Working Paper No. 37

May 2025

Analysis of the alignment between energy transition pathways for Irish carbon budgets with EU energy and climate targets

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A working paper commissioned by the Climate Change Advisory Council, Ireland.

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March 2025

Acknowledgements

The authors wish to thank members of the Energy Policy and Modelling Group, particularly Dr. Paul Deane, Dr. Vahid Aryanpur and Mr. Bakytzhan Suleimenov for reviewing this report and providing technical support. Development of the TIMES-Ireland Model is supported by the Department of Environment, Climate and Communications through the Climate and Energy Modelling Services to the Climate Action Modelling Group (CAMG) (grant No. RFT2022/S 164-466018), and also supported by MaREI, the Research Ireland Centre for Energy, Climate and Marine (grant No. 12/RC/2302_P2).

This report should be cited as: Doherty, C. & Daly, H. (2025). Analysis of the alignment between energy transition pathways for Irish carbon budgets with EU energy and climate targets. Report for Climate Change Advisory Council.

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Executive Summary

Background

Ireland has legally committed to reduce its greenhouse gas (GHG) emissions in line with commitments under the Paris Agreement. These objectives are underpinned by a programme of carbon budgets and sectoral emissions ceilings (SECs) consistent with reducing GHG emissions by 51% by 2030, relative to 2018, and achieving climate neutrality no later than 2050, as established in the Climate Action and Low Carbon Development (Amendment) Act 2021. In parallel, as a Member State of the European Union (EU), Ireland is legally obliged to contribute to EU-wide climate and energy targets under the “Fit for 55” package, the Energy Efficiency Directive, and the EU Climate Law.

The extent to which Ireland’s national decarbonisation programme is compliant and consistent with EU targets is uncertain. This raises questions about the adequacy of existing plans and policies, particularly given the financial, legal and environmental implications of non-compliance.

Aim

This study assesses the alignment between Ireland’s national energy system decarbonisation pathways and key EU energy and climate-related targets. Specifically, it examines how scenarios consistent with Ireland’s carbon budgets (approved and legally adopted in the period to 2030 and proposed in the period to 2040), and SECs, compare to EU obligations, namely:

- The EU Emissions Trading Scheme (EU-ETS)
- The Effort Sharing Regulation (ESR)
- The Energy Efficiency Directive (EED)
- Indicative 2040 GHG emissions target

The analysis focuses on energy-related sectors—electricity, buildings, transport, and industry—and excludes agriculture and land use, land use change and forestry (LULUCF), which are not included in the energy system model used.

Method

The analysis uses scenarios developed with the TIMES-Ireland Model (TIM), a least-cost energy systems optimisation model. Scenarios were developed by UCC’s Energy Policy and Modelling Group (EPMG) as part of the Climate Change Advisory Council’s second carbon budget process. These scenarios represent a range of national carbon budgets for 2021–2050, varying in climate ambition, demand levels, and biomass availability.

A composite scenario—*TIM-CBaligned*—was constructed for this analysis by averaging energy sector trajectories across the fifteen shortlisted scenarios used to inform the CCAC’s proposed third and fourth carbon budgets (2031–2040). This composite scenario was used to assess alignment with EU targets, alongside comparisons to Ireland’s With Existing Measures (WEM) and With Additional Measures (WAM) emissions projections from the Environmental Protection Agency.

Assumptions were applied to allocate TIM sectoral emissions to ETS and ESR categories in line with EU definitions. Flexibilities under the ESR (ETS and LULUCF credits) were included based on official allowances where applicable.

Key Findings

An energy transition pathway compliant with meeting carbon budgets (legally adopted in the period to 2030 and recommended by the CCAC in the period to 2040) would put Ireland in a very strong position to cutting GHG emissions in the **Emissions Trading Scheme** (**EU-ETS)** for the power and industry sectors aligned with the EU-wide target. *TIM-CBaligned* achieves a 77% reduction in ETS emissions by 2030 (relative to 2005), exceeding the EU target of -62%. This analysis excludes consideration of international aviation, which is excluded from national carbon budgets, while emissions from inter-EU flights are within the scope of the ETS.

However, the achievement of the **Effort Sharing Regulation** (**ESR)** targets is less certain. If not delivered, the State will incur significant compliance costs (unlike the ETS target). Ireland's share of GHG emissions accounted for under the ESR are particularly high by EU standards.

TIM-CBaligned reduces energy-related ESR emissions by 63% by 2030 (relative to 2005). However, whether Ireland remains within its binding national ESR cap (370 $MtCO_2$) depends on agriculture, which currently accounts for half of ESR emissions. If agriculture follows EPA's WAM projections, the carbon budget aligned pathway can meet the ESR cap, with the use of ESR flexibilities. However, if agriculture follows WEM projections, *TIM-CBaligned* exceeds the ESR cap.

The early overshoot of Annual Emissions Allocations (AEAs) in 2021, 2022 and 2023 increases the challenge of remaining within the allocated ESR target for the remainder of the decade, increasing compliance risks in the later years. Additionally, uncertainty around the 2026-2030 AEAs, access to flexibilities, and whether credits will be available to purchase underscores the importance of early action to reduce emissions.

The **Energy Efficiency Directive (EED) target** – to reduce final energy consumption to 10.45 Mtoe – is narrowly missed in *TIM-CBaligned*. In this scenario, final energy consumption falls to 11.1 Mtoe, falling just short of the target. *Low Energy Demand* pathways are most closely aligned with the EED target, indicating the value of addressing final energy demand. Of all pathways analysed, the target is only met in the *250Mt-LED*, with other low energy demand scenarios coming close – highlighting the need to lower final energy demands rather than relying solely on technology to meet energy efficiency targets

Sectoral transformation

The *TIM-CBaligned* scenario achieves deep decarbonisation across the energy system. In the **power sector**, fossil fuels are nearly phased out by 2030, with a rapid expansion of wind and solar leading to 95% renewable electricity by 2030 and 100% by 2040. BECCS deployment from 2035 delivers net-negative emissions.

In **transport**, emissions fall by 97% by 2040 through a complete shift to electric vehicles (EVs) and, in *Low Energy Demand* scenarios, a shift away from private car dominance towards public and active travel. New sales of internal combustion engine (ICE) vehicle cease by 2025 for cars and 2027 for freight. EVs account for 36% of private cars by 2030, rising to 95% by 2040.

In **industry**, emissions fall by 90% by 2040, driven by electrification, fuel switching to biomethane, and post-2030 deployment of carbon capture and storage (CCS) in cement production.

In **buildings**, emissions fall by 62–82% by 2030 and near-complete decarbonisation is achieved by 2040. This is supported by the rollout of over 880,000 heat pumps by 2030 and the expansion of district heating to 3.3 TWh. Energy demand falls substantially through efficiency gains and fuel switching.

Investment Implications

Achieving the energy transition outlined in *TIM-CBaligned* requires substantial investment but is cost-effective in the long run. Upfront cumulative investment of approximately €100 billion by 2030 and €230 billion by 2040 is necessary. However, in this scenario, overall costs in the period to 2050 are lower than WEM/WAM due to reduced fossil fuel imports and energy system operating costs. More than half of investment is concentrated in the transport sector, with substantial investment also required in electricity generation, residential buildings, and efficiency upgrades. Annual investment needs rise steeply toward the end of the decade, peaking at €16–18 billion per year by 2029–2030.

Conclusion

Ireland is currently off track to meet both its national and EU climate targets. However, the analysis shows that an energy system pathway consistent with Ireland's carbon budgets—particularly one focused on electrification, renewable deployment, energy efficiency, and demand reduction—can deliver deep emissions cuts and strong alignment with EU obligations. *TIM-CBaligned* demonstrates that the 2030 and 2040 ETS and EED targets can be met, and that Ireland's ESR gap can be substantially reduced, though full ESR compliance depends on complementary action in agriculture that goes beyond existing policies.

Delivering this pathway will require unprecedented policy clarity, investment mobilisation, and implementation capacity in the years to 2030. The window to act is narrow, but the technical feasibility and long-term cost-effectiveness of deep decarbonisation are clear.

1 Introduction

Ireland has committed to achieving a legally binding decarbonisation pathway consistent with reducing greenhouse gas (GHG) emissions by 51% by 2030, relative to 2018, and climate neutrality by 2050 at the latest, under the Climate Action and Low Carbon Development (Amendment) Act 2021 (Climate Act) (Oireachtas, 2021). The overarching framework for delivering these commitments, enshrined in the Climate Act, is the implementation of a programme of carbon budgets and sectoral emissions ceilings (SECs) which establish the maximum cumulative GHG emissions allowable over five-year periods, and sectoral allocations.

At the European Union (EU) level, ambitious climate and energy targets have been established to drive emissions reductions across Member States. These include binding GHG emissions reduction targets, aimed at achieving the EU's broader goal of climate neutrality by 2050. As a Member State, Ireland must ensure that national policy not only fulfils domestic goals but also aligns with, and contributes proportionately to, the EU-wide commitments to reduce GHG emissions, improving energy efficiency and transition to a more sustainable energy system.

While carbon budgets and SECs provide the legal framework for national emissions reductions, it remains unclear to what extent they align with the pace and scale of decarbonisation required under EU legislation. Currently, Ireland remains off course in meeting both national carbon budgets and SECs, and a range of EU targets for climate and energy (detailed later in this report). Failure to meet EU climate and energy obligations could result in steep financial penalties or compliance costs for Ireland (IFAC and CCAC, 2025), and potential legal action from the European Commission. Additionally, exceeding national carbon budgets in early periods requires compensation in later periods, which risks the feasibility of the carbon budget programme. Additionally, failure to align national and EU targets represents a missed opportunity for economic and societal benefits that the transition to a low-carbon economy could bring.

The Climate Act requires the Climate Change Advisory Council (CCAC) to provide recommendations on five-year, economy-wide carbon budgets to Government. Recently, UCC's Energy Policy and Modelling Group (EPMG) supported the CCAC as part of the Carbon Budgets Working Group (CBWG), in the development of the proposal for carbon budgets 3 (2031-2035) and 4 (2036-2040) (CCAC, 2024). As part of this process, the EPMG modelled energy system scenarios, aligned with different levels of decarbonisation ambition addressing energy supply, electricity, transport, buildings and industrial sectors.

The CCAC commissioned this research to evaluate whether Ireland's energy sector decarbonisation pathways align with the EU's legally binding climate and energy targets. Specifically, the study aims to address the primary research question outlined below:

- How do energy-related targets for the EU (the Energy Efficiency Directive, and 2030 and indicative 2040 greenhouse gas mitigation targets) align with energy system scenarios consistent with national carbon budgets (as recommended by the CCAC to Government as part of the second carbon budget programme) and Sectoral Emissions Ceilings in the Electricity, Transport, Buildings (Commercial and Public), Buildings (Residential) and Industry sectors?

Section 2 provides an overview of the key Irish and EU energy targets. Section 3 defines the energy system carbon budget scenarios included in this analysis. Section 4 evaluates the alignment of carbon budget scenarios with the EU targets, including a detailed sectoral analysis and detail on system costs. Finally, Section 5 discusses the key findings of the analysis, policy implications and limitations.

2 Background

2.1 Ireland's national climate commitments

Ireland has established a robust legal framework and a comprehensive implementation plan for reducing its greenhouse gas emissions. The Climate Act sets out legally binding targets, requiring Ireland to transition to climate resilient, biodiversity-rich, environmentally sustainable and climate-neutral economy by 2050. Additionally, it mandates a programme of carbon budgets aligned with a 51% reduction in GHG reduction by 2030 compared to 2018 levels.

To achieve these climate goals, the Climate Act introduces key policy mechanisms, including carbon budgets and SECs. Carbon budgets set an upper limit on the total GHG emissions allowed over periods of five years, ensuring emissions remain in line with reaching Ireland's climate objective. If emissions for any given carbon budget exceed the carbon budget, the exceedance must be removed from the subsequent carbon budget. The SECs set sector specific emission limits, defining the maximum allowable emissions from each sector within a given carbon budget.

The Climate Act mandates the CCAC to recommend carbon budget programmes. These budgets must align with an intermediate mitigation target for 2030, and the objective of achieving climate neutrality by 2050 at the latest. Under the Act, the CCAC is also to take account of several other factors when recommending carbon budgets, including the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, as well as climate justice, the most recent GHG emissions inventories and projections, relevant scientific advice, international best practices on GHG reporting, and maximising employment and economic competitiveness. Additionally, the CCAC must ensure carbon budgets are consistent with targets under EU law.

The first two carbon budgets (CB1 and CB2) were formally adopted in 2022 (DECC, 2022a), covering the periods 2021-2025 and 2026-2030 respectively, see Table 1. The CCAC has recently proposed the third (2031-2035) and fourth (2036-2040) carbon budgets as part of the second carbon budget programme (CCAC, 2024).

	CB1	CB2	CB3 (proposed)	Provisional CB4 (proposed)
CB Period	2021-2025	2026-2030	2031-2035	2036-2040
Carbon Budget ($MtCO_2eq$)	295	200	160	120

Table 1 Carbon budgets 1 and 2, and proposed carbon budgets 3 and 4

Within the limits of the approved carbon budgets, the Climate Act requires the Minister for the Environment, Climate and Communications to prepare the SECs for each sector, to be submitted to approval to the Government after carbon budgets are approved. The SECs for the first two carbon budget periods were approved by government in 2022 (DECC, 2022b). Table 2 presents the 2018 baseline emissions for each sector and their respective emissions ceilings, highlighting the sector-specific limits that must be adhered to in order to achieve Ireland's overarching decarbonisation goals.

However, a notable gap remains. The SEC for LULUCF is yet to be finalised, leaving an uncertainty in the overall emissions reduction framework. Additionally, for the second carbon budget period (2026-2030), there is 26 $MtCO_2$ in unallocated emissions savings, the abatement measures for which need to be identified prior to the second carbon budget period. Climate Action Plan 2024 identified potential measures that may address these, including energy efficiency and demand management, accelerating the clean energy transition, implementing sustainable food and agriculture and deployment of carbon removals technologies (DECC, 2023). However, it is uncertain whether these measures will be implemented at the scale required and how any resulting emissions savings will be allocated across the sectors to address the 26 $MtCO_2$ gap.

	2018 baseline ($MtCO_2eq$)	SEC for 2021-2025 ($MtCO_2eq$)	SEC for 2026-2030 ($MtCO_2eq$)
Electricity	10	40	20
Transport	12	54	37
Built Environment - Residential	7	29	23
Built Environment - Commercial	2	7	5
Industry	7	30	24
Agriculture	23	106	96
Other (F-Gases, Waste & Petroleum Refining)	2	9	8
LULUCF	5	-	-
Unallocated Savings			-26
Total	**68**	**-**	**-**
Legally binding Carbon Budgets		**295**	**200**

Table 2 2018 baseline emissions and sectoral emissions ceilings for carbon budgets 1 and 2

2.1.1 Current projected compliance with national carbon budgets and SECs

Based on current projections from the EPA, Ireland is not on track to meet it's 2030 emissions reduction target of 51% (relative to 2018), carbon budgets, and sectoral emissions ceilings. These projections are based on the Environmental Protection Agency's (EPA) "With Existing Measures" (WEM) scenario and "With Additional Measures" (WAM) scenario. The WEM scenario is a projection of future emissions based on the measures that are currently implemented and actions committed to by Government, while WAM includes all policies and measures included in the WEM scenario, plus those included in Government plans but not yet implemented (EPA, 2024a).

Figure 1 details the projected emissions pathways for WEM and WAM, and the annualised carbon budgets for carbon budgets 1-2, and the CCAC's proposed carbon budgets 3 and 4[1]. By 2030, under WEM projections, Ireland's total GHG emissions (including LULUCF) will fall by 9% relative to 2018, and under WAM emissions will decrease by 27% for WAM, both far short of the 51% emissions reduction target (relative to 2018).

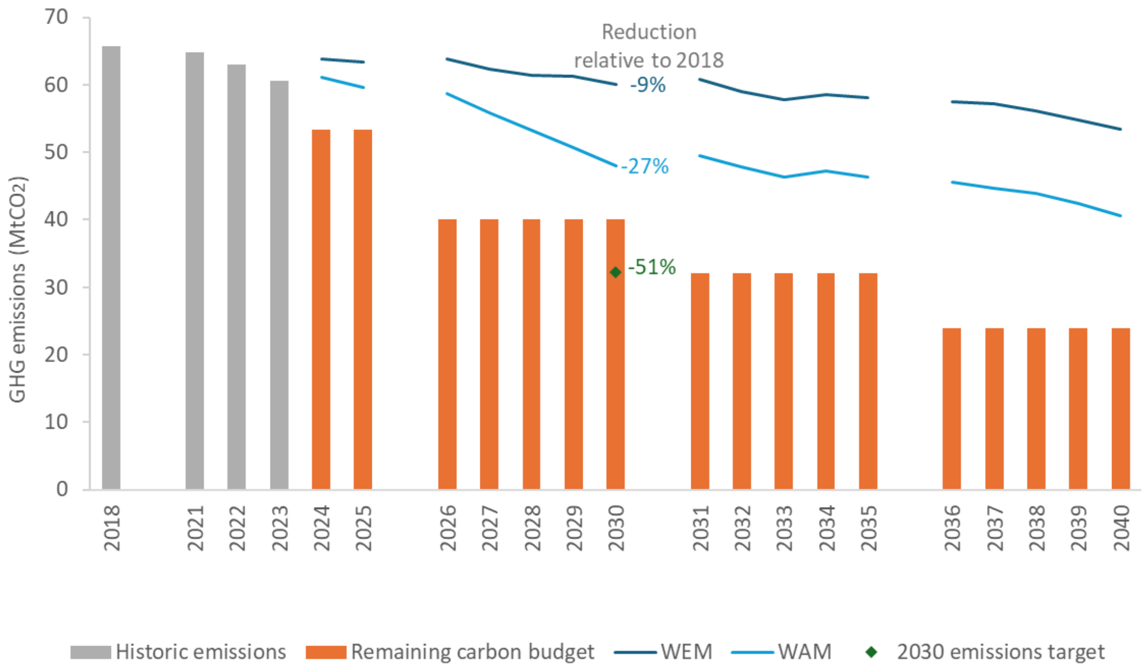


Figure 1 Historic emissions and annualised carbon budgets compared to WEM and WAM projections (including LULUCF emissions)

Around 64% of the first carbon budget has been used up in the first 3 years of the 5-year carbon budget period, leaving a maximum of 107 $MtCO_2$ to be emitted in 2024 and 2025. However, WEM and WAM projections show that sectoral emissions ceilings and carbon budgets will be exceeded in both CB1 and CB2. Table 3 details the projected sectoral emissions overshoot and total carbon budget overshoot for CB1 and CB2. Emissions in 2021-2025 are expected to exceed the carbon budget of 295 $MtCO_2$ by 21 $MtCO_2$ in WEM projections and 14 $MtCO_2$ in WAM projections (including emissions from LULUCF). For CB2, emissions are projected to exceed the 200 $MtCO_2$ allowance by 109 $MtCO_2$ under WEM and 67 $MtCO_2$ under

[1]The analysis presented in this report uses GHG emissions data from the EPA's Provisional Greenhouse Gas Emissions 1990-2023 (EPA, 2024b) and projections data from Ireland's Greenhouse Gas Emissions Projections 2023-2050 (EPA, 2024a). The EPA projections are based on the 2022 final inventory, whereas the 2023 provisional inventory includes methodological revisions – particularly in the agricultural sector – that are not reflected in the projections. Therefore, there may be slight discrepancies in estimates such as projected overshoot in carbon budget 1, and in emissions reduction figures that are reported in the EPA reports.

