CAPACITY

CLIMATE ACTION PATHWAYS & ABSORPTIVE CAPACITY

Energy system pathways under cumulative carbon budgets

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Introduction

- **Crucial climate goals are not being met**
  - Remaining Global Carbon Budget (GCB) for 50% chance of 1.5°C was 500 $GtCO_2$ from 2020, currently 200 $GtCO_2$, and likely zero without significant methane reduction or high climate sensitivity
  - Energy system (including industrial processes, excluding international aviation & shipping) 53% of Ireland's GHG emissions in 2022; 82% of CO_2
  - 86% of Ireland's primary energy is from fossil fuels

- Objectives:
  - Assess consequences of adhering to CB aligned with global temperature outcomes to inform CCAC's assessment of CB3 (2031-35) and CB4 (2036-40)
    - *In-progress, in-review analysis, not reflective of CCAC position*
  - Identify implications of overshooting CB1 & CB2
  - Examine timing of mitigation efforts and novel technologies
  - Explore timing of fossil-fuel phase-out & implications for investment & demands

Carbon budget & scenario definition

5 Carbon budgets

250, 300, 350, 400, 450 Mt

BAU and LED
(2 pathways)

Demand projections

Scenarios

1. 250Mt_BAU
2. 300Mt_BAU
3. 350Mt_BAU
4. 400Mt_BAU
5. 450Mt_BAU
6. 250Mt_LED
7. 300Mt_LED
8. 350Mt_LED

TIMES-Ireland Model (TIM)

Supply-side

- **Resources and Potentials**
  - Fossil fuel
  - Renewable
- **Power Generation**
  - Fossil-based
  - Renewables
  - CCS (Gas/Biomass)
- **Fuel production**
  - Oil products
  - Biofuels
  - Natural gas
  - Hydrogen
- **Energy Trades**
  - Electricity
  - Oil products
  - Biofuels
  - Natural gas
- **Transportation & Distribution**

Demand-side

- **End-use Technologies**
  - Cars & Trucks
  - Buses & Trains
  - Heaters
  - Boilers
  - Appliances
  - Dryers
  - Dishwashers
  - Fans & Pumps
  - Refrigerators
  - Stoves & Ovens
  - Agr. Equipment
  - Ind. Machineries
  - Others
- **Energy Service Demands**
  - Passenger
  - Freight
  - Space heating
  - Hot water
  - Lighting
  - Electricity
  - Cooking
  - Refrigeration
  - Industries
  - Data Centre
  - Others

Emission Control

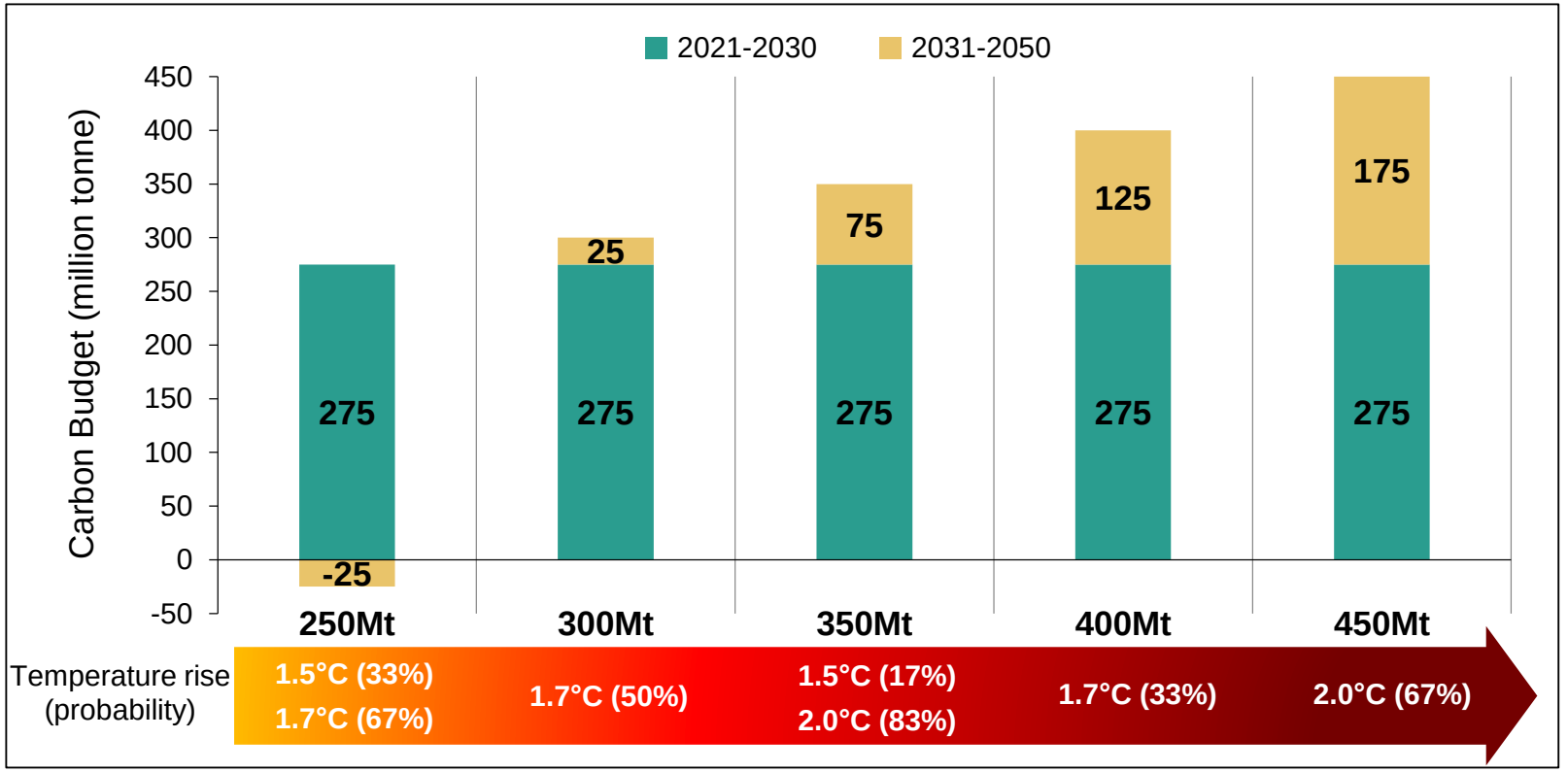
- **CO_2 Constraint**
  - Carbon Budget
- **CO_2 Removal**
  - Capture & Storage

