Ireland's Low-Carbon Opportunity:

an analysis of the costs and benefits of reducing greenhouse gas emissions

Technical Appendix

SUSTAINABLE ENERGY IRELAND

July 2009

Introduction – context of the cost curve project

- There is a pressing need for a better understanding of how we can meet our policy goals (and binding targets) for GHG reduction
- We believe this study can make an important contribution by using a coherent framework across all sectors of the Irish economy to present a ‘big picture’ analysis in a way that is easy to understand
- The analysis is not policy-prescriptive but it cuts across many sectors, many interests and policy responsibilities. The cost-curve report does not address all our knowledge gaps; indeed, it actually highlights some new ones. SEI therefore regard it as work-in-progress rather than an end-product.
- We would like to offer thanks to all those who helped in bring the work to this point, particularly the ESB who co-funded it.
- We look forward to continued collaboration with interested parties.

Note on cost curve – uses and limitations

- The Ireland GHG abatement cost curve has been developed based on the proven methodology of McKinsey's global GHG abatement cost curve. The Ireland specifics are created through consultations with over 80 Irish stakeholders and experts from all sectors
- The GHG abatement cost curve is an approach to assess technical abatement opportunities relative to a “business as usual” emissions development scenario. It does examine emission reduction potential and associated cost for each opportunity. The cost curve is based on a societal perspective and does not include behavioural abatement opportunities.

A GHG MAC curve can be used for…

- Constructing an **integrated perspective on abatement potential and opportunities** to be compared with a given target CO_2e emissions level
- **Order of magnitude** evaluation and prioritization of abatement measures within and across sectors
- Providing a **fact base** to support the assessment of possible regulatory arrangements

A GHG MAC curve can NOT be used for…

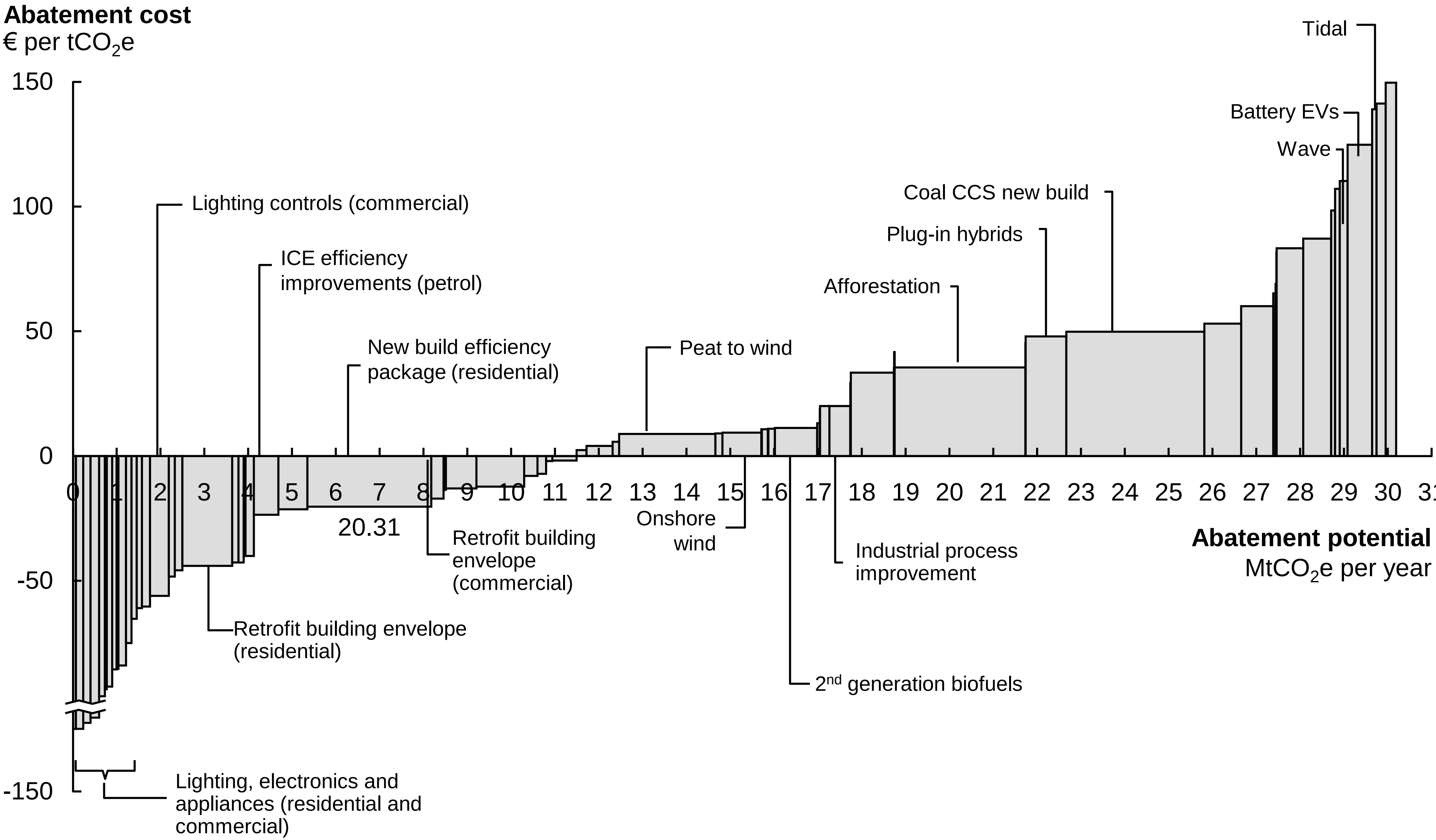
- **Definition of target CO_2e concentration level** to solve climate change issues
- Forecasting exact CO_2 prices or CO_2 regulation, or determining the technical or economic feasibility of policy targets
- Forecasting individual technologies – while there is a view on learning rates and volume development for individual technologies, in the database, the value of this work is its **comprehensive scope more than the depth in individual technologies**

How to read and use this document

- This document contains the outputs, key insights, sector details, and detailed assumptions for the Ireland greenhouse gas (GHG) abatement cost curve
- The document contains this material in three parts:
  - **Executive summary** – includes a summary of the key insights from the Ireland Cost Curve and background pages for each of these insights
  - **Sector detail** – includes an overview of each sector and background details for the scenario analysis
  - **Assumptions and methodology** – highlights the cost and volume assumptions use for each of the sector abatement opportunities. It also includes sources for assumptions and notes on the methodology

Contents

Ireland 2030 GHG abatement cost curve[1]



1 Baseline cost curve based on 2007 IEA energy price forecasts (~60 USD / barrel in 2030) and a cost of capital of 4%

Summary of insights (1/2)

1. As a result of current economic conditions, Business As Usual (BAU) emissions take a dip but are expected to trend slightly upwards, growing at 0.1% p.a. compounded from 65.6 $MtCO_2e$ in 2005 to 66.5 $MtCO_2e$ in 2030
2. The Ireland cost curve for 2020 indicates total abatement opportunities below 80 €/t of 13.2 $MtCO_2e$. This opportunity more than doubles to 28 $MtCO_2e$ by 2030. Additional abatement opportunities from EVs and other new generation technologies (which are more expensive than 80 €/t) increase opportunity to 30 $MtCO_2e$
3. Realizing full potential by 2030 will reduce abatements relative to BAU by 42%
4. In 2030, the top ten abatement levers deliver over 60% of the 2030 abatement potential
5. In 2030, power leads delivery of abatement with 11.1 $MtCO_2e$ (40% of total) but all other sectors need to contribute to realize Ireland's full abatement potential
6. In some cases, there is complex interplay across sectors. For example, the 11.1 $MtCO_2e$ of power abatement in 2030 includes 3.1 $MtCO_2e$ of demand reduction in buildings and industry. In addition, there is an increase of 0.2 $MtCO_2e$ of emissions from electric vehicles, a transport sector lever for the same period
7. Ireland's 2030 cost curve identifies 42% of "negative cost" abatements. This compares to 29% globally, 35% in the Australia and 40% in the UK (although those country studies had a somewhat lower cut-off for acceptable marginal abatement cost). Barriers must be addressed if Ireland is to achieve its "negative cost" potential.

1 Land-use, land-use change and forestry

Summary of insights (2/2)

8. 46% of total abatement opportunities are from sectors covered under the EU ETS. However, the ETS sectors only contribute 33% of emissions and therefore account for a larger relative share of abatement than non-ETS businesses

9. The abatement cost can vary significantly depending on fuel prices. A scenario of oil at $120 a barrel increases the 'negative cost' potential by ~60% to ~16 $MtCO_2e$ (from 10 $MtCO_2e$ in the base case). In addition, the order of the cost curve changes as different abatement opportunities are affected to differing degrees depending on their relative fuel intensity (with regards to the reference technology that would represent business-as-usual)

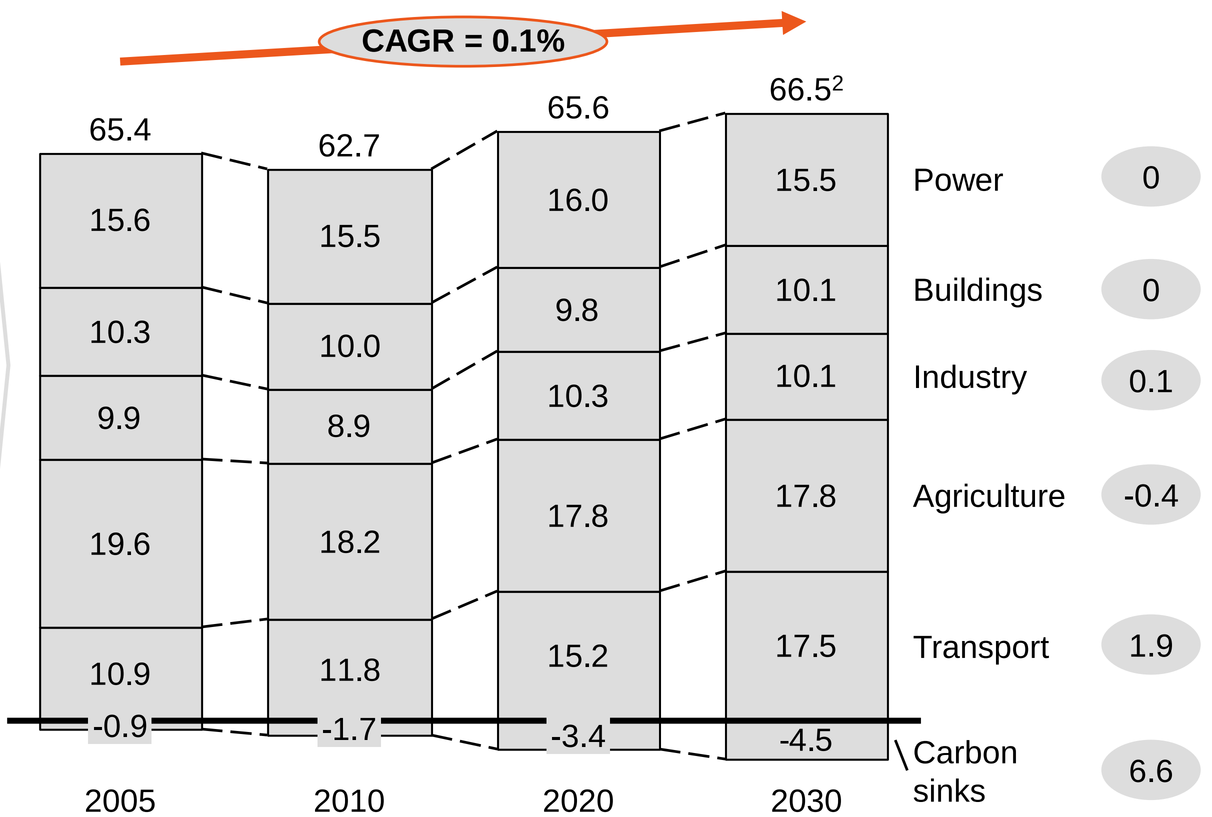
10. Behavioural levers could add significant reductions beyond the technical potential. We have preliminarily identified ~3-4 $MtCO_2e$ of additional abatement opportunity (i.e., up to a further 10% reduction to post-abatement emissions) from behavioural levers, primarily in the transport and buildings sectors. However, issues with permanence and verification will need to be addressed, and further research into the full range of behavioural options performed

1 Ireland Business as Usual (BAU) scenario growth based on projections for drivers of each sector

BAU reference scenario

- BAU reference scenario includes the emissions for modelled sectors which are based on key drivers:
  - Energy use in residential and commercial buildings (Buildings)
  - Vehicle fleet mix projection, distance travelled forecasts, and biofuel penetration projection (Transport)
  - Electricity demand and generation mix (Power)
  - Home building projections and GDP (Industry/ cement)
  - Animal herd and farm land projections (Agriculture)
  - Afforestation projection and available land (Forestry)

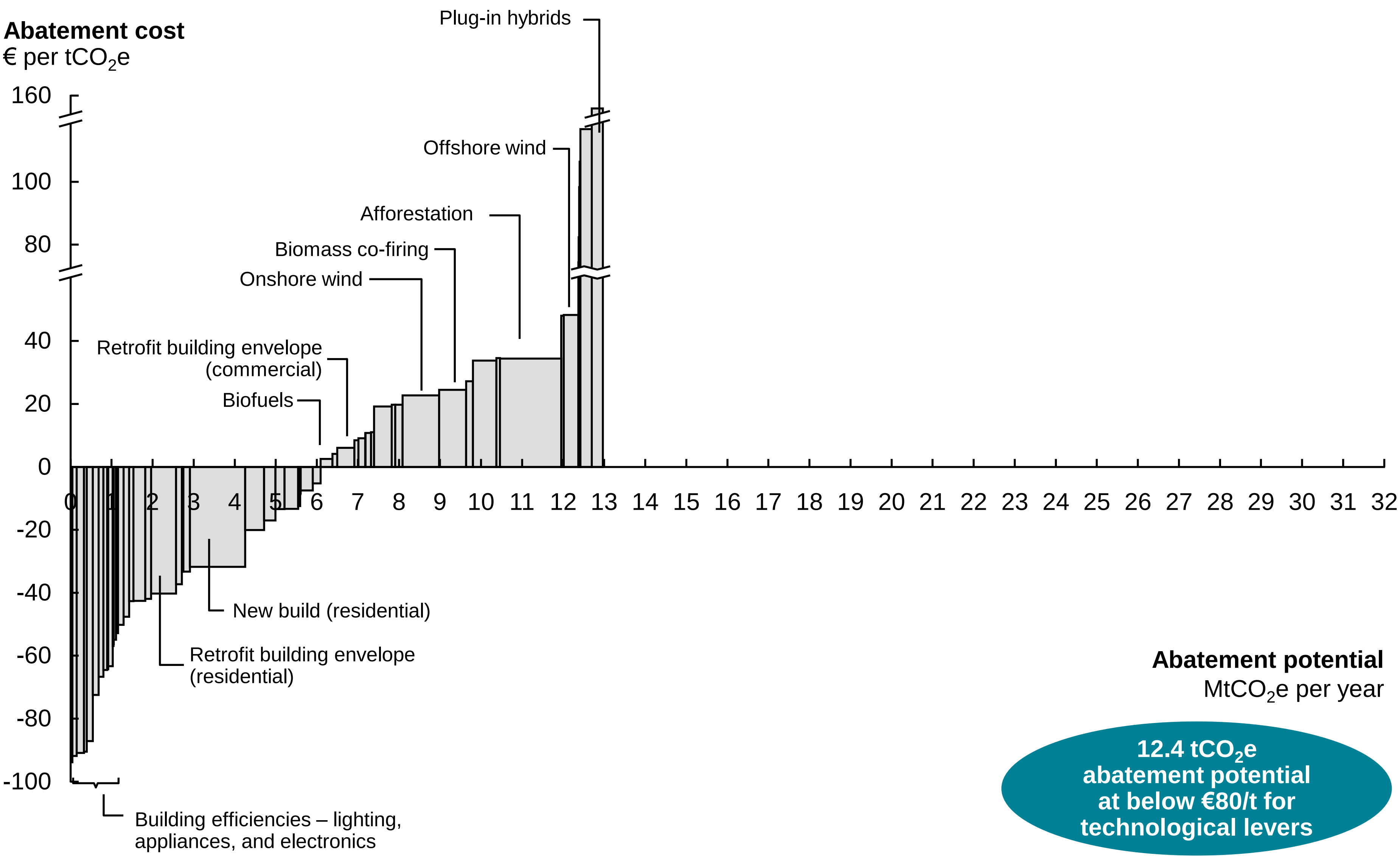
GHG emissions by sector[1]
$MtCO_2e$



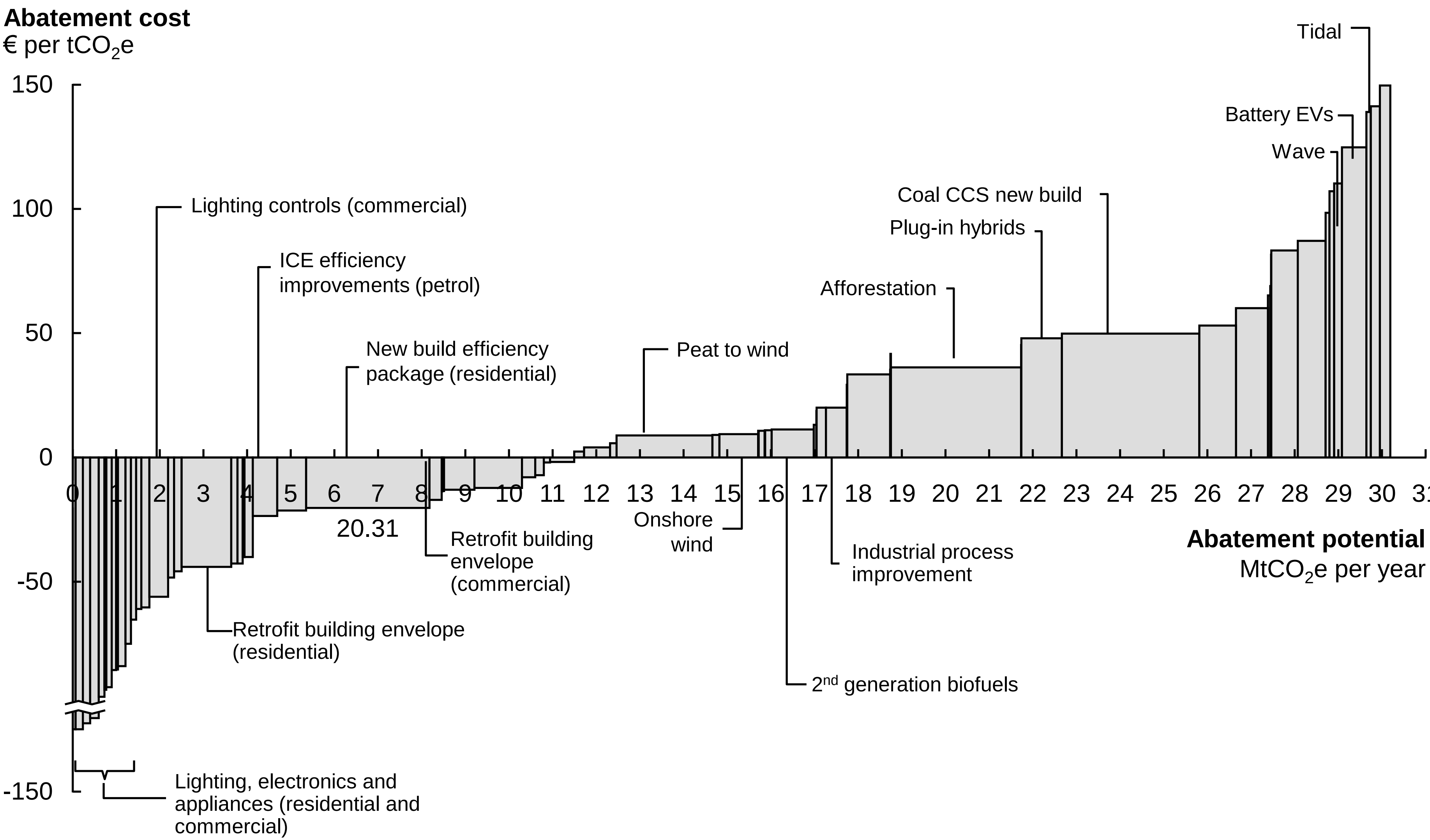
1 Representing sectors currently covered by Ireland GHG cost curve. See slide 105 for a comparison with EPA's emissions projections
2 Emissions in 2030 are based on extrapolations from various sources for each sector

