

RESEARCH
SERIES
NUMBER 179
APRIL 2024

THE IMPLICATIONS OF HIGH ENERGY AND CARBON PRICES ON IRISH FIRMS

AYKUT MERT YAKUT, SAMUEL MCARDLE AND KELLY DE BRUIN



THE IMPLICATIONS OF HIGH ENERGY AND CARBON PRICES ON IRISH FIRMS

Aykut Mert Yakut

Samuel McArdle

Kelly de Bruin

April 2024

ESRI RESEARCH SERIES

NUMBER 179

Available to download from www.esri.ie

© The Economic and Social Research Institute
Whitaker Square, Sir John Rogerson's Quay, Dublin 2

<https://doi.org/10.26504/rs179>



This Open Access work is licensed under a Creative Commons Attribution 4.0 International License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly credited.

ABOUT THE ESRI

The Economic and Social Research Institute (ESRI) advances evidence-based policymaking that supports economic sustainability and social progress in Ireland. ESRI researchers apply the highest standards of academic excellence to challenges facing policymakers, focusing on ten areas of critical importance to 21st Century Ireland.

The Institute was founded in 1960 by a group of senior civil servants led by Dr T.K. Whitaker, who identified the need for independent and in-depth research analysis. Since then, the Institute has remained committed to independent research, and its work is free of any expressed ideology or political position. The Institute publishes all research reaching the appropriate academic standard, irrespective of its findings or who funds the research.

The ESRI is a company limited by guarantee, answerable to its members and governed by a Council comprising up to 14 representatives drawn from a cross-section of ESRI members from academia, civil services, state agencies, businesses and civil society. Funding for the ESRI comes from research programmes supported by government departments and agencies, public bodies, competitive research programmes, membership fees, and an annual grant-in-aid from the Department of Public Expenditure, NDP Delivery and Reform.

Further information is available at www.esri.ie

THE AUTHORS

Aykut Mert Yakut is a Research Officer at the Economic and Social Research Institute (ESRI) and is an Adjunct Assistant Professor at Trinity College Dublin (TCD), Samuel McArdle is a Research Assistant at the ESRI, and Kelly de Bruin is a Senior Research Officer at the ESRI and is an Adjunct Associate Professor at TCD.

ACKNOWLEDGEMENTS

The research carried out in this report was funded by the Department of Enterprise, Trade and Employment (DETE) and is part of an ongoing modelling programme funded by the Department of Environment, Climate and Communications (DECC).

This report has been accepted for publication by the Institute, which does not itself take institutional policy positions. The report has been peer-reviewed prior to publication. The authors are solely responsible for the content and the views expressed.

TABLE OF CONTENTS

| | |
|---|-------------|
| LIST OF TABLES | v |
| LIST OF FIGURES | v |
| ABBREVIATIONS | vi |
| EXECUTIVE SUMMARY | vii |
| Introduction | vii |
| Main Findings | viii |
| CHAPTER 1 INTRODUCTION | 1 |
| CHAPTER 2 METHODOLOGY AND SCENARIOS | 5 |
| 2.1 The I3E Model | 5 |
| 2.1.1 Households | 6 |
| 2.1.2 Production and Investment | 8 |
| 2.1.3 Government | 12 |
| 2.1.4 Labour Market | 14 |
| 2.2 Scenarios | 16 |
| CHAPTER 3 RESULTS | 18 |
| 3.1 Macroeconomic Aggregates | 18 |
| 3.2 Sectoral Impacts | 22 |
| CHAPTER 4 CONCLUSION | 29 |
| REFERENCES | 32 |
| APPENDIX | 37 |
| A Additional Tables | 37 |

LIST OF TABLES

| | | |
|------------|--|----|
| Table 2.1: | Scenario Definitions | 16 |
| Table 3.1: | Macroeconomic Results of Main Scenarios, % change w.r.t. BaU | 18 |
| Table 3.2: | Aggregated Sectoral Results | 23 |
| Table 3.3: | Manufacturing Sectors Results, % change w.r.t. BaU | 27 |
| Table A.1: | List of Commodities | 37 |
| Table A.2: | List of Activities and Aggregation Key | 38 |

LIST OF FIGURES

| | | |
|-------------|---|----|
| Figure 2.1: | Interlinkages within the I3E Model | 5 |
| Figure 2.2: | Nested Structure of Consumption | 7 |
| Figure 2.3: | Nested Structure of Electricity Production | 10 |
| Figure 2.4: | Nested Structure of Production, Except Electricity Production | 11 |

ABBREVIATIONS

| | |
|--------|---|
| CGE | Computable General Equilibrium |
| CPI | Consumer Price Index |
| CRRA | Constant Relative Risk Aversion |
| DECC | Department of Environment, Climate and Communications |
| DETE | Department of Enterprise, Trade and Employment |
| ETS | Emissions Trading System |
| EU ETS | European Union Emissions Trading System |
| FOC | First-order Condition |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| I3E | Ireland Environment-Energy-Economy |
| LFS | Labour Force Survey |
| PP | Percentage Points |
| RHGs | Representative Household Groups |
| SILC | Survey on Income and Living Conditions |

Executive Summary

INTRODUCTION

Transitioning to a low-carbon economy requires undertaking massive investment expenditures, and how to finance these expenditures remains at the core of economic debates. However, the cost of *not* transitioning to a low-carbon economy is often forgotten in these debates. These costs have increased under current global geopolitical tensions, especially for imported fossil fuel-dependent countries, such as Ireland. This report aims to quantify the cost of decarbonisation inaction. What costs will Irish firms face if they continue with their current energy use patterns when the carbon tax (set by the Irish government) and the European Union Emissions Trading System (EU ETS) price (determined by the market conditions at the EU level) are increasing while at the same time, international energy prices are at their extremely high levels?

The report utilises the Ireland Environment-Energy-Economy (I3E) model, an intertemporal computable general equilibrium (CGE) model for Ireland, by considering three scenarios describing future energy price developments. Firstly, the impacts of a hypothetical continuation of skyrocketed international energy prices are investigated in the *HEP* scenario. In this scenario, the price of emissions allowances in the EU, i.e., the EU ETS price and the carbon tax, are fixed at their 2022 level. Secondly, in addition to high international energy prices, the impacts of a gradually increasing Irish carbon tax until 2030 as committed by the government are investigated (*CT* scenario). Finally, the *CT_ETS* scenario quantifies the impacts of gradually increasing the EU ETS price along with the carbon tax until 2030 while international energy prices are high and the carbon tax increases following the government-committed trajectory. Since the focus of the report is the implications of the energy and carbon price shocks on the macroeconomic environment and production sectors in Ireland, the results for basic macroeconomic aggregates, the aggregate production sectors, and manufacturing sub-sectors are discussed. However, the details of the distributional implications of the shocks across households, which are available upon request, are only briefly discussed.

The energy price shock triggered by a geopolitical conflict adversely affected the Irish economy, which heavily depends on imported fossil fuels. Although energy prices have substantially declined after the first six months of the shock, prices of both international energy and the EU ETS price remain higher than their pre-shock level. Moreover, the national carbon tax has continued to increase in line with the committed trajectory. International energy prices are prone to volatility due to geopolitical tensions, while carbon prices and other environmental regulations increase to meet the legally binding climate targets. Under these circumstances, the transition to a low-carbon economy is essential to mitigate the adverse impacts of climate change and lower Ireland's dependency on imported fossil fuels. Producing energy from renewable resources will improve the resilience of the Irish economy against unexpected shocks in international energy prices while reducing its emissions. The report's findings provide important insights regarding the cost of not taking necessary actions to ensure the transition.

MAIN FINDINGS

- If international energy prices are assumed to stay at their extremely high levels, the level of real gross domestic product (GDP) in 2030 will be around 0.7% lower than the business-as-usual (*BaU*) scenario, along with energy prices staying at the end of 2021 levels.
- The costs stemming from the higher carbon tax and EU ETS price have contractionary economic effects, further reducing real GDP by 0.7 and 1.1 percentage points (pp), respectively, compared to the GDP impacts of higher energy prices.
- Both higher international energy prices and higher carbon prices (the substitution effect) and the contraction in domestic economic activity (the income effect) lower import demand, leading to an improved trade balance.

- Lower tax revenue due to economic contraction leads to a higher debt-to-GDP ratio in all scenarios, but its magnitude is lower with higher carbon taxation and higher ETS prices, as the government receives carbon tax revenues and half of the ETS revenues. Both increased carbon taxation and a higher ETS price lead to the lowest debt-to-GDP ratio.
- The reductions in emissions with high energy prices (the *HEP* scenario) are amplified by the higher carbon tax and EU ETS price.
- Higher energy prices affect all sectors adversely, and the impacts are higher for the transportation, construction, and services sectors. The electricity production sector is affected positively as demand for electricity increases due to the higher fossil fuel prices. The virtually zero impact on the aggregate manufacturing sector is driven by the positively affected petroleum and natural gas supply sectors, as domestic production substitutes the imported commodities produced by these sectors.
- The impacts of the higher carbon tax are especially strong for the aggregate mining, transportation, and electricity sectors. For the aggregate electricity sector, the higher EU ETS price triggers a shift of electricity production to renewable sources, which, in turn, partially reverses the contraction in the sector.

CHAPTER 1

Introduction

Climate change is defined as the process of changes in the temperature and weather conditions triggered by the increase in greenhouse gas (GHG) emissions stemming from human activities.¹ The pace of the positive trend in the level of these emissions, especially CO₂ emissions, threatens the existence of human beings, although global economic development in the last two centuries was enabled by carbon-intensive technologies (OECD/IEA/NEA/ITF, 2015). Therefore, limiting the increase in global temperature below 2°C, which requires curbing emissions, is the prime aim of climate change policies. The process of reducing human-induced emissions, the so-called *transition to a low-carbon economy*, is described as switching energy demand from fossil fuels to renewable resources on all fronts ranging from producing electricity and transporting goods and passengers to heating homes (Gielen et al., 2019). As the transition requires the replacement of equipment used by production activities (combustion systems in factories), by households and businesses (space and water heating systems in homes and offices), and by private and public transportation services (cars/buses/trucks with internal combustion engines), the cost of investment is massive (McCollum et al., 2013; Peake and Ekins, 2017). Therefore, it can be argued that economic agents are reluctant to take necessary actions to make this transition possible, especially given the level of uncertainty involved (Haas et al., 2023).

The large body of literature examining the impacts of carbon taxation indicate that, without exception, the tax reduces emissions with negative economic impacts in the absence of additional policies (Beck et al., 2015; Cabalu et al., 2015; Sajeewani et al., 2015; Yusuf and Resosudarmo, 2015; Benavente, 2016; Calderón et al., 2016; Rivera et al., 2016; van Heerden et al., 2016; Zhang et al., 2016; Parry and Mylonas, 2017; Caron et al., 2018; Lin and Jia, 2018; Böhringer et al., 2019; Freire-González and Ho, 2019; Landis, 2019; Takeda and Arimura, 2021; Xu and Wei, 2022; de Bruin and Yakut,

¹ <https://www.un.org/en/climatechange/what-is-climate-change>.

2024).² While introducing a carbon price may also induce an innovational environment to bolster the transition to a low-carbon economy (Nordhaus, 2011; Linnenluecke et al., 2019), carbon pricing itself may not be sufficient (Stern, 2015; Campiglio, 2016).

Many questions regarding the timing and financing of the required investment emerge due to the issue's complexity. In their systemic survey, Saraji and Streimikiene (2023) argue that the duration and intensity of the transition cost concerning the decline in labour productivity resulting in GDP reduction can be limited based on the volume of investment expenditures. However, under the pressures of climate change impacts and skyrocketed international energy prices due to the rebound in economic activity in the aftermath of the COVID-19 pandemic and Russia's invasion of Ukraine in February 2022, the cost of being reluctant to transition is also quite high (Gros et al., 2016). Natural gas, coal, and oil prices were 148%, 107%, and 27% higher, respectively, at their peak levels in summer 2022 than in January 2022. In the last quarter of 2022, although prices declined after absorbing the first shock of the conflict, the yearly average prices of coal and natural gas (oil) were 150% (42%) higher compared to their average prices in 2021.³ Energy price shocks are nothing new and have recurred since the 1970s oil crisis. Many studies examine the impact of high energy prices on the economy and environment. They find that such price increases are contractionary (e.g., Doroodian and Boyd, 2003; Dybczak et al., 2008; He et al., 2010; Manzoor et al., 2012) and reduce emissions even in the absence of climate policy (e.g. Vielle and Viguié, 2007; Aydın and Acar, 2011).⁴

The crisis also affected the price in the EU-wide carbon allowance market, the so-called EU Emissions Trading System (ETS), such that the yearly average unit allowance price increased from €57 in 2021 to around €82 in 2022.⁵ Another body of literature examines the impact of emission trading systems. Similar to carbon taxation, the literature indicates that emission

² These studies cover various countries with varying levels of carbon taxation and resulting impacts. For a survey of the literature, see Timilsinas (2018); Freire-González (2018); Maxim et al. (2019); Köppl and Schratzenstaller (2022).