Legend

- Energy flow
- Data flow
- Emission flow

See Notes & Assumptions

Core Carbon Budget Scenarios



Remaining/overshoot downscaled Global Carbon Budget >2031

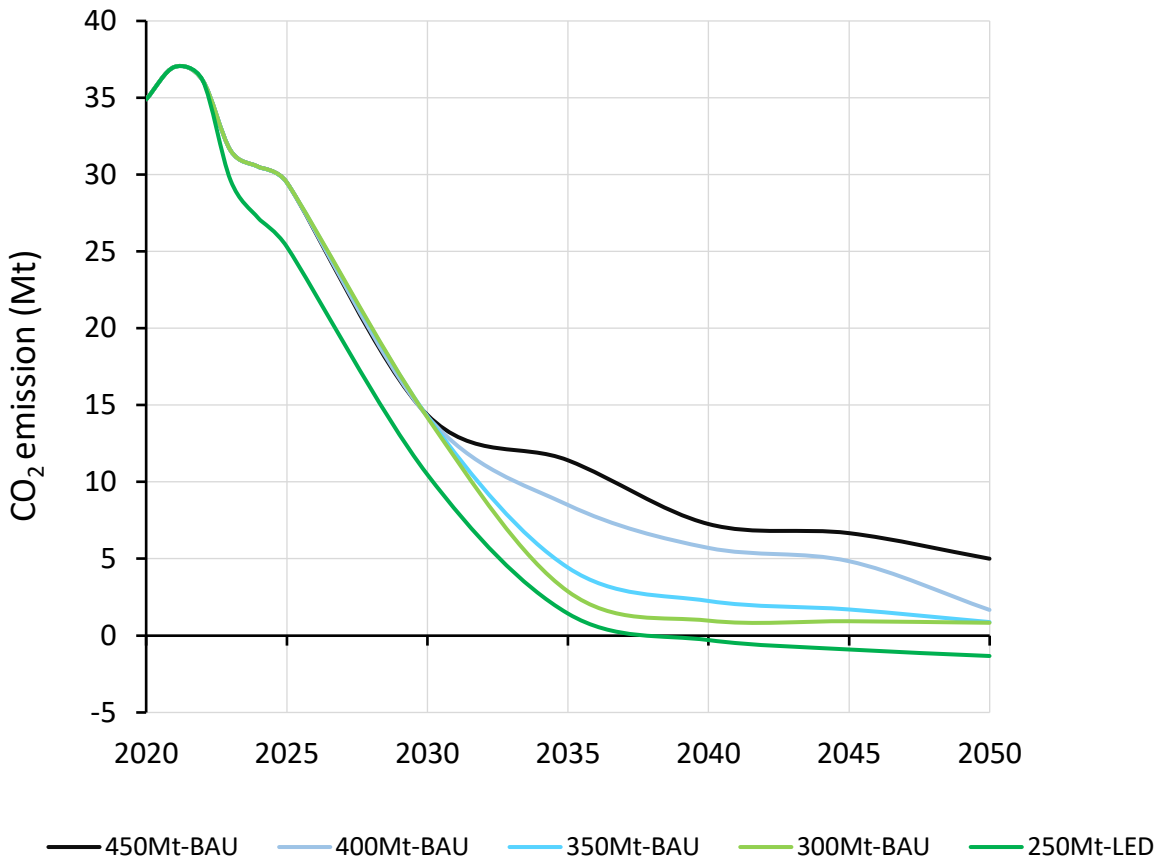
Existing Sectoral Emissions Ceiling for energy, CB1+2

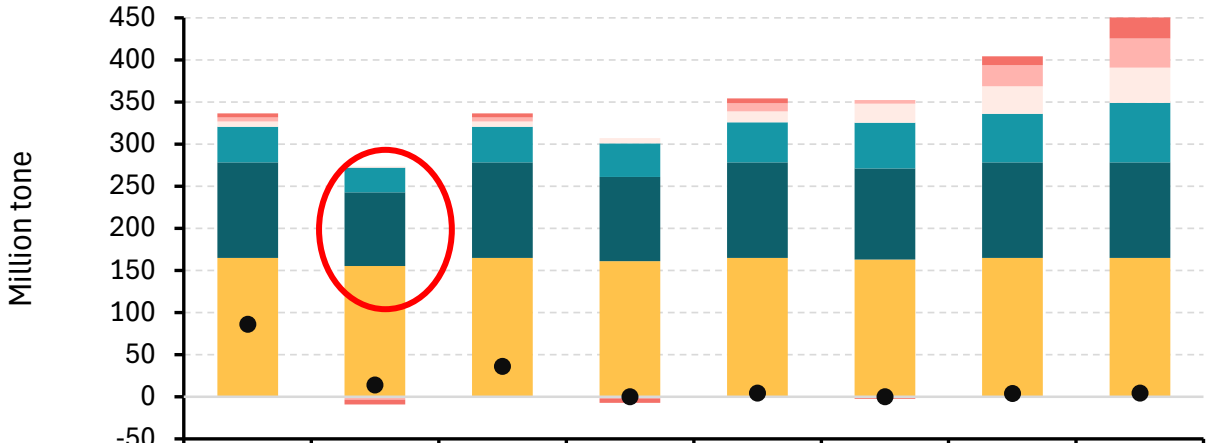
"Fair" allocation of remaining global carbon budget to Irish energy system is highly sensitive to

- Equity principles
- Methane & non-energy mitigation
- Climate sensitivity etc.

This interpretation downscales 2021 GRCB on a per-capita basis:

