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The Impacts of Electric Vehicles Uptake and Heat Pump Installation on the Irish Economy

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Abstract: This paper examines the economic and environmental impacts of the adoption path of electric vehicles (EVs) and home retrofitting in the form of heat pumps (HPs) projected in the recent Climate Action Plan (CAP21) for Ireland. This analysis assumes the level of carbon tax follows the path committed by the Irish government in June 2020 and in the CAP21; reaching €100 per tonne of CO_2 in 2030 and includes a government subsidy for HPs. The results show that an increase in the carbon tax has substantial impacts on emission reduction, and EV adoption and HP installations can further reduce emissions but to a lesser degree than the carbon tax increase. Compared to a carbon tax alone, the wide-scale adoption of EVs and HPs boost the economy and employment. This boost leads to a rebound effect, where emissions increase slightly in other sectors of the economy. The results prove the importance of simultaneous use of carbon taxation and electrification of transport and home heating, where carbon taxation increases the benefits of adopting low carbon technologies and adoption reduces the costs of carbon taxation.

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1 Introduction

In Ireland, the transport sector is responsible for 20 per cent of greenhouse gas (GHG) emissions, and residential heating is responsible for 9 per cent (Environmental Protection Agency, 2021). Meeting the Irish emission targets necessitates more energy-efficient means of transport and heating. Two technologies have emerged as areas of interest for policymakers with these aims: electric vehicles (EVs) and retrofits (including heat pumps (HPs)), there is substantial room for growth in EV and HP uptake. In Europe, EVs comprised just 3.5 per cent of newly registered vehicles in 2019 (European Environment Agency, 2020). Similarly, 1.6 million households in Europe purchased a HP system in 2020, a relatively small percentage of total households (European Heat Pump Association, 2021). This report focuses on the adoption of these technologies in the presence of two government policies, carbon taxation and HP subsidies.

Carbon taxation is at the forefront of the discussions regarding emissions reduction policies. The EU has implemented an Emission Trading System (ETS), where large emitters are required to purchase permits to cover their emissions. Furthermore, many EU member states have implemented carbon taxation over the past decades to disincentivise the use of fossil fuels not covered by the ETS (e.g., from land transportation and household heating and private transportation). Carbon taxation ensures a cost-effective way of reducing emissions (Nordhaus, 1993), while raising revenues, which can be used to finance other policies. Furthermore, as an indirect tax on energy commodities, the carbon tax directly affects the commodity prices, which are the primary drivers of behavioural changes. Though carbon taxation plays an important role in climate policies, other policies to ensure behavioural change may be needed. e.g. subsidies on low carbon switching options such as EVs and retrofits.

The Irish government introduced a carbon tax in 2009. The level of the carbon tax increased from €20 per tonne of CO_2 to €26 in 2020. This constitutes the first increase since 2014 when the government equalised its level on all fossil fuels. In 2020, the government declared its commitment to increasing the carbon tax, reaching €100 in 2030 by following a gradually increasing pattern in the recently published Programme for Government (Department of the Taoiseach, 2020). In accordance with this commitment, in 2021, the level of the carbon tax increased by €7.5 and budget 2022 includes a increase of €7.5 in 2022, the bringing the carbon tax rate to €41 per tonne. This commitment was reaffirmed in the recently published Climate Action Plan 2021 (CAP21) (Government of Ireland, 2021).

Besides carbon taxation, the Irish government has, under the CAP21, committed to substantial increases in housing retrofits and the adoption of EVs. Specifically, the CAP21 commits to the introduction of 650,000 HPs by 2030, on the following basis: 50,000 in commercial buildings, 400,000 in existing domestic buildings and 200,000 in new domestic buildings. Furthermore, the CAP21 includes a commitment to 500,000 deep retrofits to B2 by 2030 and 935,000 EVs by 2030 (845,000 passenger EVs and 95,000 electric vans). To help realise the increased application of retrofits, the SEAI has been tasked with supplying grants to home and business owners when adopting retrofits. Though deep retrofits are important, they are not included in this paper due to a lack of sufficient reliable data and instead the focus is on HPs. A considerable part of these retrofits consists of adopting non-fossil fuel HPs (SEAI, 2021b) and under the CAP21, trajectories of EV adoption and HP installation are projected.

This paper examines the economic and environmental impacts of carbon taxation (as defined in the Programme for Government and CAP21) and HPs installations and EV adoption (as defined in CAP21). Applying a dynamic intertemporal computable general equilibrium (CGE) model, the Ireland Economy-Energy-Environment (I3E) model, we investigate the macroeconomic, household and emissions impacts of EVs and HP installation in the presence of an increasing carbon tax.[1] All results include the impacts of the COVID-19 crisis described in Appendix A and an increasing carbon tax reaching €100 per tonne by 2030.

This paper is structured as follows. In section 2 an overview of the literature on carbon taxation, EVs and HPs is given, covering environmental impacts, macroeconomic impacts and policies. Section 3 presents the results concerning emissions, the macroeconomic aggregates, sectors and households. The final section draws conclusions.

2 Literature Review

2.1 Carbon taxation

Carbon taxes are charges on the carbon content of fossil fuels, including petrol, diesel, kerosene, natural gas, coal and peat. Carbon taxation increases the prices of fossil fuels, electricity, and general consumer products (based on the carbon used in their production) and therefore, promote switching to lower-carbon alternatives and energy conservation. Furthermore, by increasing the costs of fossil fuels, carbon taxation puts low-carbon alternatives on a more competitive footing. The principal rationale of carbon taxation is that by directly taxing carbon use across different fuel types and consumer goods, carbon use will be reduced where it is cheapest to do so and is considered by economists to be the most cost-effective policy option to reduce carbon emissions. A recent statement issued by the European Association of Environment and Resource Economics (EAERE) signed by thousands of economists states: "A price on carbon offers the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary. By correcting a well-known market failure, a carbon price sends a powerful signal, steering economic actors towards a low-carbon future".[2] In this statement, it is also suggested that a carbon price should be steadily increased over time until the relevant emissions goals are met.

The empirical evidence on the effectiveness of carbon taxation is large, however, results are mixed. This can be attributed to the complexity of disentangling the impact of carbon taxes and other changes in policy and the economy which is increased by the fact that the level of carbon taxation to present has been relatively low (compared to e.g. fluctuations in fuel prices). Carbon taxation is relatively new, where behavioural change may take time, furthermore, there are often exemptions to carbon taxation and

[1] A non-technical summary of the model can be found at https://www.esri.ie/current-research/the-i3e-model. For the technical detail of the model, see de Bruin & Yakut (2021b).