³ <https://thedocs.worldbank.org/en/doc/5d903e848db1d1b83e0ec8f744e55570-0350012021/related/CMO-Historical-Data-Annual.xlsx>.

⁴ Studies providing *ex-post* analyses (e.g., Martinsen et al., 2007; Berk and Yetkiner, 2014; Punzi, 2019; Przekota, 2022; Huntington and Liddle, 2022) generally confirm these findings.

⁵ <https://tradingeconomics.com/commodity/carbon>.

trading systems reduce emissions and adversely impact the economy, albeit mildly (e.g. Choi et al., 2017; Liu et al., 2017; Meng et al., 2018; Nong et al., 2020). For the case of the EU ETS, Rokicki et al. (2023), using a static CGE model of Poland, find that a €16.3 price of EU ETS carbon emissions allowance will reduce GHG emissions by 1.24% and production will fall by 0.46%. Martin et al. (2016) evaluate existing ex-post literature and conclude that while the EU ETS had a negative impact on emissions, there is no evidence that it diminished the economic performance of participating firms, this likely due to the low price level of permits at that time.

Making reliable predictions regarding international energy prices is difficult as they are more prone to political tensions than economic developments. Any volatility in these prices is quickly transmitted to other prices and, thus, generates significant economic consequences. Since oil-related products constitute the majority of our energy sources and only a few countries can extract oil, almost all countries, including economically well-developed ones, depend on imported energy products. Therefore, despite production problems in the supply of energy from renewable resources, e.g., solar and wind, transitioning to low-carbon alternatives is essential not only to reduce our emissions but also to ensure (or at least improve) our self-sufficiency in energy (see Sovacool, 2013, for the case of Denmark).

This report utilises the Ireland Environment-Energy-Economy (I3E) model, which is Ireland's first intertemporal computable general equilibrium (CGE) model. It is a single-country model treating Ireland as a small open economy, which implies that Ireland is a price-taker without any control over international prices through its supply to and demand from international markets. Although the model is amenable to examining the cost of a policy shift across various production sectors, its current version provides limited information regarding the cost of the transition to a low-carbon economy due to the lack of representation in the renewable resources used by sectors. The reason is that in 2014, the model's base year, the use of renewable resources, e.g., biomass and solar, by production sectors was negligible compared to their fossil fuel demand, especially natural gas. Therefore, we excluded these commodities from the model. On the other hand, the electricity production sector is disaggregated into three subsectors: the conventional, which uses fossil fuels as inputs; wind; and

other renewable sectors. Since the conventional electricity production sector's entire emissions are subject to the EU ETS, an increase in its price leads to a shift in the electricity production towards the wind and other renewable sectors. The shift in the composition of electricity production is endogenously solved in the model through a dynamic dividend maximisation problem. As other agents, including households and production sectors, cannot switch from fossil fuels to renewable resources, their decisions change depending on alterations in relative prices (the substitution effect) and profits and disposable income (the income effect). In addition, the implications of efficiency improvements cannot be included as the current version of the model does not incorporate efficiency parameters.

The report aims to quantify the impacts of keeping Irish firms' existing energy demand compositions the same when energy prices stay at their extremely high levels while carbon prices increase gradually. In the scenario analyses, the energy prices are assumed to stay at the (highest) levels reached in mid-2022 until the end of the model horizon, even though they have since declined substantially.⁶ Since the transition by the production sectors is not modelled, the results can be interpreted as *what would be the cost of not transitioning to a low-carbon economy under the pressure of highly troubled circumstances in international energy markets*. In this respect, it should be noted that the costs quantified in the report are the upper-end estimations as the international energy prices applied in the scenarios are high, assuming prices remain at their 2022 level, which showed the highest prices in the past two decades.

The remainder of the report is as follows. Chapter 2 explains the details of the model. Chapter 3 provides the definitions of the scenarios and discusses their results on the macroeconomic environment and the aggregate sectoral results with a special emphasis on the manufacturing sectors. Finally, Chapter 4 concludes the report.

⁶ According to the World Bank³, coal, crude oil, and natural gas prices were lower by 53%, 31%, and 65%, respectively, in the second quarter of 2023, compared to the same quarter of 2022.

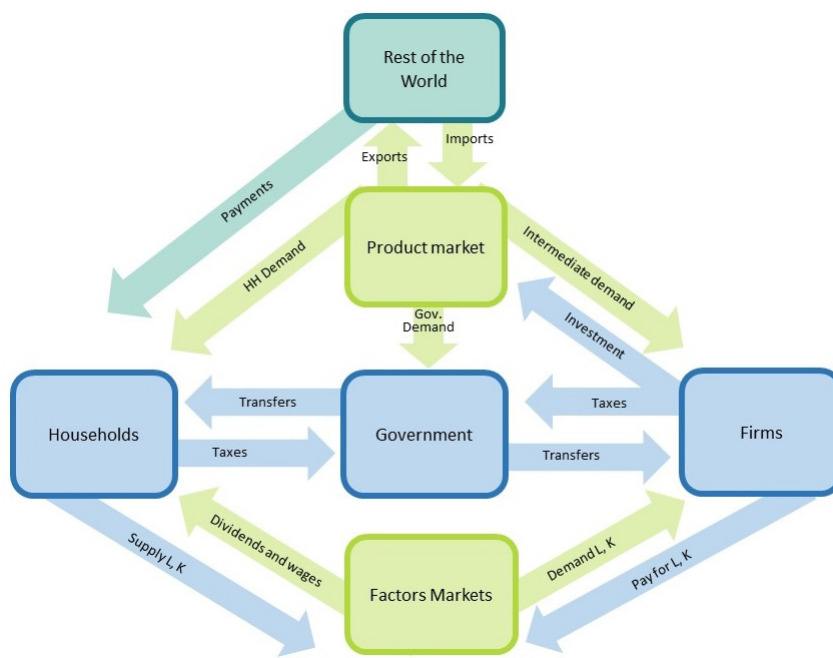
CHAPTER 2

Methodology and Scenarios

2.1 The I3E Model

This analysis applies the Ireland Environment-Energy-Economy (I3E) model. The I3E model is an intertemporal computable general equilibrium (CGE) model, which reproduces the structure of the economy in its entirety. It includes production sectors, households, and the government, among others. The model quantifies the nature of all existing economic transactions among diverse economic agents. According to microeconomic behaviour, producers/consumers maximise their profits/utility given their budget constraints. In other words, a CGE model examines how inputs and outputs flow between production sectors of the economy and, finally, result in final goods consumed by households. Figure 2.1 gives an overview of the interlinkages within the I3E model.

FIGURE 2.1: INTERLINKAGES WITHIN THE I3E MODEL



In the remainder of this chapter, the problems of households and firms will be explained first, and the role of the government and the labour market dynamics will be discussed. A complete technical description of the model and the details of data used in the calibration can be found in de Bruin and Yakut (2021b,a), respectively.

The explicit modelling of sectoral interlinkages makes it possible to investigate the wider economic impacts of a specific shock or policy through the different transmission channels in the economy. The model enables us to quantify the impacts of a policy change on the macroeconomic aggregates, labour market, fiscal balances, households, and emissions, as well as on other sectors, i.e. the spillover effect.

2.1.1 Households

There are ten representative Household Groups (RHGs) in the model. Each RHG solves the following intertemporal utility maximisation problem where the utility function is in the form of Constant Relative Risk Aversion (CRRA):

$$\max_{CC_{hh,t}} \sum_{t=1}^{\infty} \left(\frac{1 + grw_t}{1 + \rho_{hh}} \right)^t \frac{(CC_{hh,t})^{1-\theta_{hh}}}{1 - \theta_{hh}} \quad (2.1)$$

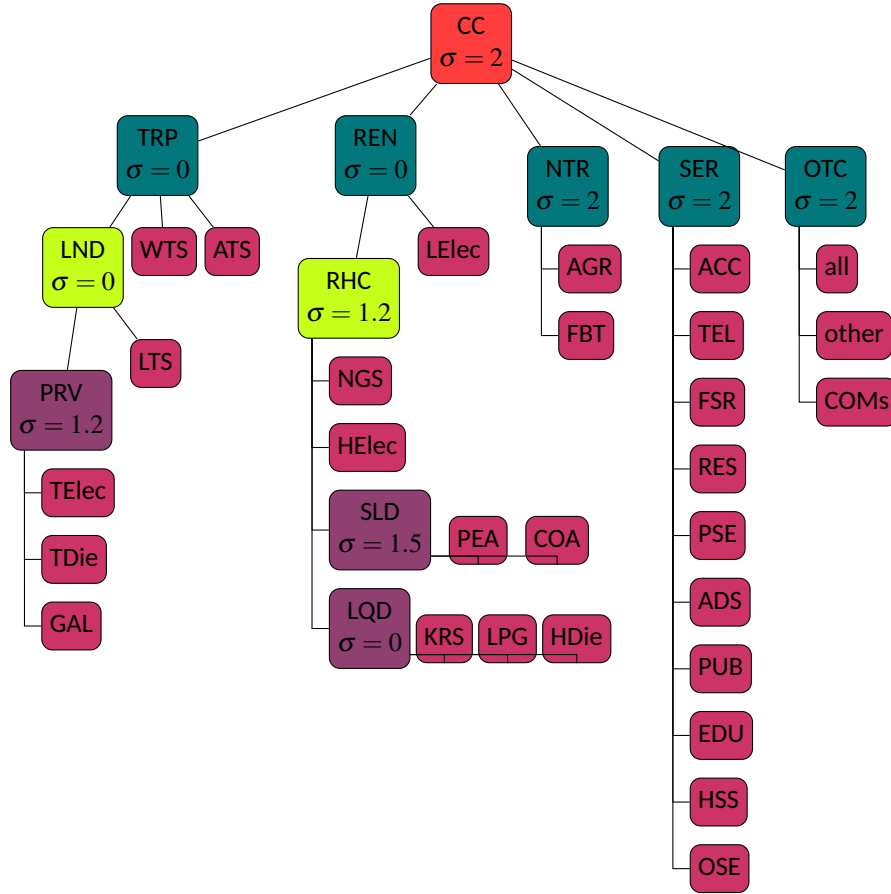
s.t

$$PCC_{hh,t} CC_{hh,t} + SAV_{hh,t} \leq WINC_{hh,t} + CINC_{hh,t} + TR_{hh,t} + PEN_{hh,t} + FAI_{hh,t} + NMTTR_{hh,t}$$

where grw_t is the economic growth rate in the period t , ρ_{hh} is time preference rate, θ_{hh} is intertemporal elasticity of substitution, $CC_{hh,t}$ is household-specific composite consumption and $PCC_{hh,t}$ is its price, $SAV_{hh,t}$ is savings, $WINC_{hh,t}$, $CINC_{hh,t}$, $TR_{hh,t}$, $PEN_{hh,t}$, $FAI_{hh,t}$, and $NMTTR_{hh,t}$ are net-of-tax wage income, net-of-tax capital income (distributed dividends), transfers from the government, pension income from the government, income from foreign asset holdings, and non-means-tested transfer income from the government, respectively. The total values of income items are disaggregated across RHGs based on the share parameters calibrated from the Survey on Income and Living Conditions (SILC). For instance, the total

net-of-tax wage income received by the labour type l is distributed across households, and $WINC_{hh,t}$ is the sum of these incomes over labour types.