WAM. Accounting for the unallocated emissions savings in carbon budget 2, this increases to 135 $MtCO_2$ and 93 $MtCO_2$, respectively.

	Carbon budget 1		Carbon budget 2	
Sector	**WEM**	**WAM**	**WEM**	**WAM**
Electricity	1.3	1.2	5.7	4.2
Transport	3.7	3.6	19.8	12.2
Built Environment - Residential	0.5	0.6	3.6	1.5
Built Environment – Commercial & Public	0.0	0.0	1.1	0.0
Industry	2.5	2.5	7.0	5.7
Agriculture	4.8	2.0	20.1	4.3
Other	0.2	0.2	0.2	0.3
Projected SEC overshoot	**13**	**10**	**58**	**28**
Overall SEC exceedance (Sum of SECs minus CB)	-20	-20	13	13
LULUCF emissions	28	24	38	25
Unallocated savings			26	26
CB overshoot (incl. LULUCF and unallocated savings)	**21**	**14**	**135**	**93**

Table 3 Projected exceedance ($MtCO_2$) of the SECs under WEM and WAM for carbon budgets 1 and 2 including the total projected carbon budget overshoot for each period (excluding overshoot carry forward for CB2). CB overshoot figures for CB2 include unallocated savings.

As carbon budgets are cumulative, any overshoot in one carbon budget period must be carried forward into the next, reducing the allowable emissions for the subsequent budgets. Figure 2 details the projected exceedance of carbon budgets 1 and 2, and the recent proposed carbon budgets 3 and 4, based on current WEM and WAM projections. This includes both projected overshoot for each carbon budget period, and the cumulative overshoot from previous carbon budget periods that are carried forward into the next. When carryover is factored in, the overshoot for WAM projections for CB2 increases from 93 $MtCO_2$ (Table 3) to 107 $MtCO_2$ (see Figure 2). As a result, the cumulative overshoot under current projections exceeds the carbon budgets proposed for both CB3 and CB4. Specifically, under WAM, the projected overshoot for CB3 is 184 $MtCO_2$ (Figure 2, right panel), which is above the proposed carbon budget for that period (160 $MtCO_2$). For CB4, the projected overshoot for WAM (including cumulative overshoot from previous carbon budgets) is 281 $MtCO_2$, which is more than double the proposed carbon budget for that period (120 $MtCO_2$).

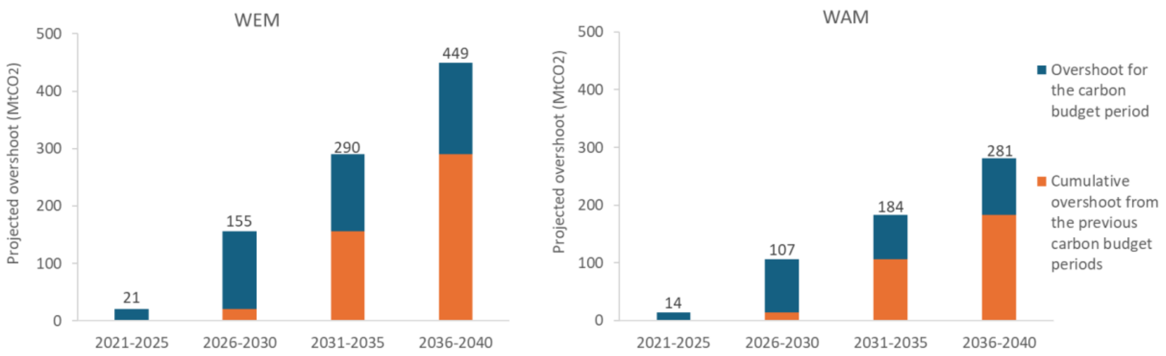


Figure 2 Total projected exceedance of carbon budgets 1 and 2, and proposed carbon budgets 3 and 4 for WEM (left) and WAM (right) projections. This includes the overshoot for each carbon budget period, and the cumulative overshoot carried forward from the previous carbon budget period. Overshoot includes LULUCF and unallocated savings in CB2 of 26 $MtCO_2$.

2.2 EU Climate and Energy Policy Framework

Independent of its national climate commitments, as an EU Member State, Ireland is legally obliged to contribute to targets set out in the EU's climate and energy framework. These targets are separate from Ireland's national targets and carbon budgets and focus on collective EU-wide goals that each Member State must help achieve.

The European Green Deal is the EU's plan to make Europe the first climate-neutral continent by 2050 (European Commission, 2019). This strategy commits the EU to achieving net-zero GHG emissions by 2050, and to reduce emissions by 55% by 2030, compared to 1990 levels. The European Climate Law writes the commitment to net zero emissions in binding legislation, legally obligating the EU to reach climate neutrality by 2050 (European Commission, 2021b). The law also provides a framework for the EU to set intermediate targets, ensuring continuous progress toward achieving the long-term goal.

The EU has outlined a roadmap for achieving its 2030 targets with the 'Fit for 55' package of legislation, which is a comprehensive set of policy initiatives designed to help to set the EU on a path to meeting its 2030 climate target in a fair, cost effective and competitive way. The 'Fit for 55' includes several key pieces of legislation that are relevant to Ireland's energy sector: the Emissions Trading Scheme (ETS), the Effort Sharing Regulation (ESR) and the Energy Efficiency Directive (EED). Country specific targets are imposed for the ESR and the EED. Each Member State is assigned specific national targets and obligations that contribute to the EU-wide targets. These national targets ensure that each Member State takes on a fair share of the overall emissions reductions or final energy consumption targets required to meet the EU's climate commitments.

2.2.1 EU-Emissions Trading Scheme

The EU-ETS is a cornerstone of EU climate policy in reducing emissions from large-scale carbon emitters - including electricity and heat production, large scale industrial manufacturing, and intra-EU aviation. The EU-ETS is based on a 'cap and trade' system, whereby a cap is set on the GHG emissions that can be emitted within ETS sectors, and ETS allowances can be traded, with one allowance equivalent to one tonne of carbon dioxide equivalent (tCO_2eq) that can be emitted. For the EU, this cap decreases annually in line with achieving a 62% reduction in ETS emissions by 2030, relative to 2005. Therefore, as the EU-ETS operates at an EU market level, there is no specific ETS target for individual Member States.

Participants within the ETS are required to surrender enough allowances to cover each tonne of emissions emitted in a year, addressing any shortfall by purchasing additional credits on the carbon market. This incentivises companies to adopt less carbon intensive technologies, as those that reduce their emissions can sell surplus allowances, while participants who exceed theirs face additional costs for their excess emissions.

Within the EU, emissions regulated under the ETS account for around 40% of total emissions (European Commission, 2024a). In Ireland, only 22% of domestic emissions are accounted for under the ETS (excluding LULUCF and international aviation). A greater proportion of Ireland's emissions are not accounted for under the ETS because of the GHG-intensive nature of agricultural activity – the sector accounts for 38% of total emissions - and transport, which accounts for 21% (excluding emissions from the LULUCF sector) (EPA, 2024b). The Irish State does not face specific targets for reducing emissions under the ETS. However, these emissions (excluding international aviation) are covered under the domestic carbon budget programme.

Figure 3 details the ETS emissions per capita in the EU for stationary installations (power plants, industrial plants and other large energy users). On a per capita basis, Ireland's ETS emissions from stationary installations are approximately 2.3 tCO_2, placing it just below the average for EU Member States. Nevertheless, Irish ETS emissions are in a good position to meet – or exceed – the overall EU ETS emissions reduction target, due to high renewable energy potential in the power sector and a lower share of emissions from heavy industry.

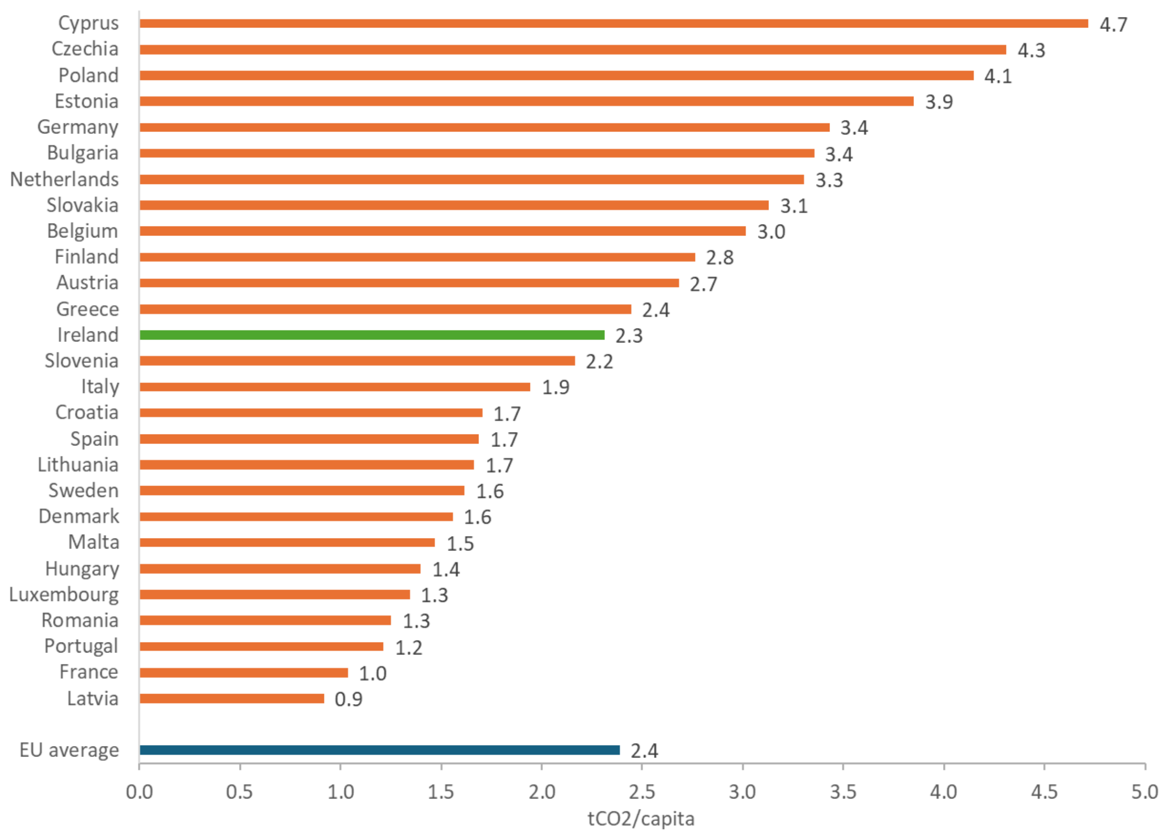


Figure 3 2023 EU-ETS emissions per capita by country for stationary installations. Source: own calculations based on ETS emissions data from the European Environment Agency (EEA, 2024) and population data from Eurostat (Eurostat, no date)

2.2.1.1 Current projected compliance with the EU-ETS

While the EU-wide target of a 62% reduction in emissions by 2030 (relative to 2005) is not binding at the individual country level, applying this target to Ireland's ETS emissions provides a useful benchmark to assess national progress toward compliance and overall climate ambition within the ETS framework. WEM and WAM projections indicate that Ireland's ETS emissions will fall by 61% under WEM, and 67% under WAM projections by 2030 (relative to 2005; Table 4). These figures are for stationary installations and domestic aviation only, and do not include international aviation emissions (for intra-EU travel), which are within scope of the ETS[1]. In other words, with existing policies, Ireland's ETS emissions are nearly on track to meeting the European average target, whereas with additional measures, the target will be over-achieved.

	2005	2030		
	Baseline	Target	WEM	WAM
Emissions ($MtCO_2$)	22.3	8.5	8.7	7.5
Emissions reduction	-	-62%	-61%	-67%

Table 4 Projected ETS emissions (excluding international aviation) under WEM and WAM scenarios compared to the 2030 emissions target equivalent to the EU target of 62% emissions reduction on baseline emissions (2005).

2.2.2 Effort Sharing Regulation

The Effort Sharing Regulation (ESR) (Regulation 2023/857) is one of the key pieces of the EU's climate policy framework. Initially adopted in 2018 and amended in 2023, the ESR sets binding GHG emissions reductions targets for Member States in sectors not covered by the EU-ETS – including agriculture, road transport, buildings, light industry and waste (collectively referred to as ESR sectors), but excludes the LULUCF sector. Collectively these ESR sectors account for approximately 60% of the EU's total GHG emissions. To achieve the EU's overall target of a 55% reduction in emissions by 2030 (compared to 1990 levels), a 40% cut in emissions from ESR sectors is required by 2030, relative to 2005 levels. The ESR ensures that each Member State contributes fairly to this goal, with countries with a higher GDP per capita assigned more ambitious reduction targets.

The regulation sets Annual Emissions Allocations (AEAs) for each Member State, which defines binding annual limits on GHG emissions for the period 2021-2030. These AEAs decrease each year, based on a trajectory to meet the 2030 emissions reduction target. Flexibilities are allowed within the ESR framework, enabling Member States to bank, borrow or trade emission allowances under specific conditions. If a Member State fails to meet its annual obligation in any year, even with the use of flexibilities, the shortfall is multiplied by a factor of 1.08 and this penalty is added to the following year's obligation.

The Commission Implementing Decision (EU) 2020/2126 initially implemented the AEAs for 2021-2030 for each Member State, but in the 2023 amendment, ambition was increased, implementing AEAs only for the period 2021-2025 (European Commission, 2023a). Post-2025 AEAs are not explicitly stated in the regulation but the method for calculating these is established. The 2025-2026 AEAs will be determined by the European Commission in 2025

[1] Emissions from international aviation are not included as part of Ireland's national emissions inventory but are reported to the EU and the United Nations Framework Convention on Climate Change (UNFCCC) as "memo items". International aviation emissions are also not included in national WEM and WAM projections.

based on GHG emissions from 2021, 2022 and 2023. This introduces some uncertainty regarding the exact allowances for the second half of the decade, until the new AEAs are published.

As part of the ESR, Ireland's GHG emissions target for 2030 is a 42% reduction below 2005 figures, with binding AEAs for 2021-2025 as shown in Figure 4. The 2026-2030 AEAs, while yet to be confirmed, are shown in Figure 4, based on figures from the EPA which have been estimated as per the methodology in the 2023 amendment of the ESR (EPA, 2024a).

There are two flexibilities available under the ESR; EU-ETS and Land Use, Land Use Change and Forestry (LULUCF). The EU-ETS flexibility allows the use of ETS allowances to help offset emissions in ESR sectors, which would otherwise be auctioned. For Ireland, the annual number of credits available is based on 4% of ESR emissions in 2005, which is 1.91 $MtCO_2$ each year. Ireland has confirmed its intention to avail of the full use of this flexibility (DECC, 2024a). The LULUCF flexibility is based on credits from action undertaken in the LULUCF sector and is equivalent to 26.8 $MtCO_2eq$ from 2021-2030 for Ireland, which is separated into two periods (2021-2025 and 2026-2030), with the credits for each period capped at half of the total allowance (13.4 $MtCO_2eq$ available in each period). However, a change in the LULUCF accounting rules post 2026 in LULUCF Regulation (EU) 2018/841, means there is a high level of uncertainty whether LULUCF credits will be available for 2026-2030. Therefore, an estimated 2.68 $MtCO_2eq$ is available to Ireland for each year from 2021-2025 only.

The AEAs including these flexibilities is shown in Figure 4, both annually and cumulatively, to meet the overall 42% reduction target for Ireland. The maximum ESR emissions that can be emitted from 2021-2030 is 370 $MtCO_2$, excluding the use of flexibilities.

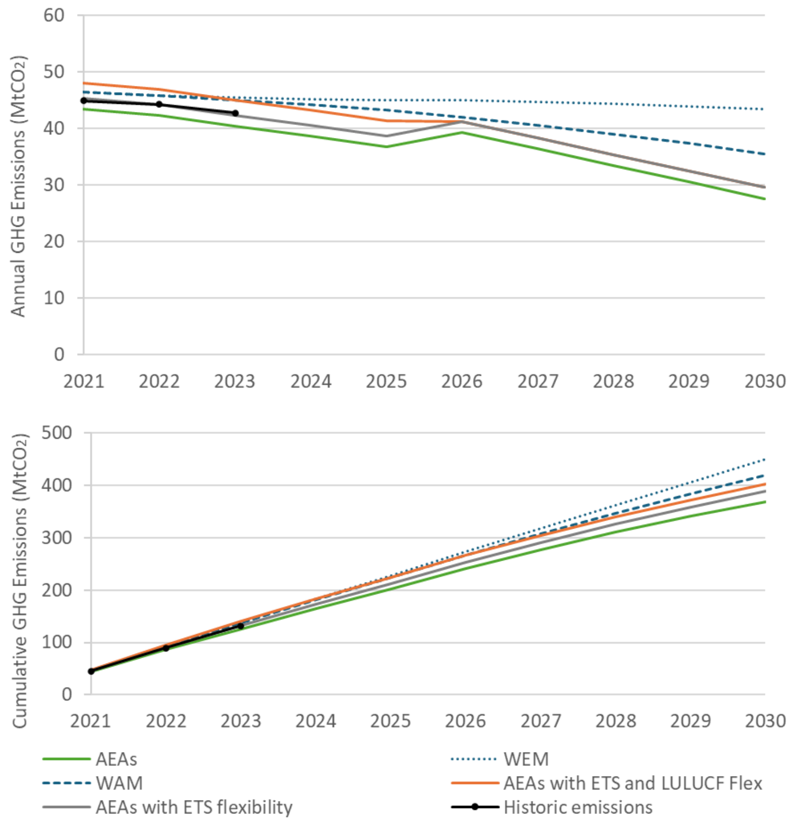


Figure 4 Ireland's Annual Emissions Allocations and historic emissions for ESR emissions, with WEM and WAM projections, shown annually (top) and cumulatively (bottom)

2.2.2.1 Current projected compliance with the ESR

Under current and planned policies, Ireland is projected to fall significantly short of the ESR targets. The projected emissions for WEM and WAM scenarios is also shown in Figure 4. Under the WEM scenario, ESR GHG emissions fall by 9% by 2030, relative to 2005, while in the WAM scenario, emissions fall by 26% over the same period, both falling significantly short of achieving the binding 42% target. Ireland's ESR emissions have already exceeded allowed AEAs for 2021 – 2023 and are projected to cumulatively overshoot AEAs by 45MtCO_2eq under WAM and approximately 74 Mt CO_2eq under WEM. If Ireland does exceed its allowance, to remain in compliance, Ireland will either have to buy credits from other Member States who have over-performed against their AEAs or be faced with infringement fines for non-compliance.