[2] https://www.eaere.org/statement/

leakage issues, where improved carbon taxation designs with clear commitments to increased taxation would improve the performance of carbon taxation in terms of emission reductions. Ghazouani et al. (2020) compare the effectiveness of carbon taxation across EU member states and conclude that the tax significantly reduces carbon emissions, and its impact differs across states due to the level of carbon tax, the scope of the tax exemption, and the different use of carbon tax revenues. Andersson (2019) filters the increase in the carbon tax from the change in gasoline prices in Sweden by using a quasi-experimental method and concludes that 60% of the emission reduction in road transport comes from the increase in the carbon tax. The results of Hájek et al. (2019) show that in four of five EU members with higher mean Gross Domestic Product (GDP) than EU average (Denmark, Ireland, Finland, Sweden and Slovenia), carbon taxation has negative impacts on per capita GHG emissions, whereas the carbon allowance price has positive impacts. Martin et al. (2014) evaluate the carbon tax exemption, which is provided based on an agreement with binding energy use or carbon emissions target, of the energy-intensive sectors in the UK, and conclude that the carbon tax substantially reduces energy intensity of not exempted sectors without significantly affecting their revenues and employment. Pretis (2019) analyses the impacts of carbon pricing (carbon tax and carbon trade) in British Columbia, Canada, and concludes that the tax has no significant impact on aggregate emissions but does reduce transportation emissions.

A meta-review of Green (2021) reveals that carbon taxation has limited implications on emissions reduction and it performs better than emission trading, such as EU ETS, and it should only be used in conjunction with other policies. Shahzad (2020) conducts an extensive literature survey and concludes that environmental taxation must be accompanied by both promoting economic agents, especially the high emitters, to use cleaner technologies and setting strategic objectives for the sustainable implementation of green technologies.

A significant concern with carbon taxation, however, is that poorer households are disproportionally negatively affected; i.e a carbon tax is regressive. The analysis of Flues & Thomas (2015) across OECD members by using Eurostat-format Household Budget Surveys show that in Ireland, taxation of heating fuels has regressive impacts across households, whereas taxes on transport fuels have an inverted U-shaped impact, i.e. the middle-income households are affected more compared to poorer and richer households. The distributional impacts of an increase in the carbon tax in Ireland have recently been analysed by Bercholz & Roantree (2019), Tovar Reaños & Lynch (2019), and de Bruin et al. (2019). The results imply that, as in other developed countries, an increase in the carbon tax has regressive impacts on household disposable income and welfare in Ireland, in the absence of additional policies. However, when carbon tax revenues are used to compensate poorer households, carbon taxation is no longer regressive and is still effective in reducing emissions (Bercholz & Roantree (2019), Tovar Reaños & Lynch (2019), and de Bruin et al. (2019)).

2.2 Electric Vehicles and Retrofits

2.2.1 Environmental Assessments

There are several options for retrofitting residential and commercial dwellings in order to make them more energy-efficient. The CAP21 includes deep retrofits, which involve improving housing insulation and HPs. The total costs to households of deep retrofits in CAP21 are higher than HP installations. In this paper, we only consider heat pumps, due to lack of data and hence do not include a sizeable extra costs to households concerning retrofitting.

HPs are well established in Europe, though on a small scale, and have significant environmental benefits. Generally speaking, HPs collect thermal energy from either the air or the ground and using the principle of Boyle's law extract it for space and water heating purposes (Sustainable Energy Authority of Ireland, 2021). They do not require geothermal heat sources, and some can even be reversed in order to cool homes during the summer months. HPs are more energy-efficient than conventional heating systems. In general, they deliver 3 to 4 times more thermal energy than is used in electricity to operate the system (Omer, 2008). Hanova & Dowlatabadi (2007) find that HPs can provide heating using 25 to 30 per cent of the energy consumed by conventional alternatives. Though the associated level of emissions depends on how electricity is generated, evidence suggests that the use of HPs results in reduced carbon emissions (Gaur et al., 2021). Notwithstanding the potential environmental benefits, HP adoption remains relatively low, where HPs met only 5 per cent of global residential heating demand in 2019 (IEA, 2021). In the EU, 1.3 million units of HPs were sold in 2018, with the highest penetration rates in Scandinavia (IEA, 2021).

As EVs create no tailpipe emissions, they have the potential to significantly decrease emissions, dependent on how electricity is generated. There has been a steady increase in the registration of EVs in Europe, from 700 units in 2010 to 550,000 in 2019. However, they continue to make up only a small proportion of the vehicle market. In 2019, EVs accounted for only 3.5 per cent of newly registered vehicles across the EU (European Environment Agency, 2020). According to Central Statistics Office (2021), the same is true in Ireland, where EVs accounted for just under 3 per cent of new private car registrations in 2020. The number of registered EVs in 2020 increased to 4,369 from 608 in 2016.

In this paper we apply the SEAI estimates concerning emission reduction potential of EVs and HPs. These estimates are based on a I3E energy demand baseline, which includes a carbon tax, these are summarised in the CAP21 (Government of Ireland, 2021).

2.2.2 Macroeconomic Assessments

Though the environmental benefit of these technologies has been studied extensively, there is little research on the economic impact of EV and HP adoption. The adoption of these technologies, as well as the policies that encourage them, will have impacts not only on households' budgets but at the economy-wide aggregates, such as government debt, employment and investment. There is evidence to suggest that at the micro level, the higher up-front cost of both EVs and HPs is offset by reduced operating and maintenance costs. At a macro level, the significant public investment required to facilitate broad adoption may result in increased employment and government investment, as well as increased public debt. Furthermore, the interaction between policies can be expected to either help or hinder their effects on emissions reductions and the economy.

Several economy-wide assessments of EV adoption have been undertaken, which often find an associated economic boost. Electric Vehicle Council, PwC, NRMA, St Baker Energy Innovation Fund (2018) use a CGE model to analyse the economic effects of an increase in EV uptake in Australia, assuming an uptake of 57 per cent of all new vehicle sales. This increase is modelled through four channels: investment in charging infrastructure, emissions reductions, consumer savings, and reduced reliance on fuel imports. They find that this results in a 3.2 billion AUD cumulative net investment in charging infrastructure from 2018 to 2030 and an increase in GDP of 2.9 billion AUD in 2030, relative to 2016-2017. In their CGE assessment of the impact of EV uptake in the US including government subsidies, Chen et al. (2021) finds a positive GDP impact.

Miyata et al. (2018) find similar results in their analysis of the effect of subsidies aimed at promoting EVs on the economy of Toyohashi city in Japan. Using a CGE model, they assess the impact of applying subsidies on EV manufacturing, EV transport, solar power, co-generation and other transport. They conclude that the subsidies result in a small increase in GDP and industrial output.

In this paper we only consider costs to households for adoption of EVs and do not consider the necessary investments in EV infrastructure.