FIGURE 2.2: NESTED STRUCTURE OF CONSUMPTION



Each RHG chooses the level of composite consumption to maximise the present discounted value of intertemporal utility. The first-order condition (FOC) of this problem, eq. (2.2), is the well-known consumption Euler equation and solves for the sequence of composite consumption where DR_t is the domestic interest rate.

$$\frac{CC_{hh,t+1}}{CC_{hh,t}} = \left[(1 + grw_t) \frac{1 + DR_{t+1}}{1 + \rho_{hh}} \frac{PCC_{hh,t}}{PCC_{hh,t+1}} \right]^{\frac{1}{\theta_{hh}}} \quad (2.2)$$

The CC is disaggregated across commodities in the second stage based on the consumption nest depicted in Figure 2.2, where Transportation (*TRP*), Residential Energy (*REN*), Nourishment (*NTR*), Services (*SER*), and other commodities (*OTC*) are the main composite commodities. The values of elasticity of substitution parameters, σ , are chosen either as 0 or in a range of 1.2 and 2 to reflect the different substitution possibilities across different commodities that constitute the composite commodity.⁷

2.1.2 Production and Investment

Firms are divided into two broad categories: dividend maximisers, *dm*, and non-dividend maximisers, *ndm*. The *dm* firms maximise the present value of the firm ($V_{dm,t}$, or equivalently the present discounted value of their dividend streams, $DIV_{dm,t}$) by choosing the level of physical investment, $PSI_{dm,t}$, the sector-specific capital, $FD_{dm,k,t}$, and composite labour, $CLD_{dm,t}$.

$$\max_{PSI_{dm,t}, FD_{dm,k,t}, CLD_{dm,t}} V_{dm,t} = q_{dm,t} FD_{dm,k,t} = \sum_{t=1}^{\infty} \left(\frac{1 + grw_t}{1 + DR_t} \right)^t DIV_{dm,t} \quad (2.3)$$

$$FD_{dm,k,t+1} = (1 - \delta_{dm,t}^{s.t}) FD_{dm,k,t} + PSI_{dm,t} \quad (2.4)$$

$FD_{dm,k,t}$ evolves according to the capital accumulation function (2.4) and depreciates at the rate $\delta_{dm,t}$. The Lagrange multiplier of this maximisation problem is Tobin's q ⁸:

$$DIV_{dm,t} = (1 - corptax_t) FP_{dm,k,t} FD_{dm,k,t} - INV_{dm,t} \quad (2.5)$$

$$INV_{dm,t} = PPSI_t PSI_{dm,t} + PVA_{dm,t} ADJ_{dm,t} \quad (2.6)$$

$$ADJ_{dm,t} = \phi_{dm,t} \frac{PSI_{dm,t}^2}{FD_{dm,k,t}} \quad (2.7)$$

where $FP_{dm,k,t}$ and $PPSI_t$ are the prices of capital and investment, respectively. The sectoral dividend equals net-of-corporate tax profit minus investment expenditures, $INV_{dm,t}$, including the cost of new investment

⁷ The full list of commodities is available in Table A.1.

⁸ Tobin's q is the ratio of the market value of existing capital to its replacement cost, also known as the marginal value of capital. See Hayashi (1982) for further discussion.

equipment and the adjustment cost, $ADJ_{dm,t}$ with a parameter $\phi_{dm,t}$, measured by the price of the value added, $PVA_{dm,t}$. Adjustment cost is an increasing and convex function of investment; for a given level of sectoral capital stock, the cost of installing new capital equipment will be greater. For the given level of $\phi_{dm,t}$, $q_{dm,t}$ and $\delta_{dm,t}$ are calibrated.

The FOCs of this dividend maximisation problem w.r.t. the levels of physical investment and capital stock, respectively, are as follows.

$$q_{dm,t} = PPSI_t + 2 PVA_{dm,t} \frac{ADJ_{dm,t}}{PSI_{dm,t}} \quad (2.8)$$

$$q_{dm,t} (1 + DR_t) (1 + grw_t) = q_{dm,t+1} (1 - \delta_{dm,t}) + PVA_{dm,t+1} \frac{ADJ_{dm,t+1}}{FD_{dm,k,t+1}} + (1 - corptax_{t+1}) FP_{dm,k,t+1} \quad (2.9)$$

For the *ndm* firms, the capital stock accumulates by (2.4) and depreciates at the rate of 0.05, and the investment (by destination) expenditure in period t is a fixed $\gamma_{ndm,t}^{invdes}$ fraction of its total net-of-corporate tax profits in period t .

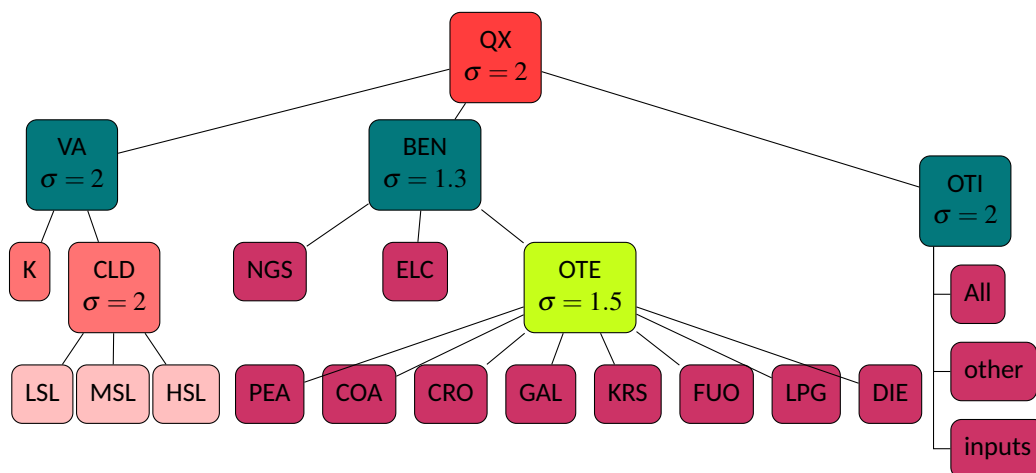
$$INV_{ndm,t} = \gamma_{ndm,t}^{invdes} FD_{ndm,k,t} FP_{ndm,k,t} (1 - corptax_t) \quad (2.10)$$

The total value of production, the LHS of eq. (2.11), is equal to payments to factors of production, i.e. value added, production taxes paid to the government, the total cost of intermediate inputs, and the net cost of the Emissions Trading System (ETS).

$$PX_{a,t} QX_{a,t} = PVA_{a,t} VA_{a,t} + PRODTAXS_{a,t} + PCIN_{a,t} CCIN_{a,t} + CETS_{a,t} - \sum_c CTXADJ_{c,a,t} \quad (2.11)$$

where $QX_{a,t}$ is the total production and $CCIN_a$ is composite intermediate input demand; $PX_{a,t}$ and $PCIN_{a,t}$ are their prices, respectively. The term $(CETS_{a,t} - \sum_c CTXADJ_{c,a,t})$ is the net cost of ETS, which excludes carbon tax rebates as firms covered by the ETS are exempt from paying the carbon tax.

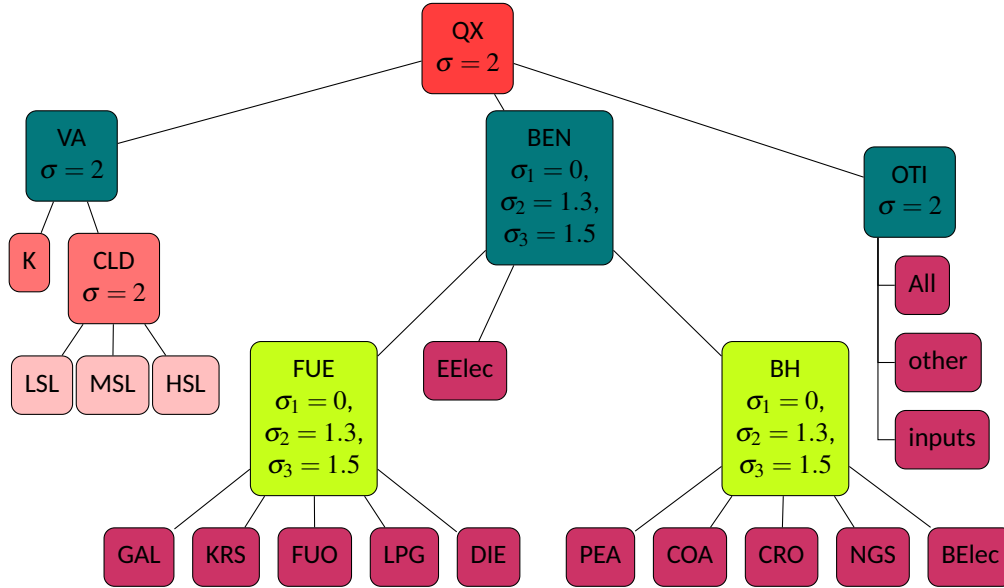
FIGURE 2.3: NESTED STRUCTURE OF ELECTRICITY PRODUCTION



The production nests of electricity producers and all other sectors are depicted in Figures 2.3 and 2.4, respectively. The production QX is an aggregate of value added (VA), business energy (BEN), and other inputs (OTI). VA is a CES aggregate of factors of production, and OTI is an aggregate of all intermediate inputs but energy. The composite labour is a CES aggregate of three types of labour. For all activities, except electricity production, the commodity BEN is assumed to be an aggregate of energy electricity (EE_{lec}), fuel (FUE) and business heating (BH). The values of σ_{BEN} and σ_{OTE} shown in Figure 2.3 are for the conventional electricity production sector (A_{CLC}), which uses all energy commodities. However, these parameters are 0 for the electricity producers using wind (A_{WND}) and other renewables (A_{ORE}).

The coverage of sectoral emissions by the ETS is 100% for the energy production, petroleum refining, mineral, and aviation sectors. On the contrary, land transportation (road or railway), agriculture, waste, and residential sectors are exempted from the ETS but are subject to the Irish carbon tax. For the other sectors, the ETS coverage varies based on the average size of production units regarding the combustion capacity, production capacity, etc. (Environmental Protection Agency (EPA), 2018). As the Irish government exempts the ETS emissions from the carbon tax to prevent double taxation, Irish firms subject to the EU ETS legislation must directly internalise both the cost of ETS and the carbon tax exemptions in

FIGURE 2.4: NESTED STRUCTURE OF PRODUCTION, EXCEPT ELECTRICITY PRODUCTION



their cost minimisation problems. As an example, the optimal level of intermediate input in the composite commodity of business heating (BH) is

$$INT_{c,a,t} = \left[\frac{PCIN_{BH,a,t} \gamma_{c,a,t}^{bh}}{PQD_{c,t} + ETSADJ_{c,a,t} - CTXADJ_{c,a,t}} \right]^{\sigma_{a,t}^{bh}} CCIN_{BH,a,t} \quad (2.12)$$

where $INT_{c,a,t}$ is intermediate input demand for commodity c by activity a , $CCIN_{BH,a,t}$ is intermediate demand on the composite commodity BH by activity a and $PCIN_{BH,a,t}$ is its price, and $\gamma_{c,a,t}^{bh}$ and $\sigma_{a,t}^{bh}$ are share and exponent parameters of the CES function, respectively. The denominator in the parentheses is the sector-specific unit cost of a commodity c for activity a where $PQD_{c,t}$ is the purchaser price of commodity c , $ETSADJ_{c,a,t}$ is the ETS adjuster and $CTXADJ_{c,a,t}$ is the carbon tax exemption adjuster. The values of these adjusters are equal to

$$\begin{aligned} ETSADJ_{c,a,t} &= \overline{PETS}_t \overline{ETStoE}_{a,t} (1 - AtoT_{a,t}) \overline{carcon}_c \\ CTXADJ_{c,a,t} &= \overline{PCAR}_t \overline{ETStoE}_{a,t} \overline{carcon}_c \alpha_{c,t} (1 + stax_{c,t}) \end{aligned} \quad (2.13)$$

where \overline{PETS}_t is the EU ETS price of a per tonne emission allowance, $\overline{ETStoE}_{a,t}$ is ETS emissions-to-total activity emissions ratio, $AtoT_{a,t}$ is the ratio of ETS allowance to ETS emissions of activity, \overline{carcon}_c is the carbon

emission factor of commodity c , \overline{PCAR}_t is the unit carbon tax per tonne eq-CO₂, $\alpha_{c,t}$ captures the carbon leakages in the economy, and $stax_{c,t}$ is the sales tax rate.