5-year carbon budgets

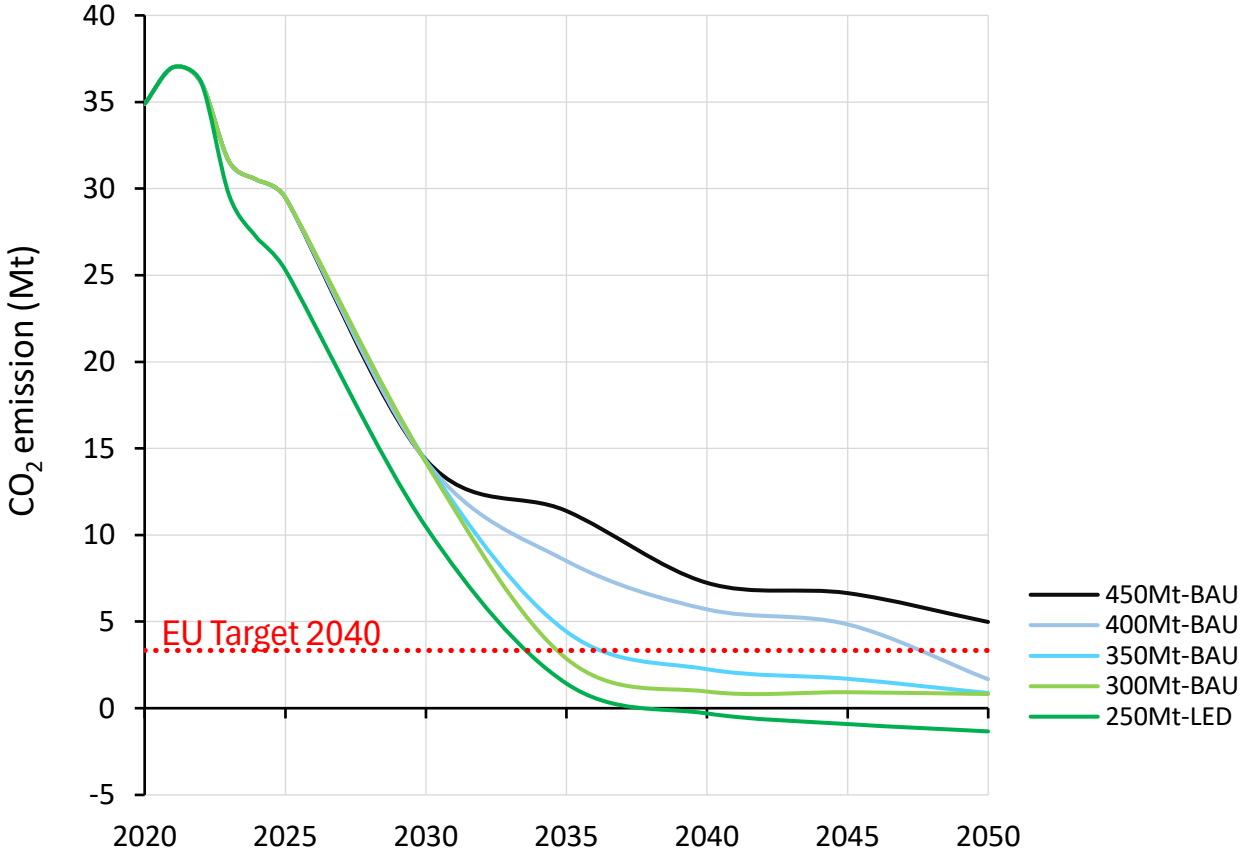




	250Mt BAU	250Mt LED	300Mt BAU	300Mt LED	350Mt BAU	350Mt LED	400Mt BAU	450Mt BAU
2046-50	4	-6	4	-5	6	-2	11	29
2041-45	5	-3	5	-2	9	5	25	35
2036-40	7	1	7	6	13	22	33	42
2031-35	42	30	42	40	48	55	58	71
2026-30	113	87	113	100	113	108	113	114
2021-25	165	155	165	161	165	163	165	165
Overshoot	86	14	36	0	4	0	4	4

To meet 250Mt & 300Mt scenarios with limited overshoot, a reduction in CB2 is necessary (here enabled by LED), along with net-zero by ~2037

Comparison with (indicative) EU target



Notes:

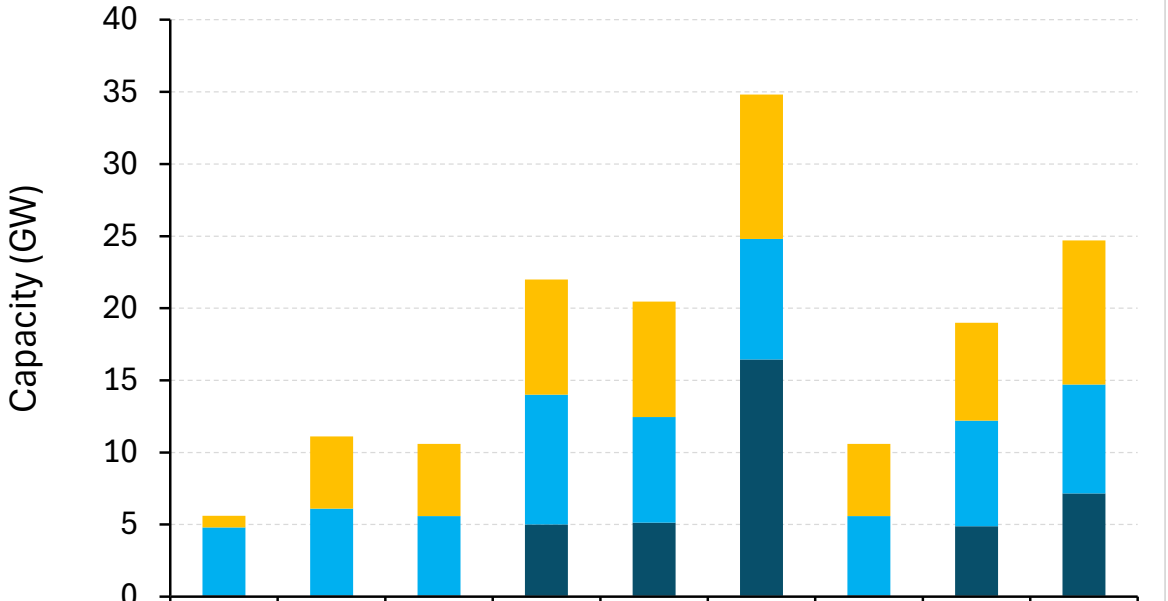
- This calculates targets based on energy CO_2 only

Calculations:

- GHG emissions (energy-related):
- 1990: 33.4Mt
- Indicative/possible 2040 target for energy (90%↓): 3.3Mt