2.2.3 Policies

There is a variety of policies governments can implement in order to encourage the uptake of low carbon technologies such as EVs and HPs. In reality, governments implement a number of these policies simultaneously. In addition to the effects on the economy they have individually, such policies can reasonably be expected to interact with one another. This can result in either positive, neutral, or negative synergies.

There are several factors that impact EV uptake. Coffman et al. (2017) separate these factors into internal (such as battery cost, purchase price, driving range and charging time) and external (such as fuel prices, policy incentives, consumer characteristics, charging station availability and travel distances). Some of these factors, such as purchase price and the availability and accessibility of charging stations, present significant barriers to market entry. The high cost of EVs relative to the cost of conventional vehicles continues to present a significant barrier to potential consumers (Karplus et al., 2010). One of the primary goals of public policy aimed at encouraging EV uptake is to reduce or eliminate these barriers to entry. Such policies include purchase price subsidies, investment in charging infrastructure, investment in battery technology, and registration tax rebates.

For the individual consumer, the decision to adopt a HP system, as opposed to a conventional heating system such as a gas boiler, is also based on several factors. The initial price of a HP is often higher than that of the alternative, but it is likely to be offset by the lower running costs (Gaur et al., 2021), e.g.

Campillo et al. (2012) find that Swedish households with HPs had saved on average 48 per cent of their energy consumption cost compared to conventional water heaters. This, however, depends on the relative cost of electricity and conventional fuels. Barnes & Bhagavathy (2020) find that due to the relatively higher taxes on electricity in the UK, HPs are less cost-effective than conventional alternatives (a clear negative synergy). More generally, higher electricity costs create a barrier to HP uptake (IEA, 2021). This is particularly relevant for Ireland, where the price of natural gas is considerably lower than that of electricity as a domestic fuel source (SEAI, 2021a). The same issue arises in the adoption of EVs, where relative prices of petrol/diesel and electricity will determine the cost-effectiveness. However, as the price of petrol/diesel is considerably higher than electricity, this impact is lower than in the case of HPs.

van den Bergh et al. (2021) assess the effectiveness of climate policy interactions by considering a broad range of policies, including carbon pricing, adoption subsidies, information provision and innovation support. They conclude that the most efficient and effective policy mix should combine adoption subsidies with carbon taxes. The authors also state that while adoption subsidies encourage the uptake of low carbon alternatives, they may also result in a decrease in energy costs and thus an increased demand for energy. For example, while a subsidy may encourage EV uptake, the lower effective energy cost per kilometre can result in increased use of the vehicle or longer distances travelled. As a result, coupling adoption subsidies with a carbon tax can further discourage the high carbon alternative (such as a combustion engine vehicle) and avoid the rebound effect (van den Bergh et al., 2021). Similarly, Lam & Mercure (2021) argues that a tax on the use of conventional vehicles, which disincentivizes their use, can increase the effectiveness of policies such as adoption subsidies. Furthermore, the revenue from a carbon tax can be used to finance a subsidy scheme, resulting in a revenue recycling policy mix (van den Bergh et al., 2021). In this report, we examine the interaction between a HP subsidy and carbon taxation.

3 Results

This section discusses the results of the EV and HP scenarios by presenting them in percentage changes compared to the carbon tax (CT) scenario in a specific year. This represents the difference along the path with the additional EV or HP policy compared to without such a policy. Hence, the results should not be interpreted as an annual impact but as a cumulative impact by the given year.

3.1 Scenarios

This section gives an overview of the scenarios investigated in this report. The table below describes the different assumptions for each scenario.

Table 1: Scenario Definitions

BaU	Includes key realisations between 2014 and 2021. See Appendix A for further details regarding the assumptions for 2020 and 2021. The carbon tax stays at its 2021 level of €33.5 per tonne.
CT	Future carbon tax follows the path announced in the Government Plan 2020 and CAP21 and reaches €100 in 2030.
CT_EV	The number of additional EVs adopted is as projected in CAP21 from 2021. The number of EVs by 2020 in this scenario is lower than the CAP19 projection as in this scenario the realised number of EVs for 2020 is used. Hence, the number of EVs will reach 807,364 rather than 840,165 (as projected in CAP21) in 2030[1]. Figure 1 shows the uptake of EVs over time as projected by CAP21. Households are assumed to increase their transportation equipment demand to buy an EV (their first car) or to substitute their existing diesel or petrol car. The additional cost of an EV is assumed to be €12,000 in 2020 and gradually decreases to €9,000 in 2030[2]. In addition, the share of electricity in the private transportation demand increases up to 2030 and stays constant at its 2030 level until the end of the model horizon, which is 2054.
CT_HP	Households upgrade their heating systems with non-fossil HPs, where Figure 1 shows the additional HPs over time as projected by CAP21. In 2030, households spend €6.16 billion, 25 per cent of which is subsidised by the government. HPs are produced by the machinery production sector (NACE Rev.2 code of the sector is 28 and is included in the HTP sector in I3E) and installed by the construction sector (NACE Rev.2 code is 40-42, corresponding to the CON activity in the model). It is also assumed that 85 per cent of the total cost of HPs is spent on the commodity produced by the HTP sector[3], and the remaining is directed to the CON sector. In 2030, even if the CAP21 target on the number of HPs (615,886) is hit, only 26.5 per cent of the existing housing stock in 2030 will have non-fossil HPs installed. Hence we assume a continuation of demand for HPs after 2030, where the level of expenditures on HPs is assumed to be constant at its 2030 level for the rest of the model horizon.
CT_HP&EV	Two policy changes are applied by the government simultaneously.

1: This figure includes only BEV and PHEV passenger cars. Other types of EVs are excluded.

2: The price differential assumptions are taken from Balyk et al. (2021, 38).

3: HPs are not produced domestically by the HTP sector but imported. In the I3E model, the HTP sector imports more than half its inputs. Though not produced in Ireland, this sector profits from the sale of HPs.