As the value of the parameter $ETStoE_{a,t}$ is 0 for non-EU ETS sectors, e.g. land transportation, $ETSADJ_{c,a,t} = CTXADJ_{c,a,t} = 0$ holds and the *incurred* cost of commodity c is equal to the purchaser price of it, $PQD_{c,t}$. As $PQD_{c,t}$ includes the carbon tax, the sector bears the carbon tax cost. If $ETStoE_{a,t}$ is positive, the sector must buy new allowances when its total ETS-covered emissions exceed its free allowances. The term $ETSADJ_{c,a,t}$ introduces this cost component into the optimality condition stemming from the cost minimisation problem. As the ETS price, the ETS emissions-to-total emissions ratio, and the carbon content of a commodity increase, the value of $ETSADJ_{c,a,t}$ also increases which, in turn, increases the sector-specific *incurred* unit cost. On the other hand, the higher value of the ratio of the allowances-to-ETS emissions, $AtoT_{a,t}$, which is an endogenous variable for the given sequence of free allowances, lowers $ETSADJ_{c,a,t}$ and thus the *incurred* unit cost. In other words, a higher level of $AtoT_{a,t}$ dampens the incentives for activities to lower their ETS emissions. Although activity a is exempted from the carbon tax based on its ETS coverage, it pays the carbon tax-inclusive price of commodity c , $PQD_{c,t}$, at the time of purchase. The term $CTXADJ_{c,a,t}$ introduces the carbon tax exemptions.

2.1.3 Government

The government collects direct taxes on labour incomes and sectoral profits, indirect taxes on the sale of commodities, carbon tax on energy commodities, production tax on production activities, export tax on exported commodities, and receives half of the total ETS cost.⁹ It allocates its total revenues to consumption and transfers to households regarding welfare transfers and pensions. The total government consumption of commodities evolves as shown in equation (2.14).

$$GOVCON_t = \overline{GOVCONA}_t + mps GDP_t \quad (2.14)$$

⁹ Export tax is positive only for electricity, of which not domestic sales but exports are subject to the carbon tax.

where $\overline{GOVCONA}_t$ is the autonomous expenditures, fixed in nominal terms, mps_t is the marginal propensity to spend, and GDP_t is the nominal GDP.

The level of welfare transfer to households is a function of both the level of consumer price index (CPI) and the unemployment rate as follows.

$$GTRHH_t = \overline{GTRHH} + gtrhh_{tunr,t} TUNR_t + gtrhh_{cpi,t} CPI_t \quad (2.15)$$

where $GTRHH_t$ is the nominal value of the total government welfare transfers, \overline{GTRHH} is the fixed transfers, $TUNR_t$ is the total unemployment rate, and $gtrhh_{tunr,t}$ and $gtrhh_{cpi,t}$ are positive parameters. The parameters were estimated using a simple Ordinary Least Square estimation procedure covering the period from 2000 to 2019 and then slightly adjusted to ensure the model dynamics were in line with other macroeconomic models for Ireland, e.g., COSMO and HERMES, as explained in de Bruin et al. (2020). The difference between total revenues and expenditures of the government is public savings:

$$GSAV_t = GOVREV_t - GOVCON_t - GTRHH_t + \overline{TOTPEN}_t CPI_t - rf_t GFDS_t \quad (2.16)$$

where $GTRHH_t$ is the total welfare transfers, \overline{TOTPEN}_t is the real value of pension payments to households, rf_t is the foreign interest rate, and $GFDS_t$ is the debt stock, which grows by the level of government savings:

$$GFDS_{t+1} = GFDS_t - GSAV_t \quad (2.17)$$

The domestic interest rate, DR_t , is one of the main determinants of households' and firms' consumption and investment decisions, respectively.

$$DR_t = \left(1 - \pi_t \frac{GSAV_t}{GDP_t} \right) rf_t \quad (2.18)$$

where π_t is a positive parameter. Since $GSAV_T = 0$ holds, $DR_T = rf_T$ holds, where T is the terminal period and ensures no-arbitrage condition. In the model, only the government has a debt stock in the economy, and it can borrow from abroad as much as needed to keep its budget balanced. A higher borrowing requirement means that the government dissaves, i.e.

$GSAV_t < 0$, which makes the domestic interest rate higher than the foreign interest rate as the term in the parentheses is more than 1. In other words, higher government indebtedness increases the risk premium in the domestic market.

2.1.4 Labour Market

Net migration flow plays an important buffering role in the Irish labour market. An increase in the wage rate during an economic expansion attracts net migration into Ireland, which, in turn, enlarges the total labour supply and thus hinders further increases in the wage rate. Higher emigration decreases the total labour supply in an economic contraction, preventing larger wage rate declines and stabilising the unemployment rate. The labour market in the I3E model allows involuntary unemployment, international migration, and labour force participation of the Irish population to adjust endogenously to cover all of those aspects. The level of net migration is a function of the wage-income differential between Ireland and the rest of the world.

The model incorporates involuntary unemployment and international migration. Total net migration, $NMIG_t$, is a function of the per-employee real net-of-tax wage income differential between Ireland and the rest of the world as follows.¹⁰

$$NMIG_t = \zeta_{0,t} + \zeta_{1,t} (NWINC_t - \overline{NFWINC}_t ER_t) \quad (2.19)$$

where $NWINC_t$ and \overline{NFWINC}_t are the per-employee real net-of-tax wage income in Ireland and the rest of the world, respectively. The latter variable is exogenous and fixed in the model, whereas the former is calculated as follows.

$$NWINC_t = \frac{\sum_{hh} WINC_{hh,t}}{CPI_t \sum_{a,l} LD_{a,l,t}} \quad (2.20)$$

¹⁰Since the I3E model is a single country model, there is no distinction between the source country of migrants. In the related literature, the net migration to Ireland is modelled as a function of the relative employment and wages (Kearney, 1998), the wage rate and unemployment rate differentials (Bergin et al., 2013), and the real after-tax earning differential (Bergin et al., 2017) between Ireland and the UK.

where $LD_{a,l,t}$ is the demand of activity a for labour type l . The total net migration is disaggregated across labour types based on the calibrated share parameters ($\mu_{l,t}$) by using the Labour Force Survey (LFS). The $\mu_{l,t}$ takes values of 0.1108, 0.3808, and 0.5084 for low-, medium-, and high-skilled labour, respectively. In other words, half of the total net migration is constituted by high-skilled individuals.

The total labour supply of each type of labour is the sum of the net migration and the fraction of the Irish population participating in the labour market.

$$LSUP_{l,t} = \tau_{l,t} \overline{TPOP}_t + NMIGL_{l,t} \quad (2.21)$$

where $\tau_{l,t}$ is the labour force participation rate of labour type l and \overline{TPOP}_t is the total Irish population. The value of $\tau_{l,t}$ evolves as a function of the labour-type unemployment rate and net-of-tax real wage rate as follows.

$$\tau_{l,t} = \tau_{0,l,t} + \tau_{1,l,t} UNR_{l,t} + \tau_{2,l,t} \frac{W_{l,t} (1 - \text{tax}_{l,t})}{CPI_t BX_t} \quad (2.22)$$

where $\tau_{0,l,t}$ is the intercept term, $UNR_{l,t}$ is the unemployment rate of labour l , $W_{l,t}$ is the composite wage rate of labour l , $\tau_{1,l,t}$ (negative) and $\tau_{2,l,t}$ (positive) are parameters, and BX is the level of labour efficiency.

The level of unemployment, $UN_{l,t}$, is the difference between the total labour supply and the total labour demand stemming from the cost-minimisation problem of firms. The unemployment rate, $UNR_{l,t}$, for each type of labour is the number of unemployed divided by the total labour supply. Separate wage equations, eq. (2.23), relating the log of the wage rate to the log of the unemployment rate, determine the equilibrium wage rate for each type of labour.

$$\log \left(\frac{W_{l,t}}{CPI_t BX_t} \right) = \omega_{0,l,t} + \omega_{1,l,t} \log(UNR_{l,t}) \quad (2.23)$$

Each labour account solves a revenue maximisation problem to disaggregate their total employment across production activities. For each labour l , the supply of labour to sector a must equal sector a 's demand for labour l . This condition solves for the equilibrium sector-specific price of labour l ; $FP_{a,l,t}$.

This structure is important since it allows the model to mimic the changes in the sectoral composition of employment, especially due to an asymmetric shock across sectors, such as the COVID-19 crisis.

2.2 Scenarios

In this report, we run three scenarios, the results of which are provided as percentage deviations from the business-as-usual (*BaU*) path. Although the I3E model is calibrated to 2014, its *BaU* incorporates numerous changes affecting the Irish economy between 2014 and 2022.

These changes include the patterns of international energy prices, the price and free allowances of the EU ETS¹¹, the change in the composition of the electricity production across electricity-producing sectors¹², the increased level of the carbon tax from €20 to €41, and, finally, the COVID-19-related alterations in the demand, supply, and public balances in 2020 and 2021. The definition of *BaU* in this report refers to a growth path given the current structure of the Irish economy, including legislation, such as the carbon tax, currently in place. Though there is a government commitment to an increasing carbon tax trajectory, we do not include this in the *BaU*, but introduce the increased carbon taxation as a separate scenario to enable the investigation of its impacts on the Irish economy.

TABLE 2.1: SCENARIO DEFINITIONS

| Scenario | Definitions |
|----------|---|
| BaU | It includes all economic realisations between 2014 (the base year) and 2022. Along this path, the energy prices are constant at their end of 2021 levels, and the carbon tax and EU ETS prices are constant at €41 and €54, respectively. |
| HEP | Energy prices stay constant at their mid-2022 levels, the carbon tax and EU ETS prices are constant at €41 and €82, respectively. |
| CT | Energy prices stay constant at their mid-2022 levels, the carbon tax gradually increases to €100 in 2030, and the EU ETS price is constant at €82. |
| CT_ETS | Energy prices stay constant at their mid-2022 levels, the carbon tax gradually increases to €100 in 2030, and the EU ETS price gradually increases to €150 in 2030. |

¹¹ Free allowances have a declining trend as projected for Phase IV: 2020–2030 of the EU ETS.

¹² Renewable resources' share in the total electricity production increased from 25.3% in 2014 to 40% in 2021.

In the first scenario, *HEP*, the energy prices are set to their extremely high levels reached in mid-2022, the carbon tax is kept constant at €41, but the EU ETS price stays constant at its 2022 levels, which is €82, to quantify the impacts of higher international energy prices. In the second scenario, *CT*, the carbon tax gradually reaches €100 in 2030 (as committed by the government, [Department of the Taoiseach, 2020](#)), and stays constant until the end of the model horizon, i.e., 2054, in addition to high energy prices. In the third scenario, *CT_ETS*, in addition to the increased carbon tax and higher energy prices, the EU ETS price increases from €82 per tonne in 2022 to €150 in 2030. The scenarios are run under the assumption of *ceteris paribus*, which implies that all other policy variables are constant at their 2022 levels.

CHAPTER 3

Results

3.1 Macroeconomic Aggregates

Table 3.1 shows the macroeconomic results as percentage deviations from *BaU* in the respective year for all variables but the unemployment rate, which is the level difference from *BaU*. These figures show how much the level of each variable will deviate from its *BaU* level due to the change.

TABLE 3.1: MACROECONOMIC RESULTS OF MAIN SCENARIOS, % CHANGE W.R.T. BAU

| Year | Scenario | Economic Activity | | | | | Labour Market | | | Emissions | | |
|------|----------|-------------------|--------------------------|-------------------------|----------------------------|-------------------|------------------|------------------------|--------------------------------|-----------|-------|---------|
| | | GDP ^a | Consumption ^a | Investment ^a | Trade Balance-to-GDP Ratio | Debt-to-GDP Ratio | Total Employment | Mean Wage ^a | Unemployment Rate ^b | Total | ETS | Non-ETS |
| 2030 | HEP | -0.7 | -1.3 | -1.6 | 0.9 | 1.0 | -0.8 | -0.1 | 0.5 | -20.1 | -23.3 | -13.0 |
| | CT | -1.4 | -2.0 | -2.9 | 1.5 | 2.3 | -1.5 | -0.1 | 1.0 | -30.2 | -25.5 | -27.6 |
| | CT_ETS | -1.8 | -2.4 | -3.6 | 1.9 | 2.0 | -1.8 | -0.2 | 1.2 | -38.2 | -39.5 | -29.5 |
| 2040 | HEP | -0.9 | -1.6 | -1.6 | 1.5 | 2.8 | -0.9 | -0.1 | 0.5 | -20.6 | -25.0 | -13.0 |
| | CT | -1.7 | -2.6 | -2.9 | 2.2 | 4.3 | -1.6 | -0.2 | 1.0 | -31.5 | -27.6 | -28.3 |
| | CT_ETS | -2.1 | -3.1 | -3.6 | 2.9 | 4.6 | -1.9 | -0.3 | 1.2 | -39.7 | -43.1 | -30.3 |

a: In real terms.

b: Difference from *BaU*.

