	−0.06	−5.78	−4.37	−1.55	−0.14	−6.93	−5.24	−1.86	−0.17
8	−0.12	−0.10	−0.05	−0.03	−2.41	−1.94	−1.01	−0.54	−6.03	−4.86	−2.52	−1.35	−7.23	−5.83	−3.02	−1.62
9	−0.13	−0.11	−0.07	−0.05	−2.50	−2.13	−1.40	−1.03	−6.26	−5.34	−3.49	−2.57	−7.51	−6.40	−4.19	−3.09
10	−0.13	−0.12	−0.10	−0.09	−2.70	−2.47	−2.03	−1.81	−6.74	−6.19	−5.07	−4.52	−8.09	−7.42	−6.09	−5.42

Table A.17
Relative net impact of various rates of “Fuel-only” carbon tax and percentage of revenue recycling under 100 % revenue recycling (%).

Income decile	$2				$40				$100				$120			
	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %
1	−0.07	0.42	1.38	1.86	−1.33	8.33	27.64	37.30	−3.33	20.81	69.10	93.25	−4.00	24.98	82.92	111.90
2	−0.09	0.16	0.66	0.91	−1.89	3.16	13.25	18.30	−4.72	7.90	33.13	45.74	−5.66	9.48	39.75	54.89
3	−0.10	0.10	0.49	0.68	−1.99	1.93	9.77	13.70	−4.98	4.82	24.44	34.24	−5.98	5.79	29.32	41.09
4	−0.10	0.06	0.39	0.55	−2.02	1.23	7.72	10.97	−5.04	3.07	19.31	27.43	−6.05	3.69	23.17	32.91
5	−0.10	0.04	0.31	0.45	−2.00	0.75	6.25	9.00	−4.99	1.88	15.62	22.49	−5.99	2.26	18.75	26.99
6	−0.10	0.02	0.25	0.37	−2.00	0.35	5.04	7.38	−4.99	0.87	12.59	18.45	−5.99	1.04	15.11	22.14
7	−0.10	0.00	0.20	0.30	−1.95	0.04	4.01	6.00	−4.88	0.09	10.02	14.99	−5.86	0.11	12.03	17.99
8	−0.10	−0.01	0.15	0.23	−1.93	−0.28	3.02	4.67	−4.82	−0.69	7.55	11.68	−5.78	−0.83	9.07	14.01
9	−0.09	−0.03	0.10	0.17	−1.86	−0.56	2.04	3.33	−4.65	−1.40	5.09	8.33	−5.57	−1.68	6.11	10.00
10	−0.08	−0.05	0.03	0.07	−1.69	−0.91	0.66	1.45	−4.23	−2.27	1.66	3.62	−5.08	−2.72	1.99	4.35

Table A.18
Relative net impact of various rates of “Economy-wide + BTA” fuel carbon tax and percentage of revenue recycling under 100 % revenue recycling (%).

Income decile	$2				$40				$100				$120			
	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %	0 %	25 %	75 %	100 %
1	−0.30	0.42	1.87	2.59	−6.05	8.44	37.41	51.90	−15.13	21.09	93.53	129.75	−18.15	25.31	112.24	155.70
2	−0.30	0.08	0.83	1.21	−6.06	1.51	16.65	24.22	−15.15	3.77	41.62	60.54	−18.18	4.52	49.94	72.65
3	−0.30	−0.01	0.58	0.88	−6.01	−0.12	11.65	17.53	−15.01	−0.30	29.12	43.83	−18.02	−0.36	34.94	52.60
4	−0.30	−0.06	0.43	0.67	−6.01	−1.14	8.60	13.47	−15.03	−2.85	21.51	33.68	−18.03	−3.42	25.81	40.42
5	−0.30	−0.09	0.32	0.53	−5.97	−1.85	6.40	10.52	−14.93	−4.62	15.99	26.30	−17.91	−5.55	19.19	31.56
6	−0.30	−0.12	0.23	0.40	−6.01	−2.49	4.54	8.05	−15.02	−6.23	11.35	20.14	−18.03	−7.48	13.62	24.16
7	−0.30	−0.15	0.15	0.30	−5.99	−3.01	2.95	5.93	−14.99	−7.54	7.37	14.82	−17.98	−9.04	8.84	17.78
8	−0.30	−0.18	0.07	0.19	−6.05	−3.57	1.38	3.85	−15.12	−8.93	3.44	9.63	−18.14	−10.72	4.13	11.55
9	−0.30	−0.20	−0.01	0.09	−6.05	−4.10	−0.21	1.74	−15.12	−10.25	−0.51	4.35	−18.14	−12.30	−0.62	5.23
10	−0.30	−0.24	−0.12	−0.06	−6.00	−4.83	−2.47	−1.29	−15.01	−12.06	−6.17	−3.22	−18.01	−14.48	−7.41	−3.87

Data availability

The authors do not have permission to share data.

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