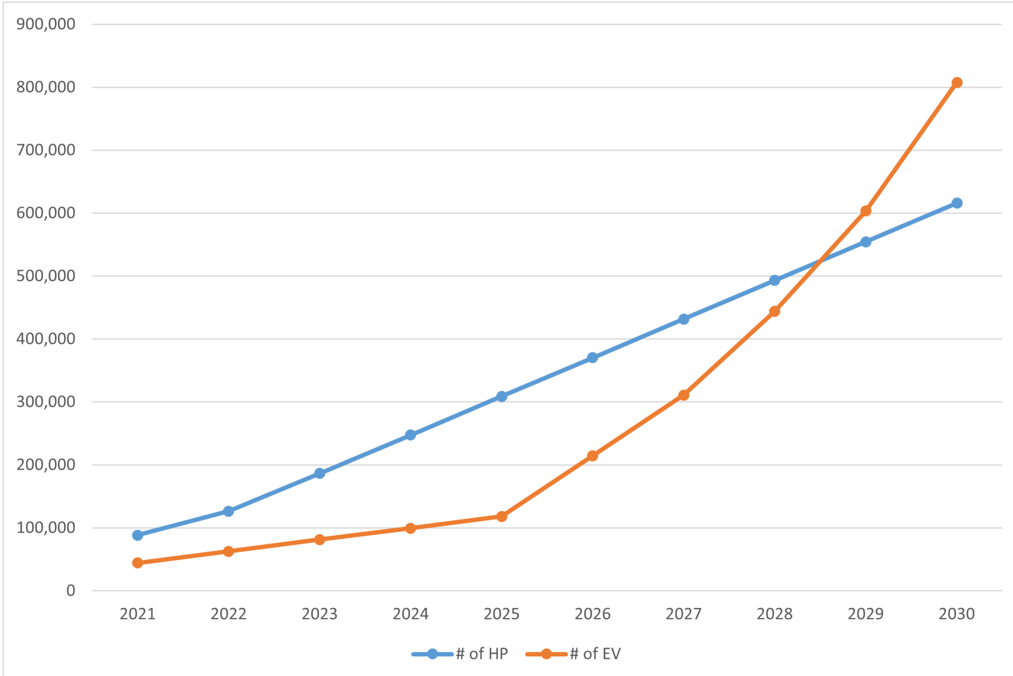

Figure 1: Stock of EV and HP

3.2 Emission Impacts

We first discuss the role of an increased carbon tax, EVs adoption and HPs installation can play in reducing emissions. Table 2 first presents the emission reduction achieved in private transportation and residential heating due to the adoption of EVs and HPs compared to carbon taxation alone (in million tonnes). The first three columns of the table present the I3E results, and the last column presents the SEAI estimates of emission reduction (on which the calibration is based). The SEAI figures give the estimated emissions reduction when an increased carbon tax is assumed and are summarised in the CAP21 (Government of Ireland, 2021) . These results show that if EVs were introduced as per the CAP21, emissions would reduce in private transportation by almost 3 million tonnes in 2030. HPs would reduce residential heating emissions by almost 1.6 million tonnes in 2030. Furthermore, the I3E results are in line with the SEAI's emission reduction estimates. The results also show that the introduction of EVs (HPs) will reduce residential heating (private transportation) emissions. This is a secondary impact, as when households spend more on EVs or HPs, they consume less of other goods and services, reducing emissions associated with the consumption of those goods and services. We discuss more secondary impacts when discussing the economy-wide emission reductions. Overall, we see a "direct" emission reduction of almost 5 million tonnes or almost 11 per cent of total economy wide emissions.

Table 3 shows the impacts of both increased carbon taxation and EVs on the total economy-wide emissions, both in million tonnes and percentage changes. This represents all combustion emissions and all non-combustion industrial emissions and hence excludes non-combustion agricultural emissions such

Table 2: Emission Reduction due to Policy Change, difference w.r.t. the CT Scenario in million tonne-eq of CO_2

	Private Transportation			
	CT_EV (I3E)	CT_HP (I3E)	CT_HP&EV (I3E)	EV (SEAI)
2025	-0.51	-0.07	-0.58	-0.51
2030	-2.90	-0.31	-3.09	-2.73
	Residential Heating			
	CT_EV (I3E)	CT_HP (I3E)	CT_HP&EV (I3E)	HP (SEAI)
2025	0.02	-0.76	-0.74	-0.76
2030	-0.20	-1.58	-1.73	-1.63

Note: Figures are million tonne-eq. CO_2 reduction in each scenario w.r.t to the *CT* scenario. Private Transportation excludes the increase in electricity emissions induced by the increase in demand.

as methane. The first column gives the emission reduction resulting from the carbon tax, CT compared to BaU and the other columns give the additional emission reduction of technology adoption (compared to CT). The increase in carbon tax results in an almost 8 per cent (16 per cent) reduction of emissions

Table 3: Total economy-wide emission Reduction due to Policy Change, difference w.r.t. the BaU and CT Scenarios and tonne of CO_2

	Percentage change			
	CT w.r.t BaU	CT_EV w.r.t CT	CT_HP w.r.t CT	CT_HP&EV w.r.t CT
2025	-7.88	-0.82	-1.46	-2.26
2030	-15.85	-4.96	-2.08	-6.78
	Million Tonnes of CO_2			
2025	-3.54	-0.34	-0.60	-0.93
2030	-8.31	-2.19	-0.92	-2.99

Note: Figures are million tonne-eq. CO_2 reduction in each scenario w.r.t to the *CT* scenario. Private Transportation excludes the increase in electricity emissions induced by the increase in demand.

in 2025 (2030) compared to no increase (CT compared to BaU). These represent 3.5 million tonnes and 8.3 million tonnes decreases in 2025 and 2030. The emission reduction impacts of the introduction of EVs is 0.8 per cent in 2025 and 5.0 per cent in 2030 compared to CT. In million tonnes, this represents a reduction of 0.3 million tonnes in 2025 and 2.2 million tonnes in 2030. The introduction of HPs results in a 1.5 per cent (0.6 million tonnes) and a 2.1 per cent (0.9 million tonnes) decrease in 2025 and 2030, respectively. When both EVs and HPs are introduced, emission reduction reaches 2.3 per cent (0.9 million tonnes) in 2025 and 6.8 per cent (3.0 million tonnes) in 2030. These figures correspond to 10 per cent and 21.6 per cent reductions in the economy-wide emissions, compared to BaU, in 2025 and 2030, respectively. Hence, the carbon tax increase results in significantly higher emission reduction than both EV adoption and HPs installations and is even greater than the sum of both. This is not surprising as the carbon tax applies to all carbon commodities, whereas EVs and HPs only apply to approximately 30 per cent of emissions. Furthermore, we assume no change in the composition of inputs to electricity generation, where a move towards low carbon electricity generation will have larger impacts on emission reduction.

Comparing the economy-wide emission reduction (Table 3) to the emission reduction in private transportation and residential heating (Table 2), we see that the economy-wide emission reduction is smaller in the case of *CT_EV* (2025 and 2030), *CT_HP* (2025) and *CT_HP&EV* (2025 and 2030) than the total reduction in residential heating and private transportation. As will be discussed in section 3.3, the adoption of EVs and HPs boost the economy, and this leads to secondary emission impacts, where increased economic activity increases emissions. Hence, though emissions decrease in the sectors adopting EVs and HPs (private transportation and residential heating), emissions increase elsewhere in the economy. This results in a rebound effect where the policies result in significantly less emission reduction than expected. Examining residential heating and private transportation emissions alone would suggest a 4.8 million tonnes reduction in emissions in 2030, whereas total economy-wide emission reduction in 2030 was only 3.0 million tonnes. The increase in emissions comes mostly from electricity use and hence could be mitigated through a switch to low carbon electricity generation.