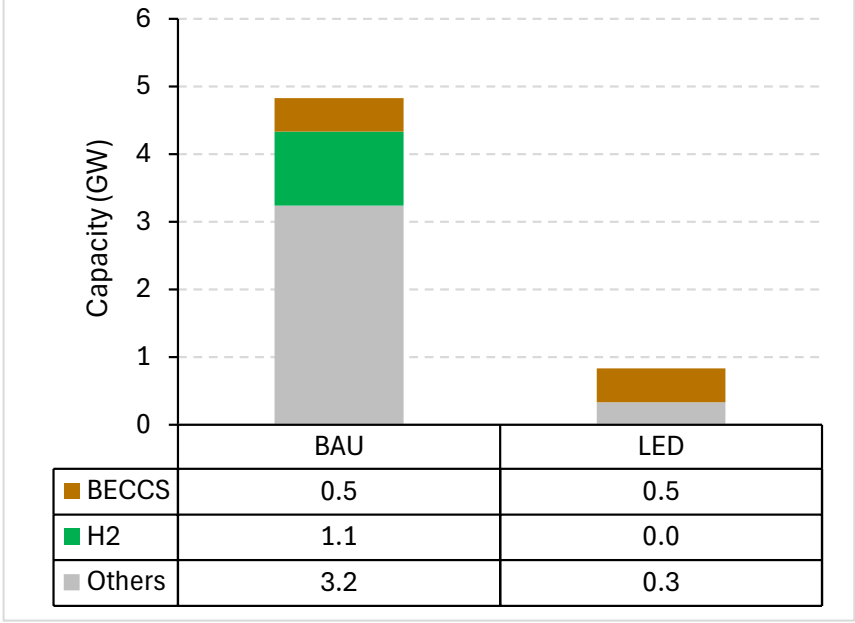
Installed capacity in power generation

Variable renewable power capacity



	2023	2025-target	2025-BAU	2030-target	2030-BAU	2050-BAU	2025-LED	2030-LED	2050-LED
Solar	0.8	5.0	5.0	8.0	8.0	10.0	5.0	6.8	10.0
Onshore wind	4.7	6.0	5.5	9.0	7.3	8.4	5.5	7.3	7.5
Offshore wind	0.1	0.1	0.1	5.0	5.1	16.5	0.1	4.9	7.2
Generation share	41%	50%	49%	80%	87%	93%	47%	92%	93%

Other technologies in 2050



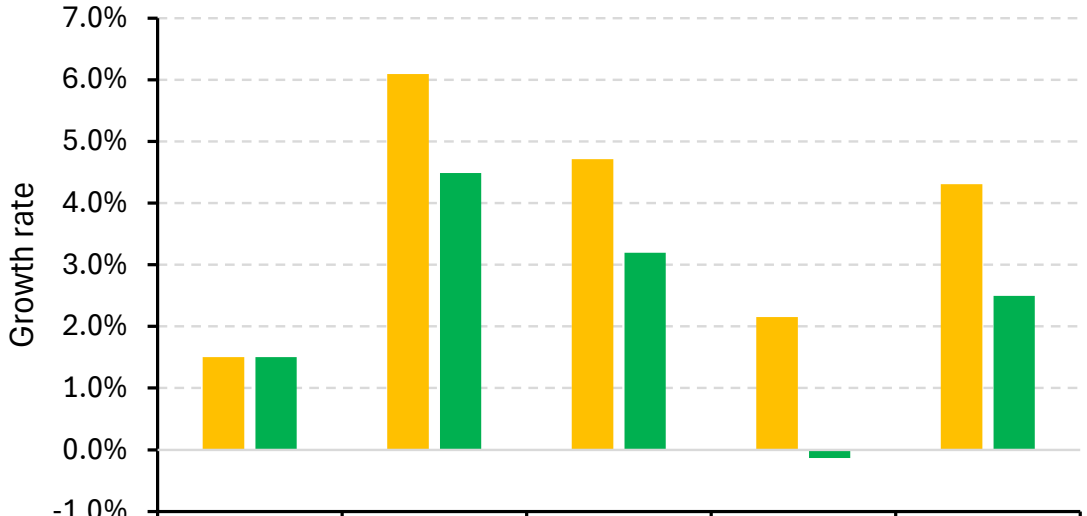
	BAU	LED
BECCS	0.5	0.5
H2	1.1	0.0
Others	3.2	0.3

Others: Gas, MSW, Hydro

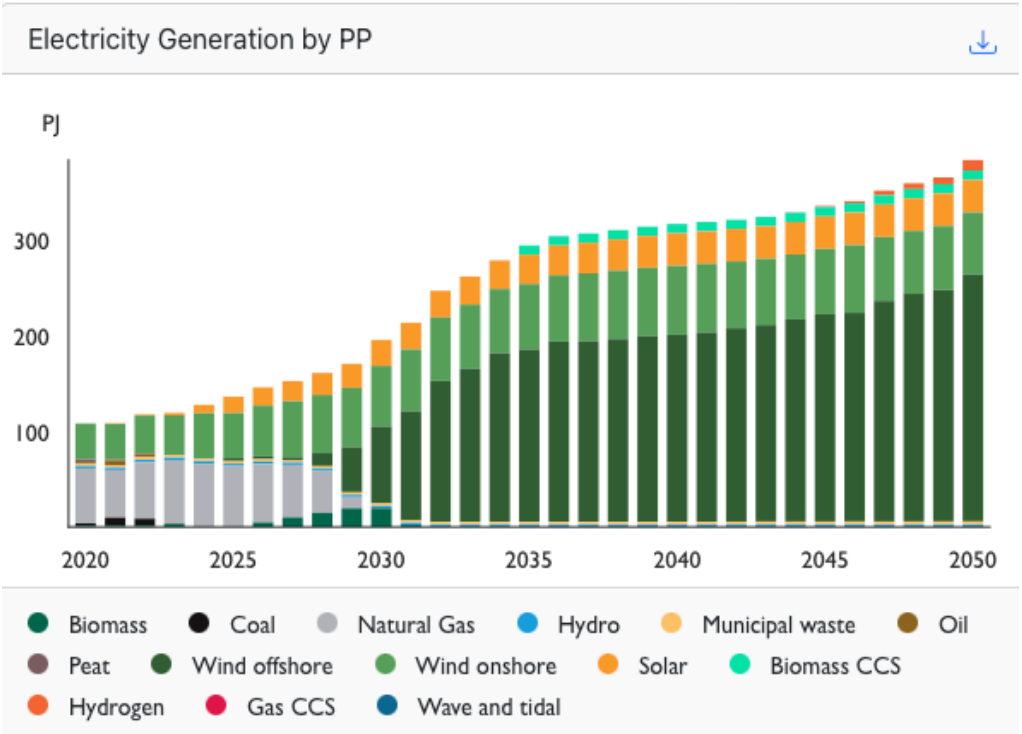
Key assumption: CAP24 power generation targets constraint total wind & solar deployment to 2030