The exceedance is the largest across all EU Member States in terms of percentage points and the largest on a per-capita basis (Figure 5 and Figure 6). Analysis undertaken by the Irish Fiscal Advisory Council (IFAC) and the CCAC estimates that Ireland could face up to as high as €16 billion in compliance costs due to exceeding AEAs under the ESR (IFAC and CCAC, 2025). This cost is projected to range between €5 - €16 billion under WEM and falls to €3 - €10 billion under WAM.

Figure 5 Member State Annual Emissions Allocations exceedance in 2030 per capita. Source data: Climate Action Progress Report (European Commission, 2024a)

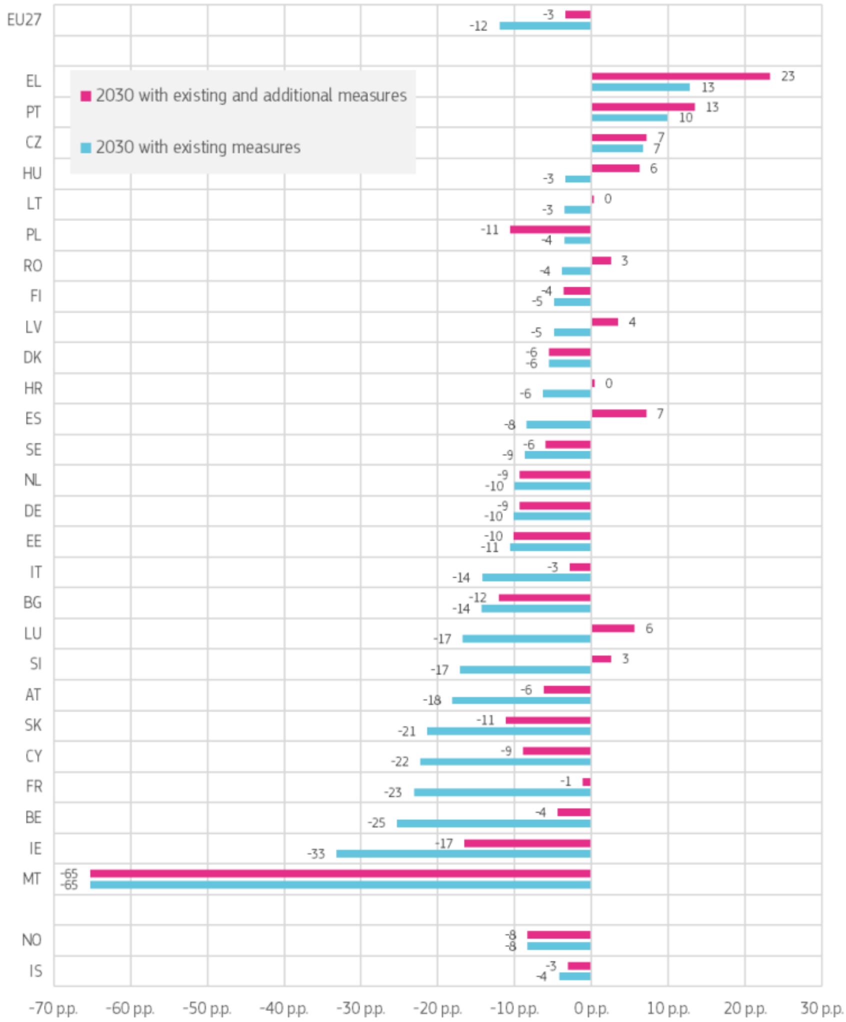


Figure 6 Gap between ESR 2030 targets and projected GHG emissions (in percentage points). Source: Climate Action Progress Report (European Commission, 2024a)

2.2.3 Energy Efficiency Directive

The recast Energy Efficiency Directive (Directive 2023/1791) is another key aspect of the EU's 'Fit for 55' package, that aims to reduce overall energy consumption within the EU, contributing to climate targets, improving energy security and reducing energy costs (European Commission, 2023b). The directive establishes a binding target at the EU level to lower final energy consumption (FEC) and requires each Member State to set an indicative (non-binding) national target to contribute to the overall achievement of the EU target[1]. Under the EED, FEC includes international aviation and excludes ambient energy[2].

Article 4 of the recast EED sets a binding target of limiting FEC in the EU in 2030 to 763 Mtoe, a 11.7% reduction compared to the 2030 final energy projections in the 2020 EU Reference

[1] Final energy consumption (FEC) refers to the energy that is used directly within end-use sectors, including transport, industry, buildings, agriculture, and other end-use sectors, and excludes energy lost during transformation and distribution.

[2] Ambient energy refers to thermal energy that is available in the environment, such as in water or air, that is typically extracted via heat pumps for space heating

Scenario, which projected final energy in 2030 of 864 Mtoe (European Commission, 2021a). The Irish Government approved and notified the European Commission of an indicative target for a final energy consumption in 2030 of 10.451 Mtoe, a 12.6% reduction on 2022 levels (DECC, 2024b).

2.2.3.1 Current projected compliance with the EED

Meeting the 2030 EED target will be extremely challenging given that the target is for an absolute reduction in final energy consumption, and any energy efficiency measures implemented to achieve energy savings will have to be sufficient to overcome huge growth in energy demand expected over the coming years. Ireland is not currently on track to meet the 2030 target, and is expected to exceed the 2030 final energy consumption target by around 20% to 30% (SEAI, 2024b), with a final energy consumption in 2030 of 13.3 Mtoe for WEM and 12.5 Mtoe for WAM, as shown in Figure 7. WEM and WAM projections also indicate that Ireland will fail to achieve the 10.451 Mtoe target figure by 2040, unless there are significant additional measures introduced to reduce final energy consumption.

There is currently no compliance framework in place for the EED. However, failing to meet these targets may make it more difficult to meet emissions reductions targets, and potentially raise the costs of achieving emissions reductions targets elsewhere (IFAC and CCAC, 2025).

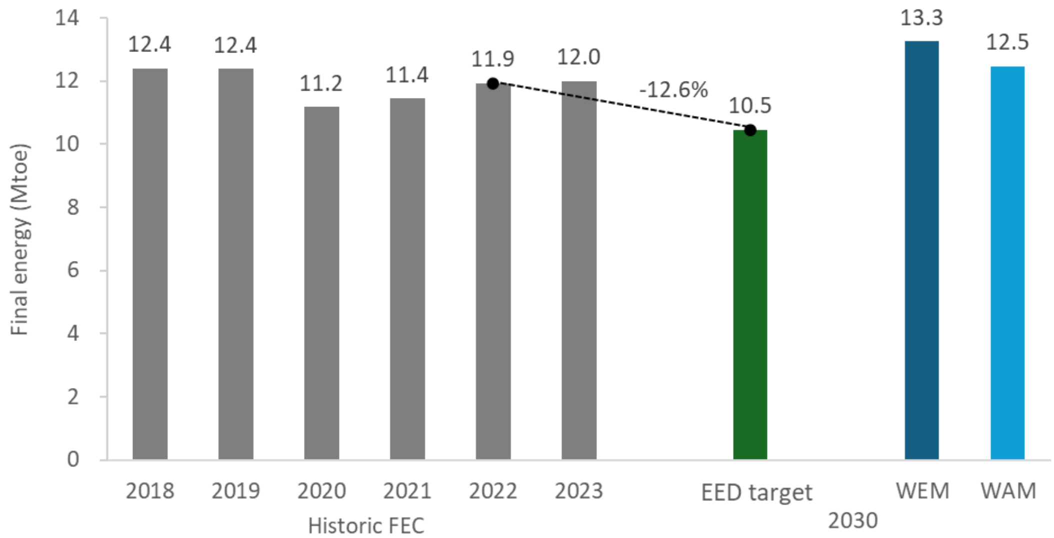


Figure 7 Ireland's historic final energy consumption under the EED and its Article 4 target for 2030. Historic FEC figures taken from the National Energy Balances (SEAI, 2024a) and WEM and WAM projections from the National Energy Projections (SEAI, 2024b)

2.2.4 EU 2040

The European Climate law requires the adoption of a 2040 GHG emissions target within the EU, as a milestone to drive the transition towards climate neutrality in 2050. It also mandates delivery of an indicative GHG budget for 2030 – 2050 that is compatible with the EU's commitment under the Paris Agreement, to pursue efforts to limit global temperature rise 1.5°C (Paris Agreement, 2015), as cumulative GHG emissions determine global warming. In 2024, the European Commission proposed a 2040 climate target, recommending a 90%

reduction in net GHG emissions by 2040 relative to 1990 levels, and a carbon budget limit of 11-14 $GtCO_2eq$ between 2030 and 2050. This target has not yet been formally adopted, nor has any indication been given on how the targets will be allocated to Member States, or how each sector will be treated.

2.2.4.1 Projected compliance with the 2040 EU indicative emissions reduction target

Ireland's projected emissions trajectory falls short when compared to the EU-wide target of a 90% reduction in GHG emissions by 2040, relative to 1990. Total GHG emissions in Ireland in 1990 was 61 $MtCO_2eq$ (including LULUCF). Applying the 90% emissions reduction target to this baseline would require emissions to fall to 6 $MtCO_2eq$ by 2040[1]. However, current projections show that emissions will only fall by 12% relative to 1990 for WEM, and by 33% for WAM, both falling far short of the 90% target (Figure 8).

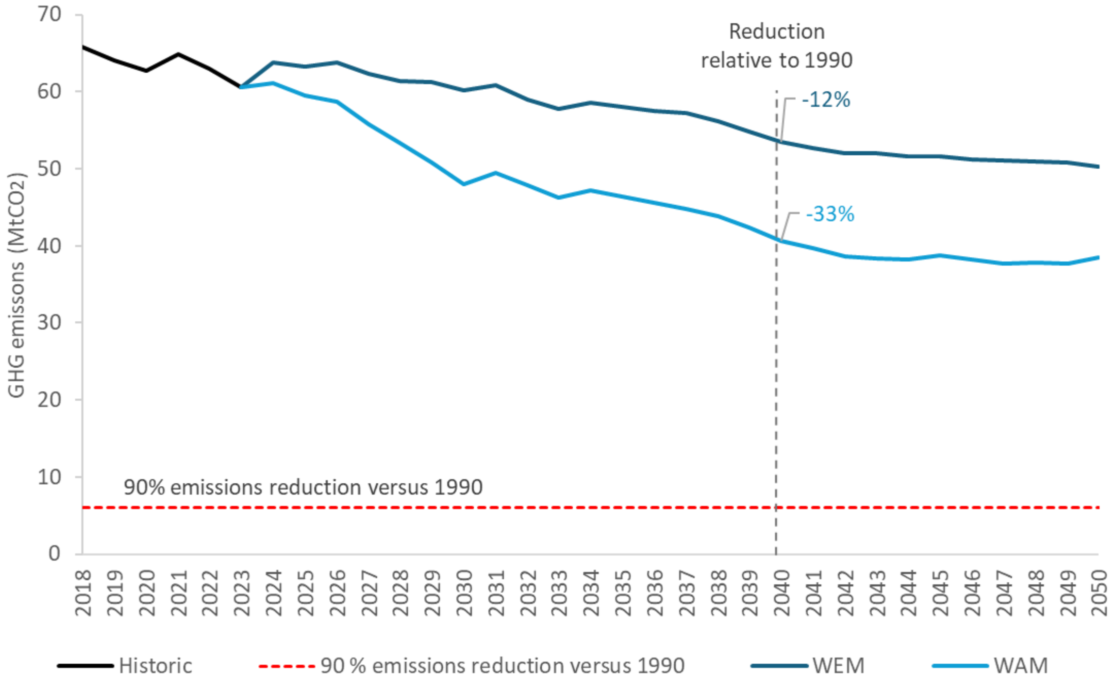


Figure 8 WEM and WAM emissions projections compared to the EU's 90% emissions reduction target, relative to Ireland's 1990 emissions (including LULUCF)

2.2.5 EU energy related targets summary

Table 5 summaries the key targets that will be included as part of this analysis, including the EU-ETS, the ESR, EED and the indicative 2040 GHG emissions target.

[1] The proposed 90% emissions reduction is an EU-wide target. Due to the disproportionately large share of agriculture in Ireland's emissions profile, achieving this scale of reduction is highly unlikely and is shown here for comparison purposes only.

Year	Key Targets	EU	Ireland	Base year
2030	2030 GHG emissions	-55%	-51% (National target)	1990 (EU) 2018 (Ireland)
	EU Emissions Trading Scheme	-62%	No binding target at National level	2005
	Effort Sharing Regulation	-40%	-42% Including binding annual emissions limitations	2005
	Energy Efficiency Directive (Final Energy consumption)	-11.7% 2030 FEC limited to 763 Mtoe	-12.6% 2030 FEC limited to 10.451 Mtoe	2030 energy projection in the 2020 EU Reference Scenario (EU) 2022 (Ireland)
2040	2040 GHG emissions	-90% (indicative)	-68% (proposed by CCAC)	1990 (EU) 2018 (Ireland)

Table 5 Summary of the key targets for the EU and Ireland considered in this study

3 Carbon budget scenarios

This report explores the alignment of energy-related targets for the EU with energy system scenarios that are consistent with national carbon budgets. These scenarios are based on several future potential pathways of the Irish energy system, comprised primarily of energy system scenarios which were developed by the UCC Energy Policy and Modelling (EPMG) to support the CCAC Carbon Budget proposal 2031-2040 (Daly *et al.*, 2024). These scenarios, forming the basis of this analysis, are derived from those shortlisted by the CCAC in their carbon budget recommendation to government (CCAC, 2024) and a more ambitious carbon budget scenario, described in Section 3.1. An additional scenario, *TIM-CBaligned,* which aligns with the CCAC's proposed carbon budget is derived from these scenarios and is outlined further in Section 3.2.

3.1 TIM carbon budget scenarios

As part of the Carbon Budget's Working Group (CBWG) for the second carbon budget programme, UCC EPMG modelled future potential pathways for Ireland's energy system, consistent with varying levels of climate ambition, using the TIMES-Ireland Model (Balyk *et al.*, 2022). These are based around five carbon budgets for the 2021-2050 period, ranging from 250 $MtCO_2$ to 450 $MtCO_2$ (Figure 9) which impose a constraint on the total GHG emissions from the sectors covered in TIM - fossil fuel combustion in power generation, buildings, transport and industry, and excluding emissions from international shipping and aviation. These five carbon budget scenarios are consistent with Ireland's per-capita share of the global remaining carbon budget under different levels of future warming.

To account for the mandated SECs under the first two carbon budgets for the energy sectors, an additional CB constraint of 275 Mt was applied for 2021-2030. Figure 9 details the five CBs analysed as part of the EPMG analysis, the carbon budget of 275 Mt for 2021-2030 to account for the SECs, and the remaining carbon budget for each scenario for the 2021-2030 period. These five scenarios are modelled using a business and usual (BAU) projection for energy services demand and are named to reflect the carbon budget they represent.

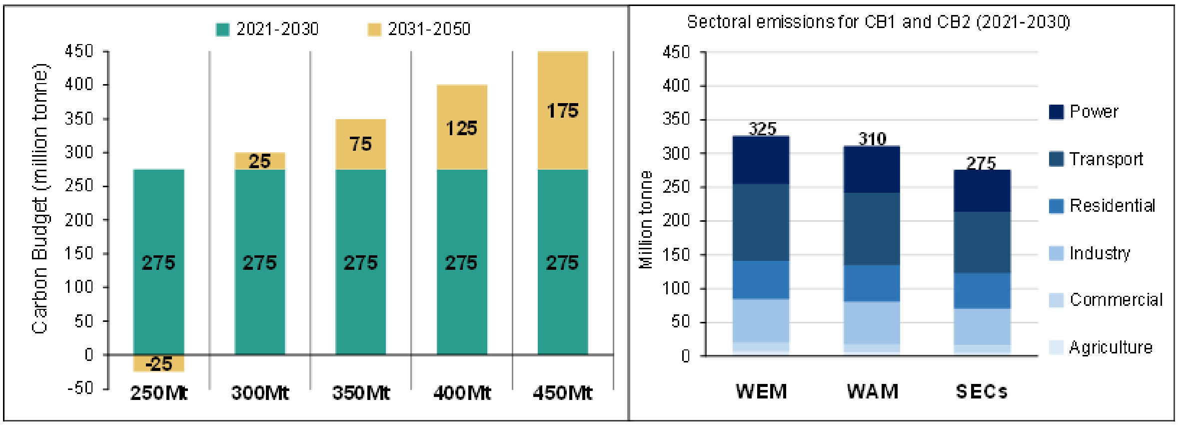


Figure 9 Carbon budget scenarios for the energy system compared to carbon budgets committed during carbon budgets 1 & 2, and the remaining carbon budget from 2031-50 (left panel), and energy system sectoral emissions for carbon budgets 1 & 2 (right panel), from EMPG Carbon Budget Analysis for the Second Carbon Budgets Working Programme (Daly et al., *2024)*

Additional scenarios are included as part of this modelling, including a *Low Energy Demand (LED)* scenario, which lowers energy services demands across industry, transport and building sectors by applying different energy service demand rates, compared to BAU demand. The full LED assumptions are available in Gaur *et al.*, (2022). Additionally, several scenarios explore greater or lower technological deployment potentials. *LowBio* scenarios limits biomass imports to current levels, preventing any increase beyond existing import levels. These scenarios are applied to the five carbon budgets and are denoted with the suffix *LED* or *LowBio*. For example, 350Mt-LED represents a total carbon budget of 350 Mt of CO_2 for 2021-2050, with low energy demand projections[1].

The scenarios are delivered using the TIMES-Ireland model, an established modelling tool which represents the Irish energy landscape and model future potential pathways for Irelands energy system, examining varying levels of ambition, covering energy supply, electricity, transport, buildings and industry sectors (Balyk *et al.*, 2022).

The TIM scenarios included as part of this analysis are as follows: *250Mt-LED, 300Mt, 300Mt-LED, 300Mt-LowBio, 350Mt, 350Mt-LED, 350Mt-LowBio*. The are selected as they are listed in the 15 shortlisted scenarios from which the CCAC derived its third and fourth carbon budget recommendations for government (Table 6). Although not included in the CCAC 15 shortlisted scenarios, the *250Mt-LED* scenario is included to represent the highest level of ambition developed by the EPMG in informing the third and fourth carbon budgets.