SOURCE: Irish EPA, projections for 2020 (March 2009 revision); Ireland GHG Abatement Cost Curve

2 Ireland GHG abatement cost curve 2020

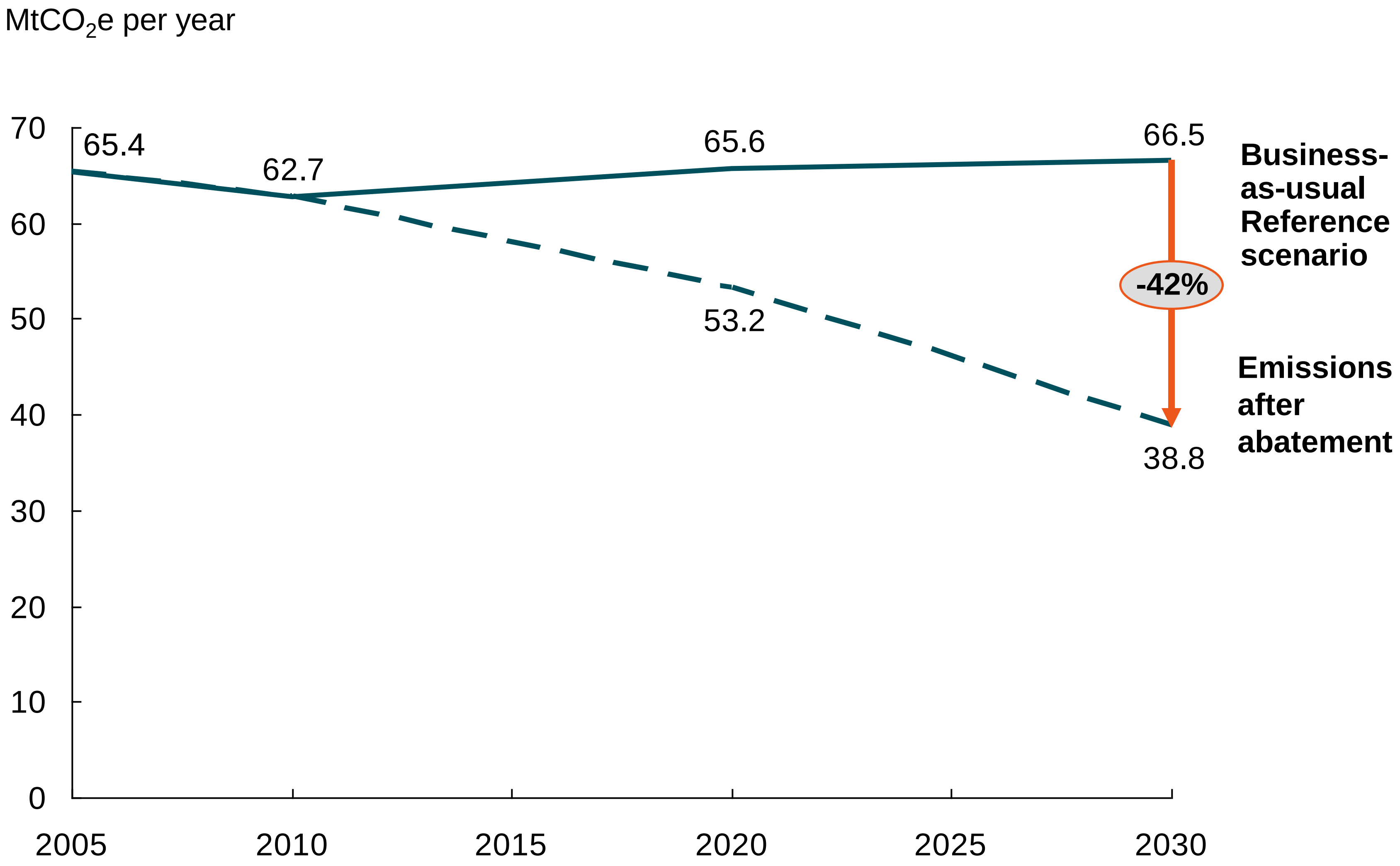


2 Ireland 2030 GHG abatement cost curve[1]



1 Baseline cost curve based on 2007 IEA energy price forecasts (~60 USD / barrel in 2030) and a real cost of capital of 4%

3 Potential post abatement pathway could deliver 45% reduction in emissions



4 Largest 10 levers could deliver >60% of the abatement

Abatement opportunities[1], 2030

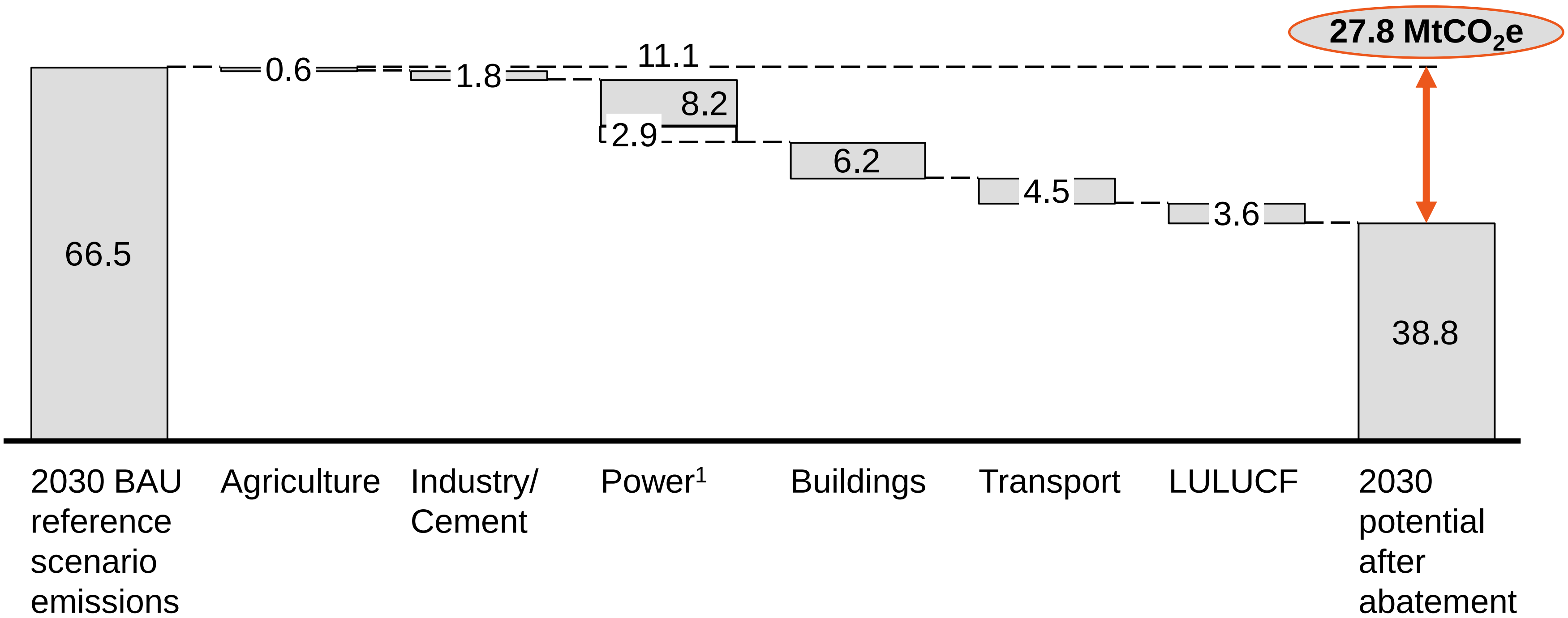
Lever	Abatement potential, Mt CO_2e	Lever cost, €/tCO_2e	Description
Onshore wind	4.1	15	▪ Including both high penetration and low penetration wind
Coal CCS new build	3.2	50	▪ Replacement of Moneypoint with CCS coal plant
Afforestation	3.0	30	▪ Increasing national forested area
Residential new build efficiency package	2.8	-20	▪ Improved new build building energy efficiency
Residential retrofit building envelope	1.1	-44	▪ Level 1 retrofit - "basic retrofit" package: attic and wall cavity insulation; weather strip doors and windows
LDV gasoline bundle 4	1.1	-12	▪ Fuel efficiency improvement for internal combustion engines
Second-generation biofuels	1.0	11	▪ Sustainable biofuels used to displace petrol and diesel use in the transport sector
Plug-in hybrid EVs	0.9	45	▪ Plug in electric vehicles that displace gasoline and diesel passenger vehicles (have both electric and ICE drive trains)
Residential retrofit building envelope, pkg 2	0.8	53	▪ Additional retrofit building improvements including high efficiency windows, doors, and high passive solar
Offshore wind	0.8	61	▪ Including both high penetration and low penetration wind

1 Not including organic soils restoration which may not be credited in the UNFCCC inventory

SOURCE: Ireland GHG Abatement Cost Curve

5 Abatement potential by sector relative to BAU reference scenario

Ireland 2030 GHG emissions and sector abatement potential
Mt CO_2e

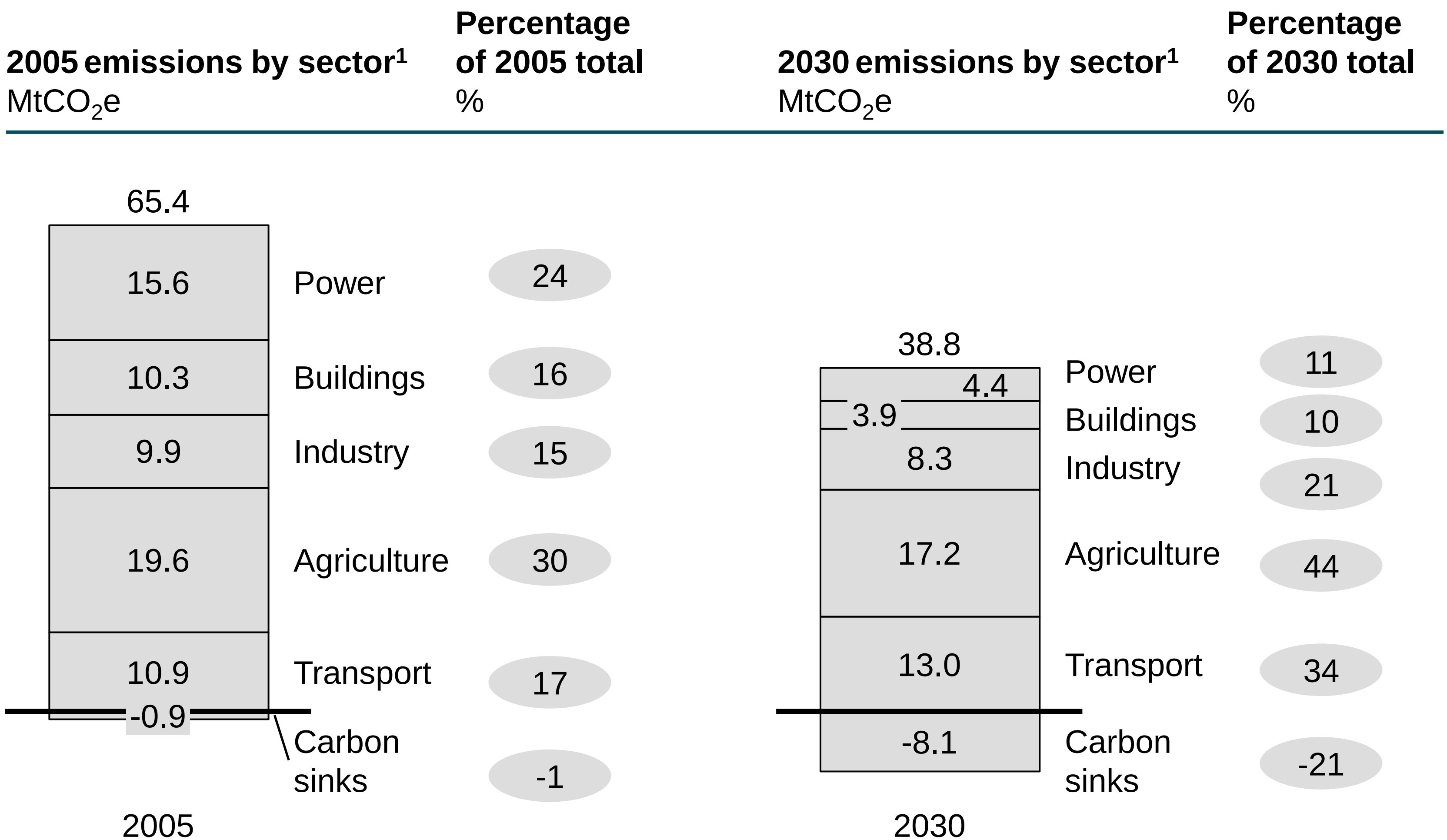


Proportion of total Abatement[1]	Agriculture	Industry/ Cement	Power[1]	Buildings	Transport	LULUCF
	2%	6%	40%	22%	16%	13%

Power sector (including demand reduction) accounts for the largest (40%) proportion of abatement potential

1 Including abatement from power sector and indirect changes from power use in other sectors

5 The sectoral breakdown of emissions after abatement would be significantly different from the current breakdown

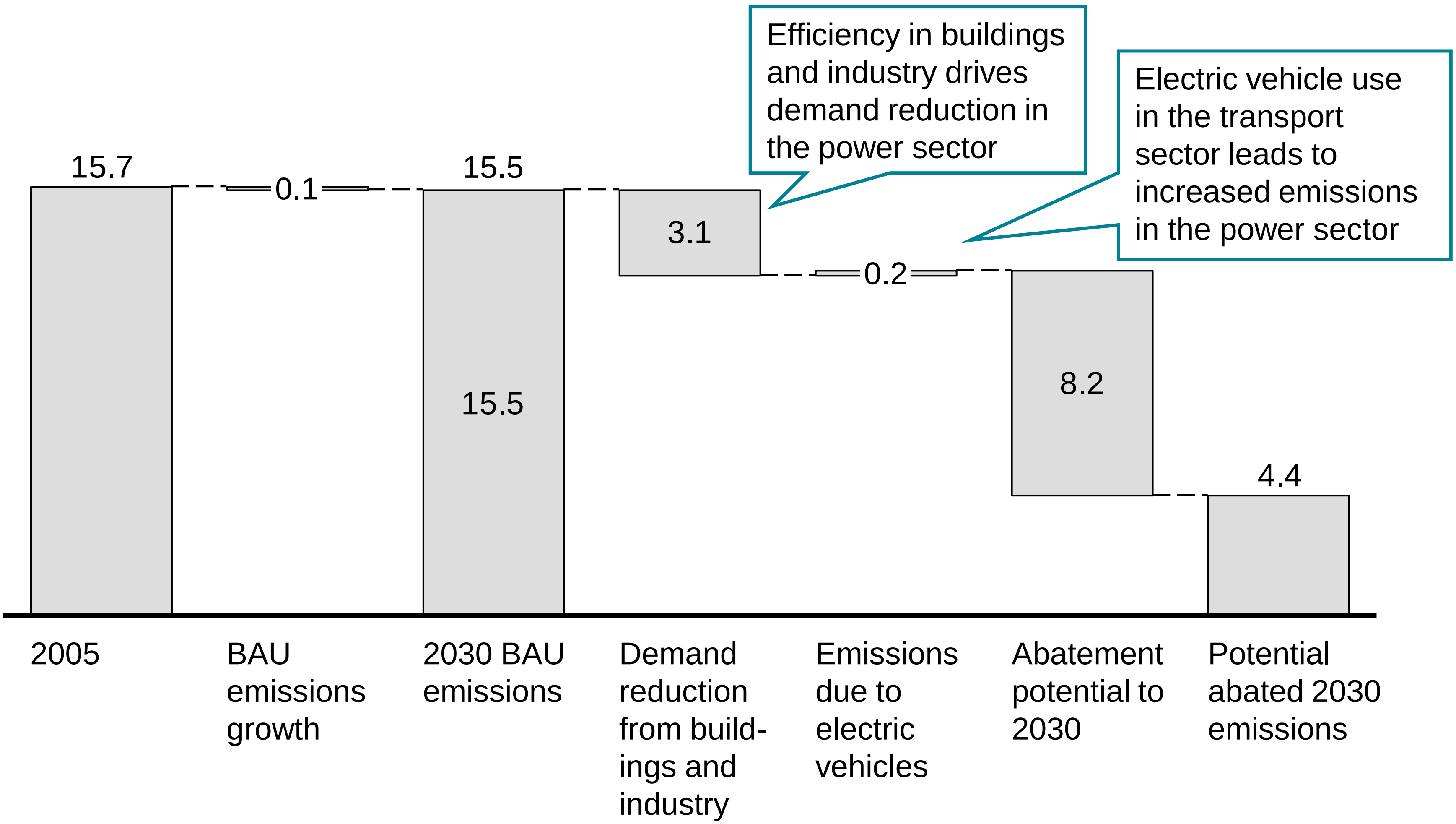


1 Representing sectors currently covered by Ireland GHG cost curve

SOURCE: EPA UNFCCC 2006 GHG inventory; Ireland GHG Abatement Cost Curve

6 There are complex interactions across sectors

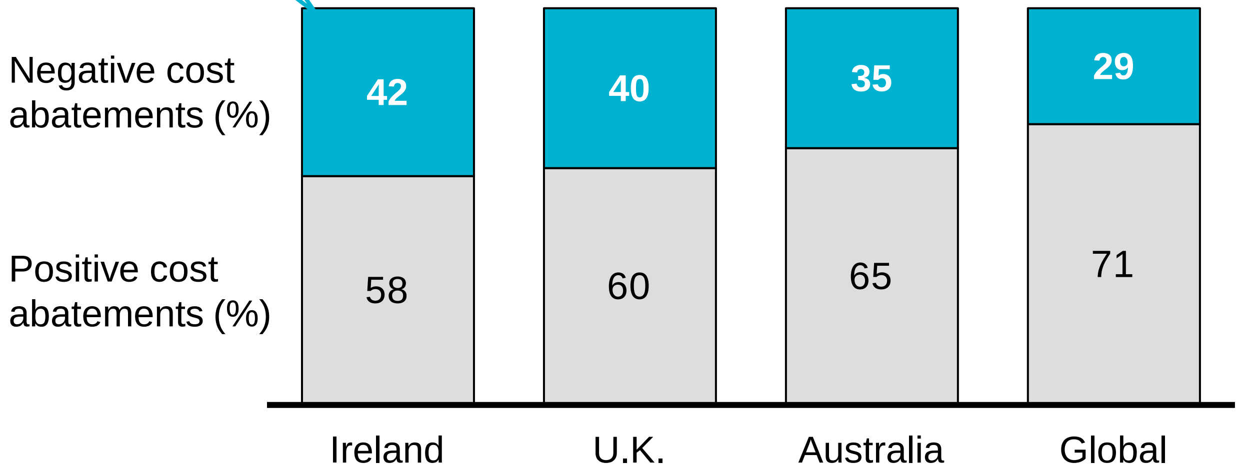
Ireland 2030 power sector emissions
$MtCO_2e$