Unprecedented growth in power generation

Average annual growth rate in power generation

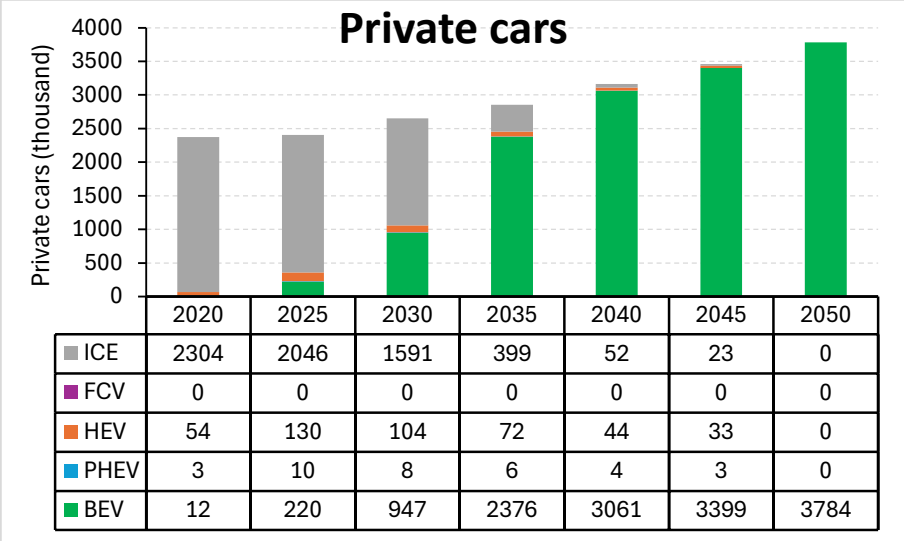


	2010-20	2020-30	2030-40	2040-50	2020-50
BAU	1.5%	6.1%	4.7%	2.2%	4.3%
LED	1.5%	4.5%	3.2%	-0.1%	2.5%

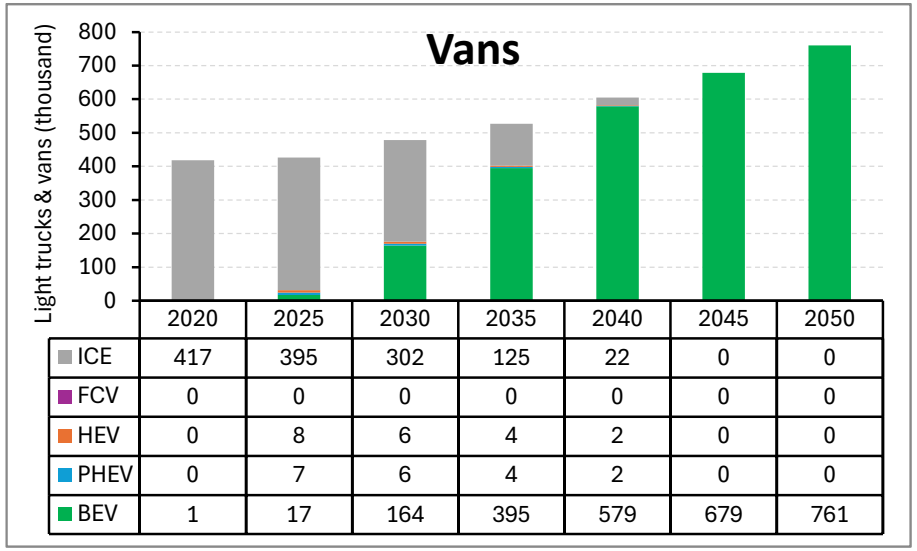


300Mt-BAU scenario

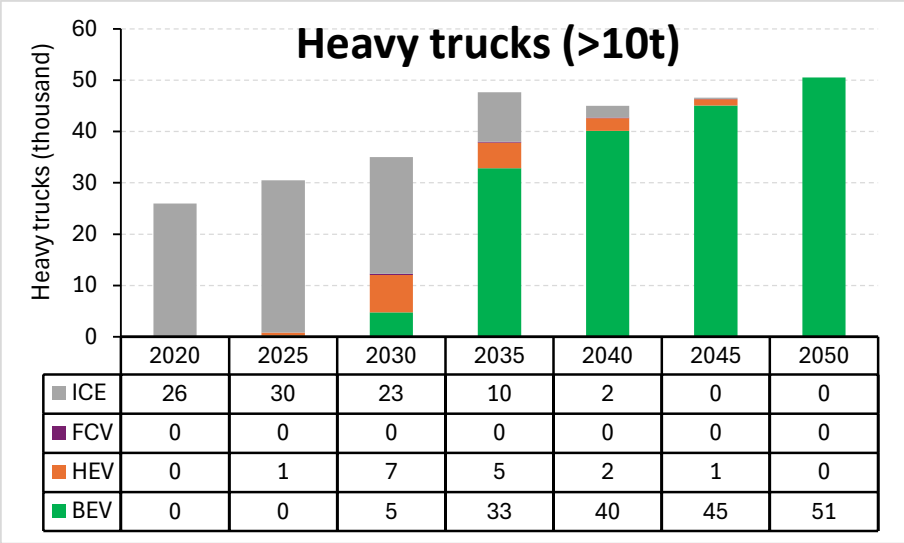
Electrification of vehicles



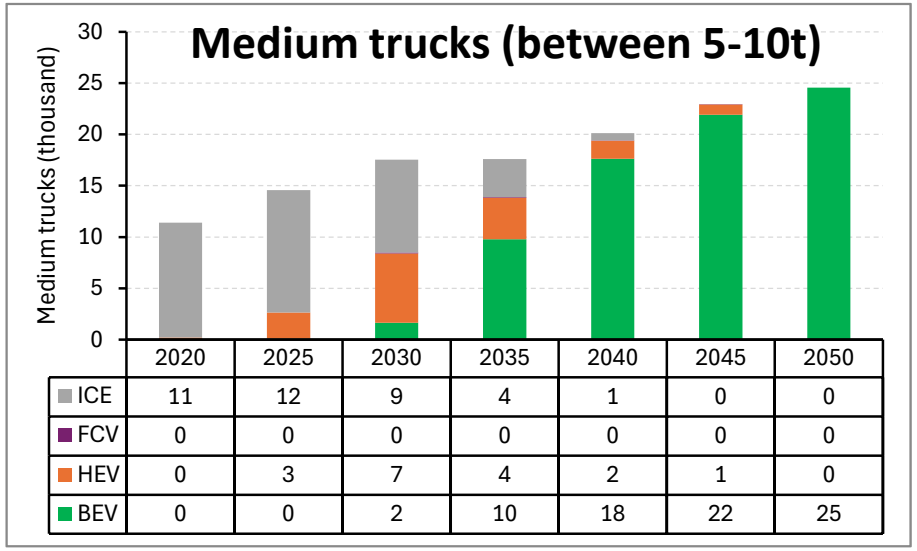
	2020	2025	2030	2035	2040	2045	2050
ICE	2304	2046	1591	399	52	23	0
FCV	0	0	0	0	0	0	0
HEV	54	130	104	72	44	33	0
PHEV	3	10	8	6	4	3	0
BEV	12	220	947	2376	3061	3399	3784



