Assessing the Macroeconomic Impact of Carbon Budgets

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Executive summary: Assessing the Macroeconomic Impact of Carbon Budgets

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The long-term costs of reaching the national climate objective in Ireland by 2050 are relatively limited because future savings in imports of fossil fuels will largely (or possibly fully) offset the long-term costs of making the change. The biggest burden of adjustment, which will have a negative impact on living standards in Ireland will be between 2025 and 2035. However, even at its peak, the reduction in living standards, conventionally measured, will be quite manageable, probably amounting to between 0.5% and 1% of national income.

This negative impact arises from the need to redirect scarce resources to undertake the necessary climate related investment. In a near fully employed economy, of necessity, this will result in some reduction in investment and output in the tradable sector of the economy. However, by the 2040s, once the surge in climate related investment is almost complete, tradable sector output will bounce back.

The way Ireland will transition to a net zero energy system will largely be through investment in renewable electricity and related technologies. In the household sector much of the investment is needed to reduce energy consumption, making alternative carbon-neutral technologies possible (e.g. heat pumps using renewable electricity).

The estimated cost for Ireland of making the transition to a climate neutral economy is significantly lower than that estimated at the time of the first set of carbon budgets (FitzGerald,2021) because:

- Investment has already being ramped up and, crucially, fossil fuel prices are higher today than in 2021, resulting in greater savings from switching to carbon-free electricity generation.
- Using the Central Bank's macroeconomic model also means that, instead of an assumption in the 2021 study that climate-related investment would fully crowd out other productive investment, a more limited (and realistic) impact on the rest of the economy is estimated.
- The costs of transition in agriculture will probably be less than previously thought based on modelling by Teagasc.

The cost of the transition will be affected by the extent to which the rest of the world follows a similar path. If climate investment across the EU and the wider world needs large-scale finance, this will raise interest rates during the peak period of climate adjustment, increasing the cost of funding climate investment.

While the costs of decarbonising the economy by 2050 seem limited, the major constraint now is the restrictions imposed on new climate-related investment by the regulatory system (including physical planning).

1. Introduction

This paper analyses the potential macroeconomic impact of the measures deemed necessary to meet the targets for reducing, and eventually eliminating, greenhouse gas emissions in Ireland. These measures are set out in the subset of 3 scenarios that were selected by the CCAC in September 2024[1] for macroeconomic analysis. It concentrates on the measures aimed at eliminating carbon dioxide emissions from the energy system, and only deals in summary form with the macroeconomic impact of measures designed to reduce emissions from agriculture and land use.

In most cases the changes that need to be made involve substantial investment, designed to both reduce energy demand and to replace fossil fuels as the major energy source with renewable electricity.

In some cases the cost of the necessary investment will be repaid through the future savings in energy costs, as imported fossil fuels are replaced by locally generated renewable electricity. While there may, thus, be a commercial return on the investment, which would mean that it would be undertaken even in the absence of the imperative of eliminating greenhouse gas emissions, in a fully employed economy the magnitude of the investment required will necessitate moving productive resources in the Irish economy from meeting existing needs, to delivering the required new energy infrastructure. This will have medium-term costs for society that will be offset by long-term savings on expenditure on fossil fuels.

In other cases, the commercial return on the investment will not repay its initial cost and the investment will require subsidisation in some form by government. In turn, raising the taxes to pay the subsidy will reduce consumption and investment elsewhere in the economy.

This analysis first considers whether the necessary changes in individual sectors will, in the end, prove to be commercially profitable or whether they will only happen with some form of government support. Then the economic implications of the necessary changes, especially the ramping up of investment, are analysed using the Central Bank's macroeconomic model of the Irish economy.

As shown in this paper, while there will be some disruption to the standard of living as the economy adjusts to reach net zero emissions of carbon dioxide and transitions to a climate neutral economy, it will be limited in magnitude. Also, once the transition is complete there will, of course, be environmental benefits, but there will also be economic benefits from eliminating the future need to pay for imported fossil fuels.

The government has already recognised the vital importance of eliminating greenhouse gas emissions in the suggested carbon price to be used in public investment decisions (Kevany and Foley, 2024). However, this paper covers the necessary policy measures that need to be implemented by both the public and the private sectors over the period to 2050 if Ireland is to fully decarbonise its economy.

Section 2 of this note summarises the expenditure required to meet the draft carbon budgets over the period to 2050. These estimates of the expenditure required are taken from the modelling work by UCC, using the TIM model. The estimates from the TIM model have been supplemented with some estimates of additional necessary expenditure that are not included in that model. Section 3

[1] The Climate Change Advisory Council, in their September 2024 Council meeting, selected three scenarios to be prioritised for macroeconomic analysis which included 300Mt & L1-S1_P2, 300Mt & L4-S2_P2, and 350Mt & L4-S2_P2.

describes in more detail the methodology adopted in this paper using the Central Bank's macroeconomic model. Section 4 describes the resulting estimates of the macroeconomic impact for two draft carbon budgets. Given the necessary uncertainty about modelling the economic impact over such a long time horizon, the sensitivity of the results to some alternative assumptions is also considered. In Section 5 there is a brief consideration of the possible impact on the agricultural and food sectors of policies aimed at curbing agricultural emissions of greenhouse gases. Finally, in Section 6, conclusions are drawn about the overall impact on the Irish economy of reaching the target reduction in emissions envisaged in the draft carbon budgets.

2. Expenditure required to implement carbon budgets

The TIM model , developed by UCC, was used to calculate the least cost changes in technology that are needed over the period to 2050 to meet specified targets for reducing emissions of carbon dioxide from the energy sector in Ireland. For each five-year period to 2050, subject to the emissions target for that period, the model chooses the least-cost mix of technologies to meet the economy's energy needs and estimates the cost of implementing the necessary investment. In most cases the expenditure needed to decarbonise the economy involves investment, with a payback over an extended period, rather than requiring one-off subsidies.