The higher international energy prices at their extremely high levels (the *HEP* scenario) result in a 0.7% decrease in economic activity measured by real GDP compared to lower energy prices along the *BaU* scenario. In line with the economic activity, investment expenditures of firms and consumption expenditures of households decrease by around 1.3% and 1.6%, respectively, in 2030. Import demand decreases due to the lower economic activity (the income effect) and international prices (the substitution effect), which leads to an improvement in trade balance as a fraction of GDP. The contraction in the domestic economic activity leads to public dissavings, increasing the

Irish government's debt stock-to-GDP ratio. The deterioration in the labour market indicators is in line with the overall economic activity. The reduction in the total CO₂ emissions stemming from the higher energy prices reaches 20.1% in 2030. The decline in the emissions subject to the EU ETS, the ETS emissions, is much larger than the reduction in the emissions subject to the Irish carbon tax, namely the non-ETS emissions. Note that the I3E model does not include agricultural non-combustion (methane) emissions; however, these make up a large share of Irish non-ETS emissions. Despite larger reductions in emissions along the *HEP* scenario in 2030, compared to their levels in the *BaU* scenario, the reductions in the cumulative total, ETS, and non-ETS emissions are 11.4%, 12.1%, and 7.5%, respectively. As international energy prices are constant from 2023 onwards, the size of the substitution effect becomes lower. The income effect, stemming from the exogenous labour productivity growth, governs the underlying dynamics and leads to lower reductions in emissions. The patterns in the emissions reductions are in line with other macroeconomic variables.

The increase in the carbon tax (the *CT* scenario) increases energy prices, which, in turn, increases the prices of other commodities due to the higher cost of production. Higher prices reduce firms' investment expenditures and households' private consumption expenditures. As a result, real GDP falls by 1.4% in 2030, compared to *BaU*, along which there is no increase in the tax. The effect of the higher carbon tax on investment expenditures is almost doubled compared to the constant carbon tax. Although the Irish government uses the raised carbon tax revenues to finance its expenditures, i.e. there is no specific recycling of the carbon tax revenues, the contracted economic activity deteriorates public fiscal balances more due to lower total government revenues. As a result, the debt-to-GDP ratio increases by around 2.3% in 2030. The reduction in public savings increases the differential between the foreign interest rate (only the government can borrow at this rate, a fixed variable in the model) and the domestic interest rate (which determines the intertemporal investment and consumption decisions of firms and households, respectively), as shown in eq. (2.18). Therefore, the negative impacts of the policy change on the public fiscal stance also increase the downward pressures on the investment and consumption expenditures and, thus, overall economic activity. On the other

hand, the improvement in trade balance and its ratio to GDP, compared to *CT*, lessens the adverse impacts of the much larger reductions coming from domestic expenditures. The labour market implications of the higher carbon tax are lower employment and higher unemployment rate, which are in line with the decline in economic activity, as well as common findings in the literature (e.g., Allan et al., 2014; Mayer et al., 2021). The higher carbon tax leads to a nearly ten percentage point (pp) further reduction in the total emissions, whereas its impact on the non-ETS emissions is around 15 pp. The cumulative levels of the total, ETS, and non-ETS emissions decrease by 15%, 13%, and 12%, respectively, compared to their cumulative levels in *BaU*.

When the increase in the carbon tax is accompanied by an increase in the EU ETS price (the *CT_ETS* scenario), the fall in real GDP is 1.8%. The reductions in private consumption and investment expenditures drive the decline in real GDP. Since the Irish government receives half of the EU ETS revenue due to legislation, the improved public savings lowers the debt-to-GDP ratio compared to the *CT* scenario, despite a larger decline in economic activity since the increase in the EU ETS price is quite steep. The decline in energy demand further reduces the import bill and increases the contribution of the net exports to real GDP. The decline in imported energy is compensated by domestic production as the higher EU ETS price shifts the composition of electricity production from the conventional production sector using imported fossil fuels (from 61% to 40%) to renewable resources between 2022 and 2030.¹³ The increase in the EU ETS price, along with high energy prices and an increased carbon tax, lowers ETS emissions by around 39% in 2030, compared to *BaU*. The reduction in the cumulative total, ETS, and non-ETS emissions reach 18%, 17%, and 13%, respectively, compared to the *BaU*.

The impacts of higher energy and carbon prices on household disposable income are in line with the changes in the overall economic activity.¹⁴ The distributional impacts are strictly progressive, i.e., the reduction in real disposable income increases as income increases. This is because the

¹³ A caveat of the study is that electricity producers using renewable resources are assumed to be sufficiently flexible to respond to the economic conditions and implicitly abstract from delays associated with the planning and legal systems.

¹⁴ As the focus of the report is on macroeconomic aggregates and production sectors, household-level impacts are not provided and discussed here in detail. The results are available upon request.

well-designed Irish welfare system compensates for adverse implications of the labour market outcomes and plays a cushioning role (Savage et al., 2019; Doorley et al., 2021; Yakut and de Bruin, 2023). Although the response of the Irish welfare system with respect to inflationary pressures, or cost-of-living crisis in general, is criticised for being ad hoc (PBO, 2021; CBO, 2022), the total budget of the welfare transfers in the I3E model is a positive function of both the consumer price index and the aggregate unemployment rate. As both variables increase in all scenarios, the total amount of welfare transfers, distributed across households in favour of poorer ones, also increases.

Dynamic CGE models converge to a new equilibrium after a shock is introduced. At the new equilibrium, economic agents tend not to change their decisions. This requires any adjustments in the model economy to be completed. In this analysis, the shocks introduced to prices are not completed until 2030. Therefore, the convergence to the new equilibrium continues after 2030. To assess whether this convergence displays new and different dynamics, results for the year 2040 have also been reported in Table 3.1. The results for 2040 are consistent with the results obtained for 2030. The economic contraction continues, with real GDP falling by 0.9%, 1.7%, and 2.1%, in the *HEP*, *CT* and *CT_ETS* scenarios, respectively. This contraction is once more reflected in private consumption expenditures, whereas there are small improvements in investment expenditures compared to the 2030 results. As investment expenditures drive capital accumulation, the slight improvement in these expenditures prevents a larger deterioration in the labour market outcome in 2040 compared to 2030. The improvement in the trade balance, primarily due to the economic contraction, is more pronounced. In the *CT_ETS* scenario, although the government still receives half of the EU ETS revenues, the increase in the debt-to-GDP ratio becomes larger than that of the *CT* scenario in 2040. By 2040, the reduction in total emissions reaches 20.6% in the *HEP* scenario. In the *CT* and *CT_ETS* scenarios, total emission reductions reach 32% and 40%, respectively, with the larger falls in ETS emissions driving the decrease. The cumulative emissions reductions in 2040 in the *CT_ETS* scenario, compared to *BaU* are 28%, 28%, and 21% in the total, ETS, and non-ETS emissions, respectively.

3.2 Sectoral Impacts

The results for the aggregated sectors and the manufacturing sub-sectors are presented in Table 3.2 and Table 3.3, respectively. The modelling of how firms internalise the costs of carbon pricing (carbon tax and EU ETS price) should be reiterated to better understand the sectoral impacts of policy changes. The Irish government exempts the sectoral emissions that fall under the EU ETS from paying the carbon tax to avoid double taxation. However, those firms subject to EU ETS pay the carbon tax when purchasing an energy commodity, as the retail prices include the carbon tax. In the I3E model, like all CGE models, all agents are price-takers, i.e., they pay the same retail price. However, we introduce two components (the so-called ETS and carbon tax adjusters as presented in eq. 2.13) to the optimality conditions of firms' (eq. 2.12) energy demand to differentiate the unit prices of energy commodities. These adjusters take different values for each sector and energy commodity depending on the EU ETS coverage of sectoral emissions, the sectoral free allowances-to-ETS emissions ratio, the levels of EU ETS price and carbon tax, and the carbon content of the energy commodity. The unit sector- and commodity-specific *incurred* cost of energy commodity is calculated by the retail price of commodity plus the ETS adjuster minus the carbon tax adjuster. These adjusters are zero if the sector is not subject to EU ETS, e.g., land transportation, mining, and construction, and it only pays the carbon tax.

TABLE 3.2: AGGREGATED SECTORAL RESULTS, % CHANGE W.R.T. BAU

| | | Sectoral Activity | | | | | | Emissions | | | | | | | | |
|------|----------------------|--------------------------|------|--------|------------|------|--------|-----------|-------|--------|-------|-------|--------|-------------|-------|--------|
| | | Value added ^a | | | Employment | | | Non-ETS | | | ETS | | | Cost of ETS | | |
| | | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS |
| 2030 | Total | -0.5 | -1.1 | -1.4 | -0.8 | -1.5 | -1.8 | -18.0 | -32.9 | -36.1 | -23.3 | -25.5 | -39.5 | 5.3 | 0.5 | 31.1 |
| | Agriculture | -0.4 | -0.8 | -0.9 | -1.0 | -1.8 | -2.1 | -14.5 | -31.6 | -32.9 | | | | | | |
| | Mining | -1.5 | -4.7 | -6.4 | -1.9 | -6.6 | -8.4 | -11.0 | -55.3 | -57.4 | | | | | | |
| | Construction | -0.7 | -1.5 | -1.7 | -1.0 | -2.0 | -2.3 | -15.9 | -33.5 | -34.9 | | | | | | |
| | Trade | -0.5 | -1.1 | -1.2 | -0.9 | -1.7 | -2.1 | -15.9 | -32.2 | -33.8 | | | | | | |
| | Financial Services | 0.0 | -0.4 | -0.3 | -0.5 | -1.2 | -1.3 | -18.4 | -34.2 | -36.0 | | | | | | |
| | Accomm. & Hotel Ser. | -0.3 | -0.6 | -0.7 | -0.5 | -0.9 | -1.0 | -15.1 | -31.1 | -32.4 | | | | | | |
| | Public Services | -1.2 | -1.7 | -2.1 | -0.8 | -1.4 | -1.6 | -16.1 | -32.1 | -33.5 | | | | | | |
| | Electricity | 3.3 | 1.2 | 3.7 | 1.0 | -1.1 | -0.1 | | | | -41.9 | -43.4 | -66.9 | -11.8 | -14.1 | -8.2 |
| | Manufacturing | -0.3 | -0.8 | -1.0 | -1.1 | -2.0 | -2.5 | -24.7 | -30.3 | -40.1 | -21.1 | -24.6 | -38.1 | 11.4 | 4.0 | 39.1 |
| | Transportation | -2.2 | -3.1 | -4.8 | -1.9 | -3.2 | -4.3 | -18.0 | -36.2 | -38.0 | -14.2 | -15.1 | -23.5 | 13.3 | 11.0 | 61.5 |
| | Services | -0.7 | -1.4 | -1.6 | -0.6 | -1.2 | -1.4 | -17.3 | -33.5 | -35.0 | -18.1 | -33.9 | -35.8 | 23.2 | -1.9 | 74.1 |
| 2040 | Total | -0.7 | -1.4 | -1.7 | -0.9 | -1.6 | -1.9 | -17.7 | -33.3 | -36.6 | -25.0 | -27.6 | -43.1 | 4.6 | -0.4 | 28.6 |
| | Agriculture | -0.8 | -1.5 | -1.7 | -1.0 | -1.9 | -2.2 | -14.2 | -32.0 | -33.2 | | | | | | |
| | Mining | -2.2 | -5.9 | -8.5 | -2.0 | -5.9 | -8.1 | -10.2 | -52.7 | -54.7 | | | | | | |
| | Construction | -0.8 | -1.6 | -1.8 | -0.9 | -1.8 | -2.1 | -15.6 | -33.7 | -35.0 | | | | | | |
| | Trade | -0.7 | -1.4 | -1.6 | -0.9 | -1.7 | -2.0 | -15.5 | -32.5 | -34.0 | | | | | | |
| | Financial Services | -0.1 | -0.6 | -0.5 | -0.4 | -1.1 | -1.1 | -17.9 | -34.5 | -36.2 | | | | | | |
| | Accomm. & Hotel Ser. | -0.5 | -0.9 | -1.1 | -0.6 | -1.1 | -1.3 | -15.0 | -31.7 | -33.0 | | | | | | |
| | Public Services | -1.3 | -1.9 | -2.4 | -1.1 | -1.7 | -2.0 | -16.1 | -32.8 | -34.3 | | | | | | |
| | Electricity | 5.1 | 2.4 | 6.0 | -0.3 | -2.5 | -3.5 | | | | -49.0 | -50.7 | -75.4 | -22.5 | -25.2 | -31.8 |
| | Manufacturing | -0.6 | -1.2 | -1.6 | -1.1 | -1.9 | -2.5 | -24.4 | -30.6 | -41.6 | -21.6 | -25.6 | -40.5 | 11.5 | 4.0 | 39.1 |
| | Transportation | -2.8 | -4.0 | -6.3 | -1.9 | -3.3 | -4.4 | -17.7 | -36.7 | -38.5 | -15.8 | -16.9 | -27.7 | 16.2 | 13.7 | 63.3 |
| | Services | -0.8 | -1.5 | -1.8 | -0.7 | -1.4 | -1.6 | -17.1 | -34.0 | -35.7 | -18.1 | -34.7 | -36.7 | 23.5 | -2.5 | 72.6 |

a: In real terms.