	2020	2025	2030	2035	2040	2045	2050
ICE	417	395	302	125	22	0	0
FCV	0	0	0	0	0	0	0
HEV	0	8	6	4	2	0	0
PHEV	0	7	6	4	2	0	0
BEV	1	17	164	395	579	679	761

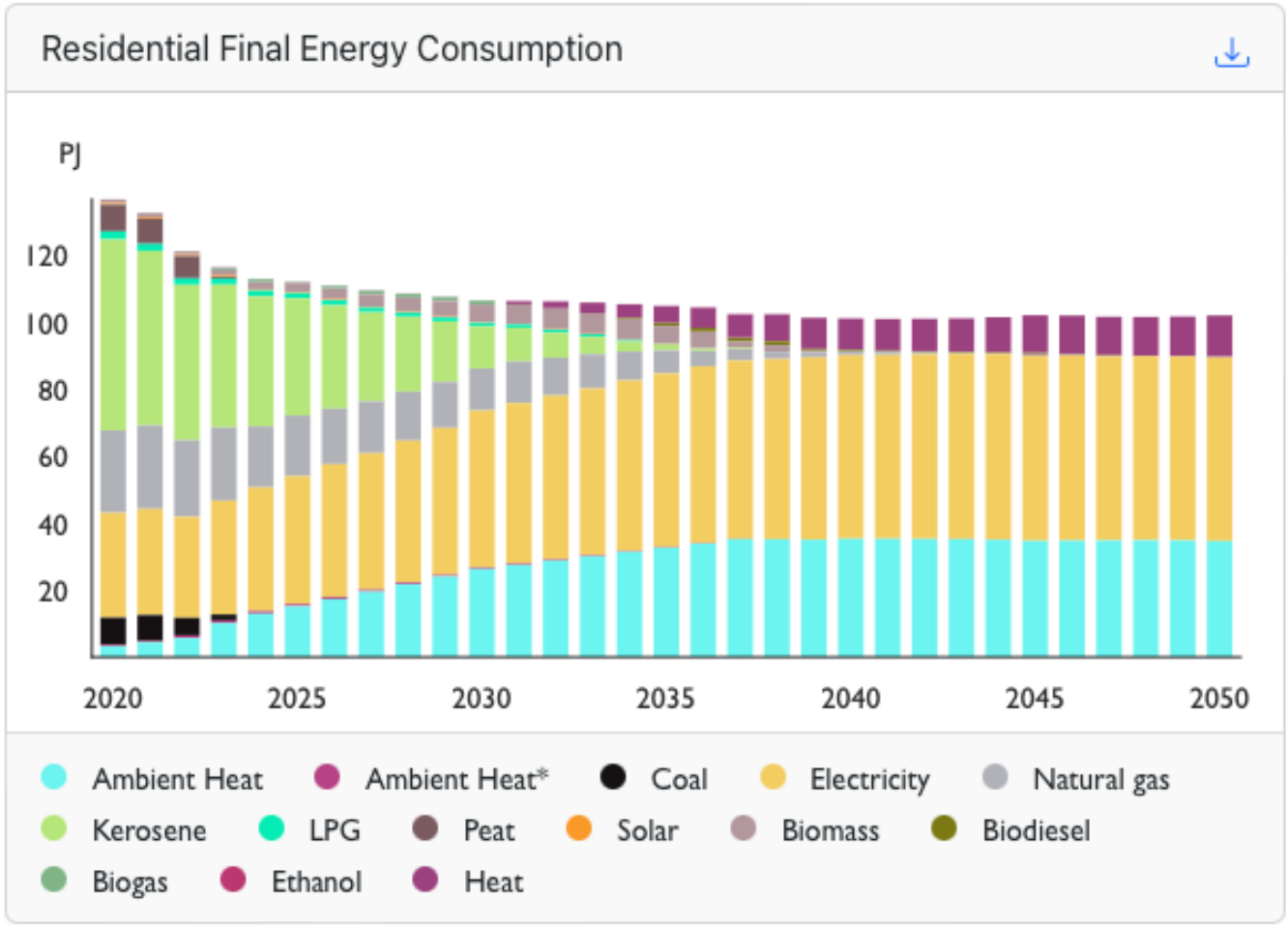


	2020	2025	2030	2035	2040	2045	2050
ICE	26	30	23	10	2	0	0
FCV	0	0	0	0	0	0	0
HEV	0	1	7	5	2	1	0
BEV	0	0	5	33	40	45	51



	2020	2025	2030	2035	2040	2045	2050
ICE	11	12	9	4	1	0	0
FCV	0	0	0	0	0	0	0
HEV	0	3	7	4	2	1	0
BEV	0	0	2	10	18	22	25

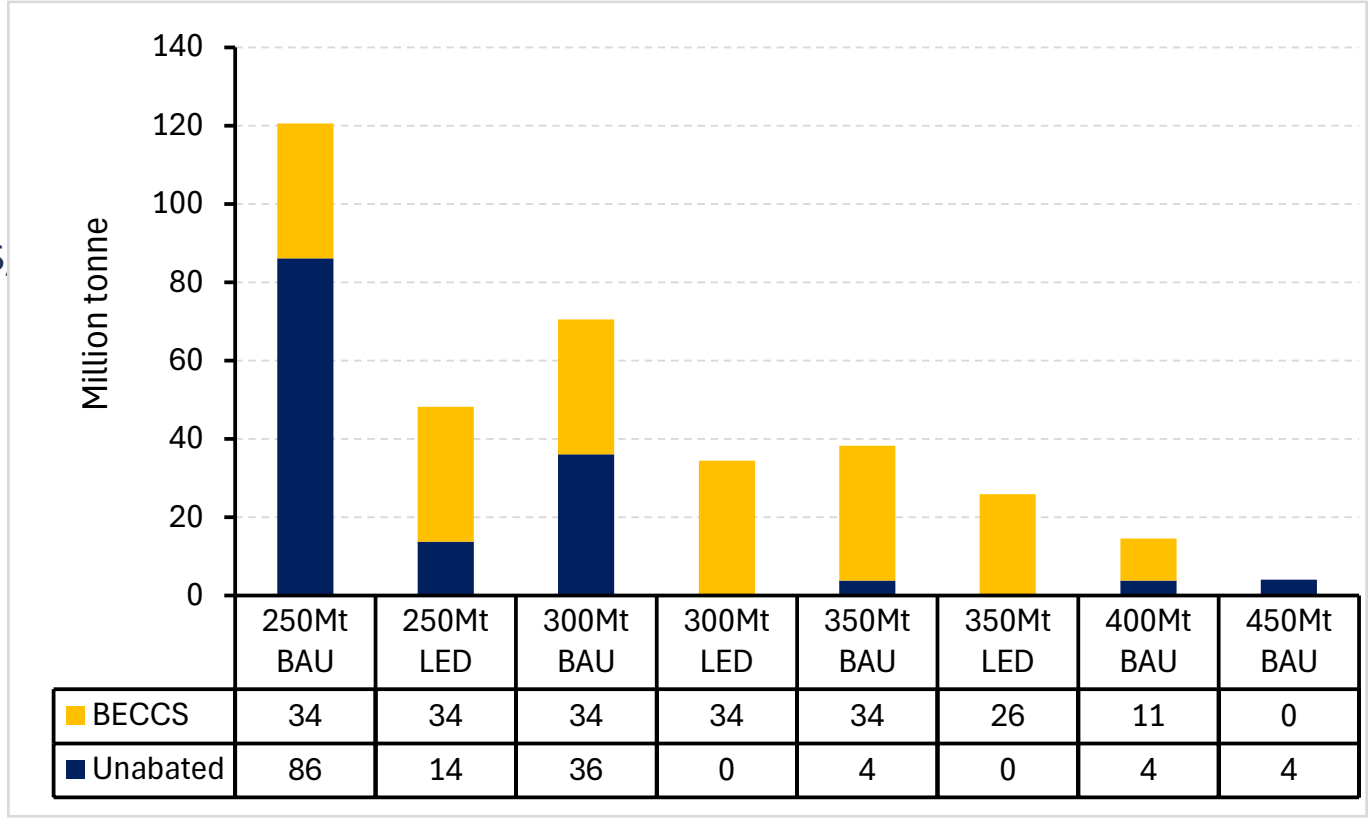
Clean heat in homes



350Mt-BAU scenario

Carbon dioxide removal & BECCS

- All pathways rely on some removals
  - **NETs is mainly required to offset early overshoot of GHG emissions, not to allow ongoing fossil fuels in the long-term**
  - BECCS removes up to 14% of the overall budget in 250Mt scenarios