SOURCE: Ireland GHG Abatement Cost Curve

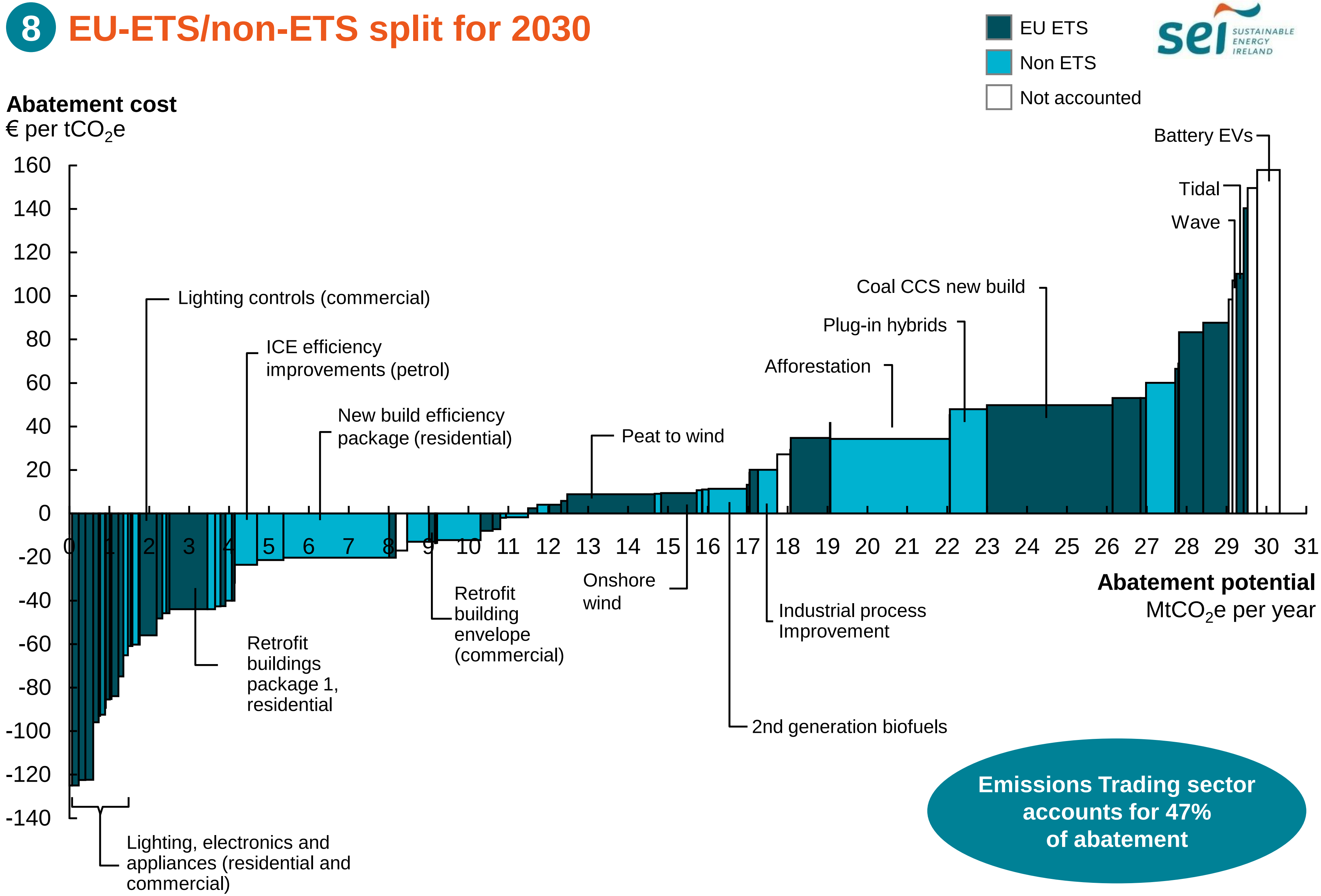
7 Although Ireland has more negative cost abatements than global average, barriers to realizing these abatements exist

- Climate and buildings likely lead to higher opportunity
- Relatively large LULUCF abatement reduces proportional size



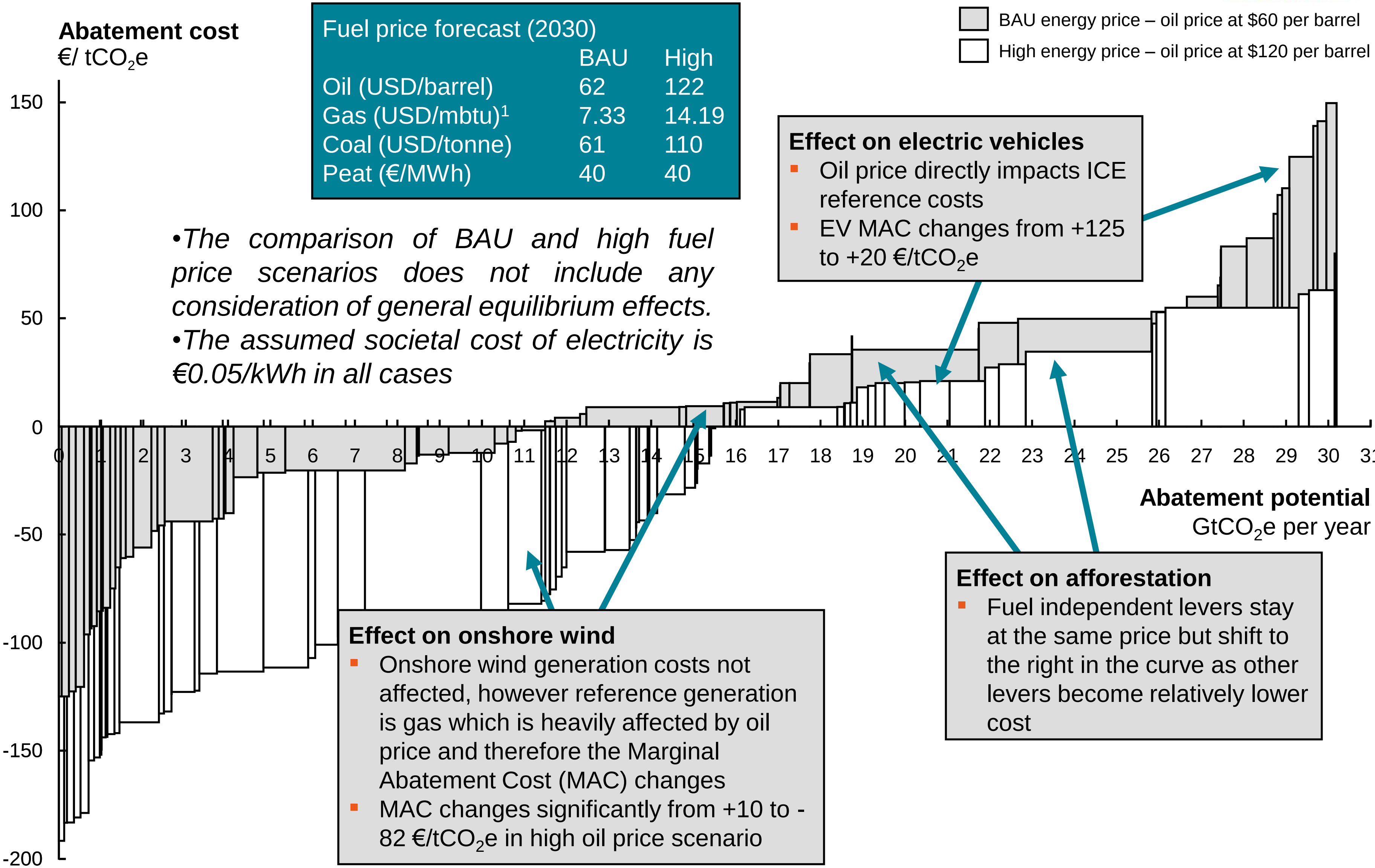
- Barriers to implementing negative cost abatements in Ireland include
  - Capex required (especially in the current economic environment)
  - Principal agent issues
  - Uncertainty around returns
  - Lack of consumer information
  - High consumer discount rates applied

8 EU-ETS/non-ETS split for 2030



9 Effect of high energy prices (oil price at $120 a barrel)

Fuel price forecast (2030)	BAU	High
Oil (USD/barrel)	62	122
Gas (USD/mbtu)[1]	7.33	14.19
Coal (USD/tonne)	61	110
Peat (€/MWh)	40	40



•The comparison of BAU and high fuel price scenarios does not include any consideration of general equilibrium effects.
•The assumed societal cost of electricity is €0.05/kWh in all cases

Effect on electric vehicles
- Oil price directly impacts ICE reference costs
- EV MAC changes from +125 to +20 €/tCO_2e

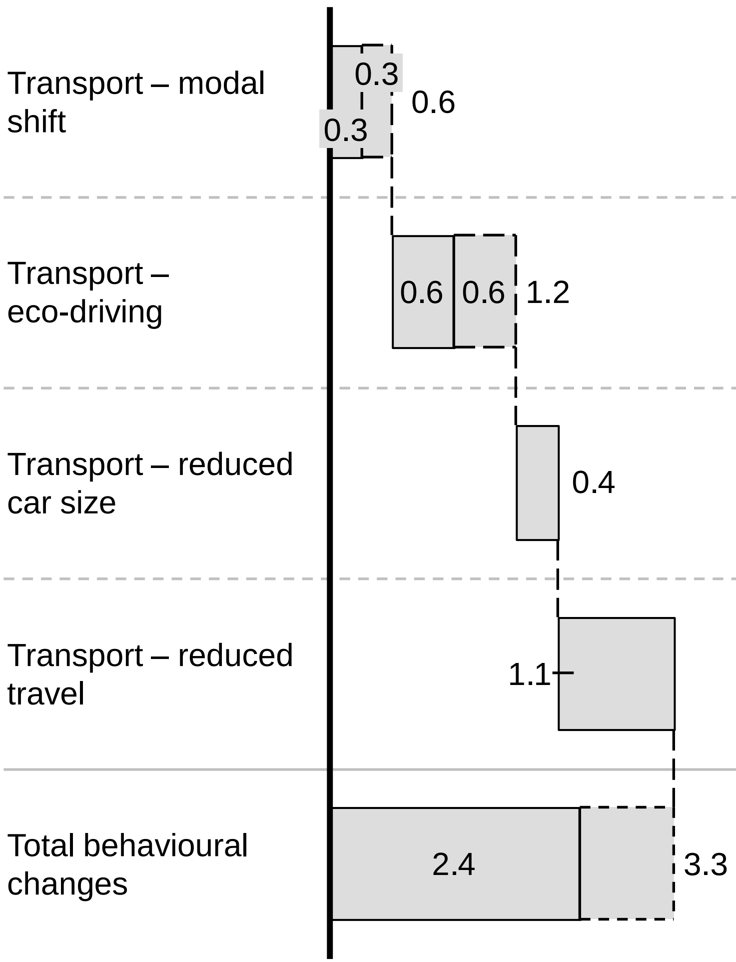
Effect on onshore wind
- Onshore wind generation costs not affected, however reference generation is gas which is heavily affected by oil price and therefore the Marginal Abatement Cost (MAC) changes
- MAC changes significantly from +10 to -82 €/tCO_2e in high oil price scenario

Effect on afforestation
- Fuel independent levers stay at the same price but shift to the right in the curve as other levers become relatively lower cost

1 UK NBP wholesale price (Stg£) plus gas network costs to Ireland. BAU gas price equates to €22.00/MWh (Gross Calorific Value).

10 Examples of potential behavioural changes beyond technical abatement measures (1/2)

$MtCO_2e$ per year; 2030



Calculation assumptions[1]

Transport – modal shift:
- 5-10% shift to public transport, cycling or walking
- Applied only to private vehicles

Transport – eco-driving:
- 5-10% reduction in fuel consumption through improved driving (e.g., change gears at lower revs, smooth acceleration and braking, decrease use of air conditioning, reduce idling, maintaining proper tyre pressure)

Transport – reduced car size:
- 50% of vehicles bought at one class smaller than currently leading to average savings of ~10gCO_2e/km
- Applied only to private vehicles

Transport – reduced travel:
- 10% road transport use reduction
- Also applied to commercial vehicles through improved route planning and more efficient use of vehicle capacity

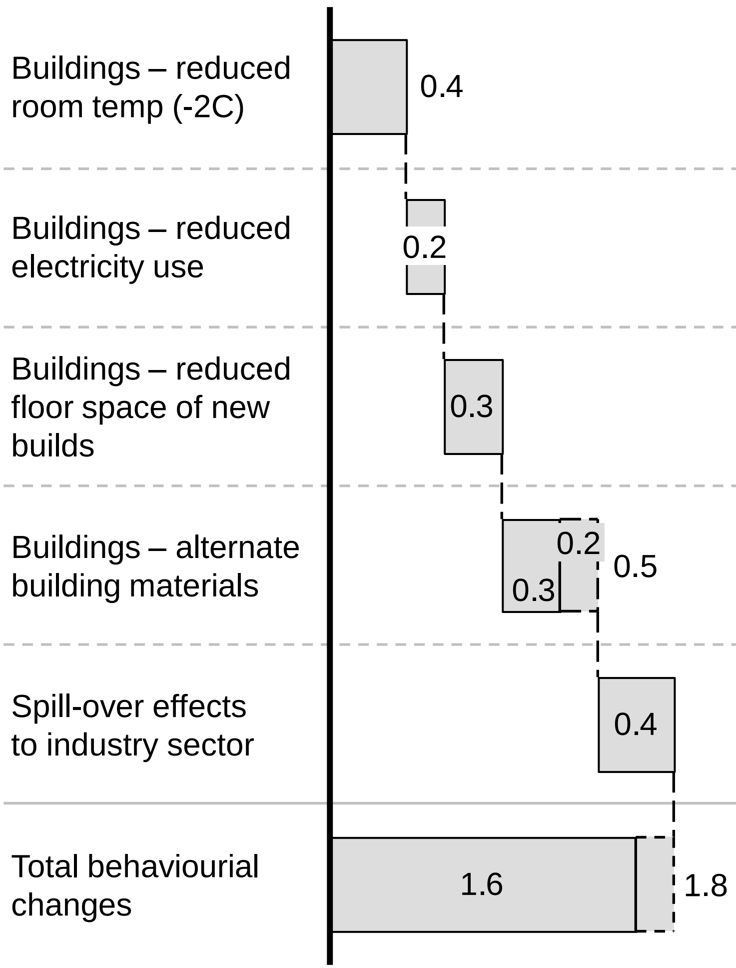
2.4 – 3.3 $MtCO_2e$ of abatement may be achievable from the transport and agriculture sectors

1 Behavioural effects accounted for after implementation of all other levers

SOURCE: Ireland GHG Abatement Cost Curve, Global GHG Abatement Cost Curve v2.0

10 Examples of potential behavioural changes beyond technical abatement measures (2/2)

$MtCO_2e$ per year; 2030



Calculation assumptions[1]

- -2°C change in HVAC equivalent to ~12% reduction in energy use
- 20% reduction in lighting, appliances, water heating and electronics
- 20% decrease in average size of new builds
- Replacement of 10-20% of cement use in buildings with alternate materials
- Cement: -15% (from floor space reduction in buildings)

Buildings behavioural levers could lead to a reduction of 1.6-1.8 $MtCO_2e$ for a total of 3.0 – 4.1 $MtCO_2e$ across the selected behavioural levers

1 Behavioural effects accounted for after implementation of all other levers

SOURCE: Ireland GHG Abatement Cost Curve, Global GHG Abatement Cost Curve v2.0

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Sector summary

BAU	▪ Power sector emissions totalled 15.7 Mt CO_2e in 2005[1] ▪ Under a business as usual (BAU) scenario, emissions could fall slightly to 15.5 Mt CO_2e by 2030 ▪ The primary driver of emissions growth is increased electricity demand ▪ Lower average CO_2 intensity through increased generation from renewables and imports, and the high proportion of gas-fired generation, limits emissions growth
Abatement potential	▪ **Onshore wind** represents Ireland's biggest abatement opportunity from renewables of 4.0 MtCO_2e due to high load factors (~30-35%) and the large number of available sites. It is also the least expensive abatement lever at low penetrations at 9 €/MtCO_2e. However, the costs of onshore wind could increase by up to 24 €/MtCO_2e as capacity grows due to additional capacity credit costs and lower load factors ▪ **Offshore wind** can achieve better load factors (~40%) than onshore wind but higher capex and opex will ensure that it remains a less attractive opportunity. Abatement will be limited to 0.8 MtCO_2e by 2030 ▪ **Wave and tidal** energy represent technologies that are in early stages of development, requiring extensive R&D / prototyping, and that have high costs per tonne of CO2 abated (100 -140 €/MtCO2e). By 2030, they will contribute 0.3 MtCO2e of abatement ▪ Ireland's three peat plants could technically **co-fire** 30% of their fuel mix with biomass which would reduce emissions by 0.6 MtCO_2e. Low capital expenditure requirements make it a very attractive opportunity at 21 €/MtCO_2e. However, this lever does not occur after 2025 due to assumption that peat plants are retired in 2025 and replaced with wind ▪ New **coal CCS** technology could provide 3.2 MtCO2e of abatement if installed on a newly-built 900MW plant. For one possible geographic arrangement (Moneypoint as the capture site and Kinsale gas field as the storage site) the abatement cost is calculated at 50 €/MtCO2e **Coal co-firing with biomass** offers 0.6 MtCO_2e but is an expensive lever due to the large difference in fuel prices (83 €/MtCO_2e)
Implications	▪ Onshore wind is the most cost effective GHG abatement lever and will be vital to any GHG abatement strategy ▪ However, other renewable technologies could also be developed, especially offshore wind which will provide higher abatement as fewer suitable onshore sites become available ▪ High levels of intermittency on the grid due to increased wind capacity could pose some technical challenges for the grid operator