TIM estimates the level of investment and final energy consumption consistent with achieving overall carbon budgets of 300 million tonnes or 350 million tonnes for the period to 2050. These estimates are used to calibrate the corresponding "shocks" or scenarios in the macroeconomic model, which represent changes relative to their baseline values. Accordingly, the choice of baseline is a key determinant of the size of shocks that are simulated by the macroeconomic model. The results presented here use the 'BAU-WEM' scenario from TIM as the baseline, which assumes mitigation in line with the EPA's 'With Existing Measures' (WEM) scenario[2].

TIM does not take account of the need to greatly expand the electricity grid to cater for much bigger flows of energy and to move the energy from where it is generated to where users are located. An estimate of the additional investment needed in the energy sector to deal with these issues is taken from McNamara, 2023[3], and included in the total investment that will be needed over the period to 2050. This additional grid investment is estimated at around seven billion euro by 2030.

TIM also does not consider the need for additional generation to ensure continuity of supply when the wind does not blow or the sun does not shine. Here we assume that existing (gas) plant is used for this purpose after 2030, so no additional investment is needed. However, as this backup plant uses gas, this would mean that the emissions after 2030 would be higher than TIM suggests until alternative carbon neutral back-up equipment is installed. If and when that equipment is installed the cost of that investment would be additional to that modelled in this paper.

In this paper, we analyse the possible macroeconomic effects of implementing two different possible carbon budgets: one would limit carbon dioxide emissions to 300 million tonnes by 2050 and the second would limit emissions to 350 million tonnes. In each case, it is the additional investment, over and above the definition of "business as usual", that is taken to represent the costs of complying with the national objective of decarbonising the economy.

[2] An overview of these scenarios can be found here: https://epmg.netlify.app/TIM-Carbon-Budget-August_2024/results/overview/emissions-and-cost?scen1=bau-wem-fx&scen2=null&diff=false

[3] McNamara, Fergal (2024). "Investing in Tomorrow: Shaping a Net-Zero Future". Davy Corporate Finance.

On this basis, Tables 1 and 2 summarise the additional annual investment needed between now and 2050 if Ireland is to achieve the targets for emissions set in the carbon budgets. It is assumed that investment expenditure is at 2020 prices.

Table 1: Investment in each 5 year period for a carbon budget of 300 million tonnes

	GNI* constant prices (first year of range)		Additional Investment		Additional public expenditure
	€ m	% change, annual	€ m	% of GNI*	% of GNI*
2021-25	275906	6.2	1493	0.5	0.1
2026-30	311412	2.5	4401	1.4	0.3
2031-35	344082	2.0	2408	0.7	0.1
2036-40	379894	2.0	-381	-0.1	0.0
2041-45	419434	2.0	1027	0.2	0.0
2046-50	463089	2.0	1561	0.3	0.1

Table 2: Investment in each 5 year period for a carbon budget of 350 million tonnes

	GNI* constant prices (first year of range)		Additional Investment		Additional public expenditure
	€ m	% change, annual	€ m	% of GNI*	% of GNI*
2021-25	275906	6.2	1471	0.5	0.1
2026-30	311412	2.5	4382	1.4	0.3
2031-35	344082	2.0	1344	0.4	0.1
2036-40	379894	2.0	140	0.0	0.0
2041-45	419434	2.0	1144	0.3	0.1
2046-50	463089	2.0	1645	0.4	0.1

GNI* is assumed to grow at 2% a year (constant prices) each year from the end of the Department of Finance's medium term projections in their *Stability Programme Update*.

In addition to the investment costs, there will be other operating costs related to the operation of the electricity system.[4] These are not taken into account here. There will also be substantial savings from the elimination of the purchase and consumption of fossil fuels, which are allowed for in the model. Generally, these savings will occur after the investment has taken place and are estimated as part of the modelling exercise implemented in the next Section. As shown, above the investment requirement, under the TIM scenario, peaks in the late 2020s and early 2030s, falling off thereafter. The savings from reduced expenditure on imported fossil fuel energy can be expected to pick up from 2035 onwards.

Financing the transition to climate neutrality will involve significant private sector investment, generally offset by prospective long-term savings in running costs. However, where expected savings do not match costs, the public sector will have to fund it – which will involve increased taxation. This

[4] Managing and balancing an electricity system with very high renewable penetraton will require a range of services, especially those needed to ensure that the electricity system is reliable when there is low availability of intermittent renewables – when the wind doesn't blow and the sun does not shine.

shortfall will represent the real economic cost of decarbonising the economy. The taxation needed to close the gap will have a knock on effect on the economy.

The increase in investment required to implement the carbon budgets is substantially lower than was assumed in FitzGerald, 2021. There are a number of reasons for this. There has already been a significant increase in investment since 2020, which is now included in the baseline. Some of the costs of decarbonisation have also come down: there is now assumed to be no additional cost from replacing fossil fuel cars with EVs, providing early scrappage is excluded. In using the macroeconomic model, the maintained assumption in FitzGerald, 2021, that climate related investment would largely crowd out other activity is modified, estimating a less costly reallocation of resources within the economy. Finally, new information, much of it incorporated in the TIM model, alters the costings.

3. Methodology

To assess the macroeconomic impact of different carbon budgets we employ the Central Bank's semi-structural model of the Irish economy.[5] The key inputs required for this scenario are the paths for investment and final energy consumption corresponding to each carbon budget. As set out in the previous Section, these are provided by TIM for both the '300mt' and '350mt' scenarios and are used to calibrate the corresponding shocks (changes) to these variables in the macroeconomic model. These shocks represent changes relative to their baseline values.

The investment required to decarbonise the energy system will have both a public and a private perspective. Government intervention will typically be required where investment will not be undertaken due to factors such as its high cost, credit constraints, network effects, or uncertainty about the profitability of the investment. While the optimal public-private financing mix is unclear ex-ante, it can be assumed that firms and households will undertake these investments if their upfront cost is less that the present value of the future savings on energy expenditure. In this analysis, we utilise existing estimates of the likely public share of transition-related investment in each sector from Carroll and Casey (2023) and McNamara (2023). Overall, these estimates suggest that the State could incur close to 20 percent of the total investment cost in each of the TIM scenarios.