  - Additional Carbon Dioxide Removal (CDR e.g., ongoing BECCS, direct air capture, afforestation) will be necessary for stringent scenarios & BAU energy demand
  - Overshoot of 4Mt in pre-2030 carbon budgets in BAU scenarios. i.e., model requires some LED to fully meet CB1 & CB2
- Relying on carbon removals brings **very significant risks & trade-offs:**
  - Technologies not proven at scale
  - Biomass with carbon capture and storage (BECCS) requires **significant land area**: up to 10% of Irish agricultural area in the 2040s for 6 $MtCO_2$ annual removal: conflict with nature, food, fibre and natural carbon sinks
  - Direct Air Capture and Storage (DACS) requires significant energy input (~2 $TWh/MtCO_2$) & cost projection >$800/t



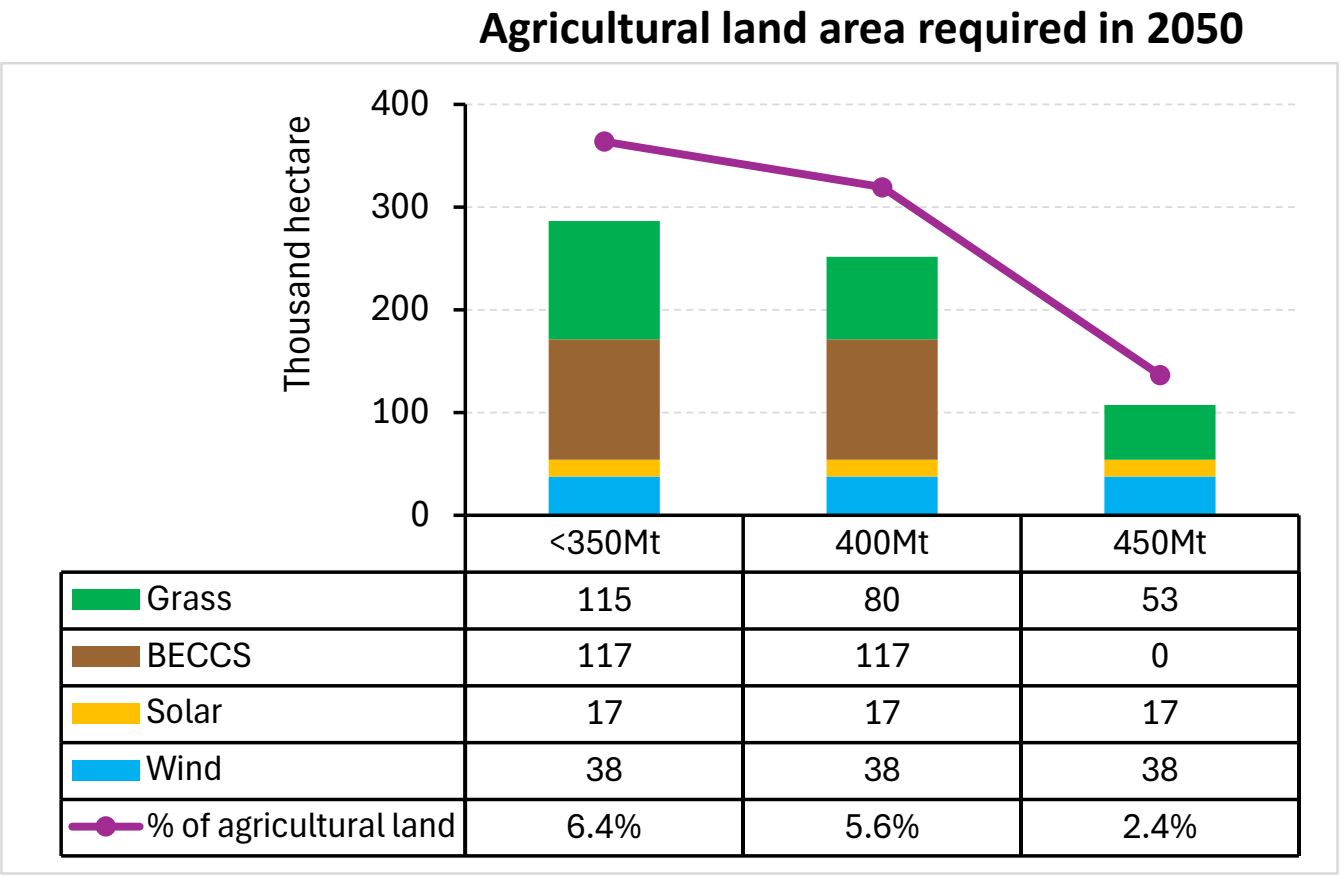
	250Mt BAU	250Mt LED	300Mt BAU	300Mt LED	350Mt BAU	350Mt LED	400Mt BAU	450Mt BAU
BECCS	34	34	34	34	34	26	11	0
Unabated	86	14	36	0	4	0	4	4