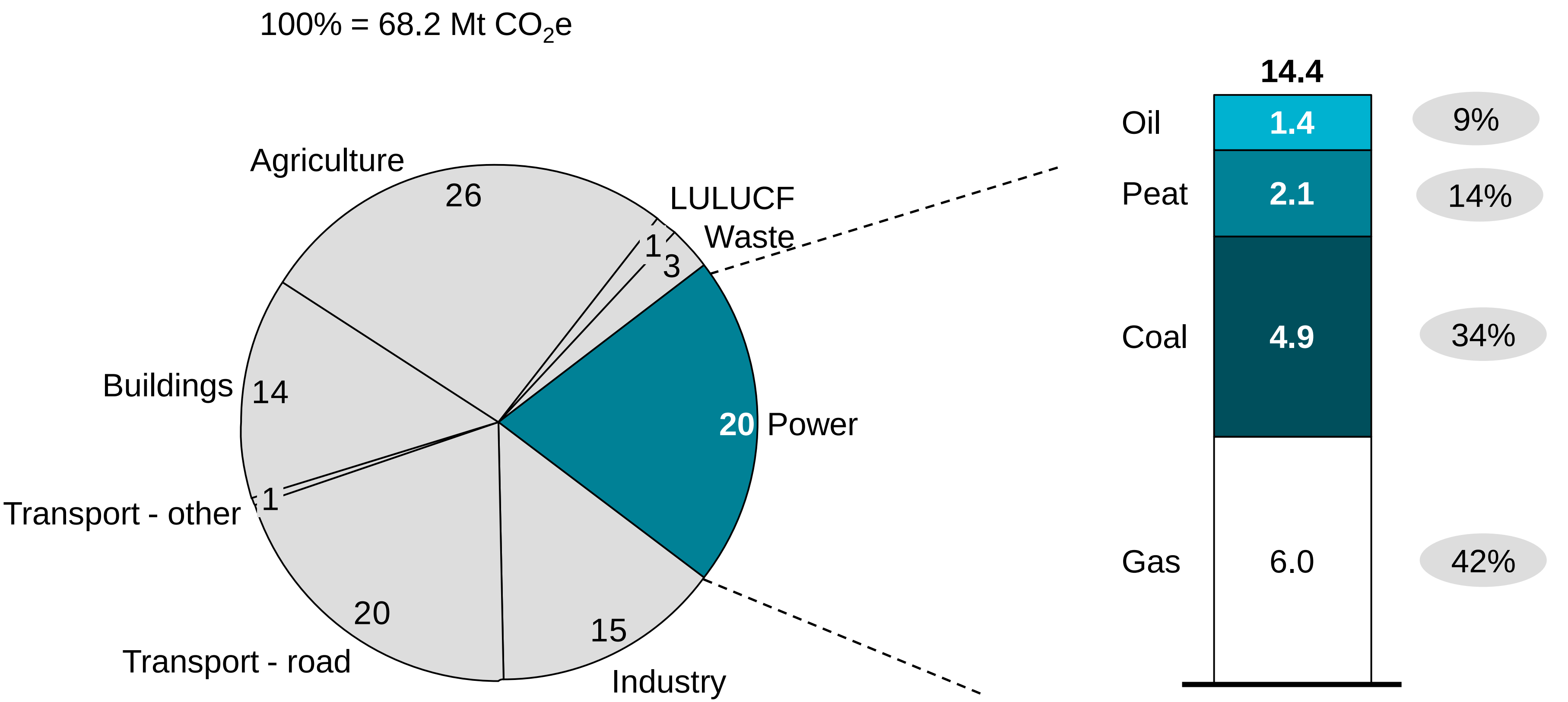
1 Based on IPCC inventory for process emissions, and model assumptions regarding energy use

SOURCE: UNFCCC emissions inventory, Ireland GHG Abatement Cost Curve

Power sector contributed 20% of total Ireland 2007 emissions

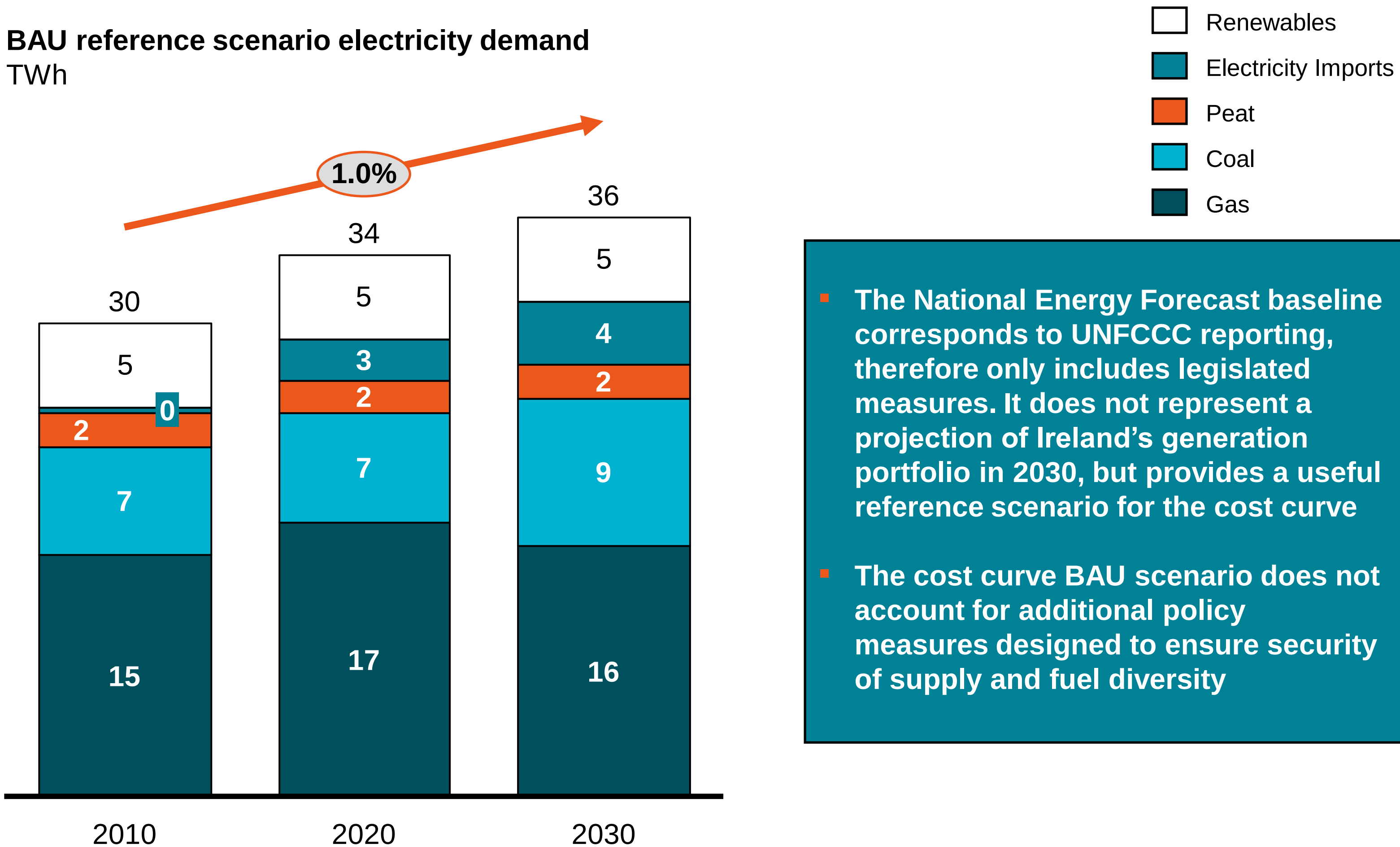
2007 total Ireland GHG emissions, %

Breakdown of 2007 GHG emissions[1], Mt CO_2e



1 Calculations use GWP conversion factors of 21 for CH4 and 310 for N2O

National Energy Forecast[1] shows increasing electricity demand over the next 20 years

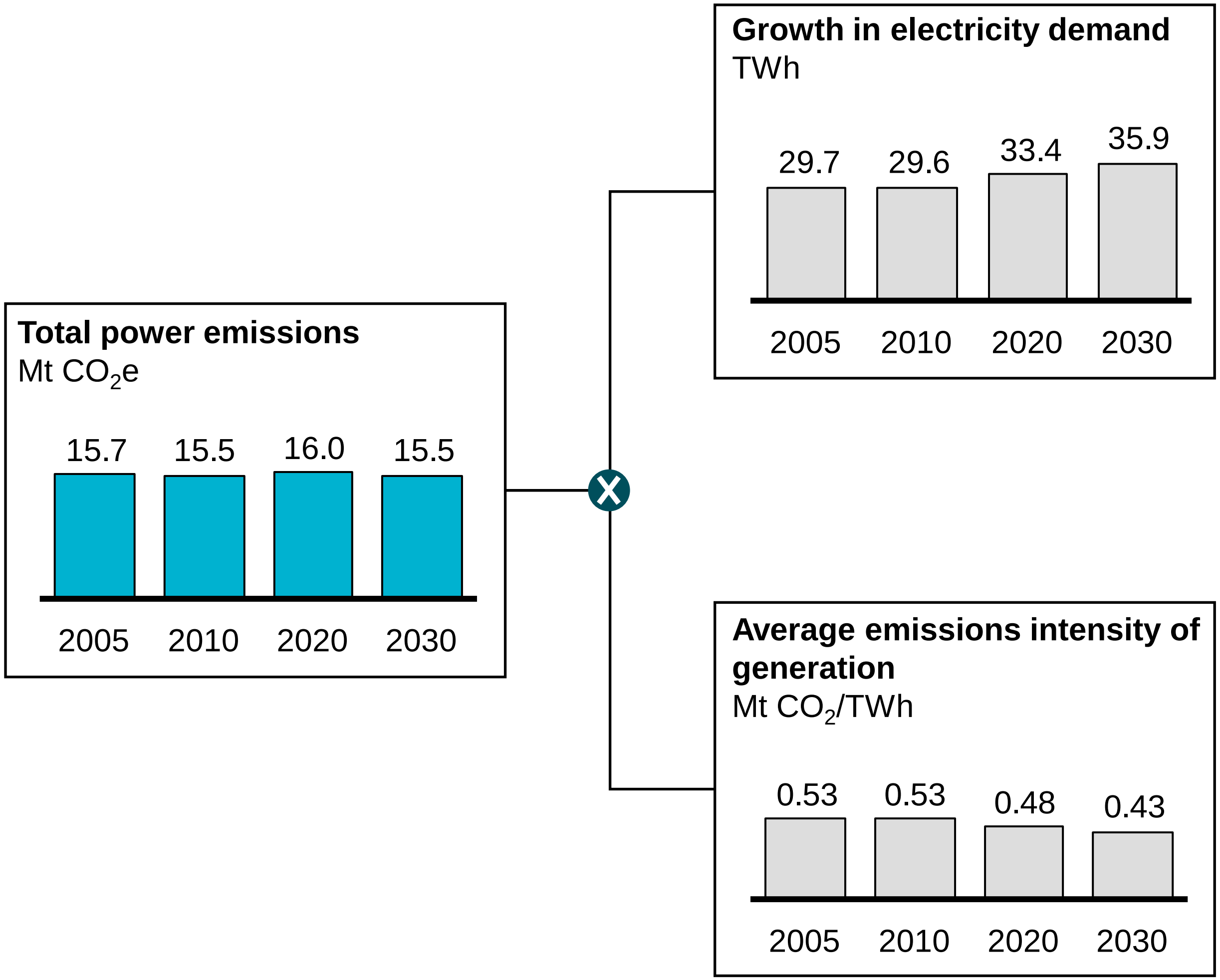


- The National Energy Forecast baseline corresponds to UNFCCC reporting, therefore only includes legislated measures. It does not represent a projection of Ireland's generation portfolio in 2030, but provides a useful reference scenario for the cost curve
- The cost curve BAU scenario does not account for additional policy measures designed to ensure security of supply and fuel diversity

1 Adjusted for increased contracted wind capacity

SOURCE: National Energy Forecast Baseline Scenario and extrapolation to 2030; Eirgrid (for adjustments)

Power sector emissions will be driven by electricity demand and the CO_2 intensity of the fuel mix



Source and notes

- National energy forecasts
- Annual growth rate from 2025–30 extrapolated from National energy forecasts to 2025

- Emissions intensity calculated by multiplying the demand for each fuel type (TWh) by the relevant CO_2 intensity and calculating the average
- Sources
  - National energy forecasts
  - NERA Market Simulation and Model valuation report

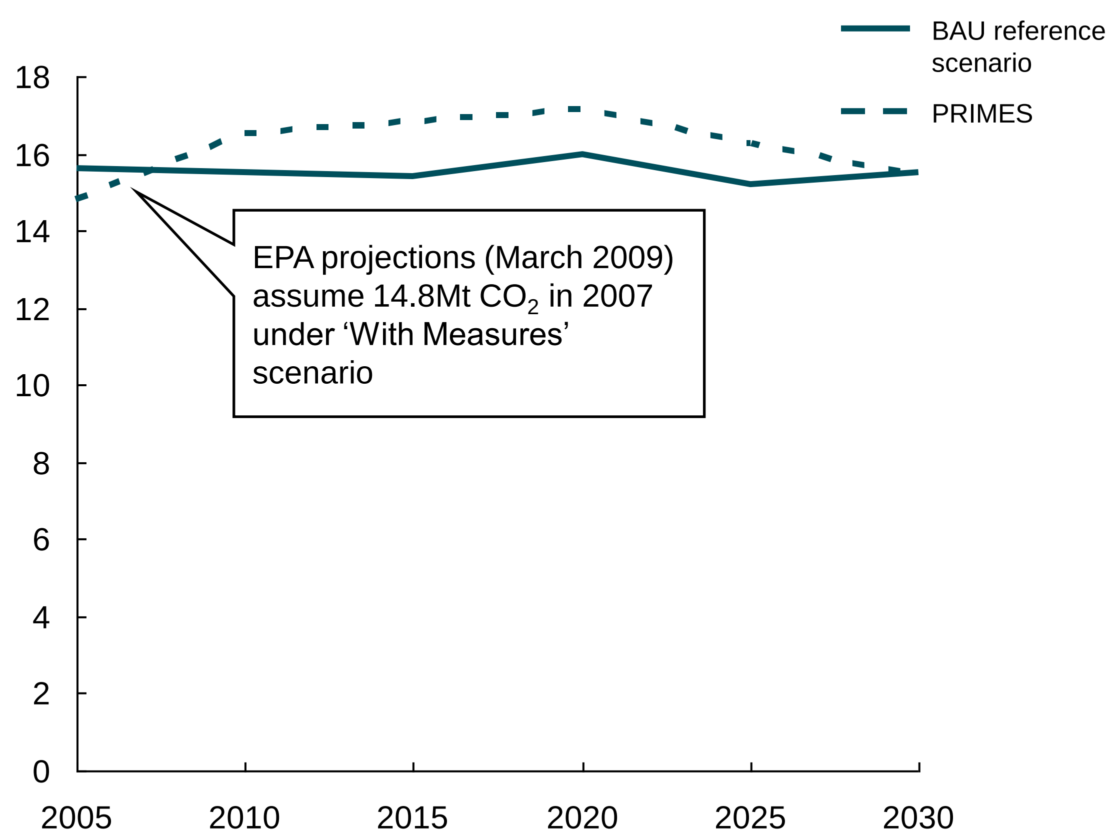
Power sector emissions BAU projections

Description of BAU reference scenario

BAU reference scenario is based on National Energy Forecast baseline scenario and adjusted for an 'Economic Shock' scenario. It includes:

- Wind capacity growth to 1413MW[1] in 2010 and no further increase
- Decommissioned plants modelled are:
  - Tarbert (590MW)
  - Marina (27MW)
  - Great Island (216MW)
  - Poolbeg (1&2)
  - Aghada (270)
- New plants modelled are:
  - Aghada (CCGT - 431)
  - Whitegate (CCGT - 445)
  - Quinn (CCGT - 400)
  - Interconnector (2x500MW)
  - OCGT (200 MW)
  - CCGT (400MW)
- Moneypoint opens a new 1000MW plant in 2025 with higher efficiency
- It is assumed that other gas plants due to retire before 2030 (e.g. North Wall) are replaced with equivalent gas plants

Projected Ireland GHG emissions
Mt CO_2e



1 National Energy Forecast includes 1261MW which has been updated to correspond with Eirgrid's current capacity total for contracted wind farms

Assumptions for abatement scenarios

1 Baseline scenario

- Nuclear power remains prohibited under current legislation
- Onshore wind is the principal renewable abatement lever but increases in cost as penetration grows
- New onshore wind connections are limited to 400MW/year
- Adoption of co-firing biomass is currently quite low (5-10% in one of three plants). However, the ending of the PSO encourages all of Ireland's three peat plants to begin co-firing from 2015 to 2025
- Peat plants are retired in 2025 and replaced by onshore wind
- Moneypoint is replaced by a new 900MW CCS plant[1] in 2025
- Offshore wind becomes viable in 2015 with a maximum of 1,000MW installed by 2030
- Tidal energy becomes viable in 2015 with 113MW installed by 2030
- One large wave installation (154MW), installed in 2025 – Tawnaghmore example taken from All-Island Grid study

- The rate of adoption of renewable generation is based on an assumption of new and replacement asset investment
- It does not fully reflect what may be achieved by means of policies designed to encourage strategically important new technologies such as wave and tidal power

2 Nuclear scenario

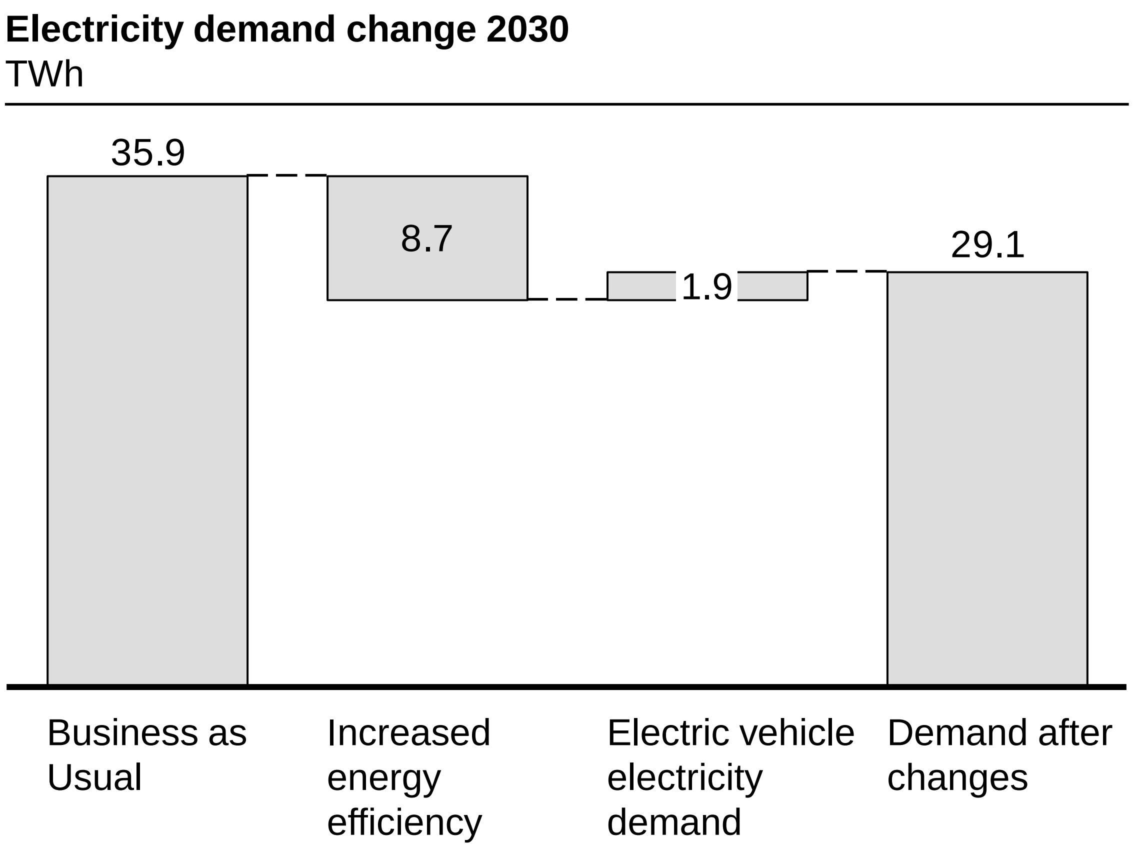
- Assuming Oireachtas removes legislative prohibition and approves new legislation to permit nuclear
- One 600MW station is built to replace the retiring Moneypoint station in 2025
- Load factor for nuclear plant is 75% - lowered due to increased level of wind on the system
- Other renewable abatement levers remain the same as baseline scenario
- Generation from renewables is limited to the same level as the baseline scenario (52%) due to network constraints