3.3 Macroeconomic Impacts

The CSO updated its national accounting framework in 2015 by adjusting the macroeconomic figures based on the special circumstances of the Irish economy, which are attributed to *globalisation*. The definitions of GDP and thus Gross National Income (GNI) include all economic activity generated by agents located in Ireland. Although some of the transactions of multi-national companies belong to Irish National Accounts, the actual economic activity is conducted outside Ireland. Therefore, the CSO introduced a new measure in 2017, namely Modified GNI or GNI*, this excludes all transactions, which are factor income of redomiciled companies, depreciation in R&D service imports and trade in Intellectual Property (IP), and depreciation of aircraft leasing. The CSO advises to use this measure *to give an even more precise indicator of the domestic economy* (CSO, 2021). Since the base year of the I3E model is 2014, the GDP figure and all its components are not affected by the methodology update, and the calculated GDP in the model produces closer results to those of the GNI* than Irish GDP metrics.

In the absence of a targeted carbon tax revenue recycling scheme, a carbon tax increase will have a dampening effect on the economy through increased prices, reducing GDP and investments, and increasing government debt. The increase in the carbon tax reduces GDP by 0.84 per cent by 2025 and 1.36 per cent by 2030 as compared to no increase in the carbon tax (scenario *CT* compared to *BaU*), see Figure 2a. Note that this does not represent a yearly decrease but an aggregate decrease by 2030. GDP still continues to grow on a yearly basis with a carbon tax increase. When EVs are adopted, the decrease in real GDP is reduced to 0.53 per cent in 2025 and 0.57 per cent in 2030. This is due to the increased value of car sales that boosts car retail and the substitution away from imported diesel/petrol to electricity, boosting the electricity sector, which is more dependent on domestic inputs (see section 3.4). The installation of HPs also has a dampening effect on the decrease in GDP. When both EVs and HPs are introduced (*CT_HP&EV*), economic activity is boosted even more compared to *CT* and largely eliminates the negative impacts of the carbon tax; the decline in real GDP becomes 0.1 per cent and 0.2 per cent in 2025 and in 2030, respectively. The adoption of EVs and HPs, under the *CT_HP&EV* scenario, results in a decrease in carbon tax receipts by 5 per cent in 2025 and 18 per cent in 2030, when compared to the *CT* scenario. This has limited impacts on government revenues as carbon tax revenues only make up approximately 2 per cent of total government revenues in 2030 (in the *CT* scenario). Furthermore, as we do not assume carbon tax revenues are recycled, the economic impacts of this reduced revenue are negligible.

The relative boost in economic activity results in increased emissions in many sectors, creating the rebound effect discussed in the previous section. The bulk of these emissions come from increased electricity use of production sectors, as we have assumed that the composition of inputs into electricity generation do not change over time, this rebound effect could be limited when shifting towards low carbon electricity generation.

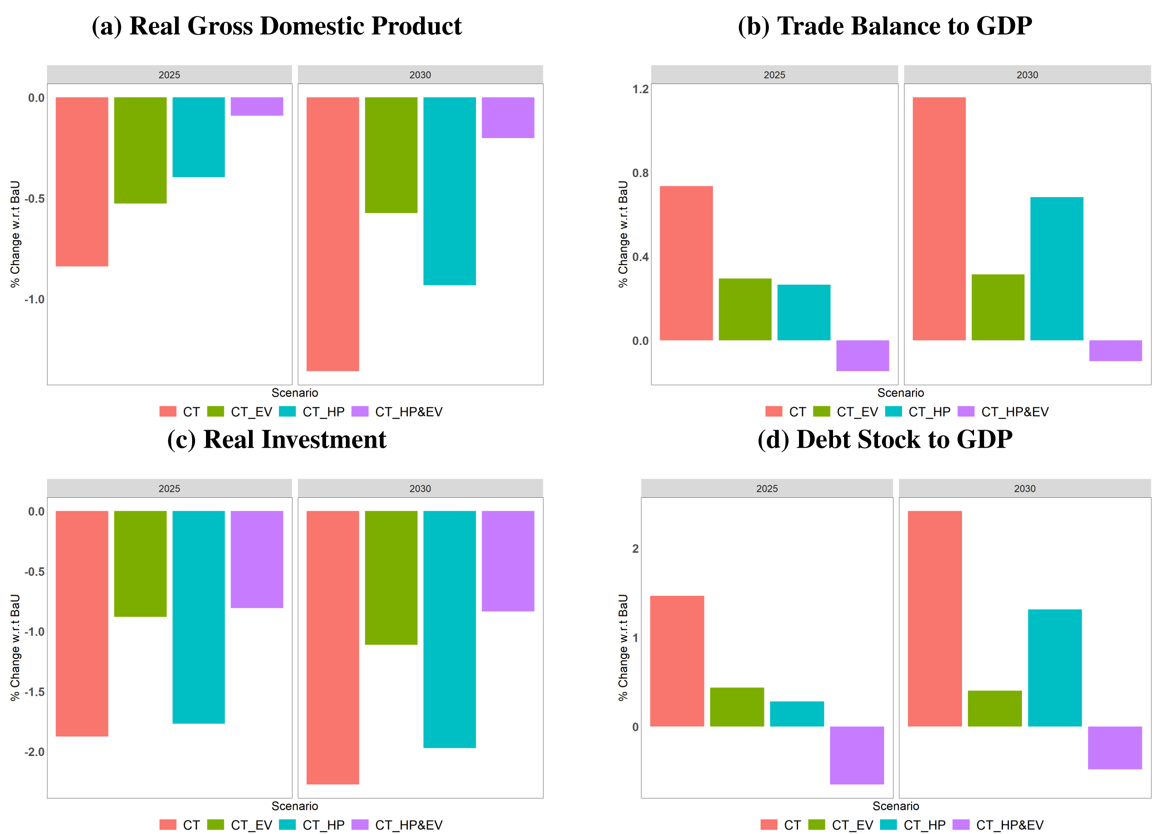

Figure 2: Macroeconomic Environment, % change w.r.t BaU

The increase in the carbon tax increases domestic energy prices and thus the cost of production, which, in turn, lowers the total exports of Irish firms. On the other hand, higher domestic energy prices lower demand for energy commodities substantially, and the slowdown in economic activity further reduces the overall import demand. As a result, the trade balance and thus its ratio to GDP improves by 1.16 per cent, 0.68 per cent, and 0.31 per cent in 2030, compared to *BaU* in *CT*, *CT_HP*, and *CT_EV*, respectively, as depicted in Figure 2b. Note that the adoption of EVs and HPs worsens the trade balance compared to a carbon tax alone due to increased import demand, including increased imports of HPs and EVs. The net exports-to-GDP ratio becomes worse off along the path of the *CT_HP&EV* scenario in which the increase in private consumption is much larger, compared to the other scenarios, which, in turn, invokes import demand. The deterioration in the net exports, accompanied by a growth in (nominal) GDP, decreases the net exports-to-GDP ratio, compared to *BaU*.