Higher international energy prices in the *HEP* scenario, compared to *BaU*, lower the aggregate real value added and employment by 0.5% and 0.8%, respectively, in 2030. The total sectoral non-ETS¹⁵ and ETS emissions decrease by 18% and 23%, respectively, and the total cost of the ETS increases by 5.3%. The sector-specific results show that only the aggregate electricity production sector is positively affected. Although the cost of electricity production by the conventional electricity production sector increases due to higher energy prices, the electricity mix across sectors shifts towards the wind and other renewable sectors. Despite the decline in demand for all energy commodities, including electricity, the sectoral shift triggers the investment expenditures of the wind and other renewable resources sector, increasing the aggregate value added. This is also reflected by the substantial reduction in the sectoral emissions, which are entirely subject to the EU ETS.

All energy prices increase, but the change in peat price is negligible as it is not subject to international trade and is unaffected by international prices. Therefore, the reduction in its demand is also negligible in the *HEP* scenario, compared to *BaU*, but the reduction in the mining sector's value added is the second-highest as the sector's main output is peat. The reductions in the sectoral non-ETS emissions are the highest for the manufacturing sector. As evident in Table 3.3, all sectors but the petroleum sector, of which all emissions are subject to EU ETS, are affected negatively, and their non-ETS emissions decline substantially. The petroleum sector is affected positively due to the price differential between crude oil and oil-related products, e.g., diesel, gasoline, and kerosene. As the prices of oil-related products are higher in international markets than crude oil, their import demand declines more, which triggers domestic production.

The increase in the carbon tax lowers the real value added and employment in all aggregated sectors (Table 3.2), and the mining and transportation sectors are hit the hardest. In addition to higher international energy prices, which increase the cost of import, the reduction in the output of energy production sectors, e.g., petroleum and natural gas supply within manufacturing (Table 3.3), increases domestic energy prices even more than

¹⁵ Household emissions, including residential and private transportation-related emissions, and government emissions constitute other non-ETS emissions.

just the impact of the higher carbon tax. The higher carbon tax lowers the demand for all energy commodities, but the impact on coal (not produced in Ireland) is substantially higher than other energy commodities. Even though the electricity production sector does not pay the carbon tax, the additional impact of the taxation is second-highest (the difference between the *CT* and *HEP* scenarios) as the increase in energy prices lowers the demand for energy commodities. The land transportation sector mainly drives the results for the aggregate transportation sector since aviation does not pay the carbon tax, which is also reflected in the non-ETS emissions (its reduction is doubled in the *CT* scenario compared to the *HEP* scenario) and a very limited further reduction in the ETS emissions of the aggregate transportation sector. The impacts of the higher carbon tax on sectoral non-ETS emissions are in line with the sectoral economic impacts.

The higher carbon tax hit the natural gas supply, other non-metallic products, basic metals, wood and wood products, and rubber and plastic sectors the hardest across manufacturing sectors, compared to *BaU*, Table 3.3. The additional cost stemming from the higher carbon tax (the difference between the *CT* and *HEP* scenarios) affects the natural gas supply sector the most. The petroleum sector's real value added still experiences an increase, compared to *BaU*, but the higher carbon tax reduces it by around 5 pp.

The increase in the EU ETS price, the *CT_ETs* scenario, lowers the total ETS emissions by around 40%, and the total cost of the scheme for the Irish firms increases by 31% in 2030, compared to *BaU*. Among the aggregate sectors subject to EU ETS, the transportation sector (driven by the contraction in the aviation sector) is hit the hardest. The cost of EU ETS decreases for the electricity production sector for two reasons. First, the lower share of fossil fuels in electricity production lowers the output level in the conventional electricity production sector, which has to buy allowances from the EU ETS market to cover all its emissions as it has zero free allowances. Secondly, the current version of the model does not allow other sectors to switch from fossil fuels to renewable energy resources, e.g., biomass, biodiesel, and renewable waste. As Ireland increases its use of renewable resources in electricity production, firms can switch to electricity, which lowers sectoral and, thus, economy-wide emissions. However, as the required investment expenditures to ensure the transition in electricity production are financed

by electricity producers through retained earnings, the higher share of renewable resources does not lead to lower electricity prices. Therefore, non-electricity producers do not pay the cost of their energy system transition to low-carbon options but pay the cost of the transition in electricity production. It should be noted that the scenario includes assumptions neither on the share of renewable resources nor the level of required investment. The model endogenously responds to the policy shock considered (along with other assumptions imposed, e.g., the COVID-19 impacts, etc.), and the level of investment expenditures made by electricity producers may not be equal to the level envisaged by the authorities or energy companies. The 21 pp increase in the share of renewable resources in electricity production positively affects the aggregate electricity production sector through higher investment expenditures of the wind and other renewable sectors and also hinders the decline in the aggregate investment expenditures. The transition in electricity production also lessens the negative employment impact of the *CT* scenario while reducing the sector's emissions substantially by around 67%, compared to *BaU*.

TABLE 3.3: MANUFACTURING SECTORS RESULTS, % CHANGE W.R.T. BAU

| | | Sectoral Activity | | | | | | Emissions | | | | | | | | |
|--------------------|----------------------------|--------------------------|-------|--------|------------|------|--------|-----------|-------|--------|-------|-------|--------|-------------|-------|--------|
| | | Value added ^a | | | Employment | | | Non-ETS | | | ETS | | | Cost of ETS | | |
| | | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS | HEP | CT | CT_ETS |
| 2030 | Food, Bev. and Tobacco | -0.6 | -1.0 | -1.1 | -1.1 | -2.0 | -2.4 | -25.6 | -29.2 | -42.6 | -25.6 | -29.2 | -42.6 | 8.3 | 2.2 | 45.4 |
| | Textile | -0.8 | -1.4 | -1.7 | -1.1 | -2.0 | -2.4 | -18.1 | -32.3 | -34.8 | | | | | | |
| | Wood and Wood Prod. | -1.6 | -2.7 | -3.4 | -1.7 | -3.0 | -3.7 | -16.3 | -31.0 | -33.4 | | | | | | |
| | Other Industrial Prod. | -0.6 | -1.2 | -1.4 | -0.9 | -1.7 | -2.0 | -17.8 | -33.5 | -35.4 | | | | | | |
| | Petroleum | 6.0 | 1.1 | -2.5 | 4.6 | -0.3 | -3.8 | | | | -13.6 | -20.5 | -36.7 | 28.1 | 16.0 | 60.5 |
| | Other Manufacturing | -1.5 | -2.0 | -2.7 | -1.8 | -2.7 | -3.7 | -28.9 | -32.2 | -47.6 | -28.9 | -32.2 | -47.6 | 6.2 | 1.0 | 40.2 |
| | Chemical Prod. | 0.3 | 0.2 | 0.5 | -0.5 | -1.1 | -1.2 | -25.6 | -28.5 | -42.6 | -25.6 | -28.5 | -42.6 | 10.2 | 5.5 | 51.2 |
| | Basic Pharmaceutical Prod. | 0.4 | 0.4 | 0.8 | -0.3 | -0.9 | -0.9 | -18.7 | -21.6 | -19.9 | -18.7 | -21.6 | -19.9 | 68.1 | 100.3 | 231.2 |
| | Rubber and Plastic Prod. | -1.5 | -2.5 | -2.9 | -1.7 | -2.9 | -3.5 | -15.6 | -33.3 | -34.7 | | | | | | |
| | Other Non-metallic Prod. | -3.3 | -3.8 | -8.6 | -3.3 | -4.0 | -8.8 | -17.8 | -19.0 | -28.3 | -7.9 | -8.5 | -17.0 | 27.3 | 25.4 | 81.3 |
| | Basic Metals | -3.8 | -3.7 | -6.6 | -4.3 | -5.2 | -6.9 | -29.4 | -32.6 | -39.6 | -29.4 | -32.6 | -39.6 | -5.5 | -17.0 | 6.3 |
| | High-Tech Prod. | -0.2 | -0.6 | -0.7 | -0.7 | -1.4 | -1.6 | -24.2 | -27.0 | -40.8 | -24.2 | -27.0 | -40.8 | 13.3 | 8.8 | 58.7 |
| | Transportation Equipment | -0.9 | -1.7 | -2.0 | -1.1 | -2.0 | -2.4 | -15.3 | -30.3 | -32.2 | | | | | | |
| | Natural Gas Supply | -1.9 | -8.4 | -15.8 | -2.0 | -8.5 | -15.7 | | | | -33.4 | -40.4 | -64.3 | 1.1 | -9.4 | -0.8 |
| Water and Sewerage | -1.5 | -2.3 | -3.1 | -0.6 | -1.2 | -1.4 | -15.1 | -30.5 | -32.1 | | | | | | | |
| 2040 | Food, Bev. and Tobacco | -0.9 | -1.6 | -1.8 | -1.1 | -2.0 | -2.4 | -25.9 | -29.9 | -44.2 | -25.9 | -29.9 | -44.2 | 9.5 | 2.9 | 45.6 |
| | Textile | -1.0 | -1.7 | -2.0 | -1.0 | -2.0 | -2.3 | -17.4 | -32.4 | -34.7 | | | | | | |
| | Wood and Wood Prod. | -1.7 | -3.0 | -3.6 | -1.6 | -2.8 | -3.4 | -15.4 | -30.9 | -32.8 | | | | | | |
| | Other Industrial Prod. | -0.8 | -1.4 | -1.7 | -0.9 | -1.7 | -2.0 | -17.4 | -33.8 | -35.6 | | | | | | |
| | Petroleum | 7.1 | 0.3 | -4.6 | 4.7 | -0.7 | -4.5 | | | | -13.9 | -21.6 | -38.9 | 28.5 | 15.5 | 58.2 |
| | Other Manufacturing | -2.1 | -2.7 | -3.9 | -1.9 | -2.8 | -3.8 | -29.0 | -32.8 | -48.8 | -29.0 | -32.8 | -48.8 | 6.5 | 0.5 | 38.3 |
| | Chemical Prod. | 0.1 | 0.0 | 0.3 | -0.4 | -1.0 | -1.0 | -25.6 | -28.9 | -43.4 | -25.6 | -28.9 | -43.4 | 11.0 | 5.7 | 51.0 |
| | Basic Pharmaceutical Prod. | 0.3 | 0.3 | 0.7 | -0.2 | -0.7 | -0.6 | -17.4 | -20.8 | -22.5 | -17.4 | -20.8 | -22.5 | -71.2 | -95.2 | -113.0 |
| | Rubber and Plastic Prod. | -1.7 | -2.9 | -3.5 | -1.6 | -2.9 | -3.4 | -14.9 | -33.4 | -34.5 | | | | | | |
| | Other Non-metallic Prod. | -4.4 | -4.9 | -11.9 | -3.9 | -4.6 | -10.7 | -20.7 | -22.0 | -34.9 | -9.4 | -10.0 | -21.1 | 28.5 | 26.9 | 81.8 |
| | Basic Metals | -4.6 | -5.2 | -7.7 | -4.1 | -5.2 | -6.9 | -27.9 | -31.9 | -41.2 | -27.9 | -31.9 | -41.2 | -14.5 | -24.0 | -1.3 |
| | High-Tech Prod. | -0.4 | -0.8 | -0.9 | -0.6 | -1.3 | -1.4 | -23.8 | -27.1 | -41.1 | -23.8 | -27.1 | -41.1 | 14.3 | 9.2 | 59.2 |
| | Transportation Equipment | -1.0 | -1.8 | -2.2 | -1.0 | -1.9 | -2.2 | -14.6 | -30.3 | -31.9 | | | | | | |
| | Natural Gas Supply | -2.9 | -11.9 | -21.5 | -2.2 | -9.0 | -16.1 | | | | -33.8 | -41.4 | -65.2 | 0.6 | -10.9 | -3.5 |
| Water and Sewerage | -1.4 | -2.2 | -2.8 | -0.7 | -1.3 | -1.6 | -14.9 | -31.0 | -32.5 | | | | | | | |

a: In real terms.