Nuclear power brings other non-GHG related challenges:

- Disposal of harmful nuclear waste
- Increased safety risks

1 Build of a 900MW CCS plant is based on a scenario from 'Assessment of the Potential for Geological Storage of CO_2 on the Island of Ireland'

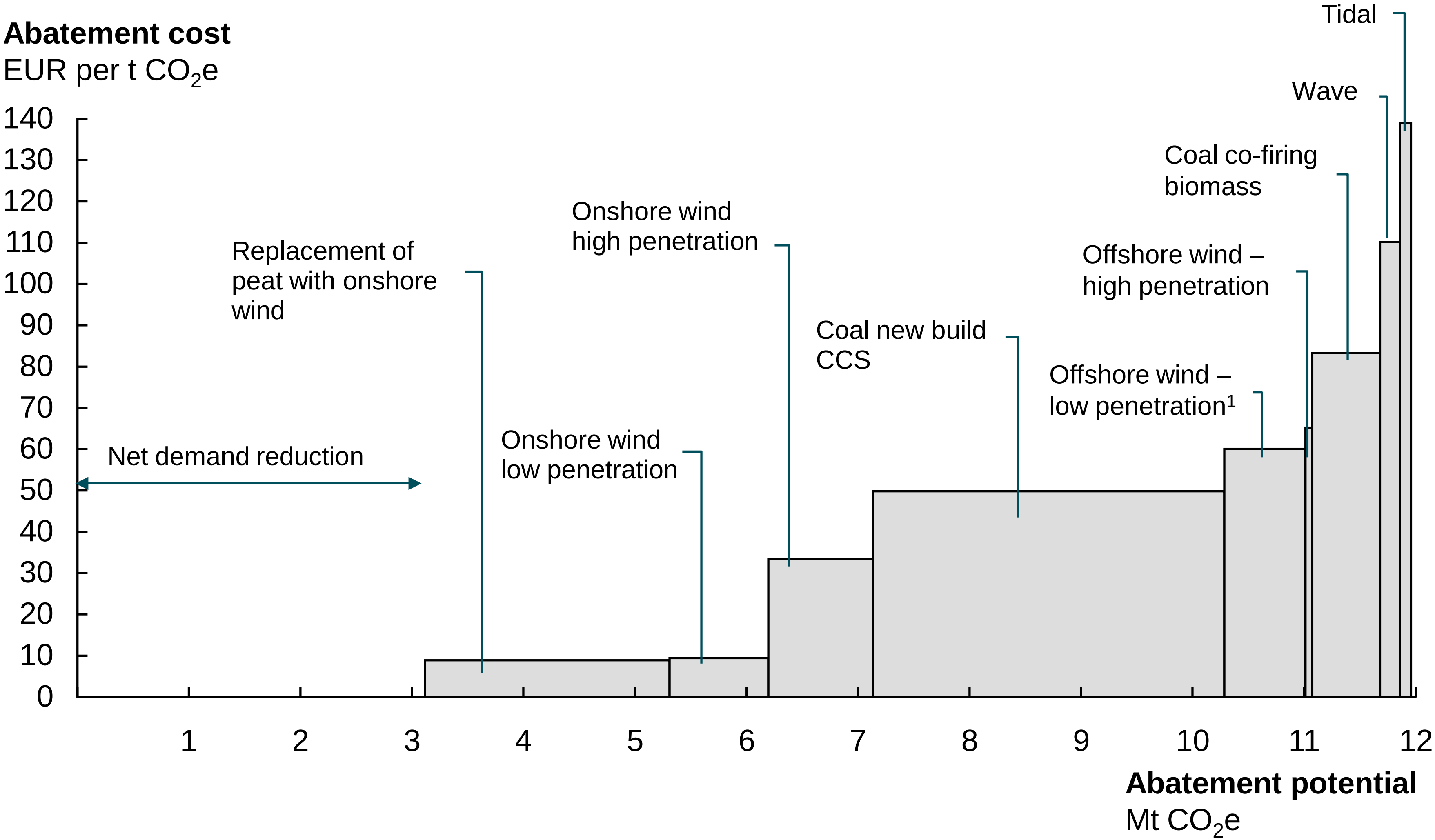
1 Demand change due to energy efficiency and electric vehicles



SOURCE: Ireland GHG Abatement Cost Curve

1 Power sector abatement cost curve – 2030

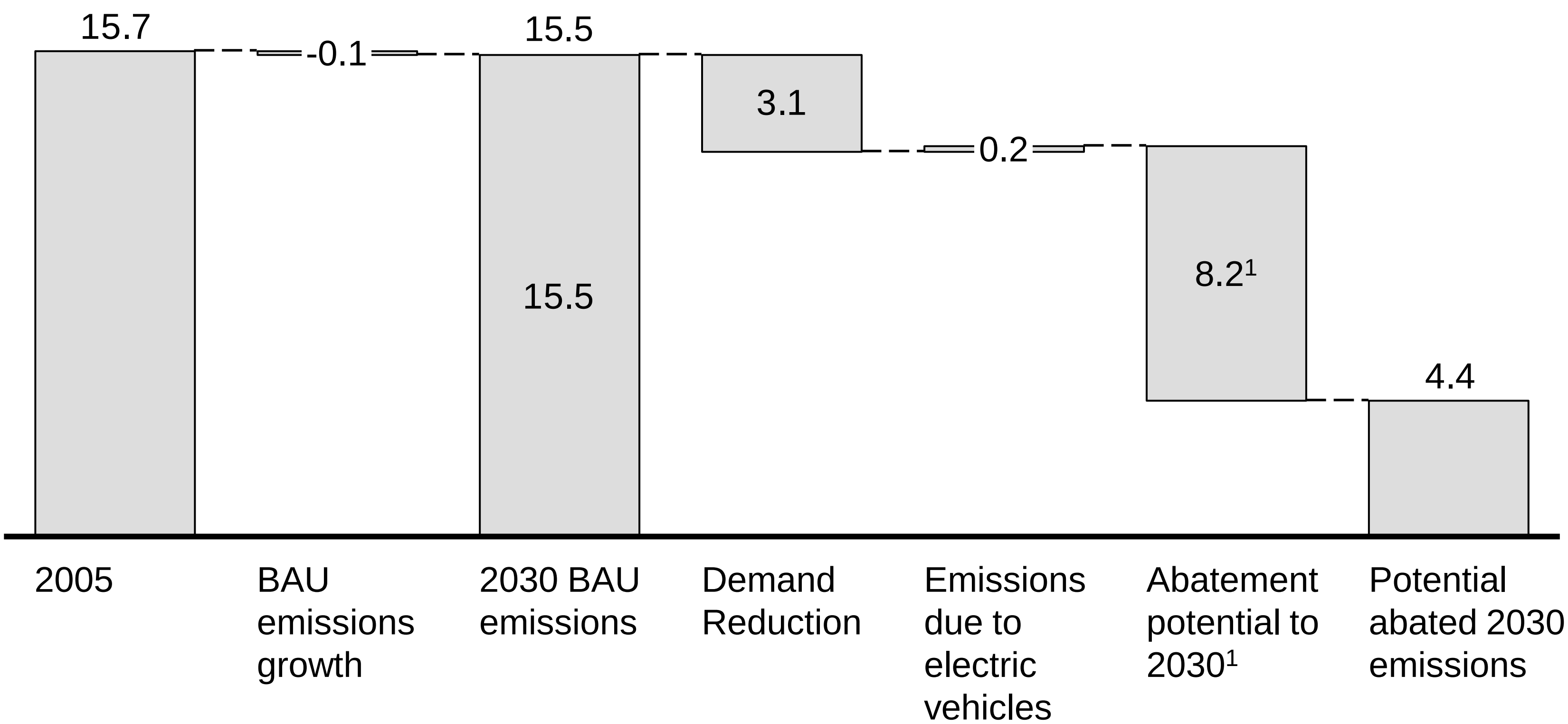
Societal perspective



1 Onshore/offshore wind low penetration represents under 4000MW of total wind capacity on the grid

1 Abatement potential for 2030

Ireland 2030 power sector emissions
Mt CO_2e

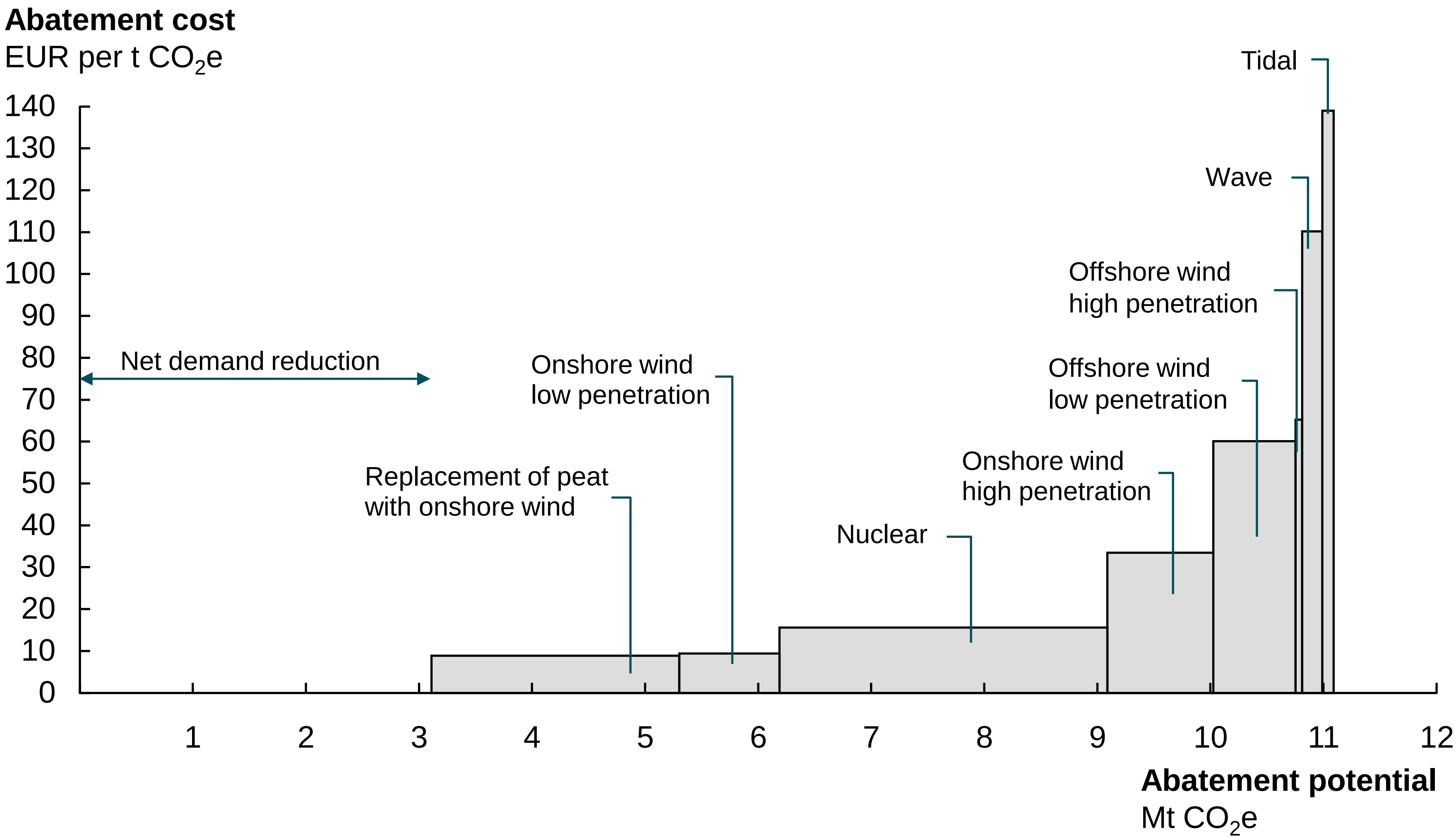


1 Apart from wave and tidal power, abatement potential only includes levers under 80 €/tCO_2e, excluding co-firing coal with biomass

SOURCE: Ireland GHG Abatement Cost Curve

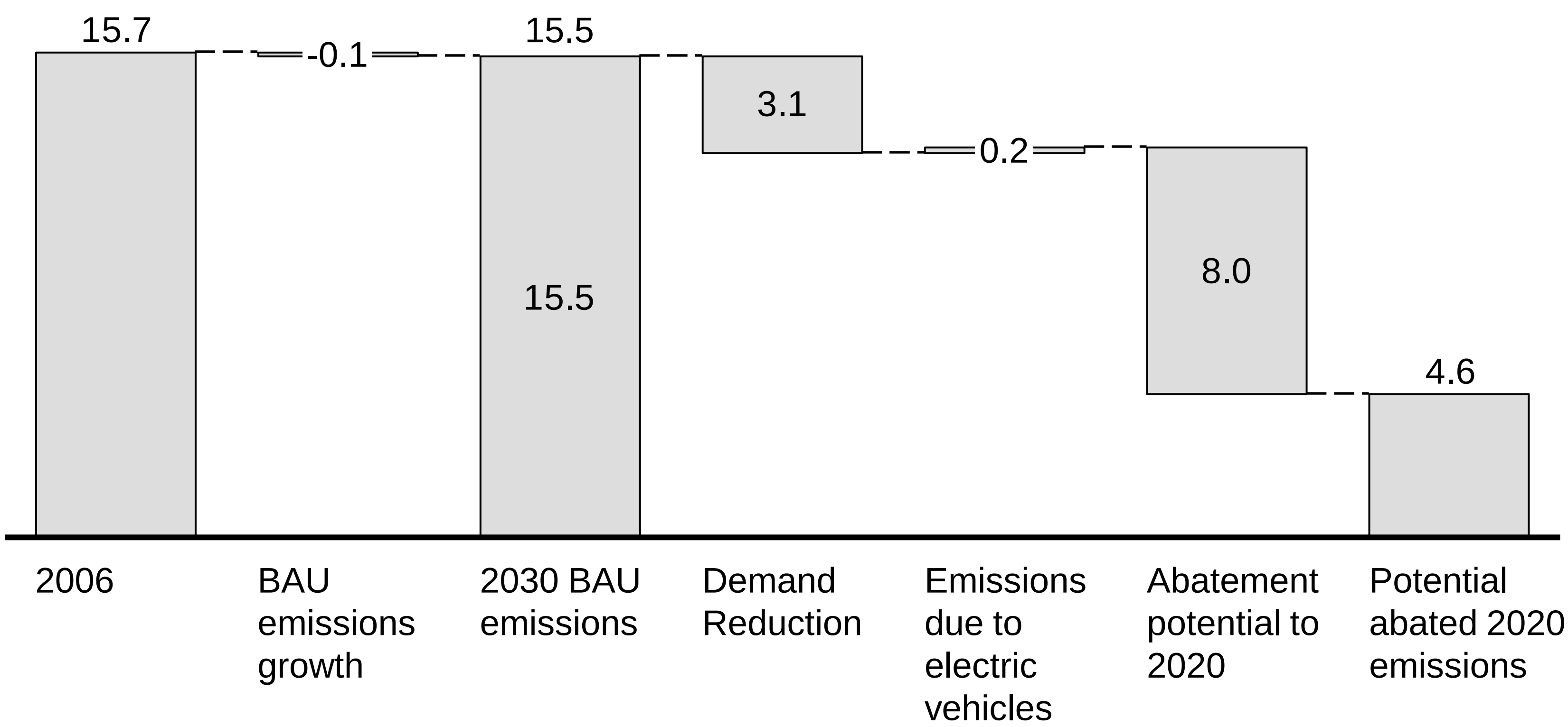
2 Nuclear scenario – power sector abatement cost curve