[1] https://epmg.netlify.app/TIM-Carbon-Budget-August_2024/about

Scenario	Energy Scenario	Agriculture and Land Use scenario	CB3 (Mt CO_2eq)	Provisional CB4 (Mt CO_2eq)
Scenario 1	300 Mt-Low Bio	L4-S1_P2	154	121
Scenario 2	300 Mt-Low Bio	L1-S2_P2	150	118
Scenario 3	300 Mt-Low Bio	L4-S2_P2	149	113
Scenario 4	300 Mt	L4-S1_P2	156	119
Scenario 5	300 Mt	L1-S2_P2	153	115
Scenario 6	300 Mt	L4-S2_P2	151	111
Scenario 7	300 Mt-LED	L4-S1_P2	162	122
Scenario 8	300 Mt-LED	L1-S2_P2	158	119
Scenario 9	300 Mt-LED	L4-S2_P2	162	128
Scenario 10	350 Mt	L1-S2_P2	163	132
Scenario 11	350 Mt	L4-S2_P2	162	128
Scenario 12	350 Mt-Low Bio	L1-S2_P2	163	132
Scenario 13	350 Mt-Low Bio	L4-S2_P2	162	128
Scenario 14	350 Mt-LED	L1-S2_P2	171	134
Scenario 15	350 Mt-LED	L4-S2_P2	170	130
Average	N/A	N/A	**159**	**123**
Proposed Carbon Budgets	N/A	N/A	**160**	**120**

Table 6 Shortlisted scenarios from the CCAC Carbon Budget Proposal report (CCAC, 2024)

3.2 Carbon budget aligned composite scenario

To represent the CCAC's proposed energy-sector pathway, a composite scenario - *TIM-CBaligned* - was developed. It is a weighted average of the energy sector trajectories from the fifteen shortlisted scenarios used to determine carbon budgets 3 and 4 (2031–2040) (see Table 6). *TIM-CBaligned* is not a separate model run but is derived from the average of the scenario outputs in the six scenarios shortlisted by the CCAC (*300Mt, 300Mt-LED, 300Mt-LowBio, 350Mt, 350Mt-LED, 350Mt-LowBio)*, weighted according how frequently they appear in the 15 overall shortlisted scenarios, to reflect the average trajectory for energy sectors under the recommended national carbon budgets. It forms the basis for the assessment of target alignments in this report.

4 Alignment of carbon budget scenarios with EU targets

This section outlines the results of the analysis and compares the results of scenarios outlined in Section 3 to the EU energy related targets mentioned in Section 2 (EU 'Fit for 55' emissions targets, the EED, and the 2040 indicative emissions reduction target). Additionally, these scenarios and targets are compared to the EPA's WEM and WAM projections, to identify the gap between Ireland's current trajectory and the measures required to meet these targets. The primary focus is on the alignment of these EU targets with the *TIM-CBaligned* scenario, described above, and the extent to which the energy transition described in this scenario (in terms of technology deployment and demand) departs from assumptions underpinning WEM and WAM. The costs associated with the energy system scenarios are also discussed, including both investment and annual running costs.

4.1 Alignment of carbon budget scenarios with EU 'Fit for 55' emissions targets

The 2030 emissions targets under the EU 'Fit for 55' package are split between ETS and ESR emissions, as discussed previously. For the purposes of projections and scenarios, this analysis makes certain assumptions regarding the allocation of emissions between ETS and ESR, based on how sectors are modelled within TIM. Industry emissions are well defined in TIM and are split between ETS and ESR emissions, based on whether the industry falls within the scope of ETS. All process emissions (from cement production) within the industry sector are counted as ETS, while energy emissions (manufacturing combustion) are split between ESR and ETS. All emissions within power generation are classified as ETS[1], and all emissions from transport and buildings (residential and commercial/public) are ESR emissions[2].

4.1.1 EU-ETS

The EU-wide ETS target of a 62% emissions reduction by 2030 (relative to 2005) applies at the EU level and is not binding at a Member State level. The target covers all sectors within the EU-ETS, including international aviation emissions from intra-EU flights. However, the EU-ETS emissions covered in this analysis are from the industry and power sectors only and exclude emissions from international aviation. Applying the 62% target to Ireland's 2005 ETS emissions for the TIM energy sector (22 $MtCO_2$) would imply a target of approximately 8.3 $MtCO_2$ in 2030.

Figure 10 details the ETS emissions pathways for *TIM-CBaligned*, WEM and WAM, and the CB scenarios with the highest (*250Mt-LED*) and lowest (*350Mt-LowBio*) level of ETS emissions reductions. All CB scenarios surpass the 2030 emissions reduction target, with *TIM-CBaligned* achieving a 77% decrease in ETS emissions by 2030, relative to 2005. While WEM projections fall just short of the target at 61%, WAM achieves a 67% reduction.

[1] Around 8% of GHG emissions in the "public electricity and heat production" subsector of the GHG Inventory fall outside the ETS. However, TIM does not include a breakdown of this sector into ETS and non-ETS.

[2] In the EPAs GHG Inventory <1% of transport emissions (domestic aviation) fall under ETS, but here they are included as ESR emissions.

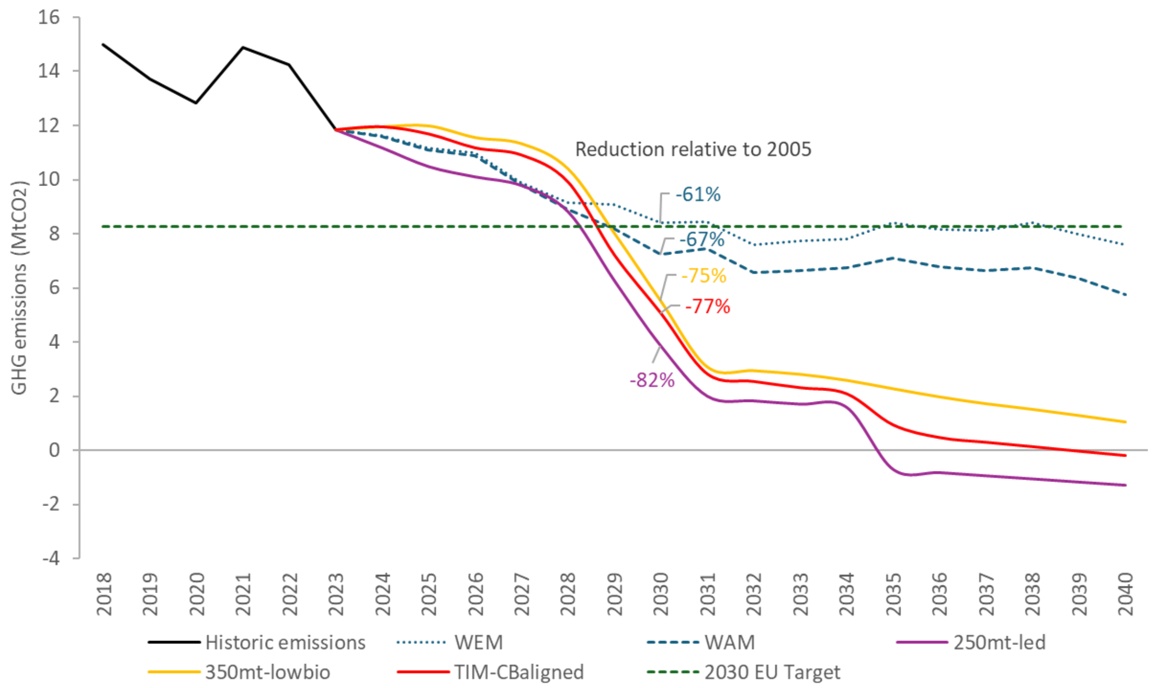


Figure 10 Ireland's ETS emissions by scenario, including only ETS emissions from electricity generation and stationary installations (excludes emissions from international aviation). However, the EU's 62% emissions reduction target (relative to 2005) applies to all ETS sectors, including internation aviation.

Figure 11 shows the 2030 breakdown in ETS emissions between industry and power sectors for WEM, WAM and *TIM-CBaligned* scenarios, along with the historic emissions from those sectors. Industry emissions are split into those from fossil fuel combustion to provide heat, steam and to power equipment, and process emissions, primarily from the cement sector.

The overall trend in ETS emissions reduction by 2030 is largely driven by the decline in power emissions. In *TIM-CBaligned* the reduction is particularly significant, with emissions dropping nearly fivefold from 6.8 $MtCO_2$ in 2023 to 1.3 $MtCO_2$ in 2030. This is due to the expansion variable renewable energy sources, such as solar photovoltaic (PV) and wind, which is discussed in more detail in Section 4.3. In contrast, total industry emissions decline more gradually, decreasing by 25% in *TIM-CBaligned*, 14% in WAM, and remaining unchanged in WEM. In *TIM-CBaligned,* cement process emissions remain at 2023 levels, but fuel combustion emissions decline, due to fuel switching in the industrial sector, which is discussed further in Section 4.3. Cement process emissions rise slightly in both WEM and WAM scenarios, reaching 2.1 $MtCO_2$ in 2030, while fuel combustion emissions in industry fall by 7% and 29% respectively, due to the roll out of energy efficiency programmes for both WEM and WAM, and use of biomethane and carbon neutral heating in WAM.

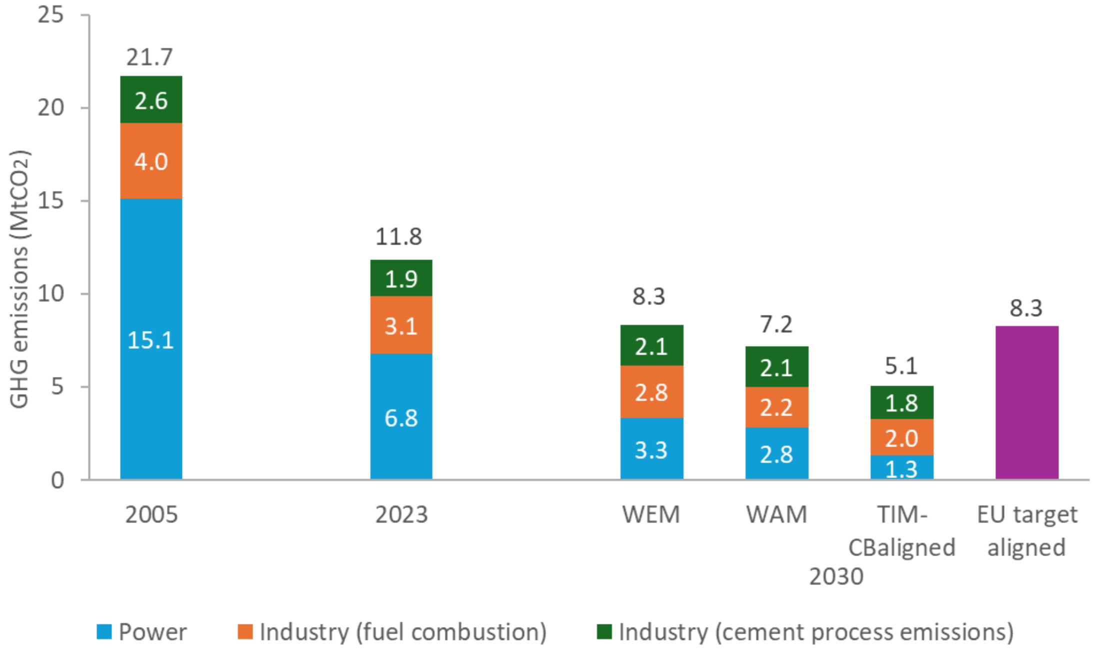


Figure 11 Historic ETS emissions and 2030 projected ETS emissions for WEM, WAM and TIM-CBaligned scenarios, by ETS sector

4.1.2 ESR

Ireland has committed to achieve a 42% reduction in ESR emissions by 2030, relative to 2005, which requires meeting binding annual emissions limits. There is no defined sectoral allocation for the AEAs, and this analysis relies on best estimates to determine the proportion available for the energy sector. Given that agriculture accounts for 38% of total GHG emissions (excluding LULUCF), and approximately half of ESR emissions, the availability of AEAs for the energy sector is significantly influenced by the emissions pathway in the agricultural sector. Therefore, this analysis is exploratory in nature and makes assumptions about agriculture that extend beyond the scope of this project. Other non-energy ESR emissions - waste and f-gases - are not captured within TIM. These currently account for 4% of total ESR emissions and for the purpose of this analysis, they will be included with the agriculture sector.

The estimation of AEAs for the energy system is derived from subtracting various projections of emissions from the agriculture sector for 2021-2030 from the total AEA available for Ireland, as set out in the ESR, and shown previously in Section 2.2.2. The different energy AEAs considered are named after the agricultural emissions projections they use:

- **Agri-2018:** agricultural and waste/f-gases emissions projections based on the 2018 ESR emissions split between energy and agriculture/waste, which is approximately a 50/50 split[1].
- **Agri-WEM and Agri-WAM:** agricultural and waste/f-gases emissions projections from the EPA's WEM and WAM scenarios.

[1] In this scenario, emissions from non-energy sources within the ESR would fall at the same pace as energy-related emissions. No scenario for agriculture emissions assessed by the Council meets this scenario.

- **Agri-CBaligned:** agricultural emissions projections from the CCAC Carbon Budget Proposal agriculture scenario. Like the *TIM-CBaligned* energy scenario, this is based on the weighted average of the agriculture and waste/f-gases emissions across the 15 shortlisted carbon budget scenarios (CCAC, 2024).

Figure 12 shows the resulting AEAs that are available for energy, based on these different agricultural projections (Agri-WEM, Agri-WAM, Agri-CBaligned, and Agri-2018), along with the projected ESR emissions for *TIM-CBaligned*. The total ESR energy emissions reductions achieved by 2030 for this scenario is 63%, compared to 2005 levels.

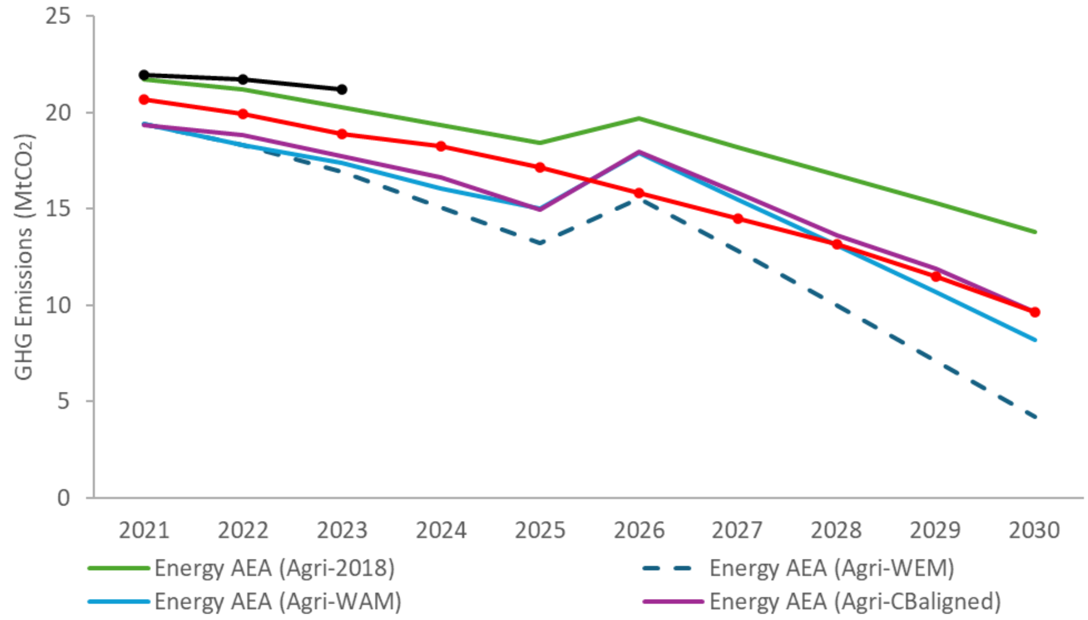
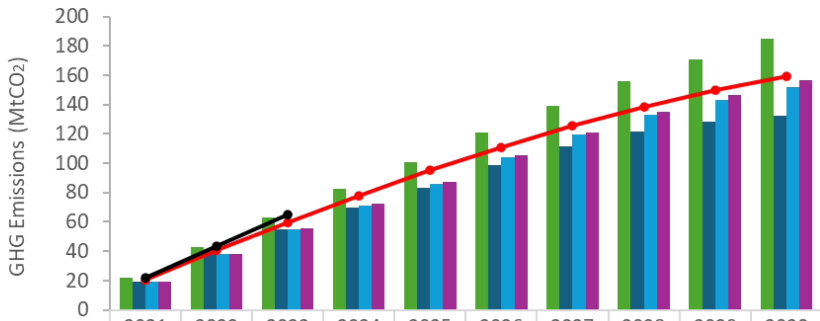


Figure 12 Annual Emissions Allocations available to energy, assuming different agricultural emissions pathways, with the projected ESR emissions pathway for the TIM-CBaligned scenario

Figure 13 details the cumulative AEAs over the 2021-2030 period and the projected emissions from *TIM-CBaligned*, showing that it exceeds the energy AEAs for Agri-WEM, Agri-WAM and Agri-CBaligned. Considering the actual cumulative ESR emissions in 2021 – 2023 for the energy sector, the AEAs have already been exceeded in each of the four AEA pathways. Table 7 details this cumulative overshoot for each energy AEA for 2021-2023. If agricultural emissions follow the WEM pathway, energy sector emissions for 2021-2023 have already exceeded this AEA by 10 $MtCO_2$.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Energy AEA (Agri-2018)	22	43	63	83	101	121	139	156	171	185
Energy AEA (Agri-WEM)	19	38	55	70	83	99	111	121	128	133
Energy AEA (Agri-WAM)	19	38	55	71	86	104	120	133	143	152
Energy AEA (Agri-CBaligned)	19	38	56	73	87	105	121	135	147	156
TIM-CBaligned	21	41	60	78	95	111	125	139	150	160
Actual ESR emissions (energy)	22	44	65							

Figure 13 Cumulative Annual Emissions Allocations available to energy, assuming different agricultural emissions pathways, with the projected ESR emissions pathway for TIM-CBaligned

	Total ESR emissions 2021-2023 ($MtCO_2$)	Energy AEA budget exceeded ($MtCO_2$)
Actual emissions	64.9	-
AEA Agri-2018	63.2	1.8
AEA Agri-WEM	54.6	10.3
AEA Agri-WAM	55.1	9.8
AEA Agri-CBaligned	55.9	9.0

Table 7 Total ESR emissions from the energy sector (2021-2023) based on EPA GHG emissions data, the total budget for each energy AEA, and the amount of the energy AEA that has already been exceeded for 2020-2023.

Figure 14 summarises the cumulative exceedance or compliance with the energy AEAs for several of the CB scenarios analysed for 2021-2030, showing the projected overshoot, and what has already been exceeded (shown in Table 7). The scenarios presented are *TIM-CBaligned*, WEM and WAM, and the scenarios that achieve the greatest (*250Mt-LED)* and smallest *(350Mt-LED)* ESR emissions reduction by 2030*.*

There is significant variation in overshoot across the four energy AEAs, and compliance depends on the chosen agricultural pathway. Assuming the 50/50 agriculture energy split (Agri-2018), cumulative emissions from every CB scenario are well below the cumulative energy AEA. The AEA is exceeded in all scenarios if agriculture follows WEM and WAM agricultural projections. If agriculture follows the Agri-CBaligned energy AEA, only *250Mt-LED* remains within the limit.