This expenditure could be funded through a range of measures including higher taxes, lower government consumption or through debt issuance. As debt-financing raises issues of intergenerational equity, transition-related investment is likely to be funded instead through a combination of both higher taxes and lower expenditure. While carbon taxation could be used to fund this investment, these revenues will also be needed to finance spending on climate adaptation and ensuring that the transition is equitable. In the scenarios below, we make the technical assumption that the government component of investment in each scenario is financed through higher personal taxes though, as set out above, this could also be funded through a range of other tax or expenditure measures. This technical assumption allows us to simplify the calibration of each scenario, and does not affect the conclusions on the overall macoeconomic impact to any significant extent.

[5] This model is similar to the COSMO model outlined in Bergin et al (2017). For further details, see Conefrey et al (2018) and McInerney (2020).

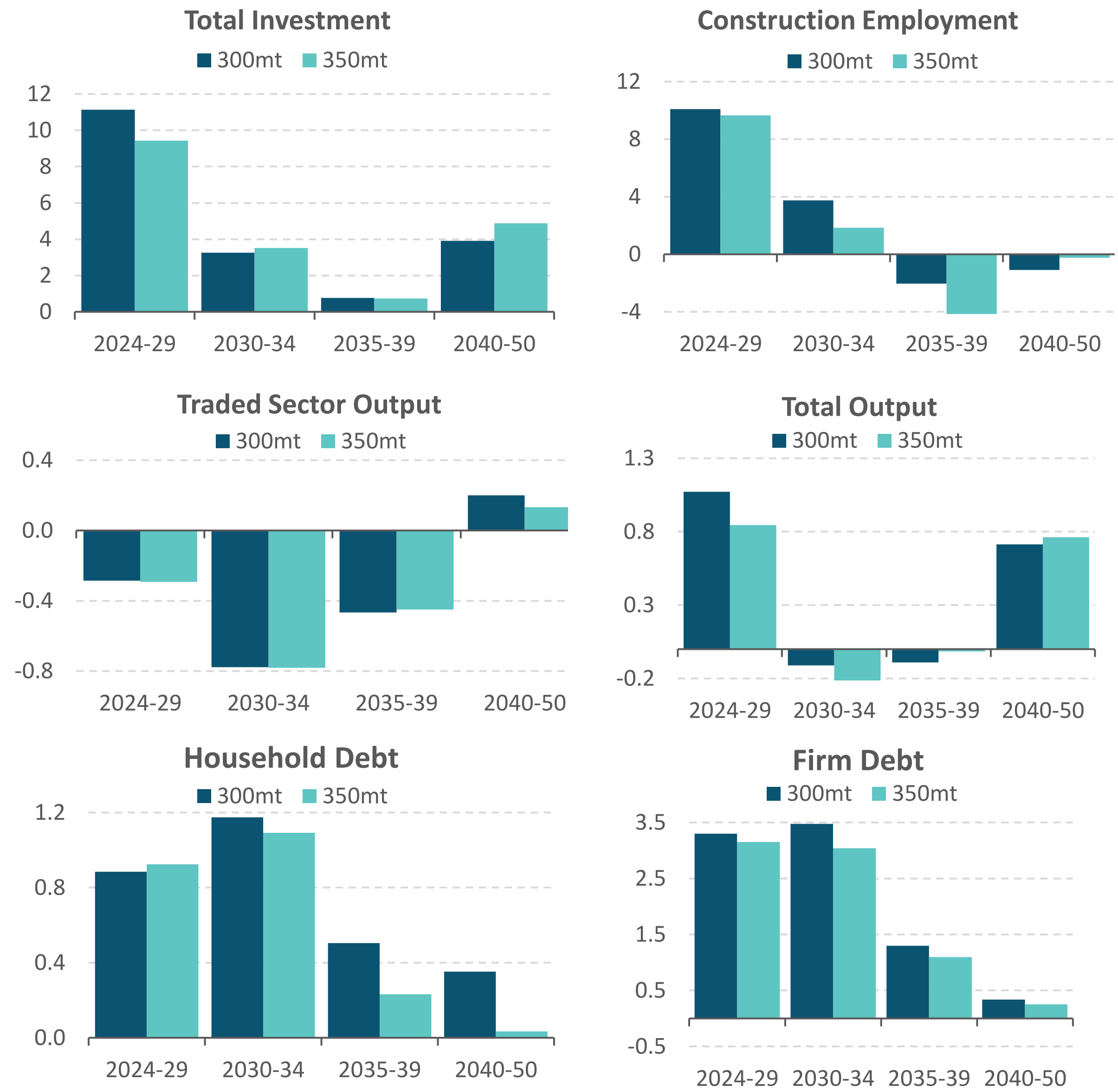
4. Results

Macroeconomic Impact of 300mt and 350mt Carbon Budgets

Figure 1 illustrates the impact of the TIM scenarios on selected macro-financial variables up to 2050. The results for investment broadly follow the path generated by TIM, but also include the endogenous response with respect to macroeconomic conditions. Investment in both scenarios is heavily front-loaded, rising by between 9.5 and 11 percent above baseline in the period to 2030. Following Pisani-Ferry and Mahfouz (2023), we assume that this investment does not increase the capital stock and therefore does not raise the productive capacity of the economy.

Figure 1: Macroeconomic impact of Carbon Budgets

(% deviation from baseline)



Notes: Figure 1 shows the response of each variable to the investment and energy consumption shocks calibrated from TIM that are simulated using the Central Bank's semi-structural model of the Irish economy. The responses are in terms of percent deviation from baseline.

The increase in investment stimulates the demand for construction labour, with employment in that sector rising by over ten percent in the short term. This implies that around 17,000 additional construction workers will be needed solely for investment projects related to decarbonising the energy system. These results highlight the temporary nature of this spike in employment with demand for construction workers declining after 2030.