Societal perspective; 2030

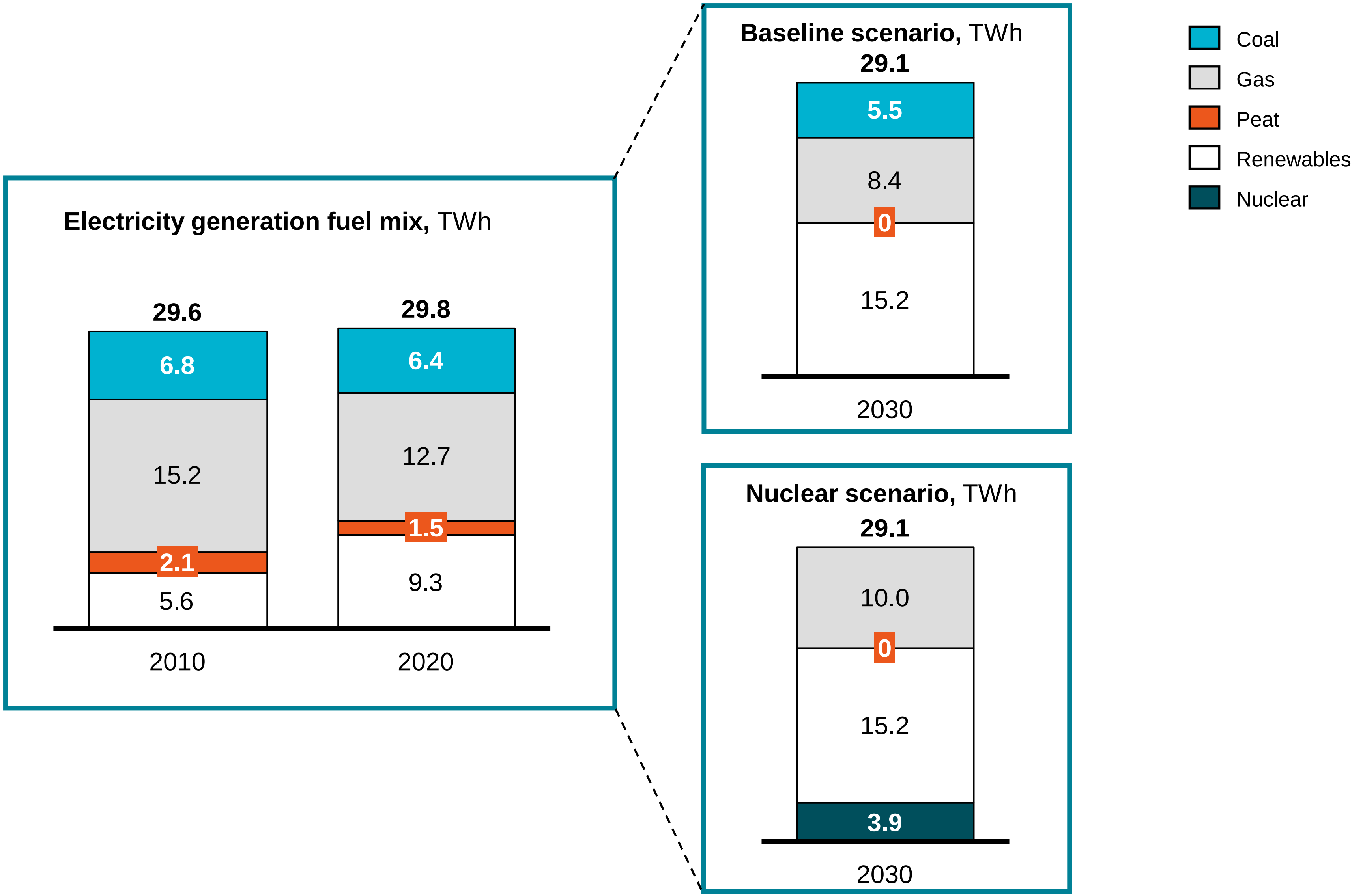


2 Abatement potential for nuclear scenario

Ireland 2030 power sector emissions
Mt CO_2e



Electricity generation fuel mix under abatement scenarios



SOURCE: Ireland GHG Abatement Cost Curve

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Sector summary

BAU	▪ Road transport emissions totalled 11 Mt CO_2e[1] in 2005 rising to 17 Mt CO_2e in 2030 – Irish registered passenger cars (53%) and goods vehicles under 16 tonnes (36%) accounted for 89% of these emissions – Growth will be driven by increasing population, GDP and car ownership per adult
Abatement potential	▪ Abatement potential of over 5 Mt CO_2e exists in 2030 ▪ The largest levers are – Improvements for LDV Gasoline ICE engines (~2 Mt CO_2e) – Electric vehicles (~1.5 Mt CO_2e) – 2nd generation biofuels (~1 Mt CO_2e)
Implications	▪ Significant abatement opportunities are reliant on continued development of internal combustion engine (ICE) improvement bundles ▪ Development of EV will require support in the medium term as they are not expected to be directly cost competitive with ICE technologies (although EV cost will reduce in the high energy price scenario)

1 Excluding fuel tourism, buses and motorcycles

Road transport sector contributed 20% of total Ireland 2007 emissions

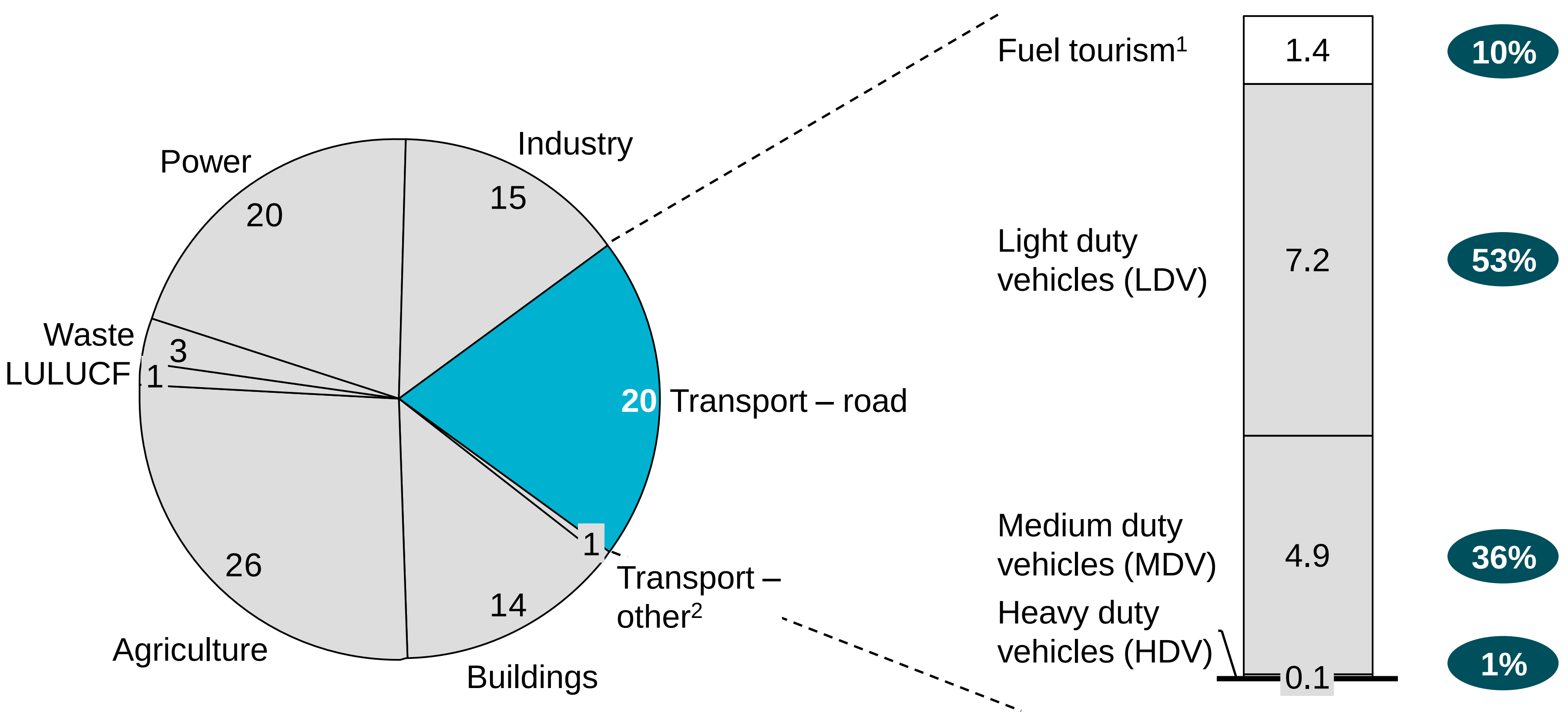
Not included

2007 total Ireland GHG emissions, %

100% = 68.2 Mt CO_2e

Breakdown of 2007 GHG emissions[1], Mt CO_2e

13.6 Mt CO_2e



1 Assumed residual 10% of emissions, consistent with fuel tourism estimates e.g. Mid Term Review 2008

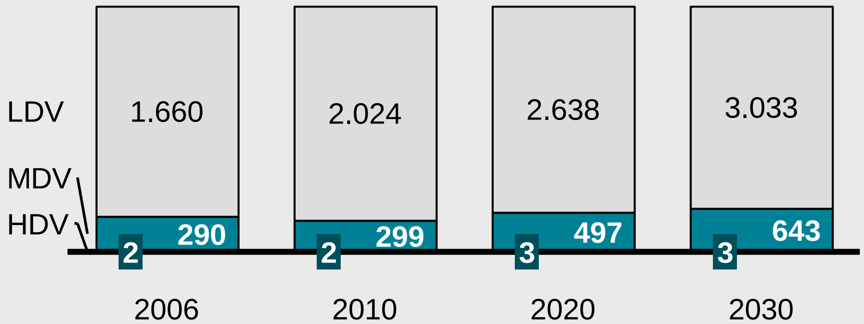
2 Includes ~0.8 mt CO2e aviation and rail

SOURCE: EPA UNFCCC emissions inventory

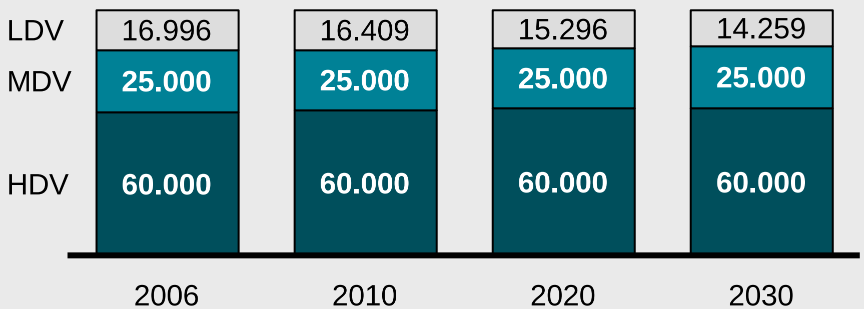
A number of drivers of emissions have been considered . . .

Driver forecast

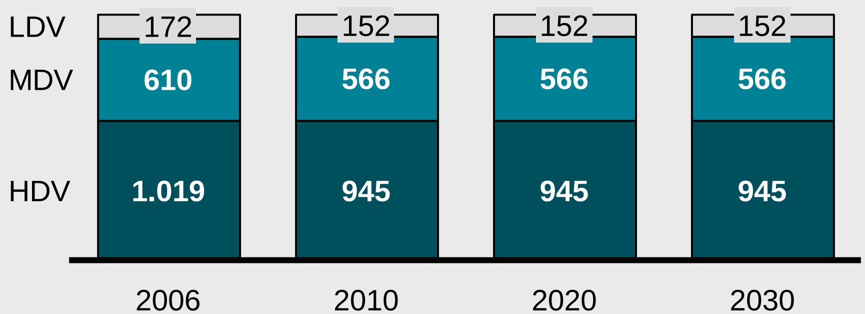
Vehicle numbers ('000)



Average annual vehicle distance travelled (km)



Average emissions (g/CO2e / km)



Notes / source

- Vehicle numbers are based on population and GDP (ESRI) growth
  - LDV are driven by population growth up and an increase of car ownership per adult to 0.7 by 2030
  - MDV / HDV are driven by GDP growth
- Average km travelled are based on NCT data for LDV's and European averages (IEA) for MDV's and HDV's
  - Small decline in LDV km driven (0.7% / year) assumed to continue to 2030 as car ownership rates increase
- Without specific abatement technologies some decrease in emissions per km are assumed over the next 3 years
- LDV emissions levels are tested emissions levels and must be scaled up to on the road emissions
- MDV / HDV are on the road emission levels

SOURCE: IEA (MDV / HDV), Authentic (LDV)

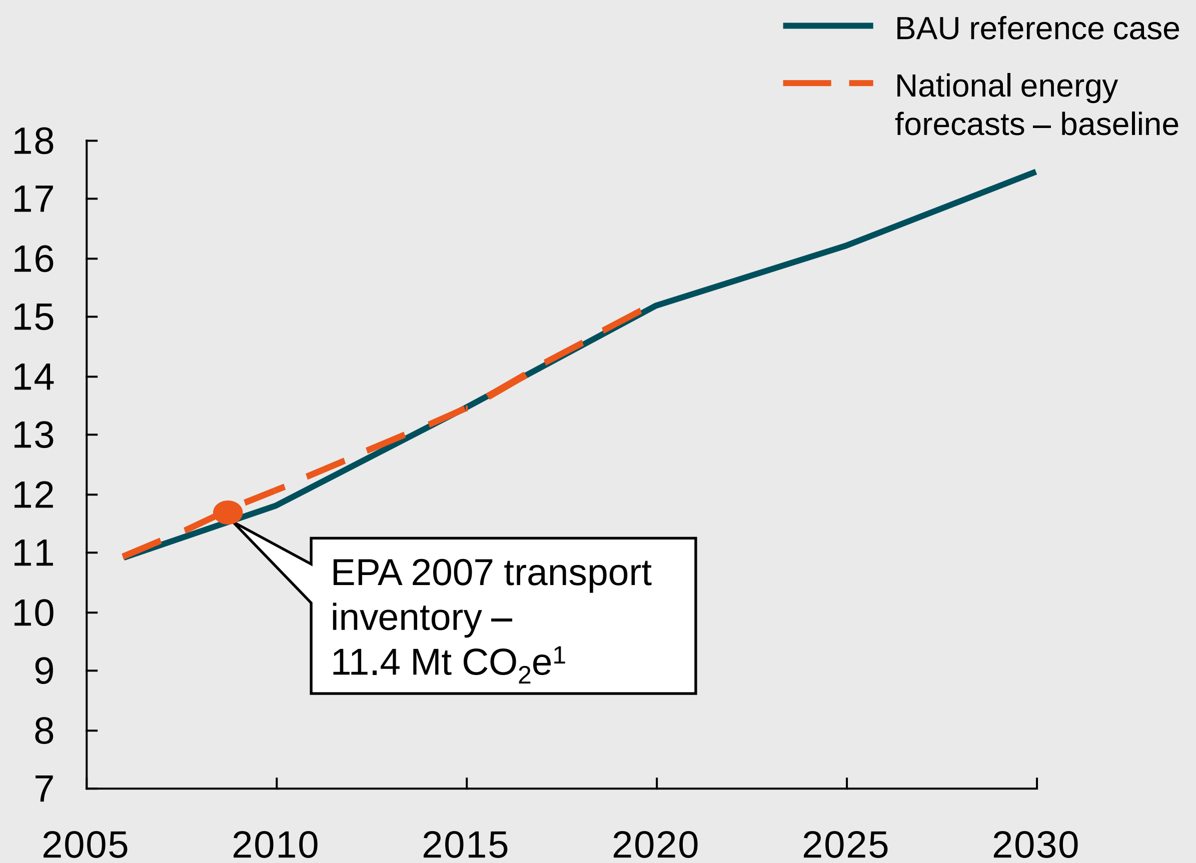
. . . leading to a business as usual emissions projection

BAU emissions

- BAU emissions projection includes forecasts of vehicle numbers in the LDV, MDV and HDV categories along with changes in KM driven and average emission per KM
- Minimal penetration of abatement levers is assumed in the BAU case e.g. biofuel generation 1 (2.2%), LDV Gas bundle 1 (3%) etc
- Buses, motorcycles, rail, aviation and marine are all excluded
- Fuel tourism does not feature, as emissions are calculated based on km travelled by Irish vehicles

Projected Ireland GHG emissions

Mt CO_2e

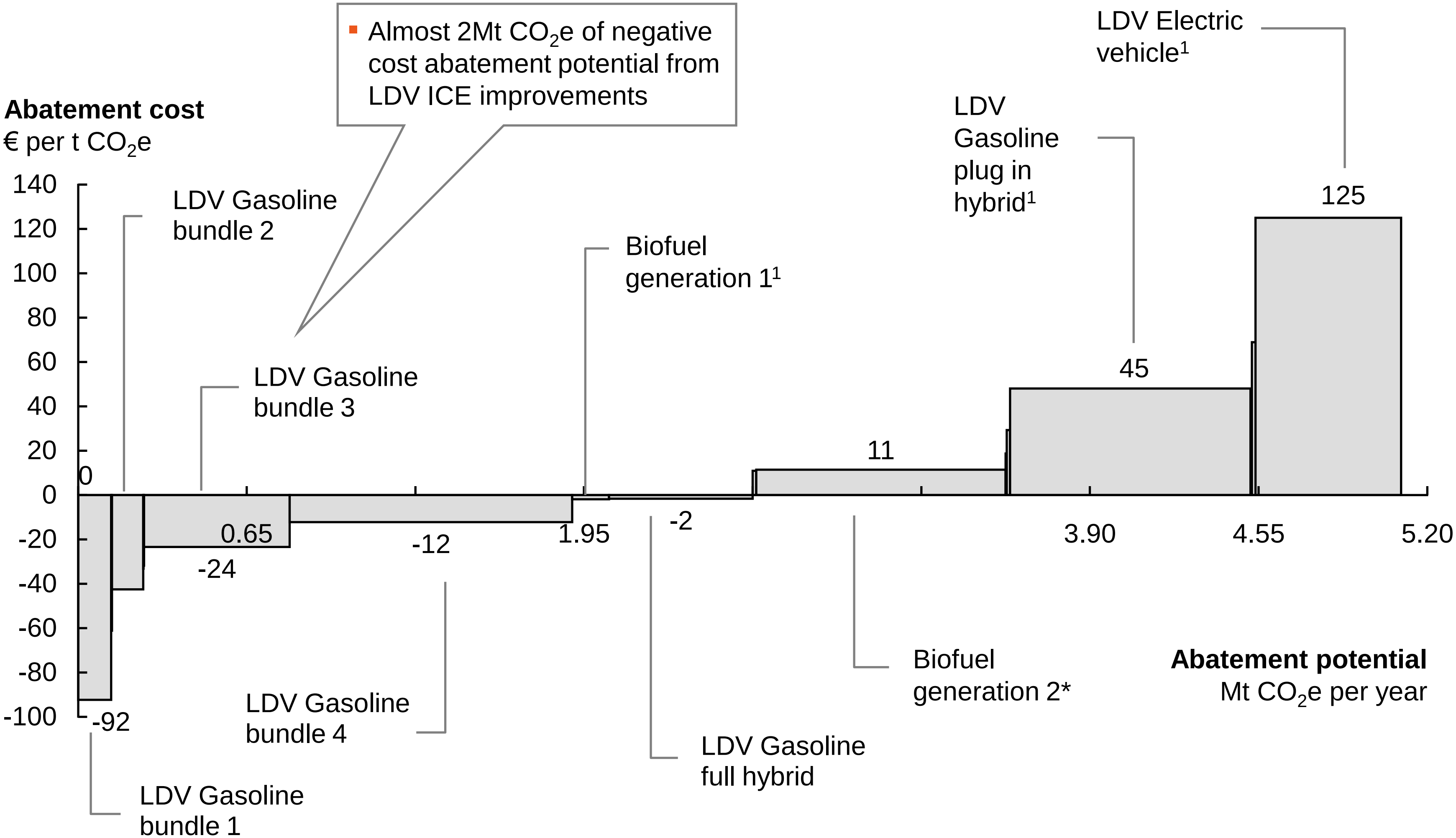


1 Adjusted for fuel tourism (~1.4 mt CO2e) and domestic aviation (~0.7 mt CO2e) and rail, buses, motorcycles and marine (~0.8 mt CO2e)

SOURCE: Ireland GHG Abatement Cost Curve; IPCC National Greenhouse Gas emissions inventory 2006 - Ireland