For *TIM-CBaligned*:

- **Agri-2018:** cumulative ESR emissions are 23 $MtCO_2$ below the AEA.
- **Agri-WEM:** cumulative ESR emissions overshoot the AEAs by 37 $MtCO_2$.
- **Agri-WAM:** cumulative ESR emissions overshoot the AEAs by 18 $MtCO_2$.
- **Agri-CBaligned:** cumulative ESR emissions overshoot the AEAs by 12 $MtCO_2$.

Utilising the full ETS flexibility (19.1 $MtCO_2$) could help to meet the Agri-WAM and Agri-CBaligned AEAs for *TIM-CBaligned*, which would ensure compliance with the ESR. However, the assumption that either ETS or LULUCF flexibilities can be fully applied to the energy sector depends on agricultural emissions aligning with the projections used to develop the various AEA pathways for energy, as outlined earlier[1]. If agriculture follows WEM projections (Agri-WEM), the combined use of both flexibilities (32.5 $MtCO_2$ in total) would be insufficient for energy sector emissions to comply with the AEAs.

WEM and WAM energy projections exceeds the cumulative emissions allowance for 2021-2030 in all AEA pathways, even with the use of both ETS and LULUCF flexibilities. Additionally, LULUCF flexibilities are uncertain, and their availability is not guaranteed.

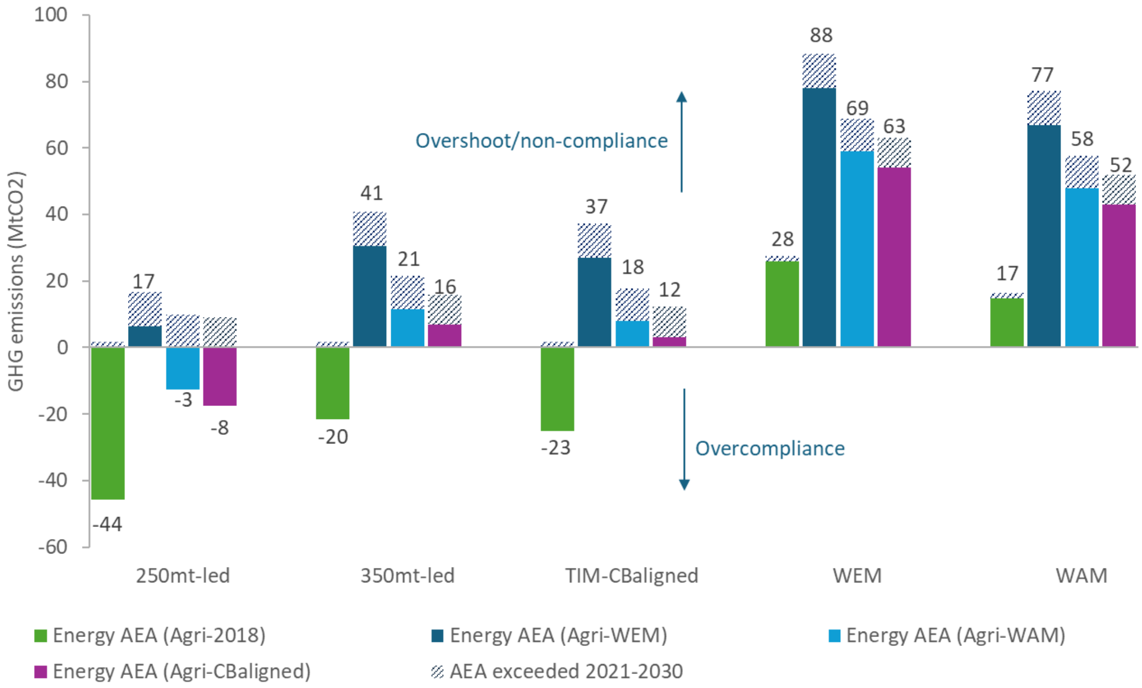
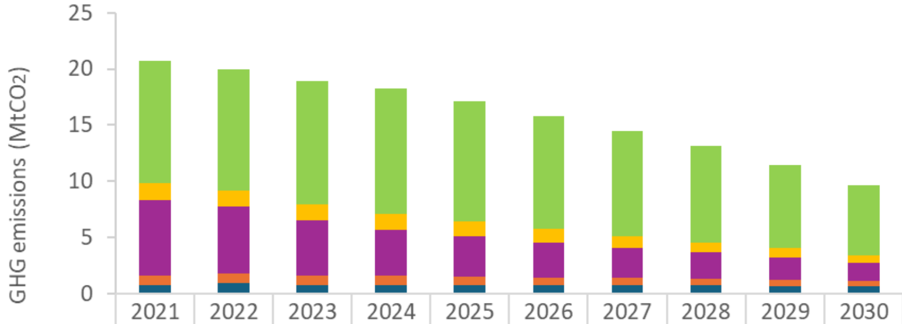


Figure 14 Exceedance of total Annual Emissions Allocation for the energy sector (2021-2030) by scenario, including EPA WEM and WAM projections, based on energy AEAs with different agricultural emissions pathways, including the emissions overshoot in 2021-2023 for each AEA pathway. Note: figures exclude the use of ETS and LULUCF flexibilities.

Figure 15 details the sectoral breakdown for *TIM-CBaligned* ESR emissions, showing transport and building sectors account for around 90% of emissions. Residential buildings achieve the highest emissions cut (71%) between 2021 and 2030, followed by commercial and public buildings (41%), industry (35%) and transport (32%). A detailed breakdown of each sector is discussed later in Section 4.3.

[1]This study focuses solely on energy sector emissions and does not examine in detail how ETS and LULUCF flexibilities may be allocated between energy and agricultural sectors. The extent to which flexibilities could be applied to the energy sector – which largely depends on progress made in reducing agricultural emissions – and the availability of these flexibilities are beyond the scope of this project.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Transport	10.9	10.7	11.0	11.2	10.8	10.1	9.4	8.6	7.4	6.2
Buildings (Commercial & Public)	1.5	1.5	1.4	1.4	1.3	1.2	1.1	0.9	0.9	0.7
Buildings (Residential)	6.7	6.0	4.9	4.1	3.6	3.1	2.7	2.3	1.9	1.6
Industry	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5
Agriculture	0.7	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6

Agriculture Industry Buildings (Residential) Buildings (Commercial & Public) Transport

Figure 15 TIM-CBaligned ESR emissions by sector. Note: Agriculture emissions here are from fuel combustion within the sector

4.2 Alignment of carbon budget scenarios with the EU Energy Efficiency Directive

Ireland's 2030 target under the EED is to limit final energy consumption to 10.451 Mtoe, representing a 12.6% reduction compared to 2022 levels. Figure 16 shows the final energy consumption for each scenario, and the historical FEC emissions from 2015 – 2023. These FEC figures exclude ambient energy (heat pumps) used in residential, commercial and public buildings, and includes internation aviation[1]. The FEC in 2030 for each scenario is detailed in Table 8, detailing the gap to meeting the 2030 FEC target, the change in FEC achieved relative to 2022, and the year that each scenario does reach the target.

250Mt-LED is the only scenario that meets the final energy consumption target, exceeding it by 0.5 Mtoe, a 17% decrease from 2022. The other *LED* scenarios are within 0.5 Mtoe of the target and meet the 2030 target in 2031 and 2032. The 2030 FEC in the remaining carbon budget scenarios falls by between 5% and 9% and come within 1 Mtoe of the target, with TIM-CBaligned meeting the target by 2033. This is significantly closer to achieving the target than WEM and WAM, which are expected to exceed the 2030 target by 2.8 Mtoe and 2 Mtoe, respectively, which is an increase on 2022 figures.

[1] International aviation emissions are not included in national carbon budgets or emissions presented in this report, but FEC for international aviation is included to align with scope of EED. FEC is based on basic fuel demand assumptions modelled within TIM. For BAU and LowBio scenarios, international aviation fuel demand in 2050 increases by 37% compared to 2018 levels (Balyk *et al.*, 2022). In LED scenarios, fuel demand remains at 2018 levels – 1.1 Mtoe based on 0% annual growth rate in fuel demand from Gaur *et al.*, (2022). Further analysis is required to determine accurate international aviation demand projections.

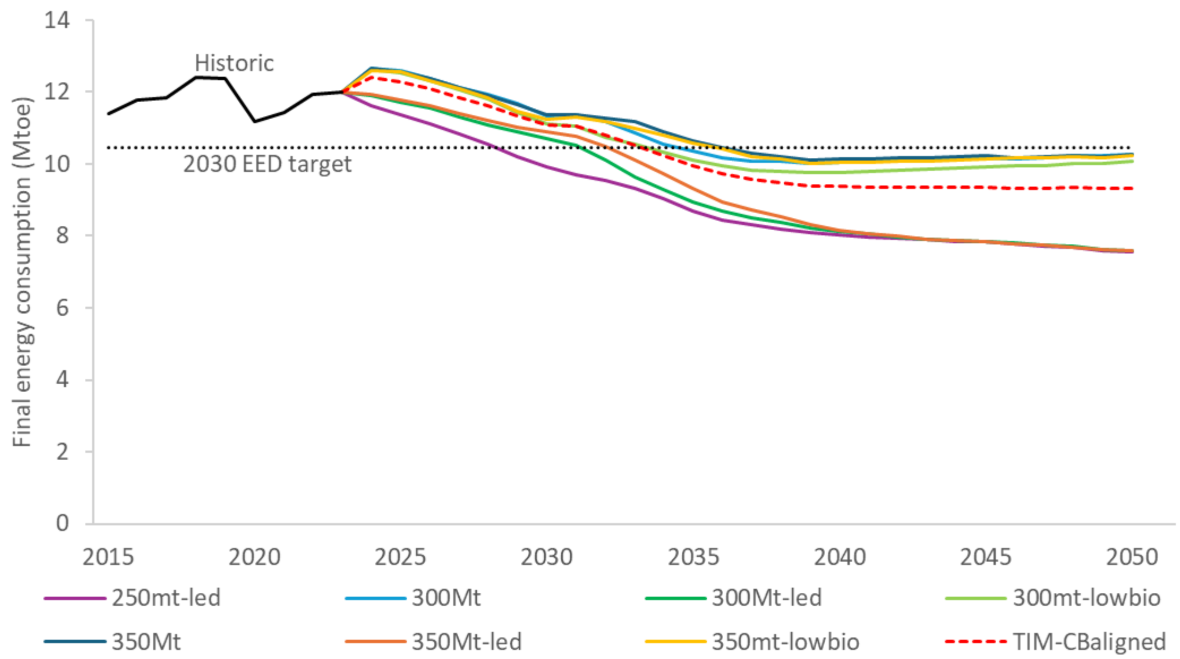


Figure 16 Final energy consumption for each scenario for 2020-2050, compared to the 2030 EED target for Ireland. Final energy consumption figures include international aviation and exclude ambient energy, as per the EED.

Scenario	2030 FEC (Mtoe)	Gap (Mtoe)	FEC change relative to 2022	Year the 2030 EED target is met
Target	10.45	-	-12.6%	-
250Mt-LED	9.90	-0.5	-17.0%	2028
300Mt	11.35	0.9	-4.8%	2035
300Mt-LED	10.71	0.3	-10.2%	2031
300Mt-LowBio	11.11	0.7	-6.9%	2033
350Mt	11.36	0.9	-4.7%	2036
350Mt-LED	10.89	0.4	-8.7%	2032
350Mt-LowBio	11.23	0.8	-5.9%	2036
TIM-CBaligned	**11.10**	**0.6**	**-7.0%**	**2033**
WEM	13.26	2.8	+11.1%	Not met by 2040
WAM	12.46	2.0	+4.5%	Not met by 2040

Table 8 2030 final energy consumption by scenario, gap to meeting the 2030 EED target, change in FEC in 2030 relative to 2022, and year that the 2030 EED target is met

4.3 Sub-sectoral emissions analysis

This section explores each energy system sector in detail comparing the scenarios in this analysis to WEM and WAM projections. This comparison specifically highlights the key sectoral mitigation measures and assumptions drawn from the SEAI National Energy Projections Report (SEAI, 2024b), with a primary focus on the year 2030[1]. This analysis also centres around

[1] Detailed information on sectoral mitigation measures for 2040 is limited in the SEAI National Energy Projections Report for 2040

on *TIM-CBaligned* and the mitigation measures required to achieve emissions reductions discussed previously under the ETS and ESR, as well as the final energy reductions outlined in Section 4.2. Section 4.3.1 first gives an overview of the total GHG emissions pathways, examining how they compare to the overall 2030 and 2040 emissions targets.

4.3.1 2030 and 2040 emissions

The European Commission has proposed an EU wide target of a 90% GHG emissions reduction, relative to 1990. Applying this to Ireland's 1990 energy systems emissions (34 $MtCO_2$) results in a 2040 emissions target of 3.4 $MtCO_2$. Figure 17 details the emissions reduction pathways for the energy sector for the scenarios analysed, compared to the 2040 target. The energy sector emissions in 2030 and 2040 and the emissions reductions achieved relative to 1990 are shown in Table 9.

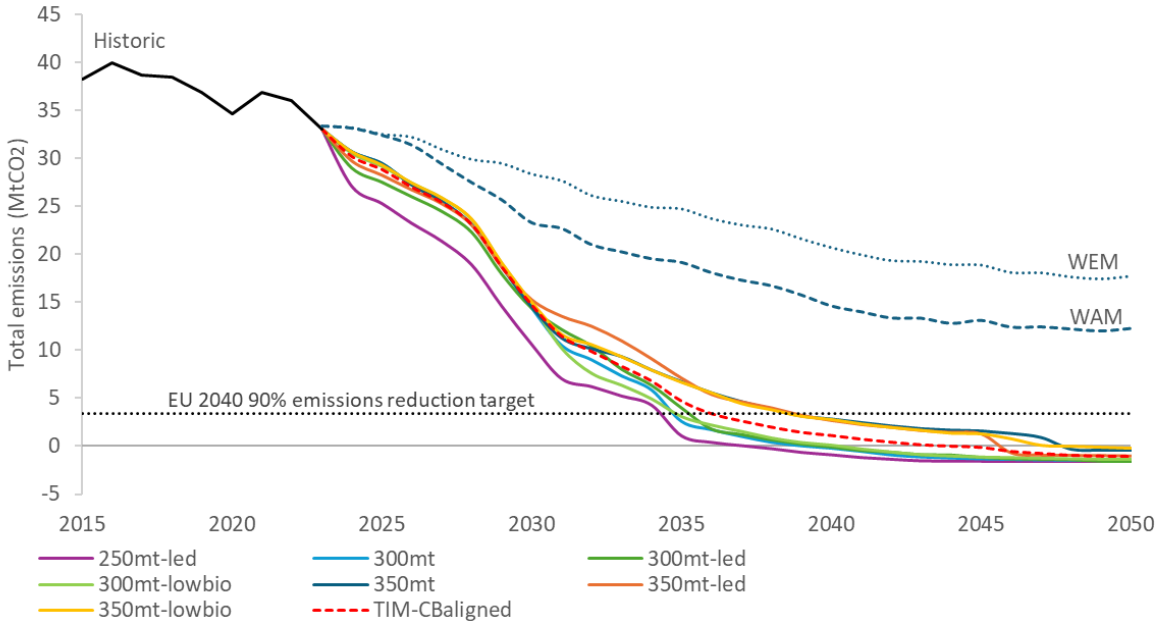


Figure 17 Scenarios emissions pathways, benchmarked against the EU 2040 reduction target of 90% (relative to 1990), applied to Ireland's 1990 energy system emissions

TIM-CBaligned is consistent with a 62% reduction in energy system emissions relative to 2018 (56% relative to 1990) by 2030, with total emissions of 15 $MtCO_2$. In their proposal for the second carbon budget, the CCAC proposed carbon budgets 3 and 4 (covering 2031-35 and 2036-40 respectively) consistent with a reduction in emissions of 68% relative to 2018 (64%, relative to 1990). The energy proportion of this (*TIM-CBaligned*) achieves a reduction of 97% relative to 2018, with emissions dropping to 1.1 $MtCO_2$ in 2040 (Table 9).

	2030		2040	
Scenario	**Emissions ($MtCO_2$)**	**Emissions change relative to 1990**	**Emissions ($MtCO_2$)**	**Emissions change relative to 1990**
250Mt-LED	10.6	-69%	-0.9	-103%
300Mt	14.4	-57%	-0.2	-101%
300Mt-LED	14.4	-57%	-0.1	-100%
300Mt-LowBio	14.8	-56%	0.1	-100%
350Mt	14.5	-57%	2.8	-92%
350Mt-LED	15.3	-55%	2.7	-92%
350Mt-LowBio	15.0	-55%	2.8	-92%
TIM-CBaligned	**14.7**	**-56%**	**1.1**	**-97%**
WEM	28.3	-16%	20.7	-39%
WAM	23.3	-31%	14.6	-57%

Table 9 2030 and 2040 energy sector emissions, and emissions reduction relative to 1990 for each scenario

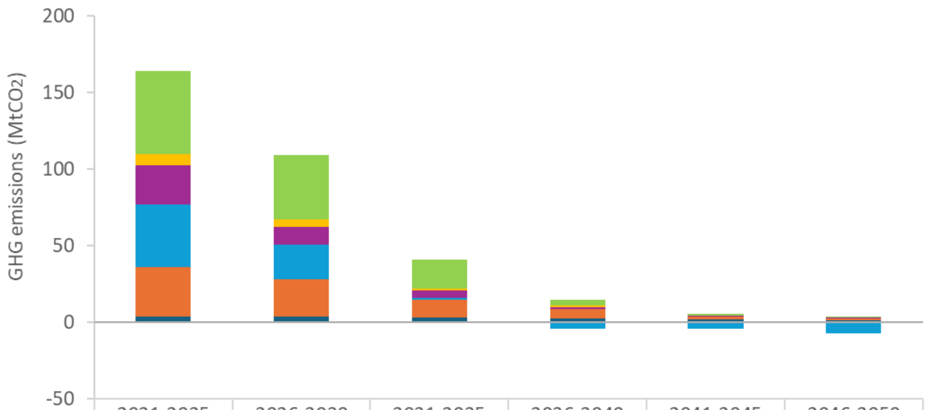
The emissions reductions achieved in individual energy sectors are comparable to those achieved in the scenarios assessed in the European Commission's Impact Assessment (European Commission, 2024b), which underpins the proposed EU 2040 target. For most sectors *TIM-CBaligned* delivers greater emissions reduction than the achieved in the Impact Assessment (Table 10).

	Electricity	**Industry**	**Residential & services**	**Transport**
TIM-CBaligned	-108%	-89%	-97%	-93%
EU Impact assessment scenario[1]	-101%	-92%	-89%	-82%

Table 10 2040 sectoral emissions reduction relative to 1990 for TIM-CBaligned and EU 2040 Impact Assessment scenario.