The lower economic activity also reduces the investment expenditure of Irish firms on sectoral capital stock, Figure 2c [3]. The total real investment expenditure will be 1.87 per cent and 2.27 per cent lower in 2025 and 2030, respectively, in the *CT* scenario. Again, this decrease in investments is dampened when adopting EVs and HPs. As the expenditures on EVs and HPs reduce household savings and thus the total savings, the decline in investment expenditures becomes stronger towards 2030. In the policy scenarios, due to the increased economic activity, sectors, especially those positively affected by the policy change, increase their investment expenditures. The ratio of the government indebtedness to GDP will be higher with a carbon tax alone or in each policy change, but it decreases in the combined scenario due to the acceleration in the economic activity, Figure 2d, compared to the other scenarios.

3.4 Sectoral Impacts

An increased carbon tax negatively impacts all sector and impacts the transportation (TRP) and electricity (ELC) sectors the most in terms of real value-added, as shown in Table 4, as demand dampens due to increased prices of energy inputs. As EVs and HPs are introduced, these impacts become positive for the ELC sector as electricity demand increases substantially. However, the TRP sector is hit harder in 2025 with the adoption of EVs as the share of EVs remains small and consumer demand shifts towards other goods. By 2030, the share of EVs will increase significantly (from the current approximately 1 per cent to approximately 35 per cent of the total car stock), resulting in a large decrease in transportation costs which, in turn, increases the value-added of the TRP sector, compared to *CT*. The construction (CON) sector sees substantial increases in value-added when HPs are installed. The same can be seen for the manufacturing (MAN) sector, though impacts for individual sectors within the aggregate MAN sector differ considerably. Firstly, the HTP sector, which delivers HPs to the market sees a significant boost as well as other sectors that supply inputs to CON and HTP (most notably; Basic Fabricated Metals (BFM), Rubber and Plastic Products (RUP), Other non-metallic products (ONM), Chemical Products (CHE), Basic Pharmaceutical Products (BPP) and Other Manufacturing (OTM)). Natural Gas Supply (NGS) sees a boost as is serves as an input to electricity generation. Other manufacturing sectors see decreases in value-added, particularly Petroleum (PET) due to decreased demand for diesel and petrol in private transportation. Mining (MIN) value-added is boosted as HTP and CON use a relatively large

[3] Note that households expenditures on EVs and HPs are modelled as household consumption in the I3E model, investment here refers solely to investment by production sectors.

amount of mining inputs and the peat sector (PEA, which falls in the aggregate mining sector) shifts from peat production to electricity production with biomass. Agriculture (AGR) also provides inputs to the CON sector and sees a boost. All services (see ACC, SER and FSR) see a boost in value-added, with the exception of Real estate services (RES within the aggregate SER sector), which sees a decrease in value-added as the price of construction increases which makes up a significant share of their inputs. Other sectors display a relative boost when EVs and HPs are introduced as the overall economic activity increases with these measures.

Table 4: Sectoral Real Value-Added, % change w.r.t. BaU

		ACC	AGR	CON	ELC	FSR	MAN	MIN	PUB	SER	TRD	TRP
2025	CT	-0.35	-0.16	-1.08	-2.14	-0.40	-0.33	-0.82	-0.93	-0.99	-0.56	-1.34
	CT_EV	-0.15	-0.17	-0.57	3.67	-0.19	-0.29	-0.25	-0.41	-0.53	-0.41	-1.96
	CT_HP	0.03	0.16	0.80	0.82	0.27	-0.00	-0.57	-0.06	-0.52	-0.07	-1.22
	CT_HP&EV	0.26	0.17	1.29	6.58	0.46	0.03	0.01	0.41	-0.06	0.08	-1.83
2030	CT	-0.90	-0.45	-1.59	-3.82	-0.81	-0.69	-1.56	-1.48	-1.26	-1.09	-2.58
	CT_EV	0.09	-0.25	-0.38	9.38	0.07	-0.31	0.06	-0.01	-0.35	-0.34	-2.45
	CT_HP	-0.49	-0.22	0.15	1.48	-0.24	-0.47	-1.48	-0.70	-0.84	-0.74	-2.57
	CT_HP&EV	0.52	-0.02	1.23	14.39	0.55	-0.15	0.13	0.62	0.02	-0.06	-2.48

Note: The acronyms for sectors are as follows: *ACC* Accommodation and Hotel Services, *AGR* Agriculture, *CON* Construction, *ELC* electricity production, *FSR* Financial Services, *MAN* Manufacturing, *MIN* Mining, *PUB* Public Administration, *SER* Other Services, *TRD* Trade Activities, and *TRP* Transportation. The list of aggregated sectors and corresponding sub-sectors is available in Appendix B.

3.5 Household Impacts

An important aspect of any policy is its impact on households, particularly concerning the distribution of income across household types. The household-specific results in the I3E model depend on the composition of disposable income. Poorer households rely more on the labour income of low- and medium-skilled labour and welfare transfers, whereas richer households receive more capital income and high-skilled labour income. The sectoral composition of employment by skill types and the share of each household in each labour type's income generate different results across households. Since we do not consider non-economic characteristics, e.g. the type and quality of dwelling or ability to shift to EVs which may be limited in rural areas, the main transmission channel is the changes in the households' disposable income, which comes from the changes in wage, government transfer and capital income.

Concerning government transfers to households, we assume the government will increase the total welfare transfers with respect to the changes in both the unemployment rate and the overall price level (overall CPI). Transfers are increased across households types in line with their original share of household transfers, i.e. all aggregate household types will see the same increase in transfers in percentage terms. However, transfers (in the baseline) are progressive, where poorer households receive a higher portion of the transfers, and hence, poorer households will be impacted more by an increase in transfers. This results in an increase of transfers of 29 per cent of the additional carbon tax revenues in 2030 in the

CT scenario. This is in line with the proposed use of 30 per cent of carbon tax revenues (i.e. resulting from carbon taxation over €20 per tonne). Note that this is not a direct revenue recycling scheme, i.e. the carbon tax revenue is not explicitly earmarked for transfers to households. However, we assume (in line with historical policies) that as CPI rises, government transfers to households will increase to ensure the real value of welfare transfers does not decline. As carbon taxation increases CPI, government transfers will increase to compensate. In addition, the government also increases its unemployment benefits, which are included in the welfare transfers, as the higher carbon tax leads to a contraction in economic activity and thus increases unemployment, relative to the *BaU* scenario. In the other scenarios, the increase in the total transfers is less than this amount due to the positive impacts of the EV uptakes and HP installation on the overall economic environment, compared to *CT*.