In the *CT_ETS* scenario, the gradually increasing EU ETS price amplifies the cost of production in the sectors subject to the EU ETS. Compared to *BaU*, the impacts are the highest in the natural gas supply, followed by other non-metallic minerals and basic metals sectors (Table 3.3). Since the ETS emissions of a sector are a fixed fraction of its total emissions from the combustion of fossil fuels, the percentage changes in the sub-sectoral ETS and non-ETS emissions in Table 3.3 are the same. The exception is the other non-metallic products sector, which has, in addition to combustion emissions, process emissions that are linked to the level of sectoral output. The cost of EU ETS decreases in the *HEP* and *CT* scenarios for the basic metals sector. In eq. (2.13), the variable *AtoT*, the free allowances-to-emissions ratio, increases for the exogenous free allowances with a decline in emissions. As it increases, it reduces the additional cost of EU ETS in eq. (2.12). The cost reduces more in the *CT* scenario than the *HEP* scenario because the increase in the carbon tax increases the carbon tax rebates received by the firm, which further reduces the unit *incurred* cost of energy commodities, and, thus the cost of EU ETS. In the *CT_ETS* scenario, however, the increase in the EU ETS price suppresses the impact of the decline in the *AtoT* and the cost of the scheme increases.

The presented outcomes are observed in 2040 as well. The aggregated sectoral results in Table 3.2 confirm that the contraction in the economy continues in 2040. Once more, the contraction is led by the mining and transportation sectors. As expected, these sectors also account for the largest percentage of emissions falls. The aggregate electricity sector's ETS cost declines due to the decline in the use of fossil fuels in electricity production; the share of electricity production from renewable resources exceeds 70% in 2040. Within the manufacturing sector, the natural gas supply, other non-metallic products, and basic metals sectors are the most adversely affected in terms of value added and employment.

CHAPTER 4

Conclusion

The transition to a low-carbon economy is crucial in lowering energy-related emissions to reach the targets set by environmental legislation. The transition requires all economic agents to switch from fossil fuels to renewable energy resources. This switching can be accomplished by replacing all combustion systems currently in use, which requires a huge amount of investment. However, avoiding undertaking the necessary actions would result in not only keeping the level of emissions higher but also having a cost, especially when carbon prices have increasing trends with substantial volatility with unexpected spikes in energy prices.

This report investigates the implications of higher energy and carbon prices under the assumption of no further policy intervention and, thus, attempts to present a picture of the cost of not moving towards a low-carbon economy. The analysis utilises an intertemporal computable general equilibrium model, namely the Ireland Environment-Energy-Economy (I3E). Given the peak energy prices observed in 2022, three scenarios are considered. The first scenario, *HEP*, includes the spikes in international energy prices and the EU ETS price to quantify the effects of the price shock in international markets. The second scenario, *CT*, includes only the increases in the carbon tax until 2030 to show how reaching the carbon tax target would affect the Irish production sectors in addition to higher energy prices. The third scenario, *CT_ETS*, examines the implications of gradually increasing the EU ETS price when energy prices and the Irish carbon tax are higher. The results for basic macroeconomic aggregates, the aggregate production sectors, and manufacturing sub-sectors are discussed. As the main focus of the report is the production sectors, the distributional implications of higher energy and carbon prices across households are briefly discussed, but their details are available upon request.

The external energy and carbon pricing shock adversely affects the Irish economy such that real gross domestic product (GDP), investment and consumption expenditures decline, and labour market outcomes

deteriorate. The only positively affected macroeconomic aggregate is the trade balance, which results from both the economic contraction (the reduction in import demand, i.e., the income effect) and the lower energy bill. The reduced economic activity leads to reduced emissions. Also, with a shrinking economy, government revenues decrease, and the government debt burden increases.

The higher carbon price in the *CT* and *CT_ETS* scenarios amplifies the negative implications of higher energy prices on macroeconomic aggregates. The *CT_ETS* scenario differs regarding its result on the government debt stock, which increases less than in the other two scenarios as the government reclaims half of the ETS revenue. The positive contribution of the higher EU ETS price in the short run, however, vanishes in the medium run as the decline in economic activity suppresses the EU ETS impact. The higher EU ETS price generates higher reductions in total emissions despite lower reductions in non-ETS emissions.

The brunt of the economic contraction is borne by the mining and transportation sectors, with substantially higher falls in real value added and employment. The electricity sector is positively affected in all scenarios due to the increased production in the wind and other renewable sectors. The positive impact is the lowest in the *CT* scenario as there is a substantial reduction in energy demand. The positive impact is the highest if the EU ETS price increases as electricity production shifts to renewable sources such that their share increases from 40% to 70%. These three sectors also account for high emission reductions. Within the manufacturing sector, the petroleum and natural gas supply sectors are hit the hardest. The carbon tax and the EU ETS price changes are assumed to end by 2030, but the model is run for a longer time horizon. An overview of the results for 2040 reveals that the core results closely follow those in 2030.

The cost of **not** transitioning to a low-carbon economy quantified in the report should be considered as the upper-end results as they are based on the assumption that energy prices will stay constant at their extremely high levels and firms will keep their current composition of energy demand across commodities. Although the current prices are substantially lower than their assumed levels in the analyses, the report provides important insights

regarding the economic costs of a sudden increase in energy prices without necessary actions to ensure the transition. The results show that becoming a low-carbon economy will not only help mitigate the adverse impacts of climate change but also make the Irish economy more resilient against an external energy price shock. The transition will also lower Ireland's dependency on imported energy commodities and improve the country's energy self-sufficiency.

One of the main concerns raised in the literature regarding the policy design is to ensure the transition without affecting certain agents, e.g., poorer households and small-size firms, more adversely than others. In other words, the target is ensuring the *just* transition. The I3E model is not capable of differentiating firms operating in a sector regarding their size as it works, like all CGE models, based on the representative agent assumption. Since the sectors subject to the EU ETS have large firms, a higher EU ETS price can generate relatively uniform effects across sectors and firms within a sector. In the case of the sectors subject to the Irish carbon tax, on the other hand, the impact of a higher level of tax can be heterogeneous across not only sectors but also firms operating in the same sector. Conducting such an analysis requires utilising a firm-level data set and model.

References

- Allan, G., Lecca, P., McGregor, P., and Swales, K. (2014). The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. *Ecological Economics*, 100, 40-50. doi: <https://doi.org/10.1016/j.ecolecon.2014.01.012>
- Aydin, L., and Acar, M. (2011). Economic impact of oil price shocks on the Turkish economy in the coming decades: A dynamic CGE analysis. *Energy Policy*, 39(3), 1722-1731. doi: <https://doi.org/10.1016/j.enpol.2010.12.051>
- Beck, M., Rivers, N., Wiglea, R., and Yonezawa, H. (2015). Carbon Tax and Revenue Recycling: Impacts on Households in British Columbia. *Resource and Energy Economics*, 41, 40-69. doi: <https://doi.org/10.1016/j.reseneeco.2015.04.005>
- Benavente, J. M. G. (2016). Impact of a carbon tax on the Chilean economy: A computable general equilibrium analysis. *Energy Economics*, 57, 106-127. doi: <https://doi.org/10.1016/j.eneco.2016.04.014>
- Bergin, A., Conefrey, T., FitzGerald, J., Kearney, I., and Žnuderl, N. (2013). *The HERMES-13 Macroeconomic Model of the Irish Economy* (Working Paper No. 460). Economic and Social Research Institute (ESRI). <https://www.esri.ie/publications/the-hermes-13-macroeconomic-model-of-the-irish-economy>.
- Bergin, A., Conroy, N., Rodriguez, A. G., Holland, D., McNerney, N., Morgenroth, E. L., and Smith, D. (2017). *COSMO: A new COre Structural MOdel for Ireland* (ESRI Working Paper No. 553).
- Berk, I., and Yetkiner, H. (2014). Energy prices and economic growth in the long run: Theory and evidence. *Renewable and Sustainable Energy Reviews*, 36, 228-235. doi: <https://doi.org/10.1016/j.rser.2014.04.051>
- Böhringer, C., Garcia-Muros, X., and González-Eguino, M. (2019). Greener and Fairer: A Progressive Environmental Tax Reform for Spain. *Economics of Energy & Environmental Policy*, 8(2), 141-160. doi: <https://doi.org/10.5547/2160-5890.8.2.cbh>
- Cabalu, H., Koshy, P., Corong, E., Rodriguez, U.-P. E., and Endriga, B. A. (2015). Modelling the impact of energy policies on the Philippine economy: Carbon tax, energy efficiency, and changes in the energy mix. *Economic Analysis and Policy*, 48, 222-237. doi: <https://doi.org/10.1016/j.eap.2015.11.014>
- Calderón, S., Alvarez, A. C., Loboguerrero, A. M., Arango, S., Calvin, K., Kober, T., ... Fisher-Vanden, K. (2016). Achieving CO₂ reductions in Colombia: Effects of carbon taxes and abatement targets. *Energy Economics*, 56, 575-586. doi: <https://doi.org/10.1016/j.eneco.2015.05.010>
- Campiglio, E. (2016). Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. *Ecological Economics*, 121, 220-230. doi: <https://doi.org/10.1016/j.ecolecon.2015.03.020>
- Caron, J., Cole, J., Goettle, R., Onda, C., Mcfarland, J., and Woollacott, J. (2018). Distributional implications of a national CO₂ tax in the U.S. across income classes and regions: a multi-model overview. *Climate Change Economics*, 9(01), 1840004. doi: <https://doi.org/10.1142/S2010007818400043>

- Choi, Y., Liu, Y., and Lee, H. (2017). The economy impacts of Korean ETS with an emphasis on sectoral coverage based on a CGE approach. *Energy Policy*, 109, 835-844. doi: <https://doi.org/10.1016/j.enpol.2017.06.039>
- Committee on Budgetary Oversight. (2022). *Report on indexation of the taxation and social protection system* (CBO Committee Report). Houses of the Oireachtas.
- de Bruin, K. C., Monaghan, E., and Yakut, A. M. (2020). *The use of the I3E model in macroeconomic analysis for the Irish economy* (Working Paper, No. 679). Economic and Social Research Institute (ESRI). <https://www.esri.ie/publications/the-use-of-the-i3e-model-in-macroeconomic-analysis-for-the-irish-economy>.
- de Bruin, K. C., and Yakut, A. M. (2021a). *Construction of the Energy Social Accounting Matrix for Ireland, v2.0* (ESRI Survey and Statistical Report Series No. 108). Economic and Social Research Institute (ESRI). doi: <https://doi.org/10.26504/sustat108>
- de Bruin, K. C., and Yakut, A. M. (2021b). *Technical Documentation of the I3E Model, v4.0* (ESRI Survey and Statistical Report Series No. 109). Economic and Social Research Institute (ESRI). doi: <https://doi.org/10.26504/sustat109>
- de Bruin, K. C., and Yakut, A. M. (2024). Efficiency-Equity Trade-off in the Irish Carbon Tax: A CGE Investigation of Mixed Revenue Recycling Schemes. *Economic Modelling*, 134, 106705. doi: <https://doi.org/10.1016/j.econmod.2024.106705>
- Department of the Taoiseach. (2020). *Programme for Government: Our Shared Future*. <https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/>.
- Doorley, K., Callan, T., and Savage, M. (2021). What drove income inequality in EU crisis countries during the Great Recession? *Fiscal Studies*, 42(2), 319-343. doi: <https://doi.org/10.1111/1475-5890.12250>
- Doroodian, K., and Boyd, R. (2003). The linkage between oil price shocks and economic growth with inflation in the presence of technological advances: a CGE model. *Energy Policy*, 31(10), 989-1006. doi: [https://doi.org/10.1016/S0301-4215\(02\)00141-6](https://doi.org/10.1016/S0301-4215(02)00141-6)
- Dybczak, K., Vonka, D., and van der Windt, N. (2008, December). *The Effect of Oil Price Shocks on the Czech Economy* (Working Papers No. 2008/5). Czech National Bank. Retrieved from <https://ideas.repec.org/p/cnb/wpaper/2008-5.html>
- Environmental Protection Agency (EPA). (2018). *Who needs a Permit?* <https://www.epa.ie/climate/emissionstradingoverview/etscheme/etsi/>.
- Freire-González, J. (2018). Environmental taxation and the double dividend hypothesis in CGE modelling literature: A critical review. *Journal of Policy Modeling*, 40, 194-223. doi: <https://doi.org/10.1016/j.jpolmod.2017.11.002>
- Freire-González, J., and Ho, M. S. (2019). Carbon Taxes and the Double Dividend Hypothesis in a Recursive-dynamic CGE Model for Spain. *Economic Systems Research*, 31, 267-284. doi: <https://doi.org/10.1080/09535314.2019.1568969>
- Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., and Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, 24, 38-50. doi: <https://doi.org/10.1016/j.esr.2019.01.006>