The total emissions for each carbon budget period to 2050 for *TIM-CBaligned* is shown in Figure 18 broken down by energy sector. The total emissions for carbon budget period 1 and 2 (2021-2030) is 274 $MtCO_2$, in line with the SEC constraints for that period, as mentioned previously in Section 3. In subsequent periods, emissions from the energy sector are 41 $MtCO_2$ for 2031-2035 and 10 $MtCO_2$ between 2036-2040. The sectoral breakdown for these periods illustrates the maximum allowable emissions from the energy sector to remain within the CCAC's proposed carbon budgets - 160 $MtCO_2$ for CB3 and 120 $MtCO_2$ for CB4. The main mitigation measures required to achieve these are discussed in the following sections.

[1] Based on scenario S3 in Part 1 of the EU 2040 Impact Assessment report, which is the most ambitious of the scenarios assessed and forms the basis of the recommendation for the EU 2040 emissions reduction target of 90%. The EU figures are derived using 2040 projections from Table 5 of the Impact Assessment Report Part 1 (European Commission, 2024b), and 1990 emissions data from the European Environment Agency (EEA) data viewer (EEA, 2025)



	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Total	164	109	41	10	1	-5
Transport	55	42	19	4	1	0
Building (Commercial and Public)	7	5	1	1	0	0
Buildings (Residential)	25	12	5	2	0	0
Power	41	23	1	-4	-4	-8
Industry	32	25	12	6	2	1
Agriculture (fuel use)	4	3	3	3	2	1

Figure 18 TIM-CBaligned scenario total emissions by sector for each carbon budget period. (Emissions from Agriculture here are only those from fuel combustion)

4.3.2 Power

Power sector emissions are detailed in Figure 19, which shows the emissions trajectories for *TIM-CBaligned* and the scenarios with upper and lower emission boundaries across the TIM scenarios (*250Mt-LED* and *350Mt*). By 2030, the emissions from the power sector for the TIM and *TIM-CBaligned* scenarios decrease to 2 $MtCO_2$ or lower – roughly half of the levels projected under WEM and WAM. By 2035, emissions turn negative in the *250Mt-LED, 300Mt, 300Mt-LED, 300Mt-LowBio* scenarios, while the *350Mt* CB scenarios reaches negative emissions after 2045. In *TIM-CBaligned,* net-negative power emissions are attained by 2035, with the implementation of Bioenergy with Carbon Capture and Storage (BECCS) power plant. The 200 MW is installed in 2035, increasing to 270 MW by 2040 and nearly 500 MW by 2050, as shown in Figure 20. This generates around 1.5-2.5% of the total electricity and removes up to 0.9 $MtCO_2$ annually by 2040, doubling to 1.8 $MtCO_2$ by 2050.

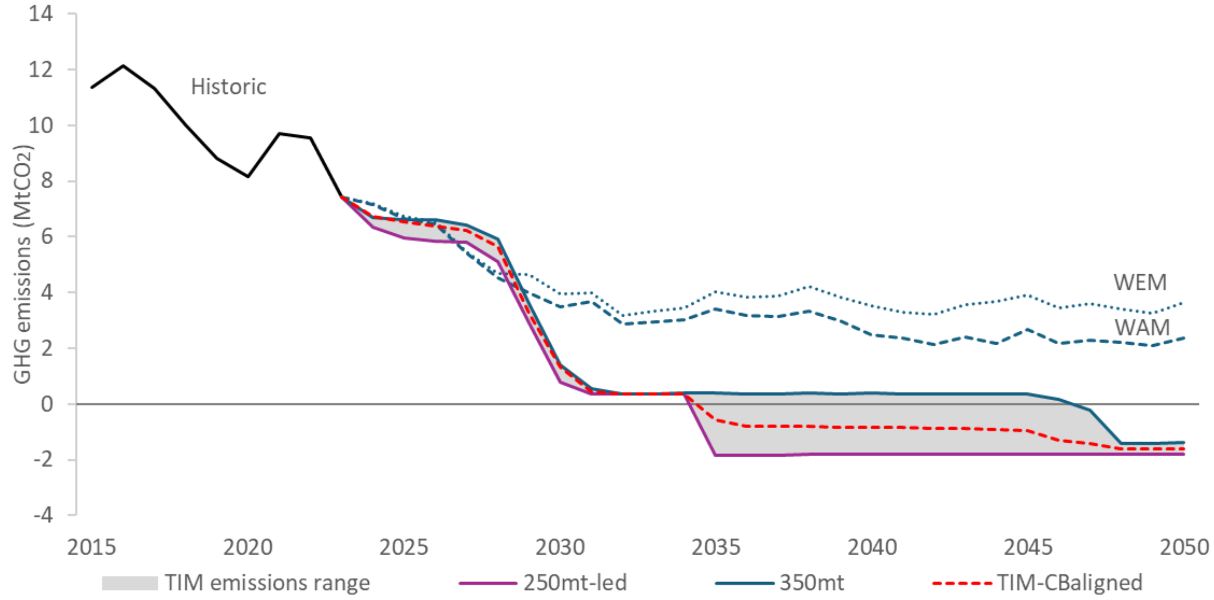


Figure 19 CO_2 emissions pathways in the power sector

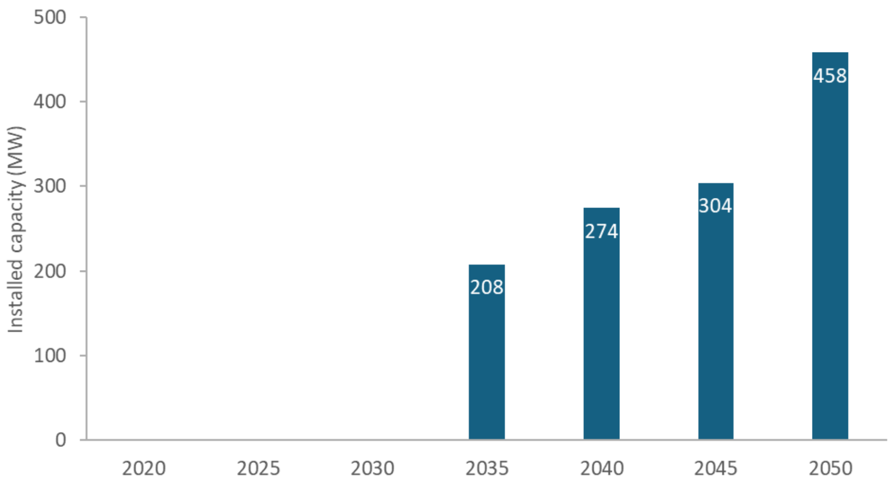


Figure 20 Biomass with Carbon Capture and Storage installed capacity for TIM-CBaligned

In all the TIM scenarios, the use of fossil fuels in electricity generation decreases dramatically after 2030 and is virtually phased out by 2040, after which the mix consists of renewables only. Figure 21 details the generator installed capacity and electricity generation by fuel type for *TIM-CBaligned*. The installed capacities of solar, wind (onshore and offshore), and the renewable energy share in electricity (RES-E) is shown in Table 11 for 2030 and 2040, showing a much higher renewable energy penetration in 2030 than in WEM and WAM.

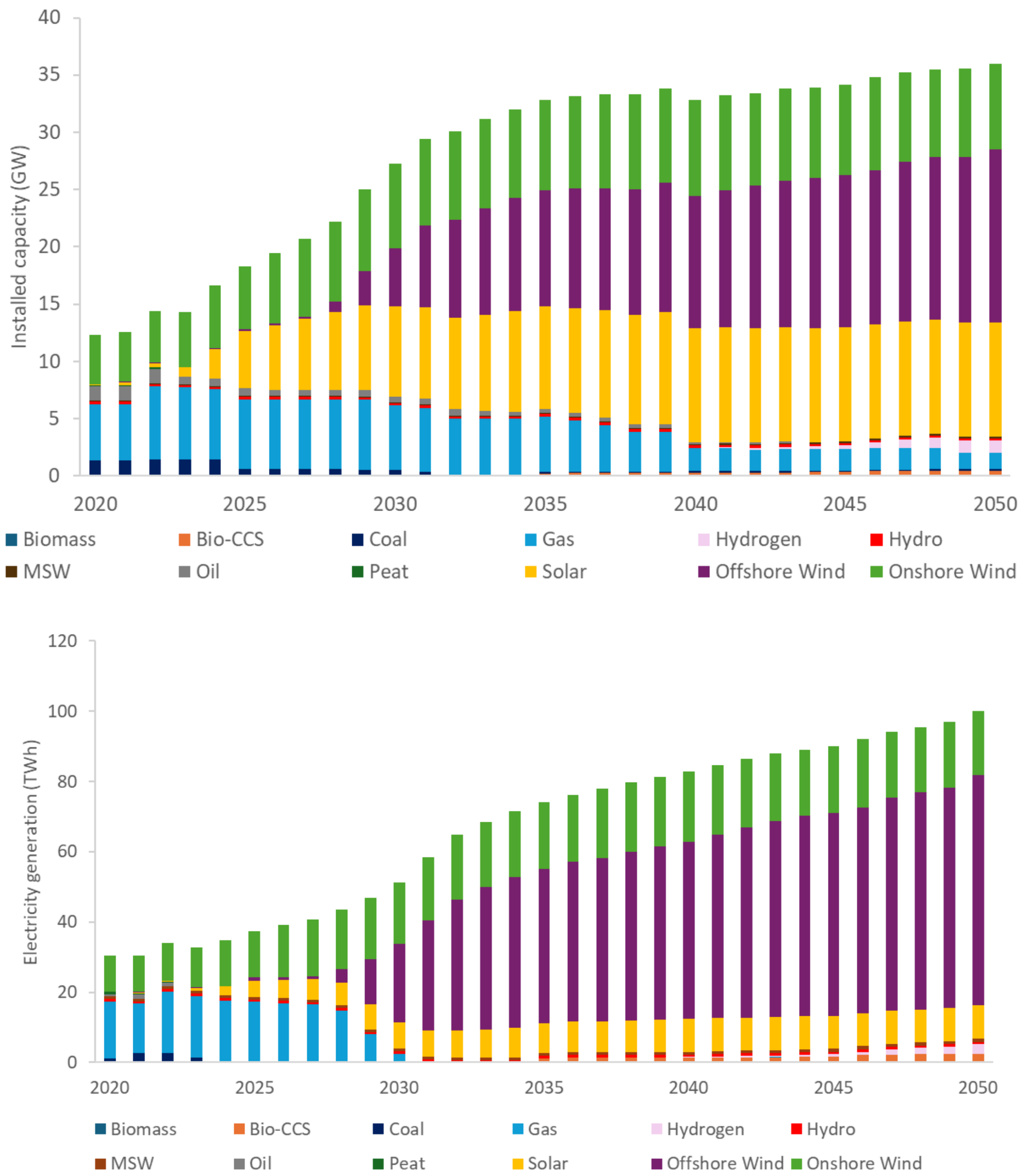


Figure 21 TIM-CBaligned scenario: Power installation capacity by fuel type for the (top) and electricity generation by fuel type (bottom). Bio-CCS – Bioenergy with Carbon Capture and Storage. MSW - Municipal Solid Waste

	2030			2040
	TIM-CBaligned	**WEM**	**WAM**	**TIM-CBaligned**
RES-E (%)	95%	69%	80%	100%
Solar capacity (GW)	8	5.7	6.5	10
Onshore wind capacity (GW)	7.5	6.8	7.2	8.5
Offshore wind capacity (GW)	5	2.7	4	11.5

Table 11 Renewable electricity generation capacity comparison for TIM CB-aligned, WEM and WAM

Electricity demand experiences substantial growth across all sectors. In *Tim-CBaligned*, electricity demand rise by approximately 50% by 2030, compared to 2020. By 2040, it reaches almost 60 TWh, double the 2020 electricity demand, as shown in Figure 22. Electricity's share of total final energy consumption increases significantly – from 22% in 2020 to 36% in 2030 and 59% by 2040. The surge in electricity demand is driven by electrification across end-use sectors – transport, buildings and industry. In addition, there is a strong demand growth for electricity from data centres. In *TIM-CBaligned*, electricity demand from data centres grows fourfold - from 3 TWh in 2020 to 12 TWh in 2040 – after which is stays at this level through to 2050.

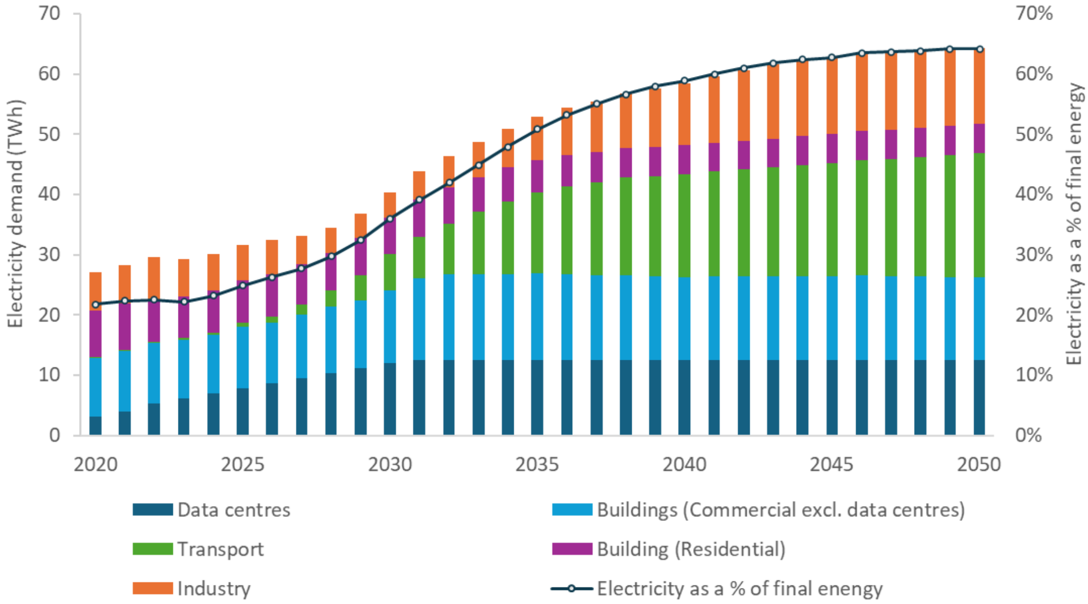


Figure 22 Electricity demand by sector for the TIM-CBaligned scenario, and electricity consumption as a percentage of final energy. Data centres

4.3.3 Transport

The transport sector undergoes rapid decarbonisation in all scenarios, roughly halving by 2030, and reaching below 1 $MtCO_2$ by 2040. In *TIM-CBaligned*, transport emissions fall to 6 $MtCO_2$ in 2030 and 0.4 $MtCO_2$ by 2040, a 97% reduction in emissions. In comparison, WEM projected emissions fall slightly to 11 $MtCO_2$ in 2030 and WAM projections are almost double this in 2030 and only fall to 6 $MtCO_2$ in 2040.

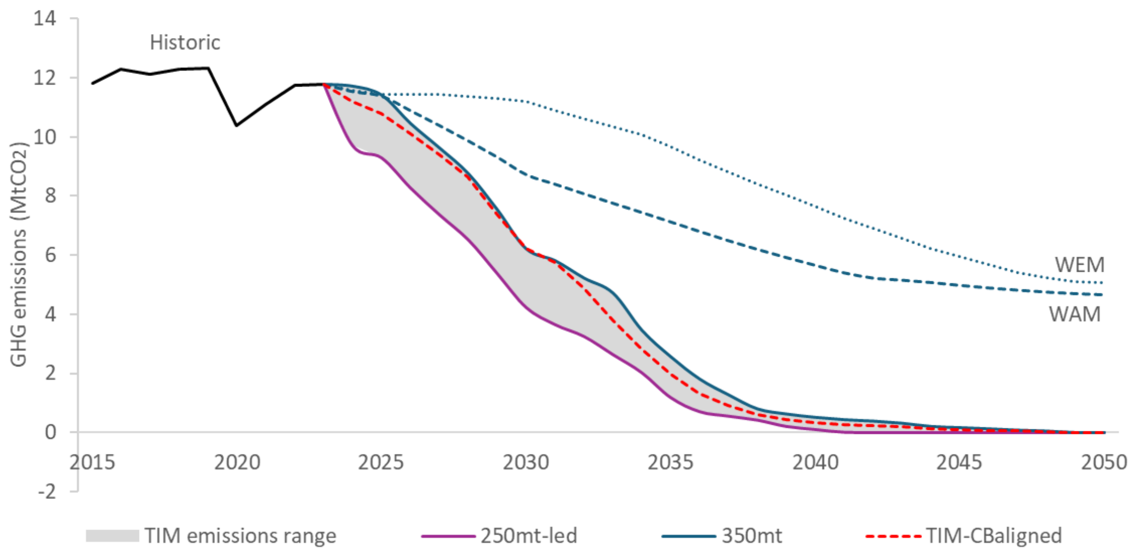


Figure 23 CO_2 emissions pathways in the transport sector

Electrification of land transport is the key driver of decarbonisation within the transport sector. This also assumes the end of new internal combustion engines by 2025 for private vehicles and 2027 for freight vehicles.

Figure 24 details the breakdown of vehicle across private cars and freight vehicles (vans and trucks) for *TIM-CBaligned*. By 2030, there are around 1 million EVs across private cars and freight vehicles, including battery electric vehicles (BEV), hybrid electric vehicles (HEV) plug-in hybrid electric vehicle (PHEV). In 2030, BEVs account for 31% of the total private car stock, increasing to 95% in 2040. By 2040, the vehicle stock reaches near full electrification, with only a small portion (less than 6% of the total vehicle stock) of ICE and hybrid vehicles remaining across private cars, vans and trucks. By 2030, electricity accounts for 17% (0.5 Mtoe) of final energy consumption in the transport sector (excluding aviation) rising to 81% of final energy by 2040, the remainder of which is made up of biodiesel and petrol.

Activity levels for passenger cars for 2030 and 2040 are detailed in Figure 25 for *LED, BAU* and *TIM-CBaligned* scenarios, compared to 2019, showing an increase in all scenarios.