"1.5°C will never die… Even if we overshoot the 1.5°C limit, we must return as quickly as possible" – Joeri Rogelj

Delivering more stringent carbon budgets

- Earlier phase out of fossil fuels:
  - Diesel in transport, oil in residential, gas in residential & industry
  - Enabled by
    - Lower energy demand – this allows faster decarbonisation in CB2
    - Earlier deployment of energy transition technologies, e.g., electric trucks
    - Early retirement of fossil fuel technologies (vehicles, home boilers)
    - Greater electricity demand in transport & residential sectors
    - Greater use of novel technologies, e.g., biogas, hydrogen, district heat
    - Increasing RE speed & scale could enable deeper FF phase-out, with more bullish assumptions
- Bioenergy concentrated in more valuable areas
  - e.g., industry and BECCS rather than heating
- More BECCS; earlier BECCS
- Higher overshoot (more CDR post-2050)

Potentially significant land use implications of deep decarbonisation



	<350Mt	400Mt	450Mt
Grass	115	80	53
BECCS	117	117	0
Solar	17	17	17
Wind	38	38	38
% of agricultural land	6.4%	5.6%	2.4%

- More stringent climate change scenarios, and greater NETs, requires more land area
- Land for solar & wind can complement other uses
- Assumes majority of utility-scale solar is on greenfield, rather than unused areas
- Assumes all biomass for BECCS is derived from purpose-grown perennial crops, like miscanthus. This could potentially instead be derived from waste products – requires further analysis

Preliminary analysis based on MSc dissertation research by Ciara Doherty, UCC

Critical model assumptions

- Important assumptions that require further consideration: “feasibility”
  - Cement CCS technology is available in 2029 for all Irish cement plants
  - Offshore wind operating as per CAP24 target in 2030
  - Bioenergy & BECCS pathways: requires significant new fuel supply chain
  - Nearly-zero carbon power system by early 2030s
  - All scenarios see full phase-out of new ICE personal vehicles in 2024. More stringent scenarios bring forward date that all new freight vehicles are electrified (to 2030 in 250Mt-BAU)
  - By 2030, 80% increase in electricity demand across all BAU scenarios. 250% increase by 2050. Major implications for distribution and transmission grid: are upgrades being planned?

Conclusions

- Net-zero by 2050 is (far) too late for consistency with Paris Agreement goals
- Nearly complete **phase-out of all fossil fuels** required in 2040s in all scenarios.
  - Phase out of coal & oil most urgent
  - Nearly no remaining carbon budget for additional fossil fuel equipment (e.g., ICE vehicles)
  - Planned decommissioning of natural gas infrastructure, with local heat plans required.
    - Gas still used for industrial heat in model, but new solutions are under development
  - Overshoot of SECs creates risks for stranded assets and/or carbon lock-in
- Failure to curb GHG emissions now is already threatening ability to meet later carbon budgets:
  - There is an urgency to accelerate the energy transition
  - Approach to "sufficiency" – moderating final energy demands through structural change – is necessary
- Detailed results available:
  - https://epmg.netlify.app/TIM-Carbon-Budget-2024/results/
  - Public peer-review of report for CCAC will soon be open: https://www.ucc.ie/en/epmg/

Notes, assumptions & references

- **Carbon budget assumptions**
  - CB: downscaling remaining Global Carbon Budget from the beginning of 2020 on a **per-capita basis** to estimate Ireland's share
  - **Global RCB:** from IPCC AR6 Table SPM.2, beginning from 2020 the global RCBs (see here)
  - 5 energy-related CBs for Ireland, **rounded** to 250 to 450 Mt for the period of **2021-2050**
  - Recent estimates indicate that GCB is reducing – from beginning of 2023, 250 Gt for 50% probability of 1.5C (Lamboli et. al., 2023). Inadequate non-CO2 mitigation exhausts this budget already (https://doi.org/10.21203/rs.3.rs-3326772/v1)
  - This analytical framework **covers energy systems** CO_2 emissions (excluding Int. Aviation and Shipping, excluding LULUCF)
  - Acknowledgement that downscaling on a per-capita basis, and starting from 2020, are conservative assumptions from the perspective of climate justice (Mintz-Woo, *in prep*)
- **TIM**
  - Energy system calibrated to 2022 energy balances
  - Social discount rate: 2%
  - Planning horizon: 2023-50
  - "Unmitigated emissions": mitigation backstop technology €2000/tonne CO2
  - Costs include fuel imports and production, energy technology investments and partially infrastructure costs

- **TIM Documentation Paper**
  - O. Balyk *et al.*, "TIM: Modelling pathways to meet Ireland's long-term energy system challenges with the TIMES-Ireland Model (v1.0)" *Geoscientific Model Development*, vol. 15, 2022 (Link)
- **TIM Application**
  - **Trucks:** V. Aryanpur, F. Rogan, "Decarbonising road freight transport: The role of zero-emission trucks and intangible costs" *Scientific Reports*, vol. 14, 2024 (Link)
  - **District Heating:** Mc Guire *et al.*, "Is District Heating a cost-effective solution to decarbonise Irish buildings?" *Energy*, vol. 296, 2024 (Link)
  - **Private cars:** V. Aryanpur *et al.*, "Decarbonisation of passenger light-duty vehicles using spatially resolved TIMES-Ireland Model" *Applied Energy*, vol. 316, 2022 (Link)
  - **Low Energy Demand:** A. Gaur et al., "Low energy demand scenario for feasible deep decarbonisation: Whole energy systems modelling for Ireland" *Renewable Sustainable Energy Transition*, 2022 (Link)
  - **Residential Sector:** J. Mc Guire *et al.*, "Developing decarbonisation pathways in changing TIMES for Irish homes" *Energy Strategy Reviews*, vol. 47, 2022 (Link)
  - **Power Sector:** X. Yue *et al.*, "Least cost energy system pathways towards 100% renewable energy in Ireland by 2050" *Energy*, vol. 207, 2020 (Link)
- **Results Visualisation Website**
  - link
- **TIM Source Code on GitHub**
  - https://github.com/MaREI-EPMG/times-ireland-model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