The increase in labour demand due to the rise in economic activity puts upwards pressure on wages throughout the economy. The resultant increase in prices leads to a deterioration of Irish competitiveness relative to its trading partners, as indicated by the significant fall in the output of the traded sector up to 2040. The recovery in the output of the sector after 2040 is mainly due to the dissipation of the investment shock, which reduces employment in domestically-oriented sectors and allows wages to converge back towards baseline.

From an aggregate economy perspective, our results also suggest that, while the impact of each carbon budget for the energy sector on the total output of the economy differs in the short to medium term, the long-term impact is broadly similar. In addition to the channels discussed above, an important driver of the positive long-run macroeconomic impact of decarbonisation is the fall in imports that follows from the substitution of renewables for imported fossil fuels. The decline in energy imports occurs over time so that by 2050 total imports are more than three percent below baseline in both carbon budget scenarios (not shown). The reduction in imports thus provides additional stimulus to the economy.

Finally, Figure 1 also shows how the volume of (bank-intermediated) credit to both households and firms evolves under each carbon budget. Following McNamara (2024), we assume that 90 percent of the increase in the private share of investment is financed by debt, with the remainder sourced from savings (households) and retained earnings (firms). This implies a significant rise in private debt in the short- and medium-run, which is almost fully amortised by 2050.

Macroeconomic impact with short-term Capacity Constraints

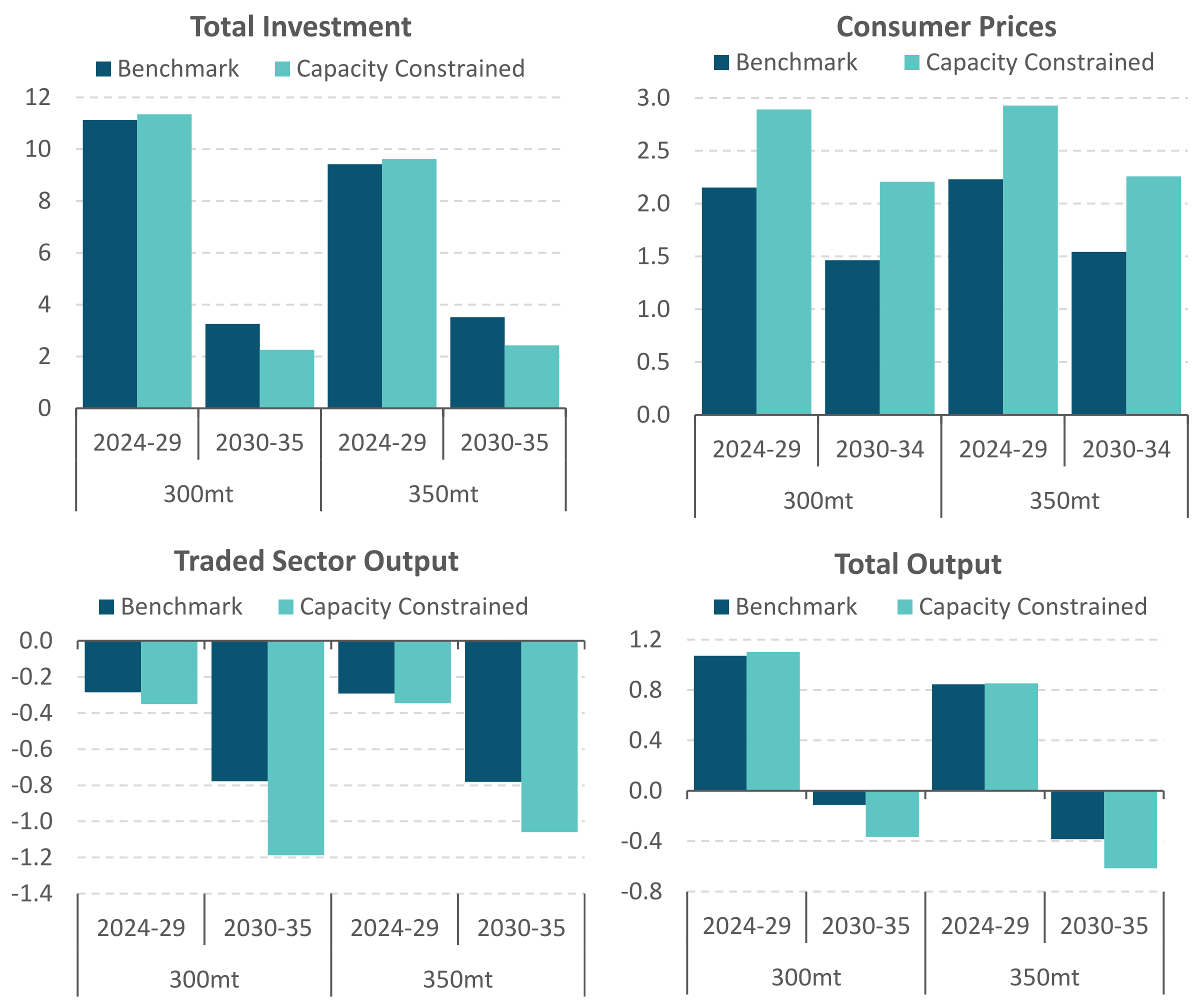
As discussed above, the increase in investment in both carbon budget scenarios generates a significant rise in the derived demand for construction labour in the short term. In addition, the stimulus to aggregate demand from the investment shock leads to higher demand for workers in other sectors of the economy. As the Irish labour market is currently at, or close to, full employment, the sharp impulse to aggregate demand could lead to an acceleration in wage growth and inflation, potentially resulting in the crowding out of other types of investment and a further deterioration in competitiveness.

The results presented in Figure 1 assumed that wage and price growth is similar even when economic activity is above its long-run level. We label these results as our ‘benchmark’ model. We now consider a scenario in which labour constraints are binding in the short-run so that labour supply cannot easily expand in response to the derived demand from the investment shock. These results are shown in Figure 2, with the results from the benchmark model also included for comparison.