Private cars

	2020	2025	2030	2035	2040	2045	2050
PHEV	3	25	21	17	11	9	0
ICE	2304	2108	1652	451	71	30	0
HEV	54	152	125	89	57	42	0
BEV	12	158	794.675	2083	2711.033	3008	3304

Vans

	2020	2025	2030	2035	2040	2045	2050
PHEV	0	2	5	4	2	1	0
ICE	417	433	333	143	33	0	0
HEV	0	8	6	4	2	0	0
BEV	1	10	72	208	291	289	286

Heavy trucks (>10 t)

	2020	2025	2030	2035	2040	2045	2050
PHEV	0	0	0	0	0	0	0
ICE	26	30	22	9	2	0	0
HEV	0	0	1	1	0	0	0
BEV	0	0	14	28	33	36	40

Medium trucks (5-10 t)

	2020	2025	2030	2035	2040	2045	2050
PHEV	0	0	0	0	0	0	0
ICE	11	11	8	3	1	0	0
HEV	0	2	4	3	1	1	0
BEV	0	0	3	9	15	17	19

Figure 24 Vehicle stock by fuel type for the TIM-CBaligned scenario
BEV: Battery electric vehicle, HEV: hybrid electric vehicle, ICE: Internal combustion engine, PHEV: plug-in hybrid electric vehicle

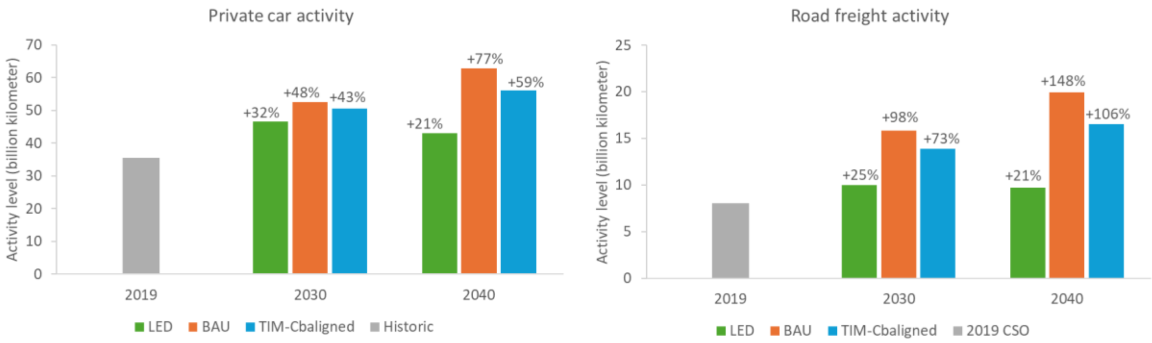


Figure 25 Road transport activity level for LED, BAU and TIM-CBaligned for private cars (left) and goods vehicles (right), with change in activity level relative to 2019

The 2030 electric vehicle stock figures for WEM and WAM are detailed in Table 12, along with assumptions for each scenario for ICE car sales, and activity levels for and goods vehicles.

		TIM-CBaligned	WEM	WAM
Electric vehicles	Car EVs[1]	940,718	693,319	845,156
	EV share of total car stock	36%	29%	35%
	HGV EVs	157,77	1,750	3,500
	LGV EVs	83,688	47,500	95,000
ICE vehicles	ICE sales	No new ICE post 2025	No new ICE car or LGV post 2035	100% new car sales EV by 2030
Change in activity relative to 2019 (%)[2]	Car kilometres	+43%	+12%	-12%
	Road freight kilometres	+73%	+26%	+26%

Table 12 2030 transport sector mitigation measures for TIM-CBaligned, WEM and WAM.

4.3.4 Industry

By 2030, total industrial emissions (ETS and ESR) fall by around 40% for most of the TIM scenarios, compared to 2018 levels (Figure 26), while final energy consumption in the sector drops by 6% in 2030 and 15% in 2040, relative to 2018 (Figure 27). By 2040, emissions drop below 1 $MtCO_2$, a 90% reduction on 2018, while final energy is between 1.8 and 2 Mtoe, 15% less than in 2018. WEM and WAM pathways achieve a much smaller emissions reduction in comparison to the TIM scenarios. By 2030 WEM and WAM emissions reduce by 11% and 24%, to 6 $MtCO_2$ and 5 $MtCO_2$ respectively. By 2040, WEM emissions drop by a further 0.5 $MtCO_2$ and WAM emissions by 0.7 $MtCO_2$.

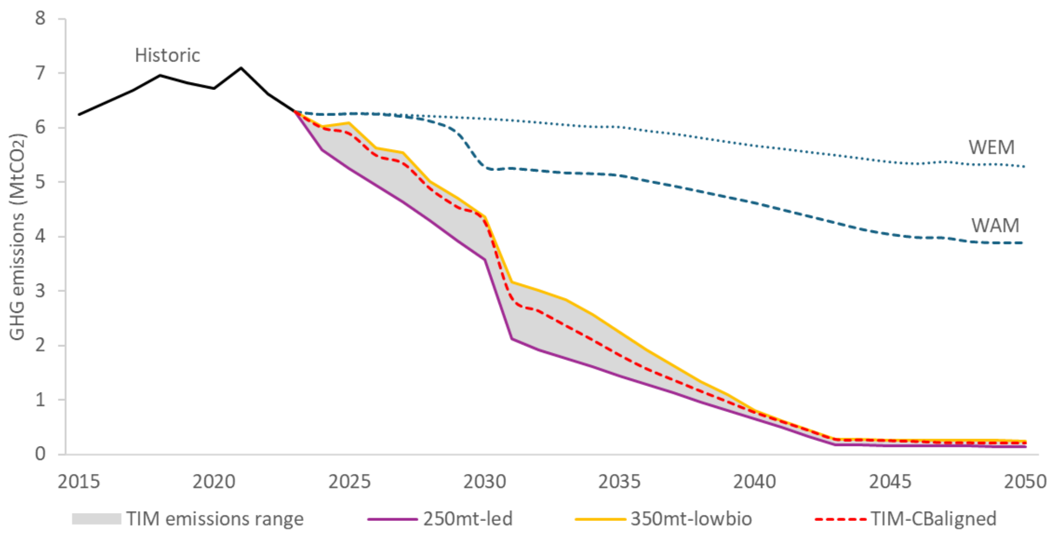


Figure 26 CO_2 emissions pathways in the industrial sector

[1] For TIM-CBaligned this includes BEVS, HEVs, and PHEVs. WEM and WAM figures include BEV and PHEVs (no HEV data available in the SEAI National Energy Projections report).

[2] 2019 activity levels (for TIM-CBaligned change in activity) are sourced from the CSO Transport Omnibus (CSO, 2020)

Electrification is one of the key levers driving decarbonization within the sector. In *TIM-CBaligned*, electricity accounts for 30% of FEC in 2030, and doubles by 2040. WEM and WAM achieve slightly higher levels of electrification by 2030 (Table 13). In the short to medium term, fuel switching – from solid fuels to solid biomass, and natural gas to biogas – serves as transitional measures to cut emissions from energy use. In 2030, overall biomethane supply in *TIM-CBaligned* is 3 TWh, compared to 5.7 TWh in WAM (Table 13), with around 2 TWh used in industry in both. In all the CB scenarios considered (*250Mt, 300Mt, 350Mt* and *TIM-CBaligned*) carbon capture and storage (CCS) in cement manufacturing is deployed post 2030 to decarbonise process emissions. This results in an immediate cut in cement process emissions of around 1.4 $MtCO_2$.

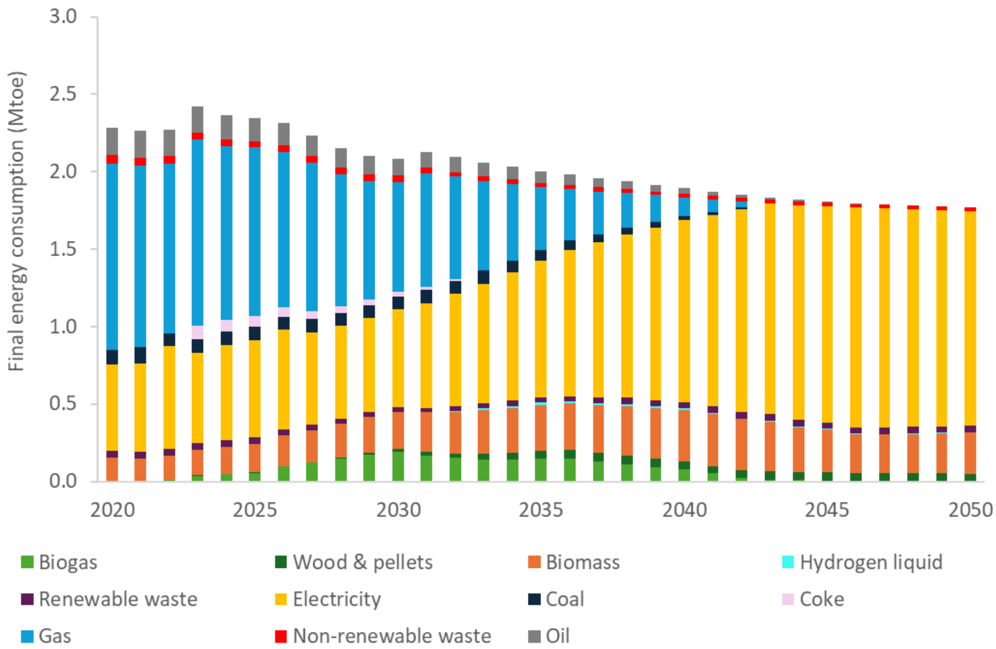


Figure 27 Final energy demand by fuel type in the industrial sector for TIM-CBaligned

	2030			2040
Scenario	**TIM-CBaligned**	**WEM**	**WAM**	**TIM-CBaligned**
Total Biomethane supply (TWh)	3	0	5.7	2
Biomethane for industry (TWh)	2.2	0	2.1	0.9
Share of electricity in industry FEC	30%	34%	34%	62%
Share of renewables in industry FEC	23%	16%	31%	27%

Table 13 Assumptions for the biomethane supply and industry sector final energy for TIM-CBaligned, WEM and WAM

4.3.5 Buildings

Emissions from the buildings sector (residential and commercial/public) are shown in Figure 28. Emissions fall between 62% and 82% by compared to 2018 and achieve near full decarbonisation by 2040 in most scenarios (94-100% emissions reductions relative to 2018). WAM projections shows similar emissions reductions, with a 90% drop in emissions between 2018 and 2040.

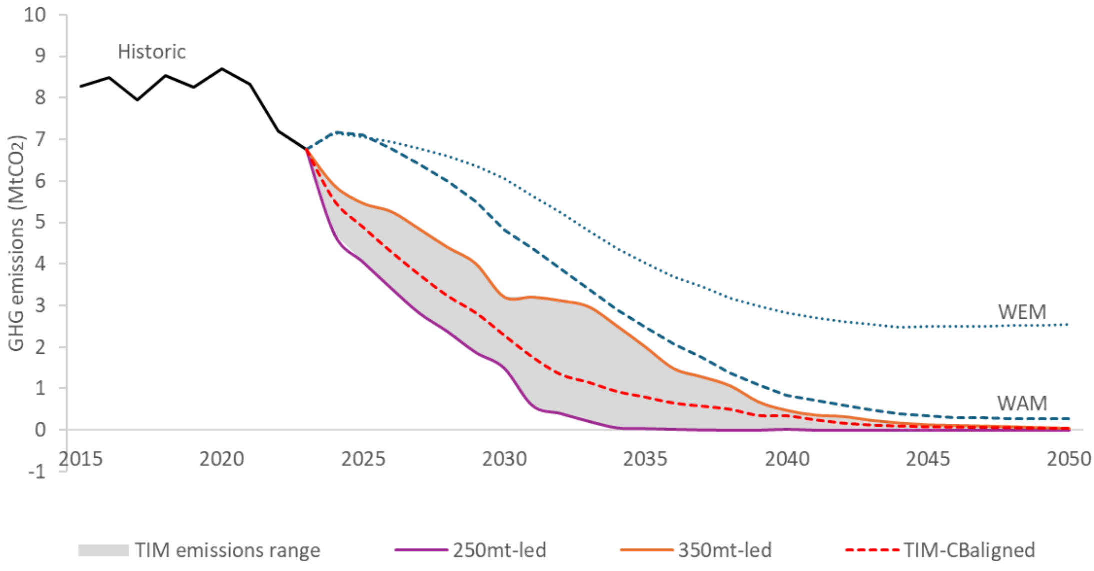


Figure 28 CO_2 emissions pathways in the buildings sector (residential and public/commercial)

This decarbonisation is driven by a strong reduction in fossil fuel use and an increase in electrification, ambient heat from heat pumps and district heating, detailed in Figure 29 for residential buildings. Table 14 shows the level of heat pump and district heating deployment for *TIM-CBaligned* and WEM and WAM. *In TIM-CBaligned*, 883 thousand heat pumps are deployed by 2030 in the residential sector, which is 23% higher than WAM heat pump deployment and 49% more than WEM. An additional 470 thousand heat pumps are deployed between 2031-2040. In *TIM-CBaligned*, 3.3 TWh of district heating is delivered by 2030, and 3.8 TWh by 2040.

	2030			2040
Scenario	**TIM-CBaligned**	**WEM**	**WAM**	**TIM-CBaligned**
Total number of domestic heat pumps	883,313	594,350	717,189	1,351,163
District heating (TWh)	3.3	0.075	2.7	3.8

Table 14 Buildings sector assumptions for domestic heat pumps and district heating for TIM-CBaligned, WEM, and WAM.

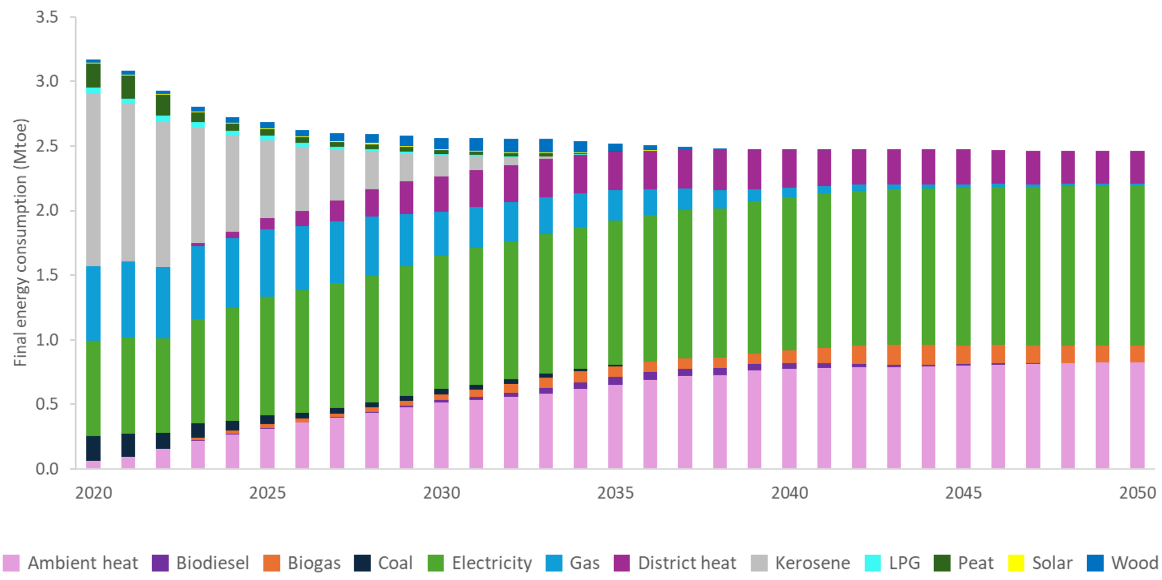


Figure 29 TIM-CBaligned residential buildings final energy consumption by fuel type

4.4 System costs

The section examines the costs associated with the energy system, including investment costs, and energy system running costs.

Table 15 details key indicators in 2040, including annualised and cumulative costs, gross and net CO_2 emissions, and reductions in energy-related CO_2 emissions relative to 2020. Annualised costs in *TIM-CBaligned* – which amount to 2% of 2020 GDP in 2040 – are nearly identical to a "No Mitigation" scenario and are lower than WAM, because mitigation solutions cut the demand for expensive fossil fuels. Significant upfront investment is required, but this is largely cost effective and paid back through a reduction in fossil fuel imports. Significantly, the "With Additional" and "With Existing Measures" cases are more costly than "NoMitigation" cases, and are more costly than several carbon budget scenarios, because they do not phase out fossil fuels.

Meeting ambitious decarbonisation pathways for the energy system aligned with climate commitments requires substantial upfront investments, which are largely, or wholly paid back in the long-term from fuel savings, is a critical finding echoed in global analyses (IEA, 2024).

	250Mt -LED	300Mt	300Mt-LED	300Mt-LowBio	350Mt	350Mt-LED	350Mt-LowBio	TIM-CBaligned	WEM	WAM	No Mitigation
2040 Annualised System Costs (B€ 2018)	19.8	25.3	19.1	25.5	24.5	18.3	25.5	23.0	24.7	24.6	23.2
Cost as % of 2020 GDP	1.7%	2.2%	1.7%	2.2%	2.2%	1.6%	2.2%	2.0%	2.2%	2.2%	2.0%
2031-2040 Cumulative System Cost (B€)	190	229	180	232	224	174	224	211	223	222	212
Gross Domestic CO_2 Energy Emissions (Mt)	0.9	1.6	1.7	1.4	2.8	2.7	2.8	1.9	20.7	14.6	13.0
Carbon Dioxide Removal from Energy Sector (Mt)	-1.8	-1.8	-1.8	-1.3	0.0	0.0	0.0	-0.8	0	0	0
Net Domestic CO_2 Energy Emissions (Mt)	-0.9	-0.2	-0.1	0.1	2.8	2.7	2.8	1.1	20.7	14.6	13.0
Energy CO_2 Reduction Relative to 1990	103%	101%	100%	100%	92%	92%	92%	97%	39%	57%	60%

Table 15 Key indicators across scenarios in 2040

The cumulative lump sum investment cost by scenario is shown in Figure 30. *TIM-CBaligned,* a cumulative investment of €100 billion is required by 2030, increasing to €230 billion investment by 2040. *LED* scenarios require lower overall investment, while *LowBio* and *BAU* requires higher investment.

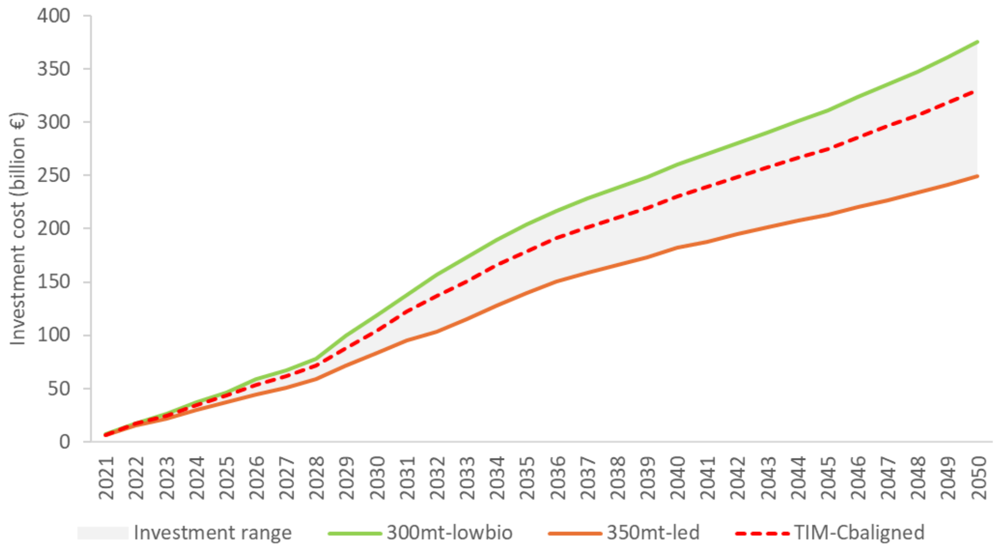


Figure 30 Cumulative investment cost by scenario

In *TIM-CBaligned* over 50% of total investment from 2021-2050 is in the transport sector[1], followed by 20% for power and 17% for the residential building sector (Figure 31). The highest investment costs are incurred the end of this decade, into the beginning of the next, with between €16 - €18 billion required each year from 2029 -2030.