Figure 3 shows the impacts in terms of real disposable income across household types.[4] In the I3E model, we distinguish between 10 household types based on income and location (rural vs urban). Rural households are denoted by r1-r5, where r1 is the poorest household and r5 is the richest. Urban households are similarly denoted by u1-u5. We also display the average of all households, given in red in Figure 3. When the carbon tax is increased, all households are worse off compared to *BaU*. Impacts are highest for the high-income households, i.e. the carbon tax has a progressive impact thanks to the automatic stabilising role that the welfare transfer structure (in the I3E model) plays.

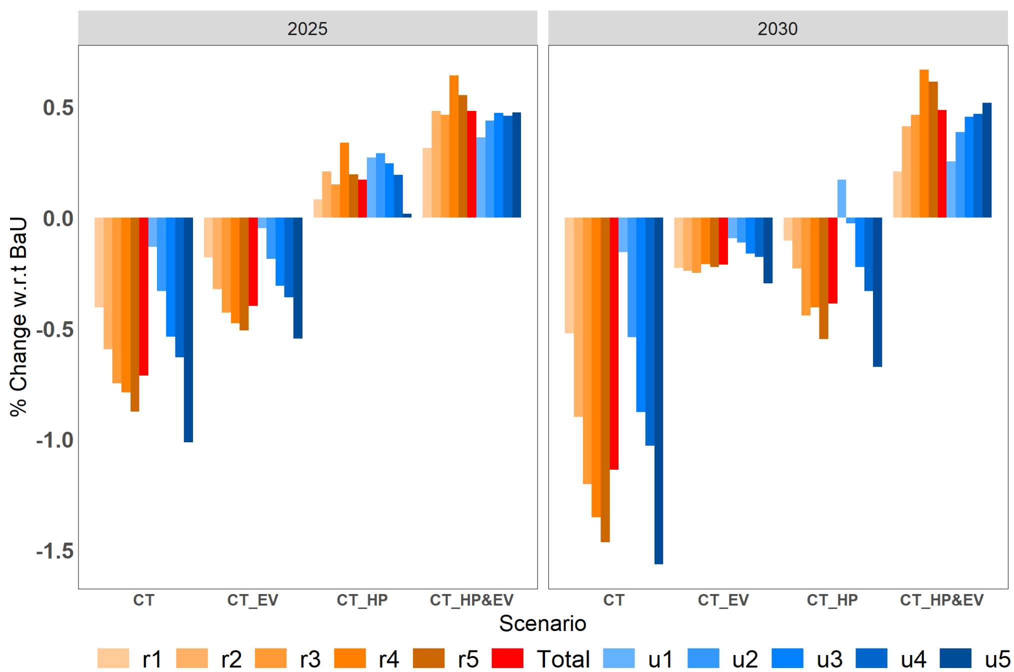

Figure 3: Real Disposable Income, % change w.r.t BaU

[4] Note that this does not represent household welfare, where household welfare would depend on consumption.

If EVs are adopted, household income is less affected (better off than under *CT*) but still decreases (worse off compared to *BaU*). Hence, adopting EVs decreases the negative household income impacts of the carbon tax in line with the accelerated economic activity. When HPs are introduced, households are better off in terms of income (compared to both *CT* and *BaU*) in 2025, where middle-income households in rural areas and low-income households in urban areas benefit the most. Installation of HPs results in an increase in disposable income due to the increased economic activity, compared to both *BaU* and *CT*. In 2030, If EVs and HPs are adopted separately, the negative impacts of the carbon tax outweighs the positive impact of EV uptake and HP installation, and households are worse off compared to *BaU* but still better off compared to *CT*. If EVs are adopted in addition to HPs, household income increases more, where, again, middle-income households benefit the most in rural areas, but high-income households benefit the most in urban areas. Overall we can conclude that the benefits of EVs and HPs outweigh the costs of an increased carbon tax, making all households better off in terms of disposable income.

4 Conclusions

This report shows that a carbon tax increase has negative impacts on households, production sectors and dampens economic activity. A shift away from fossil fuel usage through the adoption of EVs and the installation of HPs can reduce these negative impacts. This works through two main channels. Firstly, adopted measures that reduce households' and firms' reliance on fossil fuels which, in turn, lowers their costs as the carbon tax significantly increases fossil fuel prices. Secondly, adopting EVs and installing HPs result in a boost in economic activity through increased car sales, HP sales, and construction demand.

Concerning emission reduction, we see that the introduction of HPs and EVs reduces emissions but to a lesser degree than the sole carbon tax increase. However, this is not to say that these measures are contradictory. Increased uptake of technologies such as electric vehicles and heat pumps, and carbon taxation can together aid the Government in reaching their climate ambitions. Furthermore, we find rebound effects, where due to secondary impacts, the total emission reduction of these measures is lower than expected. This is due to the relative economic boost of these measures resulting in increased emissions in other sectors of the economy. This highlights the importance of considering policies simultaneously.

Overall, we can conclude that incentivising households and businesses to divert fossil fuel usage will have significant positive benefits.

It should be noted that the methodology applied here cannot include several concerns that will arise with the wide-scale adoption of EVs and HPs. Firstly, the construction demand in Ireland continues to increase significantly, and there are concerns about whether the sector can keep up supply in line with the additional demand increase. Secondly, there are issues whether households and businesses have the finance to invest in adopting expensive technology, where adoption rates have fallen far short of expectations in recent years. For example, the EV adoption rate estimated in CAP19 for 2020 was approximately 54,000 passenger cars, whereas CSO data finds adoption of approximately 21,000 passenger cars. Thirdly, the results shown here are dependent on future energy prices, should the fuel and gas prices rise significantly, EVs and HPs would be more beneficial, vice versa. Fourthly, there are concerns about whether the electricity grid can handle the increased electricity demand as more new technologies depend run on electricity. With the capacity constraints, increased electricity demand could have significant impacts on electricity prices and hence the cost-effectiveness of these technologies. Fifthly, our framework assumes labour is mobile across sectors, which in real life may be limited due to skills mismatches across sectors. Finally, this analysis is limited to the policies discussed and does not take other (climate) policies into account.