The response of investment in both scenarios is similar in the short-run. However, in the medium-term (the 2030-35 period) the effects of ‘overheating’ become clear as higher investment in decarbonisation crowds out other types of investment. This is mainly due to the rise in labour costs which are passed on to higher prices and which reduce competitiveness. The latter is reflected in a larger fall in the output of the traded sector relative to that from the benchmark model, which has a higher elasticity of labour supply. Overall, incorporating labour constraints has a material impact on the total output of the economy in both carbon budget scenarios, with aggregate production falling by between 0.4 and 0.6 percent relative to baseline by 2035 depending on the scenario.

Figure 2: Impact of Carbon Budgets with short-term Capacity Constraints

(% deviation from baseline)



Notes: 'Benchmark' refers to model simulations that assume labour supply is relatively elastic. 'Capacity-Constrained' refers to simulations with labour supply constraints that bind in the short run. The responses are in terms of percent deviation from baseline.

Macroeconomic impact with lower productivity

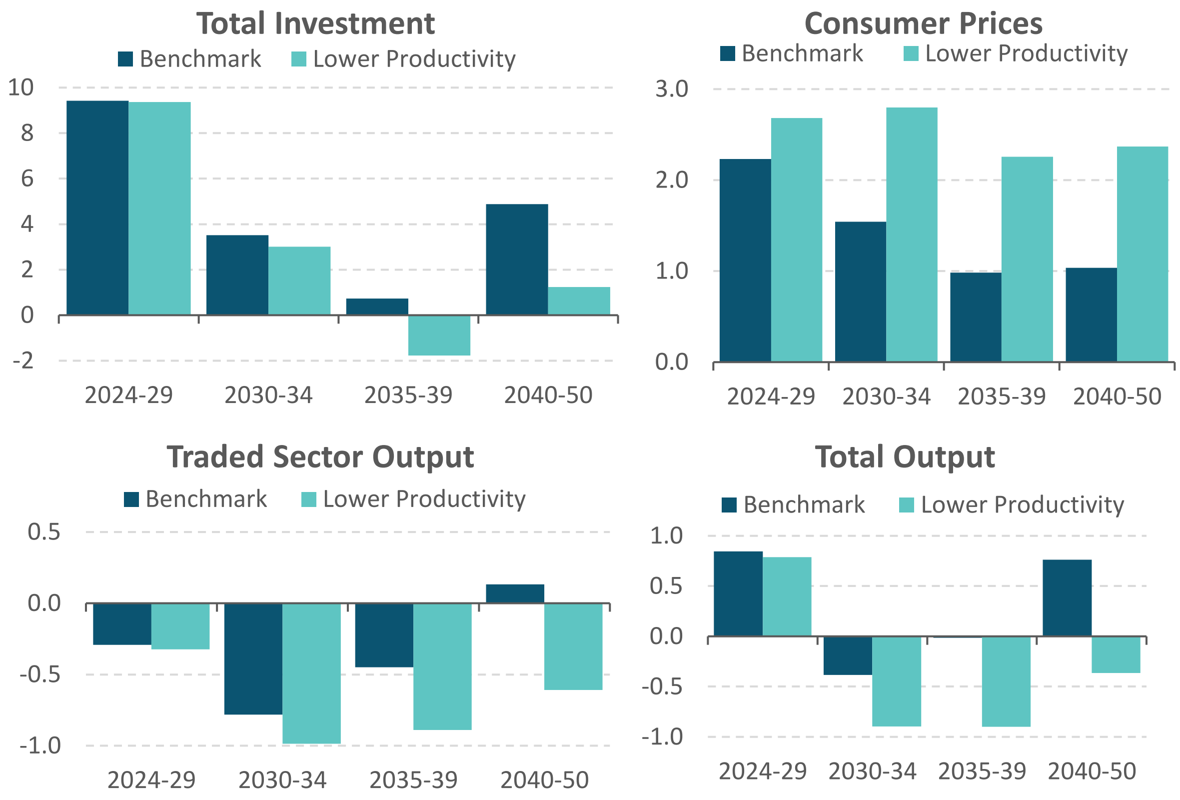
As Pisani-Ferry and Mahfouz discuss, the transition to a low-carbon economy may have a negative impact on productivity. Intuitively, the transition represents a negative supply shock, requiring that firms and households finance investments whose profitability is uncertain.[6] This investment is aimed at reducing emissions rather than enhancing efficiency or stimulating innovation. This diversion of resources may therefore result in lower output growth relative to the case where this crowding out does not occur.

[6] Here profitability excludes the benefits in terms of the reduced contribution to global warming.

We now consider a scenario in which the implementation of carbon budgets results in a reduction in productivity. Specifically, we assume that the decarbonisation results in a 0.5 percent reduction in the level of firm productivity. For expository reasons we report the results for the 350mt carbon budget only. These are shown in Figure 3.

Figure 3: Impact of 350mt Carbon Budget with lower Productivity

(% deviation from baseline)



Notes: 'Benchmark' refers to model simulations where productivity responds endogenously in line with the model's equations. 'Lower Productivity' refers to simulations with a 0.5 percent reduction in productivity relative to the Benchmark. The responses are in terms of percent deviation from baseline.

Lower productivity reduces the returns on investment with the endogenous (non-decarbonisation) component of investment generating a fall of close two percent relative to the benchmark model over the medium to long term. The reduction in the productive capacity of the economy also implies higher prices for a given level of demand, with consumer prices rising significantly over the simulation horizon.

The increase in prices relative to trading partners leads to a deterioration in competitiveness. In particular, the reduction in productivity results in a level of traded sector output that is around 0.7 percent lower in the long run than in the benchmark model. Overall, the reduction in domestic and external demand results in a fall in the total output of the economy of close to one percent in the medium term.

It should be emphasised that the productivity shock in this scenario is calibrated to persist over the entire scenario horizon. The assumption that the potential productivity loss associated with the transition to a low-carbon economy is permanent likely constitutes the most adverse case. The simulation results should therefore be interpreted with the caveat in mind.