- Gros, D., Lane, P. R., Langfield, S., Matikainen, S., Pagano, M., Schoenmaker, D., and Suarez, J. (2016). *Too late, too sudden: Transition to a low-carbon economy and systemic risk* (Reports of the Advisory Scientific Committee No. 6). doi: <https://doi.org/10.2849/703620>
- Haas, C., Jahns, H., Kempa, K., and Moslener, U. (2023). Deep uncertainty and the transition to a low-carbon economy. *Energy Research & Social Science*, 100, 103060. doi: <https://doi.org/10.1016/j.erss.2023.103060>
- Hayashi, F. (1982). Tobin's Marginal q and Average q: A Neoclassical Interpretation. *Econometrica*, 50(1), 213-224.
- He, Y., Zhang, S., Yang, L., Wang, Y., and Wang, J. (2010). Economic analysis of coal price–electricity price adjustment in China based on the CGE model. *Energy Policy*, 38(11), 6629-6637. doi: <https://doi.org/10.1016/j.enpol.2010.06.033>
- Huntington, H., and Liddle, B. (2022). How energy prices shape OECD economic growth: Panel evidence from multiple decades. *Energy Economics*, 111, 106082. doi: <https://doi.org/10.1016/j.eneco.2022.106082>
- Kearney, I. (1998). *Is There A Stable Migration Equation For Ireland?* (Working Paper No. 97). Economic and Social Research Institute (ESRI). <https://www.esri.ie/publications/is-there-a-stable-migration-equation-for-ireland>.
- Köppl, A., and Schratzenstaller, M. (2022). Carbon taxation: A review of the empirical literature. *Journal of Economic Surveys*, 1-36. doi: <https://doi.org/10.1111/joes.12531>
- Landis, F. (2019). Cost Distribution and Equity of Climate Policy in Switzerland. *Swiss Journal of Economics and Statistics*, 155(11). doi: <https://doi.org/10.1186/s41937-019-0038-2>
- Lin, B., and Jia, Z. (2018). The Energy, Environmental and Economic Impacts of Carbon Tax Rate and Taxation Industry: A CGE Based Study in China. *Energy*, 159, 558-568. doi: <https://doi.org/10.1016/j.energy.2018.06.167>
- Linnenluecke, M. K., Han, J., Pan, Z., and Smith, T. (2019). How markets will drive the transition to a low carbon economy. *Economic Modelling*, 77, 42-54. doi: <https://doi.org/10.1016/j.econmod.2018.07.010>
- Liu, Y., Tan, X.-J., Yu, Y., and Qi, S.-Z. (2017). Assessment of impacts of Hubei Pilot emission trading schemes in China – A CGE-analysis using TermCO2 model. *Applied Energy*, 189, 762-769. doi: <https://doi.org/10.1016/j.apenergy.2016.05.085>
- Manzoor, D., Shahmoradi, A., and Haqiqi, I. (2012). An analysis of energy price reform: a CGE approach. *OPEC Energy Review*, 36(1), 35-54. doi: <https://doi.org/10.1111/j.1753-0237.2011.00200.x>
- Martin, R., Muûls, M., and Wagner, U. (2016). The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years? *Review of Environmental Economics and Policy*, 10(1), 129-148. Retrieved from <https://EconPapers.repec.org/RePEc:oup:renvpo:v:10:y:2016:i:1:p:129-148>.
- Martinsen, D., Krey, V., and Markewitz, P. (2007). Implications of high energy prices for energy system and emissions—The response from an energy model for Germany. *Energy Policy*, 35(9), 4504-4515. doi: <https://doi.org/10.1016/j.enpol.2007.03.003>

- Maxim, M. R., Zander, K. K., and Patuelli, R. (2019). Green Tax Reform and Employment Double Dividend in European and Non-European Countries: A Meta-Regression Assessment. *International Journal of Energy Economics and Policy*, 9(4), 342-355. doi: <https://doi.org/10.32479/ijeeep.7776>
- Mayer, J., Dugan, A., Bachner, G., and Steininger, K. W. (2021). Is carbon pricing regressive? Insights from a recursive-dynamic CGE analysis with heterogeneous households for Austria. *Energy Economics*, 104, 105661. doi: <https://doi.org/10.1016/j.eneco.2021.105661>
- McCollum, D., Nagai, Y., Riahi, K., Marangoni, G., Calvin, K., Pietzcker, R., . . . van der Zwaan, B. (2013). Energy Investments Under Climate Policy: A Comparison Of Global Models. *Climate Change Economics (CCE)*, 4(04), 1-37. doi: <https://doi.org/10.1142/S2010007813400101>
- Meng, S., Siriwardana, M., McNeill, J., and Nelson, T. (2018). The impact of an ETS on the Australian energy sector: An integrated CGE and electricity modelling approach. *Energy Economics*, 69, 213-224. doi: <https://doi.org/10.1016/j.eneco.2017.11.017>
- Nong, D., Nguyen, T. H., Wang, C., and Van Khuc, Q. (2020). The environmental and economic impact of the emissions trading scheme (ETS) in Vietnam. *Energy Policy*, 140, 111362. doi: <https://doi.org/10.1016/j.enpol.2020.111362>
- Nordhaus, W. (2011). Designing a friendly space for technological change to slow global warming. *Energy Economics*, 33(4), 665-673. doi: <https://doi.org/10.1016/j.eneco.2010.08.005>
- OECD/IEA/NEA/ITF. (2015). *Aligning Policies for a Low-carbon Economy*. OECD Publishing. doi: <https://doi.org/10.1787/9789264233294-en>
- Parliamentary Budget Office (PBO). (2021). *Social Welfare Rate Changes 2011-2022*. https://data.oireachtas.ie/ie/oireachtas/parliamentaryBudgetOffice/2021/2021-12-09_social-welfare-rate-changes-2011-2022_en.pdf.
- Parry, I. W., and Mylonas, V. (2017). Canada's Carbon Price Floor. *National Tax Journal*, 70(4), 879-900. doi: <https://doi.org/10.17310/ntj.2017.4.09>
- Peake, S., and Ekins, P. (2017). Exploring the financial and investment implications of the Paris Agreement. *Climate Policy*, 17(7), 832-852. doi: <https://doi.org/10.1080/14693062.2016.1258633>
- Przekota, G. (2022). Do High Fuel Prices Pose an Obstacle to Economic Growth? A Study for Poland. *Energies*, 15(18). doi: <https://doi.org/10.3390/en15186606>
- Punzi, M. T. (2019). The impact of energy price uncertainty on macroeconomic variables. *Energy Policy*, 129, 1306-1319. doi: <https://doi.org/10.1016/j.enpol.2019.03.015>
- Rivera, G. L., Reynès, F., Cortes, I. I., Bellocq, F.-X., and Grazi, F. (2016). Towards a low carbon growth in Mexico: Is a double dividend possible? A dynamic general equilibrium assessment. *Energy Policy*, 96, 314-327. doi: <https://doi.org/10.1016/j.enpol.2016.06.012>
- Rokicki, B., de Souza, K., and Ribeiro, L. C. (2023, 12). Modelling the Effects of the EU Emissions Trading System in Poland: A Comparison Between IO And CGE Results. *Journal of Regional Analysis and Policy*, 53, 54-69. doi: <https://doi.org/10.22004/ag.econ.339977>

- Sajeewani, D., Siriwardana, M., and McNeill, J. (2015). Household Distributional and Revenue Recycling Effects of the Carbon Price in Australia. *Climate Change Economics*, 6(3), 1550012. doi: <https://doi.org/10.1142/S2010007815500128>
- Saraji, M. K., and Streimikiene, D. (2023). Challenges to the low carbon energy transition: A systematic literature review and research agenda. *Energy Strategy Reviews*, 49, 101163. doi: <https://doi.org/10.1016/j.esr.2023.101163>
- Savage, M., Callan, T., Nolan, B., and Colgan, B. (2019). The Great Recession, Austerity and Inequality: Lessons from Ireland. *Review of Income and Wealth*, 65(2), 312-336. doi: <https://doi.org/https://doi.org/10.1111/roiw.12337>
- Sovacool, B. K. (2013). Energy policymaking in Denmark: Implications for global energy security and sustainability. *Energy Policy*, 61, 829-839. doi: <https://doi.org/10.1016/j.enpol.2013.06.106>
- Stern, N. (2015). *Why Are We Waiting?: The Logic, Urgency, and Promise of Tackling Climate Change*. The MIT Press. doi: <https://doi.org/10.7551/mitpress/10408.001.0001>
- Takeda, S., and Arimura, T. (2021). A Computable General Equilibrium Analysis of Environmental Tax Reform in Japan with a Forward-looking Dynamic Model. *Sustainability Science*, 16, 503-521. doi: <https://doi.org/10.1007/s11625-021-00903-4>
- Timilsinas, G. R. (2018). *Where Is the Carbon Tax after Thirty Years of Research?* (Policy Research Working Paper, No. 8493). The World Bank. <https://openknowledge.worldbank.org/handle/10986/29946>.
- van Heerden, J., Blignaut, J., Bohlmann, H., Cartwright, A., Diederichs, N., and Mander, M. (2016). The Economic and Environmental Effects of a Carbon Tax in South Africa: A Dynamic CGE Modelling Approach. *South African Journal of Economic and Management Sciences*, 19(5), 714-732. doi: <https://doi.org/10.17159/2222-3436/2016/v19n5a3>
- Vielle, M., and Viguier, L. (2007). On the climate change effects of high oil prices. *Energy Policy*, 35(2), 844-849. doi: <https://doi.org/10.1016/j.enpol.2006.03.022>
- Xu, J., and Wei, W. (2022). Would Carbon Tax be an Effective Policy Tool to Reduce Carbon Emission in China? Policies Simulation Analysis based on a CGE Model. *Applied Economics*, 54, 115-134. doi: <https://doi.org/10.1080/00036846.2021.1961119>
- Yakut, A. M., and de Bruin, K. C. (2023). The importance of having a more realistic welfare transfer determination rule: A CGE analysis for Ireland. *Economic Analysis and Policy*, 80, 1310-1325. doi: <https://doi.org/10.1016/j.eap.2023.10.021>
- Yusuf, A. A., and Resosudarmo, B. P. (2015). On the Distributional Impact of a Carbon Tax in Developing Countries: The Case of Indonesia. *Environmental Economics Policy Studies*, 17, 131-156. doi: <https://doi.org/10.1007/s10018-014-0093-y>
- Zhang, X., Guo, Z., Zheng, Y., Zhu, J., and Yang, J. (2016). A CGE Analysis of the Impacts of a Carbon Tax on Provincial Economy in China. *Emerging Markets Finance and Trade*, 52(6), 1372-1384. doi: <https://doi.org/10.1080/1540496X.2016.1152801>

Appendix

A Additional Tables

TABLE A.1: LIST OF COMMODITIES

| CODE | NAME | CODE | NAME |
|--------|-----------------------------|-------|----------------------------|
| 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 services |
| 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 | Public 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 A.2: LIST OF ACTIVITIES AND AGGREGATION KEY

| CODE | 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 |
| A_WND | Wind | | ELC |
| A_ORE | Other Renewables | | ELC |
| A_BFM | Basic Metal Manufacturing | 24-25 | MAN |
| 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 |
| A_PEA | Peat | | MIN |
| A_ATS | Air Transportation | 51 | TRP |
| 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 |
| 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). The activities without NACE codes are further disaggregated sectors.

Whitaker Square,
Sir John Rogerson's Quay,
Dublin 2
Telephone **+353 1 863 2000**
Email **admin@esri.ie**
Web **www.esri.ie**
Twitter **@ESRIDublin**