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Appendix A Assumptions for 2020 and 2021

The COVID-19 pandemic has led to change the structure of the economy in several aspects. Along the baseline, namely *BaU*, scenario, all these realisations are incorporated, and it is assumed that all those changes will be 50per cent effective in 2021 as the country was in the lockdown during the first half of the year. In other words, we assume that the effects associated with lock down in 2020 will continue but to a lesser degree in 2021. We assume that the disruption to the economy will be approximately half that of 2020. In this respect, all structural variables of the Irish economy will go back to their original values, which have been calibrated by using the Irish energy Social Accounting Matrix (ESAM), in 2022 (de Bruin & Yakut, 2021a).

The CSO announced the national accounts for the year of 2020. The overall economic activity is calculated by expenditure and production approaches. The model parameters are adjusted in order to catch the impact of the COVID-19 related lockdown measures on production (sectoral gross value added - GVA), households (private consumption) external demand (exports), government expenditures, capital formation, and net factor income of households. The sectoral parameters on production and value-added generation are adjusted in order to catch the percentage changes in the sectoral GVAs in 2020, compared to 2019. By using the Retail Sale Index of the CSO, the structural parameters of household demand are altered. In order to introduce the labour market shock, the labour force participation rates (LFPRs) of each type of labour are lowered, and the low-skilled labour is assumed to be hit harder than the high-skilled labour. Due to the economic shutdown, employees and self-employed individuals are supported by the government. The total amount of COVID-19-related transfers ('COVID-19 Pandemic Unemployment Payment'-PUP, and a Temporary Wage Subsidy Scheme-TWSS) is introduced into the household budget constraint as a non-means-tested government transfer. The net factor income of households, which is a fixed variable in real terms in the model, is lowered by following CSO estimates.

In late 2019, the prices of oil, coal, and natural gas declined by around 20 per cent, 16 per cent, and 19 per cent, relative to their closing prices in 2018. In the first months of 2020, energy prices have plunged to the lowest levels in nearly two decades, which in turn soften the negative economic impacts of the virus crisis by lowering both the cost of production and the import bill of energy commodities for energy-importer countries.[5] In this note, along the path of *BaU*, in order to take into account the cushioning impacts of the lower energy prices, it is assumed that energy prices remained at their low level in 2020. However, in the first quarter of 2021, the prices of oil and coal increased by 40 per cent and the price of natural gas is doubled, compared to their average prices in 2020. This remarkable surge in prices occurred in a period where the lockdown measures were in place across globe, and there was a contraction in economic activity. Due to the vaccination roll out in the developed countries and the attempts to ease/lift the lockdown measures, a strong rebound effect is expected due to the delayed

[5] The main reason for the lower prices was the price war between OPEC+ members. As of the 13^{th} of April, the war seems to have subsided as the members have agreed to cut the oil production by 9.7 million barrels per day (bpd) in May-June. The reduction in daily production will be 7.6 million bpd until the end of the year, and 5.6 million bpd in 2021 (Economic Times, 2020).

consumption in 2020. Therefore, along all scenario paths, the energy prices are assumed to be constant at their levels at the end of the first quarter of 2021. The carbon tax is assumed to stay at its 2021 level of €33.5 per tonne.

Appendix B Lists of Activities and Commodities

Table B.1: Commodities

C_AGR	Agriculture	C_HTP	High-tech products
C_PEA	Peat	C_TRE	Transportation equipment
C_COA	Coal	C_ELC	Electricity
C_CRO*	Crude oil	C_NGS	Natural gas
C_OMN*	Other mining	C_WAT	Water and sewerage
C_FBT	Food, beverage, and tobacco	C_CON	Construction
C_TEX	Textile	C_TRD	Trade
C_WWP	Wood and wood products	C_LTS	Land transportation
C_OIN	Other industrial products	C_WTS	Water transportation
C_GAL	Gasoline	C_ATS	Air transportation
C_KRS	Kerosene	C_OTR	Other transportation
C_FUO*	Fuel-oil	C_ACC	Accom. and hotel serv.
C_LPG	Liquid petroleum gas	C_TEL	Telecommunication services
C_DIE	Diesel	C_FSR	Financial services
C_OPP	Other petroleum products	C_RES	Real estate services
C_OTM	Other manufacturing	C_PSE	Professional services
C_CHE	Chemical products	C_ADS	Admin and support services
C_BPP	Basic pharmaceuticals	C_PUB	Publis services
C_RUP	Rubber and plastic	C_EDU	Education
C_ONM	Other non-metallic minerals	C_HHS	Health
C_BFM	Basic fabricated metals	C_OSE	Other services

*: Not subject to private consumption.

Table B.2: Activities

Activity		NACE Codes	Aggregate Sector	
A_ACC	Accommodation and Hotel Services	55-56	ACC	
A_AGR	Agriculture	1-3	AGR	
A_CON	Construction	41-43	CON	
A_FSR	Financial Services	64-66	FSR	
A_PUB	Public Sector	84	PUB	
A_TRD	Trade	45-47	TRD	
A_ELC	Conventional		ELC	Electricity
A_WND	Wind		ELC	
A_ORE	Other Renewables		ELC	
A_BFM	Basic Metal Manufacturing	24-25	MAN	Manufacturing
A_BPP	Basic Pharmaceutical Products	21	MAN	
A_CHE	Chemical Products	20	MAN	
A_FBT	Food, Beverage and Tobacco	10-12	MAN	
A_HTP	High-Tech Products	26-28	MAN	
A_NGS	Natural Gas Supply		MAN	
A_OIN	Other Industrial Products	17,18,33	MAN	
A_ONM	Other Non-metallic Products	23	MAN	
A_OTM	Other Manufacturing	31-32	MAN	
A_PET	Petroleum		MAN	
A_RUP	Rubber and Plastic Products	22	MAN	
A_TEX	Textile	13-15	MAN	
A_TRE	Transportation Equipment	29-30	MAN	
A_WAT	Water and Sewerage	36,37-39	MAN	
A_WWP	Wood and Wood Products	16	MAN	
A_OMN	Other Mining Products		MIN	Mining
A_PEA	Peat		MIN	
A_ATS	Air Transportation	51	TRP	Transportation
A_LTS	Land Transportation	49	TRP	
A_WTS	Water Transportation	50	TRP	
A_OTR	Other Transport (Storage and Postal)	52-53	TRP	
A_EDU	Education Sector	85	SER	Services
A_HHS	Health Sector	86-88	SER	
A_RES	Real Estate Services	68	SER	
A_TEL	Telecommunication Services	61	SER	
A_PSE	Professional Services	69-75	SER	
A_ADS	Admin and Support Services	77-82	SER	
A_OSE	Other Services	remaining	SER	

*: It excludes NACE codes 5-9 (Mining, Quarrying and Extraction), 19 (Petroleum Products), and 35 (Electricity and Gas Supply).

Note: The activities without NACE codes are further disaggregated sectors.