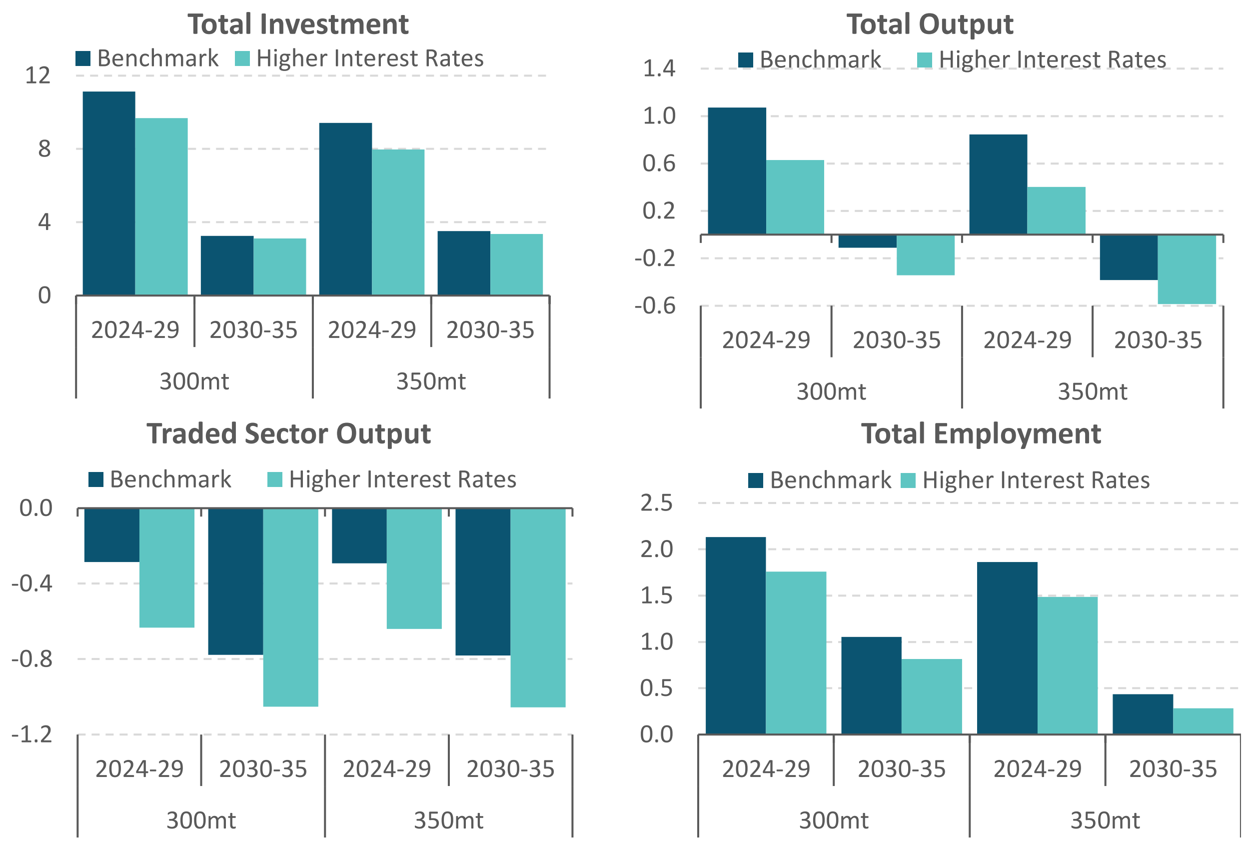
Macroeconomic impact with higher interest rates

From a global perspective, achieving the target of carbon neutrality by 2050 is likely to require additional investment of 2-3 percent of GDP (Pisani-Ferry, 2021). For a given level of savings, this surge in investment demand could put upward pressure on global interest rates. A rise in interest rates could therefore 'crowd-out' other investment and consumption that is not associated with the transition, thereby resulting in lower aggregate demand.

To illustrate the macro-financial impact of higher interest rates on the Irish economy, we first use the NiGEM model of the global economy to simulate a 50 basis point increase in interest rates that lasts for three years.[7] We then impose the resulting paths for key Irish variables in the model such as world demand, competitor prices and interest rates as constraints on the trajectories of the corresponding variables in the Central Bank's macroeconomic model. The results of this scenario are shown in Figure 4.

Figure 4: Impact of TIM Scenarios with higher global Interest Rates

(% deviation from baseline)



Notes: 'Benchmark' refers to model simulations with constant global policy rates. 'Higher Interest Rates' refers to simulations where global policy rates rise by 50 bps for three years The responses are in terms of percent deviation from baseline.

The increase in interest rates results in a fall in investment of around 1.5 percent relative to the benchmark model in the short-term. However, the effects on total output are significantly larger, mainly due to the spillovers from lower aggregate demand in Ireland's trading partners. This is clearly illustrated in the response of traded output to the shock, which is around 0.4 percent lower

[7] https://www.niesr.ac.uk/nigem-macroeconomic-model

than in the benchmark scenarios over the 2024-29 period. With relatively weaker aggregate demand, firms also reduce their demand for labour, with total employment over 0.3 percent lower than in the benchmark case over the same period.

5. Agriculture and Land Use

Lanigan G.J., Hanrahan, K., Donnellan, T. and Richards, K.G., 2024[8], (Teagasc) provide a range of scenarios for the agricultural sector combining estimates of emissions and of agricultural output and income. Here we only consider the results of their research in summary form. Thus, the conclusions are provisional in nature.

The Teagasc study looks at three agricultural output scenarios S1 - the base case, S2 - lower output and S3 - higher output. They also consider two scenarios on emissions reduction: the Ambitious (P1) and the Very Ambitious Mitigation scenarios (P2). Here we concentrate on the difference between the Base case scenario and the Lower growth scenario, because estimates of the additional cost of implementing the Very Ambitious Mitigation scenario are not available.

Because of updated assumptions, the macroeconomic implications of these scenarios are rather different from the conclusions in FitzGerald, 2021.

Here we summarise the implications of the Teagasc analysis on agricultural income and output. If the Lower output scenario (S2) is assumed to result from measures to reduce greenhouse gas emissions in agriculture, then the difference between it and the Base case (S1) could be considered to be the cost to the agricultural sector of reducing emissions.