In addition to lump sum investment costs, the system incurs annual energy system running costs from operations and maintenance (O&M), which includes fuel costs, and both fixed and variable operation and maintenance cost. The average annual energy system costs for each 5-year carbon budget period are shown in Figure 32, split into investment costs and O&M costs. The O&M costs increase annually, while investment costs are highest between carbon budget periods 2 and 3 (2026 – 2035).

[1] TIM costs cover the upfront, maintenance and fuel costs of vehicles but do not include network costs, such as road and rail. Similarly, costs in the power sector related to the installation and operation of generation capacity and exclude the cost of networks.

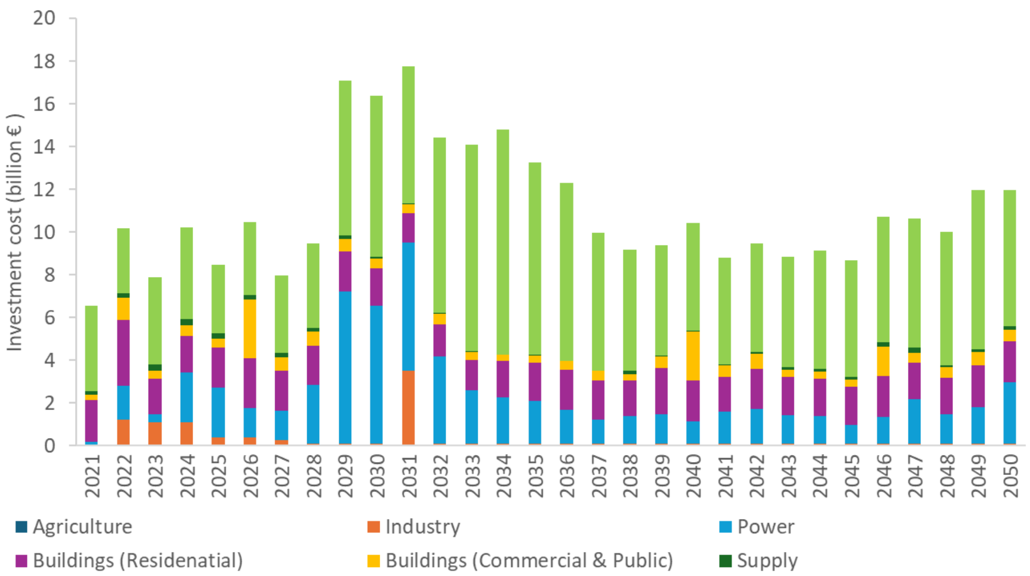
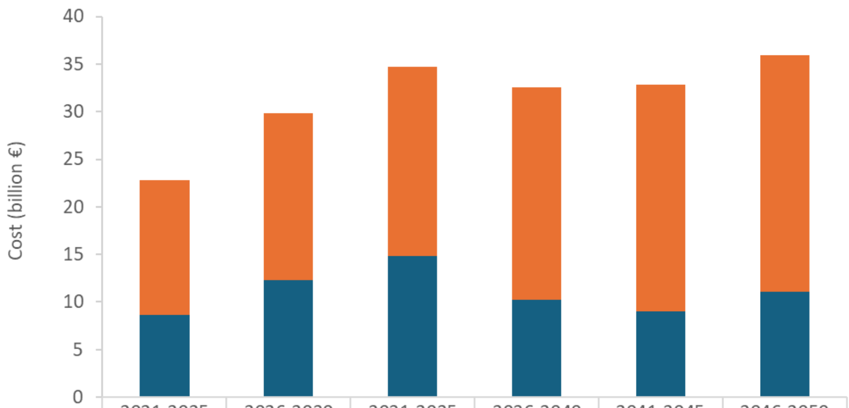


Figure 31 TIM-CBaligned annual investment cost by sector



	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Total	23	30	35	33	33	36
O&M	14	18	20	22	24	25
Investment	9	12	15	10	9	11

Figure 32 TIM-CBaligned average annual energy system costs (including investment, O&M and fuel costs) per five-year carbon budget periods

5 Conclusions

5.1 Summary and key findings

This study was commissioned by the Climate Change Advisory Council (CCAC) to assess whether Ireland's energy-sector decarbonisation pathway—consistent with national carbon budgets and Sectoral Emissions Ceilings (SECs)—is aligned with the European Union's climate and energy targets. Specifically, it evaluates the alignment of energy system emissions and energy use with:

- The EU Emissions Trading Scheme (EU-ETS)
- The Effort Sharing Regulation (ESR)
- The Energy Efficiency Directive (EED)
- The indicative EU 2040 target for greenhouse gas (GHG) emissions reduction

The analysis uses energy system scenarios developed with the TIMES-Ireland Model (TIM), with a particular focus on the composite *TIM-CBaligned* scenario, which reflects the average energy sector trajectory underpinning the CCAC's proposed carbon budgets for 2031–2040. This is compared to Ireland's current emissions projections under the EPA's With Existing Measures (WEM) and With Additional Measures (WAM) scenarios to allow for an assessment of progress in existing and planned policies in delivering on national and EU targets.

Key findings include:

- Alignment with the **Emissions Trading Scheme (ETS)** is strong. An energy transition pathway compliant with meeting carbon budgets (legally adopted in the period to 2030 and recommended by the CCAC in the period to 2040) would put Ireland in a very strong position to cutting GHG emissions in the **EU-ETS** for the power and industry sectors aligned with the EU-wide target. *TIM-CBaligned* achieves a 77% reduction in ETS emissions by 2030 (relative to 2005), exceeding the EU target of 62%. Ireland can use up to 4% of its ETS allowances to meet ESR obligations under EU flexibility rules. However, any ETS allowances beyond this threshold cannot be used to offset ESR shortfalls and must remain within the ETS framework[1].

- However, compliance with the **Effort Sharing Regulation (ESR)** remains a challenge. Ireland is currently set to significantly miss its ESR targets under both existing and planned policies. Unlike the EU ETS, non-compliance with ESR targets carries substantial financial risk, as the State would be required to purchase allowances or face penalties. Ireland's share of ESR-covered emissions is particularly high by EU standards, largely due to the dominance of agriculture and transport. Delivering the decarbonisation measures consistent with the national carbon budgets - such as those reflected in the *TIM-CBaligned* scenario - would reduce energy-related ESR emissions by 63% by 2030 relative to 2005. This goes well beyond the EU's required 42% reduction for all ESR emissions and would substantially improve the outlook for Ireland's compliance.

[1] This analysis excludes consideration of international aviation, which is excluded from national carbon budgets, while emissions from inter-EU flights are within the scope of the ETS.

However, Ireland's overall compliance with its binding national ESR cap of 370 $MtCO_2$ ultimately depends on agricultural emissions, which currently account for approximately half of total ESR emissions. If agriculture follows the EPA's WEM projections – where emissions rise by 15% or fall by just 5% respectively between 2005 and 2030 - the ESR cap is set to be breached even under the most ambitious scenario for the energy system, in which energy-related ESR emissions fall by 78%. Only the most ambitious energy scenario - *250Mt-LED* - stays within ESR limits if agriculture also follows a strong mitigation pathway. However, with the use of ESR flexibilities, *TIM-CBaligned* can achieve compliance with AEAs if agriculture follows either WAM projections, or a pathway consistent with the agriculture sector emissions in the Council's carbon budget proposal.

Ireland has already exceeded its Annual Emissions Allocations (AEAs) for 2021, 2022 and 2023, compounding the challenge of remaining within the allocated ESR emissions limit for the remainder of the decade. This early overshoot heightens compliance risks in later years and reduces available headroom for future emissions. Uncertainty around the final AEAs for 2026–2030, the availability of flexibility mechanisms, and whether credits can be purchased from other Member States further underscores the urgency of taking decisive and early action to reduce emissions.

- Ireland's target under the **Energy Efficiency Directive**– to reduce final energy consumption to 10.45 Mtoe by 2030 – is narrowly missed in *TIM-CBaligned*. In this scenario, final energy consumption falls to 11.1 Mtoe, which represents a significant gain but falls short of the target. *Low Energy Demand (LED)* pathways are most closely aligned with the EED target. This shows that relying on efficiency gains and fuel switching alone is unlikely to deliver the required outcome without a broader shift to reduce overall energy demand.

- Sectoral transformation is technically feasible: Deep reductions in power, transport, buildings, and industry are possible, driven by electrification, renewable deployment, efficiency, and fuel switching. Net-zero or negative emissions are achieved in the power sector by 2035. Table 16 lists the key mitigation measures and deployment rates for *TIM-CBaligned*.

- Current policy pathways are insufficient: WEM and WAM exceed national carbon budgets by large margins, with projected ESR non-compliance costs reaching up to €16 billion. Ireland has already exceeded AEAs for 2021–2023, further increasing compliance pressure.

- Investment needs are substantial but cost-effective: Achieving *TIM-CBaligned* requires €100 billion in investment by 2030 and €230 billion by 2040. However, these costs are lower than WEM/WAM over the long term due to reduced fossil fuel imports and energy system operating costs.

		2030	2040
Power	Solar capacity (GW)	8	10
	Onshore wind (GW)	7.5	8.5
	Offshore wind (GW)	5	11.5
	BECCS capacity (GW)	0	0.3
	RES-E	95%	100%
Transport	Total passenger BEVs (thousand)	795	2,711
	LGV BEVs (thousand)	72	291
	HGV BEVs (thousand)	14	33
	Change in car activity (relative to 2019)	+43%	+59%
	Change in road freight activity (relative to 2019)	+73%	+106%
Biomethane	Biomethane (TWh)	3	2
Buildings	Number of domestic heat pumps (thousand)	883	1,351
	District heating (TWh)	3.3	3.8

Table 16 Key technology deployment rates and demands in TIM-CBaligned

5.2 Discussion: Policy implications

The EPA's WEM and WAM scenarios show that Ireland's current policies are insufficient to meet national carbon budgets and EU emissions targets under the ETS, ESR and EED. However, this analysis shows strong alignment between the measures necessary to transform the energy system to align with domestic carbon budgets in the period to 2040, and to meet EU targets. Achieving this alignment will require substantial emissions reductions in sectors beyond electricity, particularly in transport, buildings, and industry. The findings highlight the importance of early emissions reductions, clear planning for sectoral contributions, and timely implementation of existing policy commitments. Demand-side measures and sustained investment are also likely to play a central role in enabling compliance and avoiding long-term cost and feasibility risks.

Significant practical and political barriers are associated with delivering the energy transition depicted in these modelling scenarios, particularly the immediate phase-out of new ICE personal vehicles, achieving a 90%+ renewable electricity mix in the early 2030s, lowering energy demands through efficiency measures and electrifying end-use sectors. Some of these barriers are explored in Daly *et al.* (2024).

5.3 Limitations and future research direction

While this analysis provides a robust benchmark for assessing the alignment between Ireland's energy system transformation for domestic carbon budgets and EU targets, several limitations and caveats apply:

- Limitations in model and scenario scope:
    - Emissions from agriculture, LULUCF, waste and F-gases are not modelled in TIM, which covers only energy- and process-related emissions (electricity, transport, buildings and industry). Emissions from agriculture are key to achievement of the ESR, as they make up 50% of current emissions accounted for in this regulation.
    - *TIM-CBaligned* is a composite scenario, rather than a single internally consistent modelled pathway. This may limit the internal consistency of results.
    - ETS/ESR emissions allocations in TIM are approximate for the industry sector.
    - The analysis does not include a full economic or social cost-benefit analysis or assess macroeconomic implications. While TIM is a cost-optimal model, certain costs and benefits are not quantified within the scope of the model. Omitted costs include, for example, networks (such as road, rail, pipeline and power infrastructure). Benefits which are outside the model's scope include reduced environmental – including climate – damages, economic opportunities from the energy transition, and greater wellbeing and health associated with clean energy. Therefore, TIM carbon budget scenarios should not be considered as the "optimal" or recommended pathways, but as pathways which are internally consistent, meet demands and carbon budgets.
    - Absence of international aviation emissions projections within scope of EU-ETS –further analysis is required to address this gap to assess its implications for Ireland's overall emissions within the ETS.
    - Greater detail on assumed technology deployment post-2030 in WAM and WEM modelling is required to fully assess the policy gap in the period to 2040 and 2050.
- Uncertainty in targets and compliance
    - ESR AEAs for 2026-30 are not yet confirmed. Estimates in this report rely on provisional methods. Therefore, compliance in the latter half of this decade is subject to additional uncertainty.
    - Similarly, availability of LULUCF credits/flexibilities is uncertain: post-2026 accounting rules are unclear, making access to future credits unreliable.
    - There is currently no compliance framework associated with the EED. The current target is non-binding, and non-compliance is not yet penalised.
- Future research priorities:
    - Future analyses could integrate agriculture and LULUCF modelling into a unified scenario framework.
    - Examine the compliance of carbon budget pathways with the EU's Renewable Energy Directive (RED).
    - Sensitivity analysis and uncertainty modelling would strengthen the robustness of findings.
    - Broader co-benefits and system integration challenges (e.g. grid readiness, workforce needs) warrant further exploration

References

Balyk, O. *et al.* (2022) 'TIM: Modelling pathways to meet Ireland's long-term energy system challenges with the TIMES-Ireland Model (v1.0)', *Geoscientific Model Development*, 15(12), pp. 4991–5019. Available at: https://doi.org/10.5194/gmd-15-4991-2022.

CCAC (2024) *Carbon Budget Proposal Report 2024*. Available at: https://www.climatecouncil.ie/councilpublications/ (Accessed: 17 March 2025).

CSO (2020) *Transport Omnibus 2019: Road Traffic Volumes.*, *Central Statistics Office*. Available at: https://www.cso.ie/en/releasesandpublications/ep/p-tranom/transportomnibus2019/roadtrafficvolumes/ (Accessed: 18 March 2025).

Daly, H. *et al.* (2024) *PATHWAYS FOR IRELAND'S ENERGY SYSTEM TO 2050. Modelling analysis to support the Climate Change Advisory Council on the Second Carbon Budget Programme*. Available at: https://www.climatecouncil.ie/media/CBWG%20Report%20TIMES-Ireland%20Model.pdf (Accessed: 19 March 2024).

DECC (2022a) *Carbon Budgets 2022*. Available at: https://www.gov.ie/en/publication/9af1b-carbon-budgets/ (Accessed: 17 March 2025).

DECC (2022b) *Sectoral Emissions Ceilings*. Available at: https://www.gov.ie/en/publication/76864-sectoral-emissions-ceilings/ (Accessed: 17 March 2025).

DECC (2023) *Climate Action Plan 2024*. Available at: https://www.gov.ie/en/publication/67104-climate-action-plan/#climate-action-plan-2024 (Accessed: 19 March 2025).

DECC (2024a) *Ireland's integrated National Energy and Climate Plan 2021-2030*. Available at: https://www.gov.ie/en/publication/a856a-national-energy-and-climate-plan-necp-2021-2030/? (Accessed: 14 March 2025).

DECC (2024b) 'National Energy and Climate Plan (NECP) 2021-2030'. Available at: https://www.gov.ie/en/publication/a856a-national-energy-and-climate-plan-necp-2021-2030/? (Accessed: 17 March 2025).

EEA (2024) *EU Emissions Trading System (ETS) data viewer*. Available at: https://www.eea.europa.eu/en/analysis/maps-and-charts/emissions-trading-viewer-1-dashboards (Accessed: 18 March 2025).

EEA (2025) *EEA greenhouse gases – data viewer*. Available at: https://www.eea.europa.eu/en/analysis/maps-and-charts/greenhouse-gases-viewer-data-viewers.

EPA (2024a) *Ireland's Greenhouse Gas Emissions Projections 2023-2050*. Available at: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/irelands-greenhouse-gas-emissions-projections-2023-2050.php (Accessed: 14 March 2025).

EPA (2024b) *Ireland's Provisional Greenhouse Gas Emissions 1990-2023*. Available at: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/irelands-provisional-greenhouse-gas-emissions-1990-2023.php.

European Commission (2019) *The European Green Deal*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640 (Accessed: 17 March 2025).

European Commission (2021a) *EU reference scenario 2020: energy, transport and GHG emissions : trends to 2050.* LU: Publications Office. Available at: https://data.europa.eu/doi/10.2833/35750 (Accessed: 20 March 2025).

European Commission (2021b) *Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119 (Accessed: 17 March 2025).

European Commission (2023a) *Comission Implementing Decision (EU) 2023/1319*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023D1319 (Accessed: 17 March 2025).

European Commission (2023b) *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766 (Accessed: 17 March 2025).

European Commission (2024a) *Climate action Progress Report 2024*. LU: Publications Office. Available at: https://data.europa.eu/doi/10.2834/8000893 (Accessed: 18 March 2025).

European Commission (2024b) *Commission staff working document Impact assessment Report Part 1. Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society*. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:6c154426-c5a6-11ee-95d9-01aa75ed71a1.0001.02/DOC_1&format=PDF.

Eurostat (no date) *Demography, population stock and balance*. Available at: https://ec.europa.eu/eurostat/web/population-demography/demography-population-stock-balance/database (Accessed: 17 March 2025).

Gaur, A. *et al.* (2022) 'Low energy demand scenario for feasible deep decarbonisation: Whole energy systems modelling for Ireland', *Renewable and Sustainable Energy Transition*, 2, p. 100024. Available at: https://doi.org/10.1016/j.rset.2022.100024.

IEA (2024) *Strategies for Affordable and Fair Clean Energy Transitions*. Paris: IEA. Available at: https://www.iea.org/reports/strategies-for-affordable-and-fair-clean-energy-transitions (Accessed: 24 March 2025).

IFAC and CCAC (2025) *A colossal missed opportunity: Ireland's climate action and the potential costs of missing targets*.

Oireachtas (2021) *Climate Action and Low Carbon Development (Amendment) Act 2021*. Dublin: Oireachtas. Available at: https://www.gov.ie/en/publication/984d2-climate-action-and-low-carbon-development-amendment-bill-2020/ (Accessed: 31 January 2024).

Paris Agreement (2015) *Paris Agreement to the United Nations Framework Convention on Climate Change, T.I.A.S. No. 16-1104.* Available at: https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf (Accessed: 17 March 2025).

SEAI (2024a) *National Energy Balance*. Available at: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance (Accessed: 17 March 2025).

SEAI (2024b) *National Energy Projections 2024*. Available at: https://www.seai.ie/sites/default/files/publications/National-Energy-Projections-Report-2024.pdf (Accessed: 14 March 2025).