Transport sector abatement cost curve – 2030

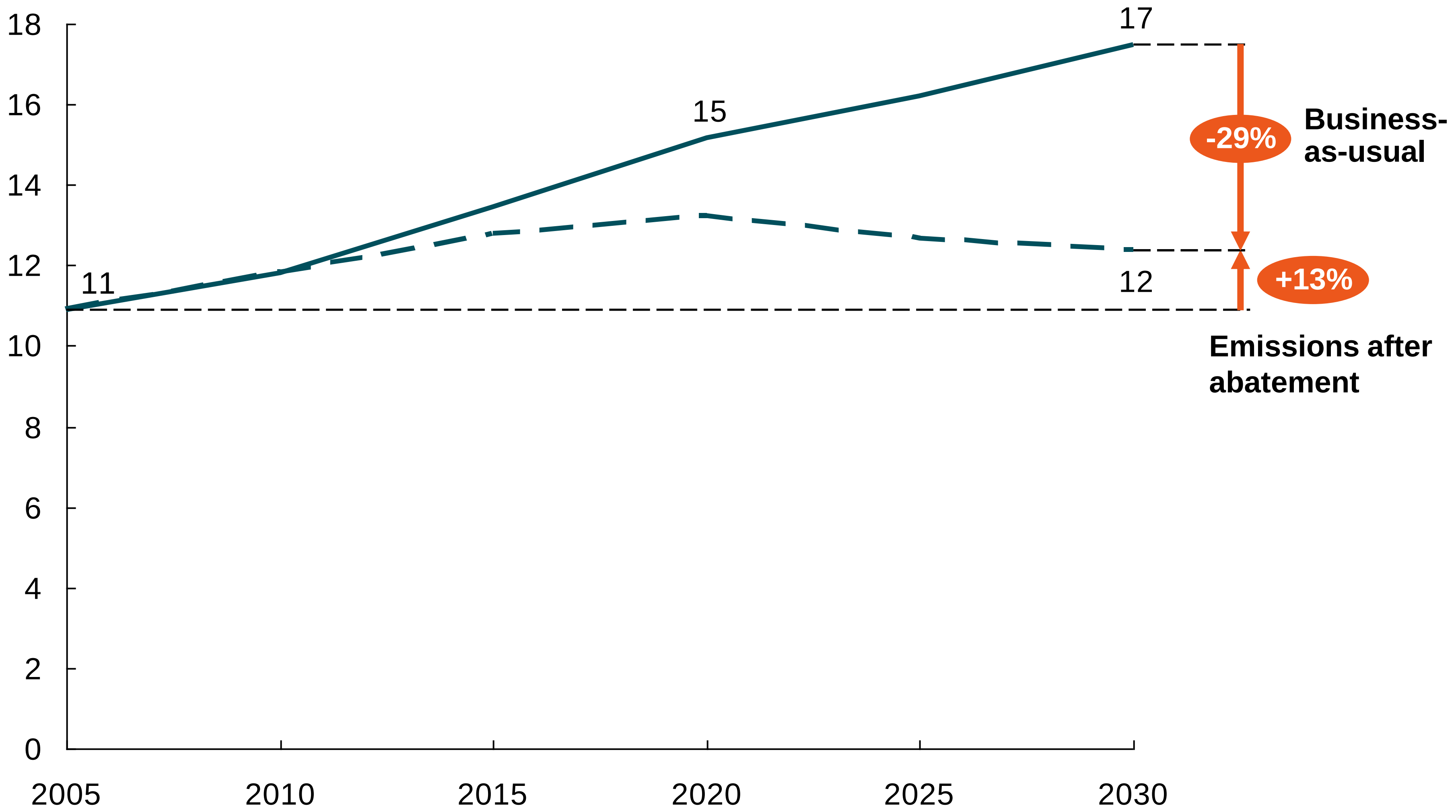
Societal perspective; 2030



1 Costs assume no premium on locally produced biofuels, and full incremental battery cost for plug-in hybrid and EVs passed on by non-Irish manufacturers

Sector emissions projections

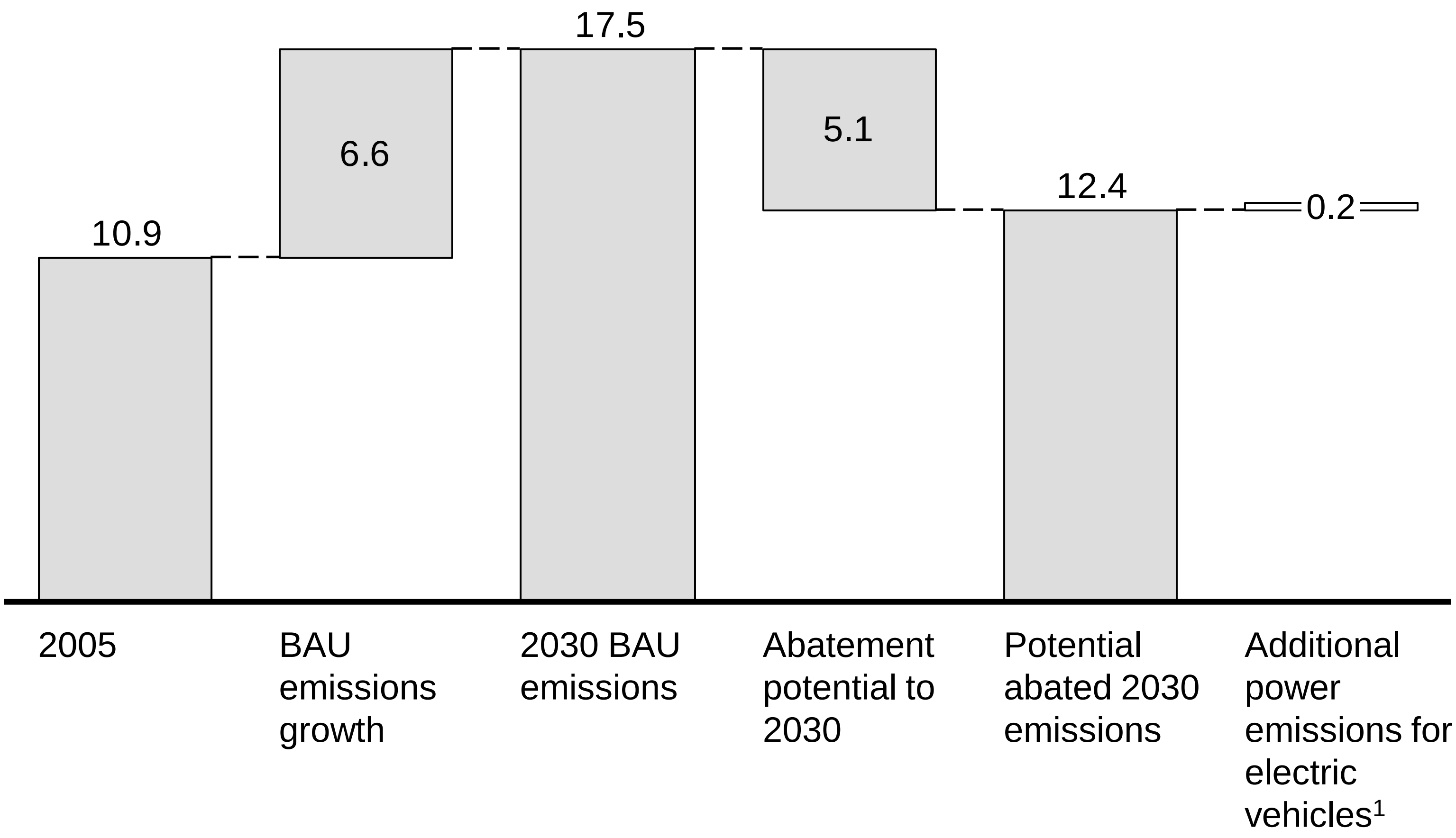
MtCO2e per year



Transport sector abatement cost curve

Ireland 2030 transport sector emissions

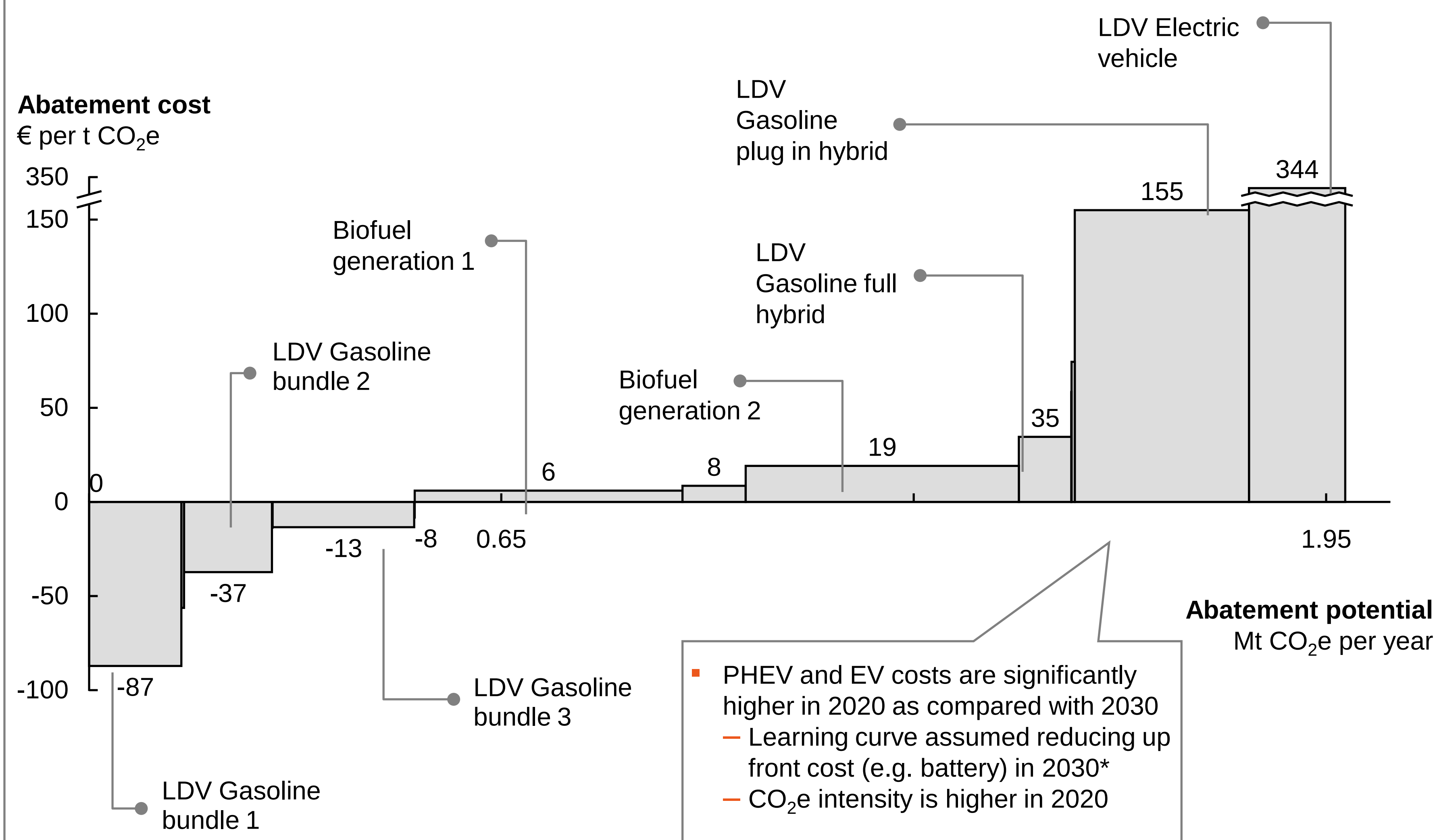
Mt CO_2e



1 Emissions accounted for in power sector

Transport sector abatement cost curve – 2020

Societal perspective; 2020



- PHEV and EV costs are significantly higher in 2020 as compared with 2030
  - Learning curve assumed reducing up front cost (e.g. battery) in 2030*
  - CO_2e intensity is higher in 2020

Contents

Sector summary

BAU

- Buildings accounted for 10.2 $MtCO_2e$ in 2005
  - 73% Residential
  - 27% Commercial
- Energy use is forecast to increase but emissions in buildings remain stable until 2020 due to a change in fuel mix to lower CO_2e intensity fuels

Abatement potential

- There is an abatement potential in 2030 for 9.1 $MtCO_2e$
  - 6.1 direct emissions
  - 2.9 indirect emissions
  - 6.2 $MtCO_2e$ residential
  - 2.9 $MtCO_2e$ commercial
- The top 3 levers are
  - New build efficiency package residential (2.8 $MtCO_2e$)
  - Retrofit building envelope package 1 - residential (1.1 $MtCO_2e$)
  - Retrofit building envelope, package 2 – residential (0.8 $MtCO_2e$)

Implications

- The majority of the abatement opportunities in buildings are cost negative – there are a number of reasons why they have not been implemented already
  - High consumer discount rate applied to capex
  - Principal / agent issues
  - Access to finance

Buildings contributed 14% of total Ireland 2007 emissions

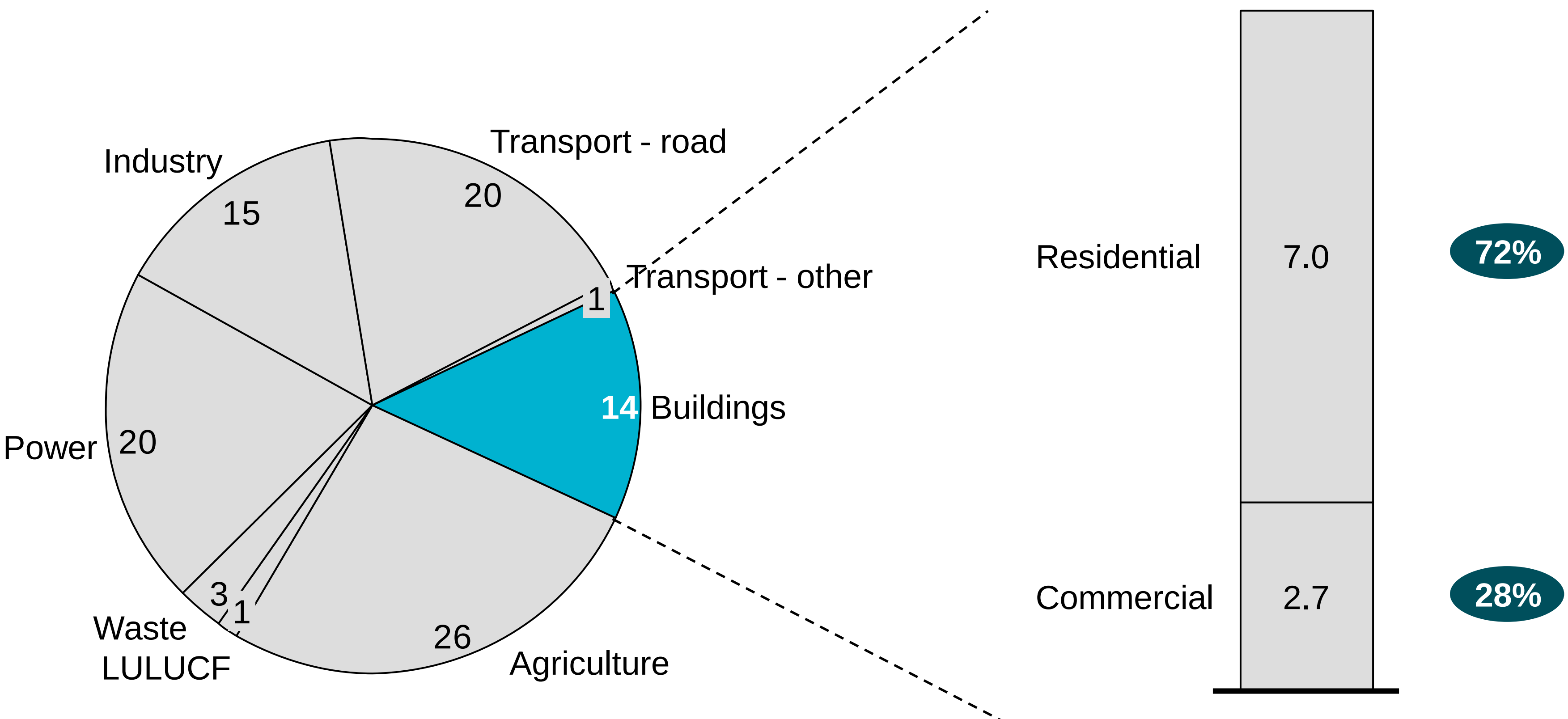
Not included

2007 total Ireland GHG emissions, %

100% = 68.2 Mt CO_2e

Breakdown of 2007 GHG emissions, Mt CO_2e

9.7 Mt CO_2e



SOURCE: EPA UNFCCC emissions inventory

We have developed a business as usual projection based on residential completions and GDP

2005 emissions

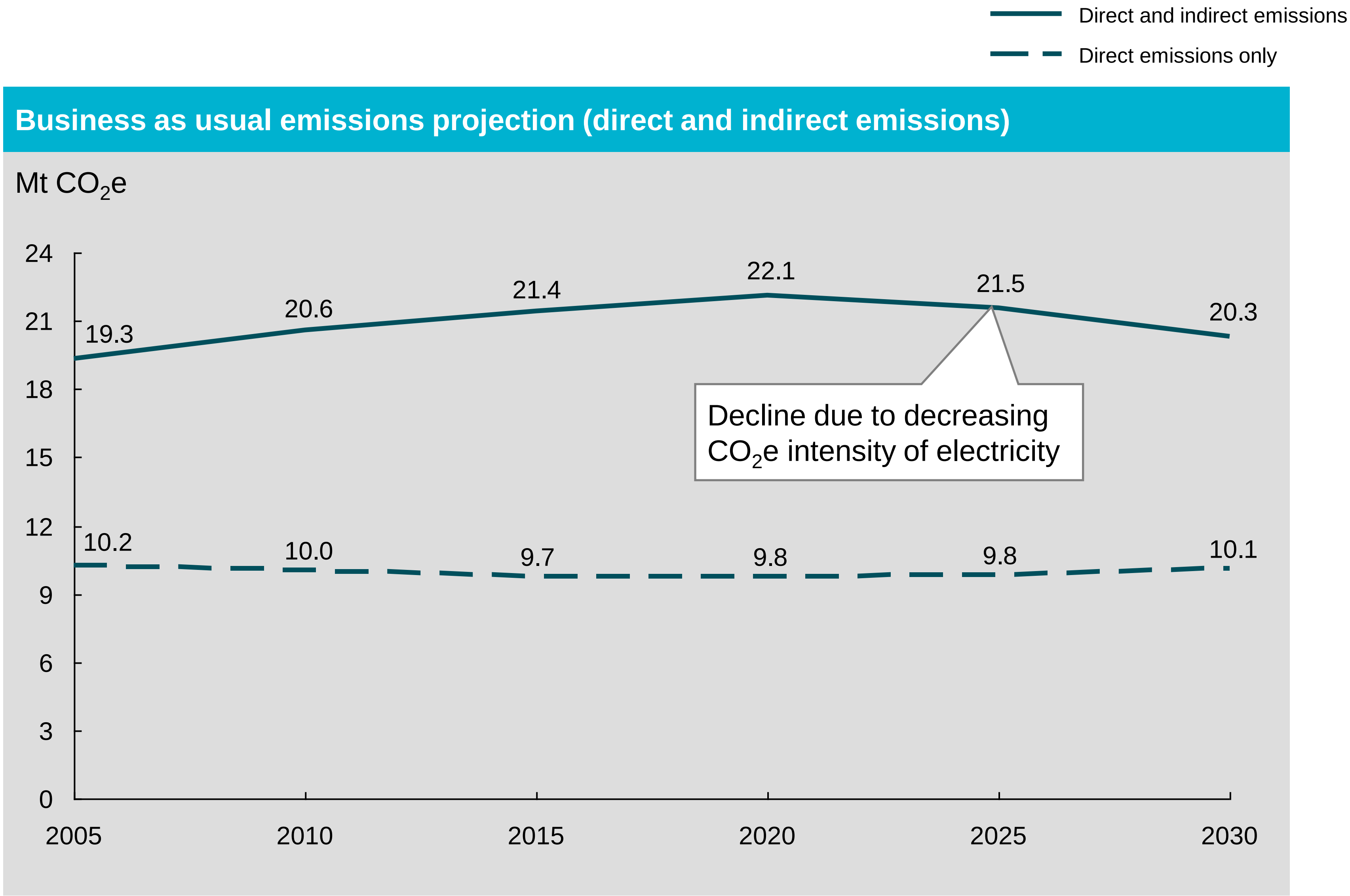
- Energy usage for 2005 taken from the National Energy Forecasts
- SEI emissions factors assumed for each fossil fuel type (tCO_2e / MWh)
  - Coal 0.34
  - Oil 0.27
  - Gas 0.20
  - Other 0.39
- Electricity emissions come from cost curve analysis of the power sector