However, given the low profitability of the sector even in the Base case, it is possible that the actual outcome for the sector, independent of action on climate change, could be closer to the Lower output scenario. Also, if it proved profitable for farmers to use some of their land for alternative uses, such as agri-forestry, that could see lower output of beef being offset by some increased income from the alternative source. Thus the difference between income and output in the Base case and the Lower output case could be taken to be the maximum loss in income and output from implementing measures to reduce greenhouse gas emissions in the sector by reducing the level of economic activity.

Table 3: Teagasc Assumptions on prices and volumes of milk and beef

Average annual change, %

Scenario	Product	Volume	Price	Value
S1	Milk	1.1	1.3	2.5
S1	Beef	-0.4	-0.2	-0.6
S1	GVA (Farm income)			1.6
S2	Milk	0.9	1.0	1.9
S2	Beef	-1.1	-0.2	-1.3
S2	GVA (Farm income)			0.9
S3	Milk	1.4	1.5	3.0
S3	Beef	-0.2	-0.2	-0.3
S3	GVA (Farm income)			2.1
	Consumer prices			2.0

[8] Herrreafter referred to as Teagasc.

The cost of implementing the Very Ambitious Mitigation measures would be additional to any costs arising from the reduction in output estimated here.

The background assumption in the Teagasc paper is that consumer prices rise on average by 2% a year over the period to 2050. In all three output scenarios Teagasc assume that beef prices fall significantly relative to the overall (consumer) price level (Table 3). They also assume some real fall in milk prices, though by much less than beef prices. These output price assumptions are a key determinant of the long-term profitability for farmers of the different products.

In the base case (S1) milk production, which is today profitable, remains sufficiently profitable over the period to 2050, so that there is an increase in the volume of output of just over 1% a year. However, in the case of beef, output falls by around 0.4% a year, reflecting the very unfavourable trend in prices even in the Base case. The combined effect of volume and price changes is that the value of milk output would rise by 2.5% a year, slightly more than the background change in consumer prices, while the value of beef output would fall by 0.6% a year. Together these assumptions would mean the Gross Value Added in the agricultural sector, roughly equivalent to farm income, would rise by 1.6% a year, implying a steady small fall in purchasing power.

In the lower output scenario S2, whether because of the unfavourable trend in prices or because of policy action to reduce greenhouse gas emissions (through increasing the cost of production), output is lower than in the Base case S1. GVA (farm income) would rise by only 0.9% a year in this scenario. This reduction in the growth in GVA can be taken to be an estimate of the cost of reducing emissions through reducing output.

The difference in the growth rate of GVA (farm income) in the Base case and the Lower output scenario would amount to around 0.65% a year (Table 3). While significant for the farm sector, because agricultural income accounts for only 1.5% of GNI* today, such a reduction would not have a noticeable effect on national income.

The reduction in output of beef cattle and milk in the Lower output scenario, compared to the Base case, would have implications for the food processing sector. By 2050 milk output under the Lower output scenario would be 7% below what it would be in the Base case and beef cattle output would be 17% below the Base case. In turn, this reduction in inputs would reduce the output of the meat processing and the dairy processing sectors.

Table 4: Food Processing Sector Output and Employment

	2021	2022
Dairy Processing		
GVA, % of GNI*	0.53	0.46
Employment, % of total employment	0.36	0.36
average wage, €(000)	49.07	47.48
Meat processing		
GVA, % of GNI*	0.48	0.50
Employment, % of total employment	0.81	0.81
average wage, €(000)	32.2	33.5

Source: Eurostat, Structural Business Statistics

In manufacturing, the value added of the meat processing sector amounted to just under 0.5% of GNI* in 2022 (Table 4). Employment in the sector had a bigger weight in total employment in the economy, amounting to 0.8% of the total in 2022, reflecting the fact that earnings were below the economy average at €33,500. Comparing the Lower output and the Base case scenario, the volume of beef cattle produced would be 17% lower in 2050 (Teagasc, 2024). This fall in the input of beef cattle would negatively impact on the value added and employment in this sector.

The value added in the dairy processing sector in 2022 was of a similar order of magnitude to that in beef processing, around 0.5% of GNI* (Table 3). Employment was lower than in meat processing at 0.4% of total employment in the economy, and average wages were €47,500. The reduction in the milk intake into the dairy processing sector in the Lower output scenario, compared to the Base, case would see a fall in the output of the dairy processing sector of up to 7%.

While significant in terms of the individual sectors, because today they account for only 1% of GNI*, the overall impact of their reduced output on the economy as a whole would not be significant. When combined with the limited fall in farm income, this would suggest that, under the low growth secnario, the economic effects of the changes in output in farming and food processing, designed to reduce greenhouse gas emissions, would have a quite limited impact on GNI* by 2050.

The Teagasc analysis also suggests that the reduction in cattle numbers, combined with a fall in land devoted to crops, would see significant agricultural land become available for other uses in the Low growth scenario (c. 400,000 hectares). The research undertaken using Goblin (Styles *et al.*, 2024) suggests that extensive planting of trees between now and 2050 could sequester a substantial amount of carbon dioxide out of the atmosphere, accelerating Ireland's progress in reaching climate neutrality. In the long term, the harvesting of this timber would also provide a potential income stream. This could provide an opportunity for a profitable alternative use of the land freed up from reducing output of traditional agricultural products.

No account is taken here of the costs of the many measures required to reduce emissions in the agriculture sector under the Very Ambitious Mitigation scenario. If these costs were taken into account it would increase the likely loss of income. Further modelling work on the change in farm costs would be required to be more precise on the final impact on farm incomes.

Under the S2P2 scenario, Teagasc's modelling suggests that agricultural emissions would be reduced by 48%. In FitzGerald, 2021, a 50% reduction in emissions was estimated to derive primarily from a reduction in agricultural output and a resulting reduction in output in the food processing sector. The prospective cost to the government of replacing that lost income by 2030 was estimated by FitzGerald to amount to between 0.5% and 1.0% of GNI*. By contrast, in this analysis of the difference between the Base and the Low growth scenarios, the loss of income and output is likely to represent a much smaller share of GNI*.

Further modelling would be required to arrive at a more complete picture of the wider economic implications of the changes needed in land use and in the agricultural sector to reach climate neutrality by 2050. The link between agricultural production and output and employment in the food processing sector of manufacturing would need to be modelled in more detail.

6. Conclusions

The key findings from our study can be summarised as follows:

1. The long-term costs of reaching climate neutrality by 2050 in Ireland are likely to be relatively limited. Future savings in imports of fossil fuels will largely (or possibly fully) offset the long-term costs of making the change.
2. The way Ireland will transition to climate neutrality will primarily be through investment in renewable electricity and related technologies. In the household sector much of the

investment is needed to reduce heat loss and, hence, energy consumption, making alternative carbon-neutral technologies possible (e.g. heat pumps using renewable electricity).

3. The estimated cost for Ireland of making the transition to a climate neutral economy is significantly lower than that estimated for Ireland at the time of the first set of carbon budgets (FitzGerald,2021). The reduction in the estimated cost since 2021 is because:
   - Investment has already being ramped up and, crucially, fossil fuel prices are higher today than in 2021, resulting in greater savings from switching to carbon-free electricity generation.
   - Using the Central Bank's macroeconomic model also means that, instead of an assumption in the 2021 study that climate-related investment would fully crowd out other productive investment, a more limited (and realistic) impact on the rest of the economy is estimated.
   - The costs of transition in agriculture will probably be less than previously thought based on modelling by Teagasc.
4. The biggest burden of adjustment, which will have a medium-term negative impact on living standards, will be between 2025 and 2035. However, even at its peak, the reduction in living standards, conventionally measured, will be limited, probably amounting to between 0.5% and 1% of national income.

   This negative impact arises from the need to redirect scarce resources to undertake the necessary climate related investment. In a near fully employed economy this, of necessity, results in some reduction in investment and output in the tradable sector of the economy. However, by the 2040s, once the surge in climate related investment should be almost complete, tradable sector output should bounce back.
5. The cost for Ireland of making the transition estimated in this paper would be lower than the costs estimated for some other economies such as France (Mahfouz and Pisani-Ferry, 2023) or for the wider world economy (Pisani-Ferry, 2021). In both these studies the medium-term costs were estimated to fall between 2% and 3% of national income but the longer-term effects, after the adjustment is completed, were undoubtedly lower than the up-front costs, as in the Irish case.

   An analysis by Rodriguez, Fouré and Lanzi, 2024, for Spain paints a rather similar picture to that shown in this paper for Ireland. There would be significant costs in making the adjustment in the 2030s and early 2040s. However, they also suggest significant longer-term gains as a result of replacing imported fossil fuels with renewable energy.

   To some extent the lower cost estimated for Ireland than in the French case reflects the fact that the investment needed to decarbonise the Irish economy has already begun to be ramped up. As a result, the necessary further increase in investment is more limited.
6. The cost of the transition will be affected by the extent to which the rest of the world follows a similar transition path. If there are similar demands to finance climate investment across the EU and the wider world, this will raise interest rates during the peak period of climate adjustment, increasing the cost of funding climate investment.
7. While the costs of decarbonising the economy by 2050 seem limited, the major constraint now is the restrictions imposed on new climate-related investment by the regulatory system (including physical planning). A recent study by Longoria et al., 2024, quantifies the

additional costs imposed on vital investment to allow the deployment of renewable electricity, arising from the inefficient regulatory system. They also quantify the unnecessary additional greenhouse gas emissions which arise from this regulatory failure. This is but one aspect of the non-financial obstacles to meeting our climate targets.

There are several caveats to our analytical approach that should be considered when interpreting our results in terms of the calibration of carbon budgets.

Our modelling framework quantifies the macroeconomic costs and benefits of reducing emissions in terms of the net impact on output. It should be noted, however, that macroeconomic aggregates can be poor proxies for societal welfare, particularly in the context of climate change and environmental degradation.[9] In particular, our analysis abstracts from other benefits of climate action, such as the avoidance of more permanent and severe costs associated with non-abatement. Thus, no account is taken of the macroeconomic impact of the costs of adapting the Irish economy to the problems arising from climate change over the period to 2050. We also do not consider the numerous co-benefits that accrue from mitigating climate change such as lower air pollution, higher life expectancy and reduced biodiversity loss. A qualitative evaluation of the impact of these additional benefits on welfare would be a useful complement to the model-based estimates that we provide here.

The analysis in this paper assumes that, where the state has to help fund the necessary investment to move the economy to a net-zero carbon dioxide emissions path by 2050, it is financed by higher personal taxes rather than carbon taxes. This investment could be funded through a range of measures including higher direct or indirect taxes, lower government consumption or through debt issuance, but this technical assumption allows for simplification of the calibration of each scenario in the model. Financing expenditure through other more distortionary taxes would obviously raise the output cost of the measures. The analysis also assumes that the bulk of the investment costs (c. 80%) are funded by the private sector. In particular, the major investment in the power sector will all be financed by that sector, and ultimately paid for by consumers of electricity, both households and business. Accordingly, our calibration of the private-public investment mix implicitly assumes that households and firms are not credit constrained, and thus that the macro-financial environment is relatively benign.

Finally, we assume that the additional climate-related investment does not raise the productive capacity of the economy. Rather, the new investment is valuable because it serves to reduce emissions, although it does not increase the ability of the economy to produce goods and services for sale in the market economy (Pisani-Ferry and Mahfouz, 2023). This excludes the possibility that investments in clean technologies may generate spillovers that stimulate innovation in other areas, which would raise output growth in the long run.[10]

[9] See Stiglitz et al (2009) and Dasgupta (2021) for a discussion of the limitations associated with using output growth as an indicator of economic performance and improvements in societal welfare.
[10] See Dechezlepretre et al (2014) for evidence on productivity spillovers from investment in clean technologies.

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