BAU projection

- Residential completion rates based on SEI data
  - 22,500 completions in 2010 rising to 40,000 in 2014 and stabilizing
  - Average new build assumed to be
    - 130 m2
    - 150 kWh / m2
  - Building life of 60 years
- Commercial growth based on GDP growth (ESRI ‘credit crunch’ projections, adjusted)

- **2008 building regulations are not included in our BAU**
- **Regulations on incandescent light bulb use are not included in our BAU**
- **Rationale: consistency with National Energy Efficiency Action Plan**

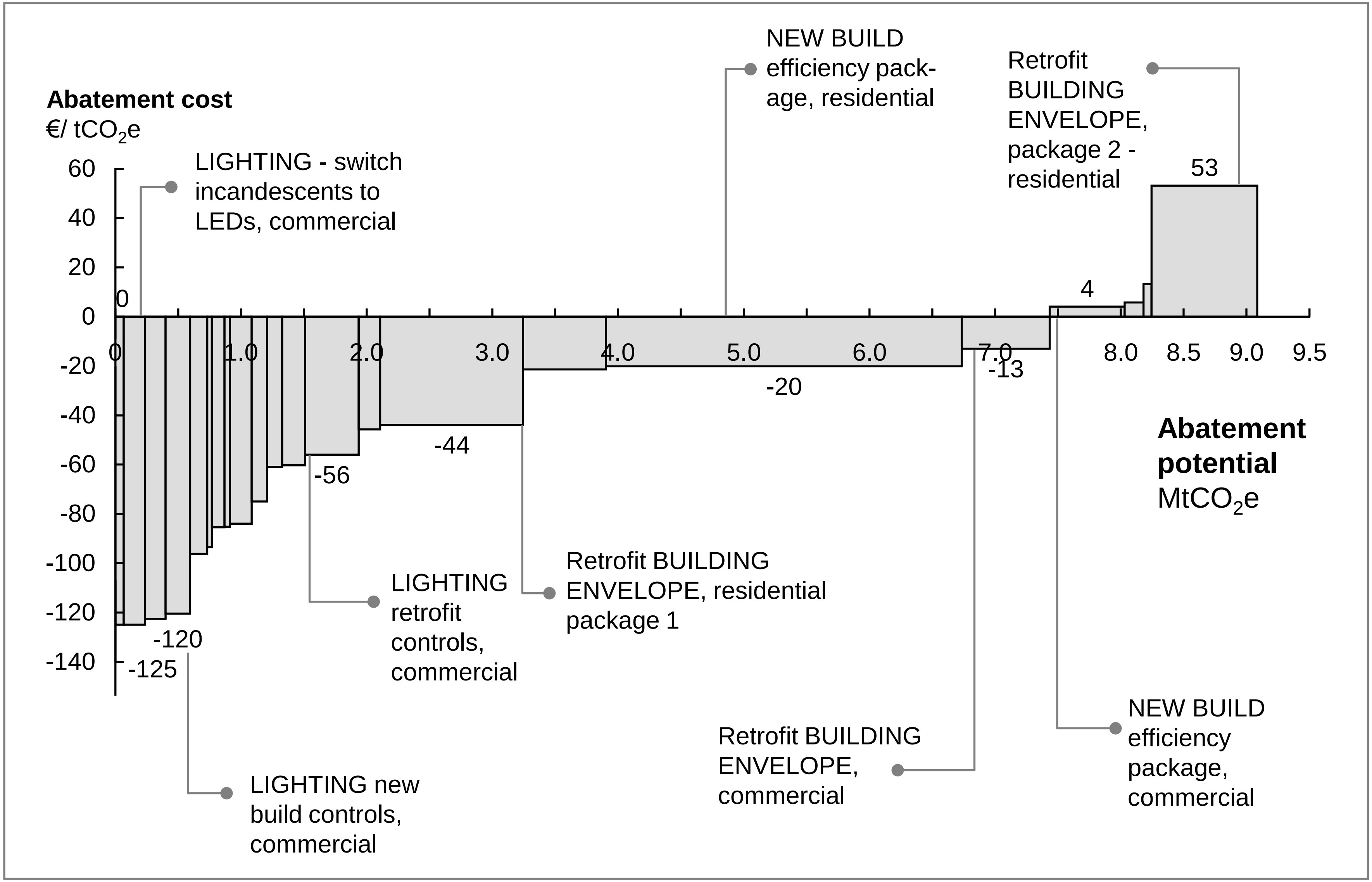
Business as usual emissions projection



SOURCE: National energy forecasts, SEI emissions factors; SEI housing competition projections

Buildings sector abatement cost curve

Societal perspective; 2030



Buildings sector abatement levers – residential

Societal perspective; 2030	**Abatement potential** (Mt CO_2e)	**Price** (EUR/ Mt CO_2e)
ELECTRONICS - consumer, residential	0.07	-125
LIGHTING – switch incandescents to LEDs, residential[1]	0.16	-125
APPLIANCES - residential	0.14	-96
LIGHTING - switch CFLs to LEDs, residential	0.04	-93
Retrofit HVAC - electric resistance heating to electric	0.17	-84
Retrofit HVAC maintenance – residential[2]	0.18	-60
Retrofit BUILDING ENVELOPE, package 1, residential	1.14	-44
Retrofit HVAC - gas/oil heating, residential	0.66	-21
NEW BUILD efficiency package, residential	2.83	-20
Retrofit BUILDING ENVELOPE, package 2 - residential	0.84	53
Total / **Average**	6.2	-€11

1 Regulations on incandescent light bulb use are not included in our BAU

2 Includes behavioural element

SOURCE: Ireland GHG Abatement Cost Curve

Buildings sector abatement levers – commercial

Societal perspective; 2030	**Abatement potential** (Mt CO_2e)	**Price** (EUR/ Mt CO_2e)
LIGHTING – switch incandescents to LEDs, commercial[1]	0.17	-125
LIGHTING new build controls, commercial	0.20	-120
ELECTRONICS - office, commercial	0.10	-85
APPLIANCES - refrigerators, commercial	0.04	-85
LIGHTING - switch CFLs to LEDs, commercial	0.12	-75
Retrofit HVAC controls, commercial	0.12	-61
LIGHTING retrofit controls, commercial	0.43	-56
Retrofit HVAC, commercial	0.17	-46
Retrofit BUILDING ENVELOPE, commercial	0.70	-13
NEW BUILD efficiency package, commercial	0.60	4
WATER HEATING - replacement of electric, commercial	0.15	6
LIGHTING - T12 to T8/T5, commercial	0.06	13
Total / **Average**	**2.9**	**-€9**

1 Regulations on incandescent light bulb use are not included in our BAU

Description of abatement levers in buildings sector – residential

New build efficiency package

- Achieve energy consumption levels comparable to passive housing (40 kWh / M2)
  - Reduce demand for energy consumption through improved building design and orientation
  - Improve building insulation and airtightness; improve materials and construction of walls, roof, floor, and windows
  - Ensure usage of high efficiency HVAC and water heating systems

Retrofit building package, level 1 and level 2

- Level 1 retrofit - “basic retrofit” package (improve average dwelling to 175 kWh / m2 or C2 BER)
  - Improve building airtightness by sealing baseboards and other areas of air leakage
  - Weather strip doors and windows
  - Insulate attic and wall cavities
- Level 2 retrofit
  - Incremental improvement to 150 kWh / m2 (C1 BER)
  - Potential improvements include window replacement, external insulation or internal dry lining

Retrofit Package 1 together with Retrofit HVAC corresponds approximately to the domestic efficiency measures promoted by SEI’s Home Energy Saving Scheme

Retrofit HVAC, residential

- When current gas / oil furnaces or boilers expire, replace with the highest efficiency model, with AFUE (annual fuel utilization efficiency) rating above 95
- Replace electric furnace with high efficiency electric heat pump
- Reduce energy consumption from HVAC and AC through improved maintenance
- Improve duct insulation to reduce air leakage and proper channeling of heated and cooled air
- Ensure HVAC system is properly maintained, with correct level of refrigerant and new air filters

Retrofit water heating systems

- When existing standard gas water heaters expire, replace with solar water heater, or with tank less / condensing models
- When existing electric water heater expires, replace with solar water heater or electric heat pumps

New and retrofit lighting systems

- Replace incandescent bulbs with LEDs
- Replace CFLs with LEDs

New and “retrofit” appliances and electronics

- Purchase high efficiency consumer electronics (e.g., PC, TV, VCR / DVD, home audio, set-top box, external power, charging supplies) instead of standard items
- When refrigerator/freezer, washer / dryer, dishwasher, and fan expires, replace with high efficiency model

SOURCE: Daiwa, expert interviews

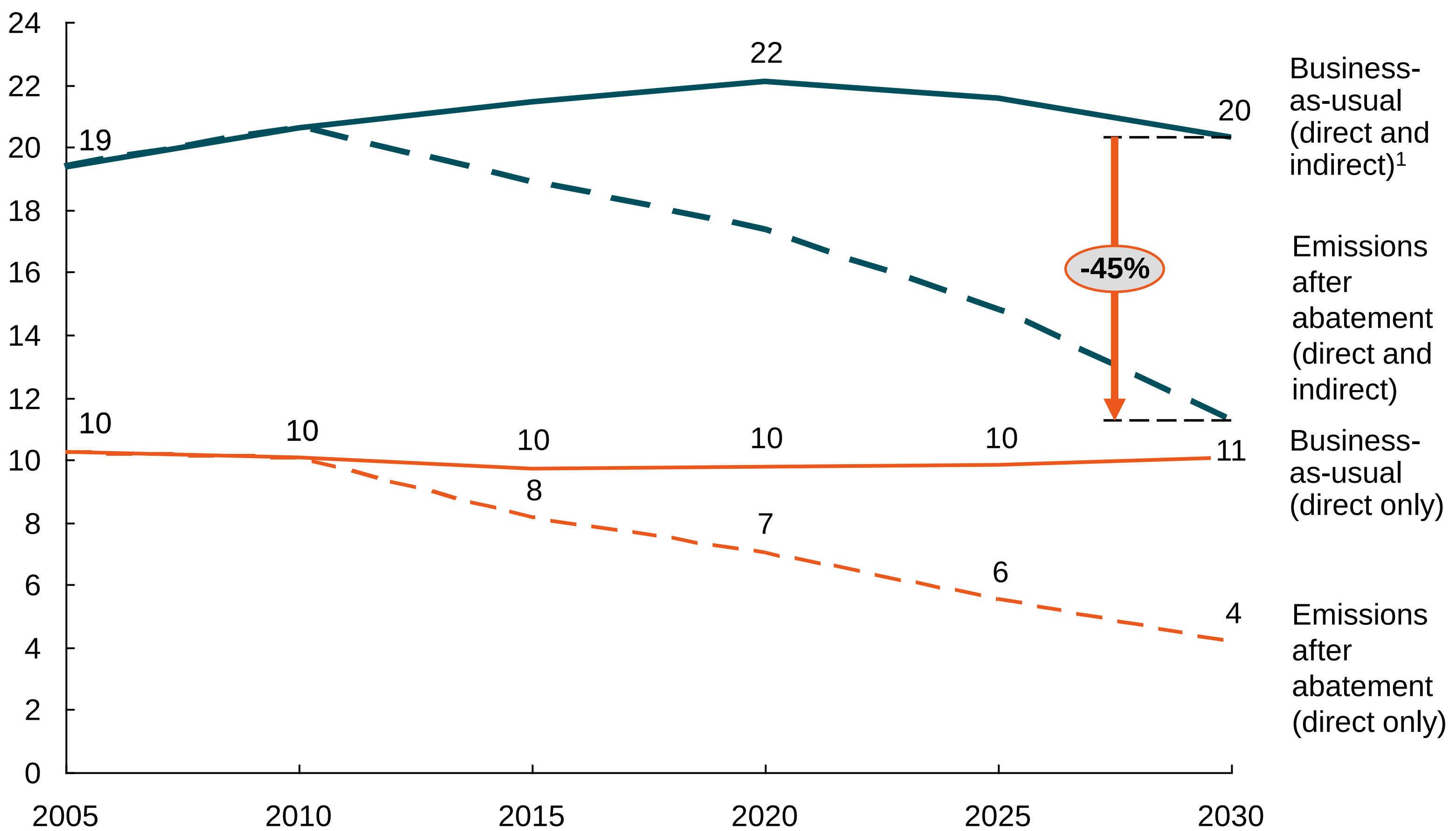
Description of abatement levers in buildings sector – commercial

New build efficiency package	▪ Reduce demand for energy consumption through improved building design and orientation ▪ Improve building insulation and airtightness; improve materials and construction of walls, roof, floor, and windows ▪ Ensure usage of high efficiency HVAC and water heating systems
Retrofit building envelope	▪ Level 1 retrofit - "basic retrofit" package (~50 kWh / m2 energy improvement) – Improve building air tightness by sealing areas of potential air leakage – Weather strip doors and windows
Retrofit HVAC and HVAC controls, residential	▪ When HVAC system expires, install highest efficiency system ▪ Improve HVAC control systems to adjust for building occupancy and minimize re-cooling of air
Retrofit water heating systems	▪ When existing standard gas water heaters expire, replace with tankless gas, condensing gas, or solar water heater ▪ When existing electric water heater expires, replace with heat pump or solar water heater
New and retrofit lighting systems	▪ Replace incandescent bulbs with LEDs ▪ Replace CFLs with LEDs ▪ Replace inefficient T12s / T8s with new super T8s and T5s ▪ New build – install lighting control systems (dimmable ballasts, photo-sensors to optimize light for occupants in room) ▪ Retrofit – install lighting control systems (dimmable ballasts, photo-sensors to optimize light for occupants in room)
New and "retrofit" appliances and electronics	▪ Use high efficiency office electronics (e.g., printer, copier, fax) instead of standard items ▪ For food service / grocery, use high efficiency refrigerators / freezers

SOURCE: Energy Star; expert interviews

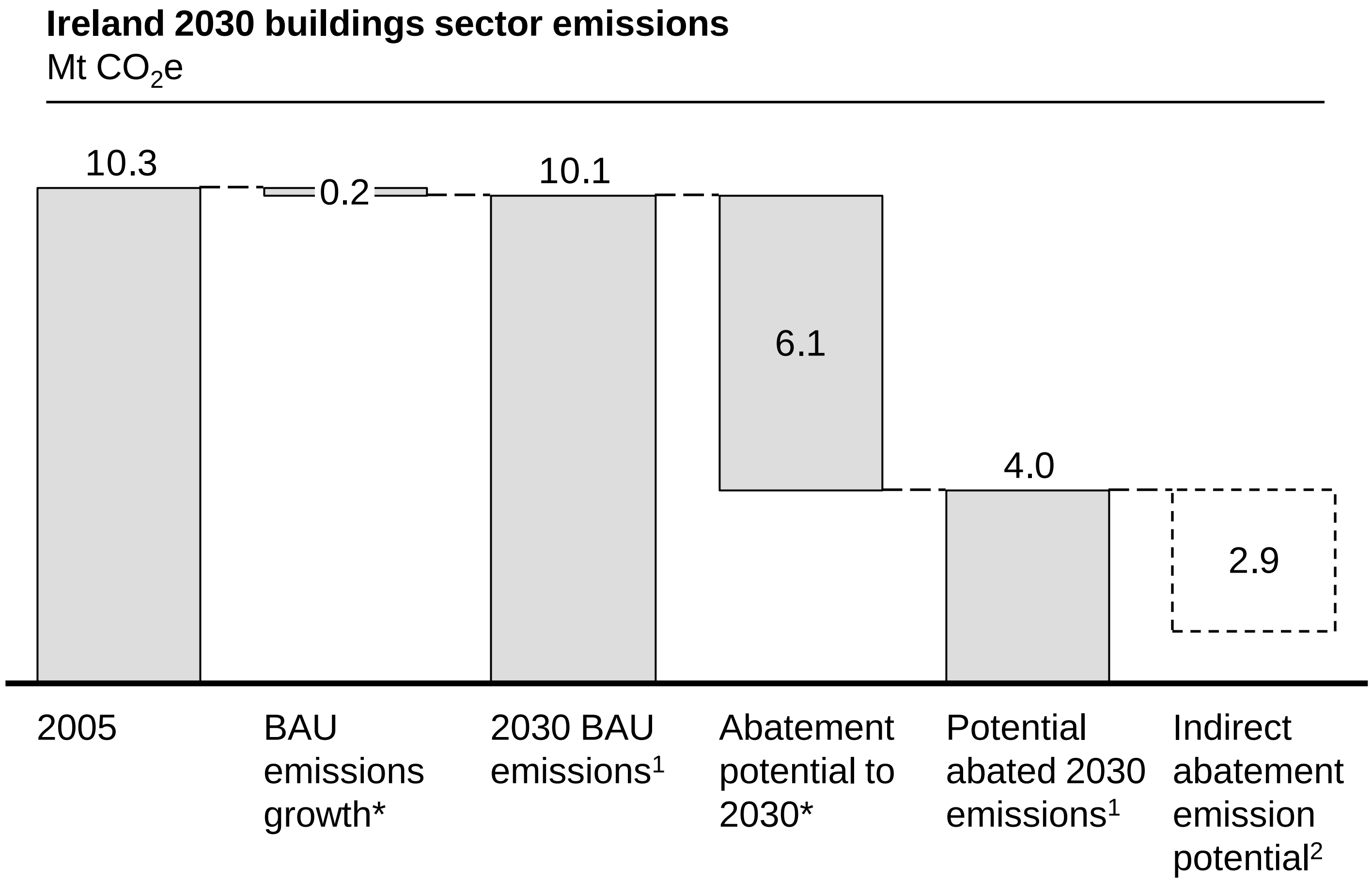
Sector emissions projections

MtCO2e per year



1 Indirect emissions accounted for in the power sector

Buildings sector abatement cost curve

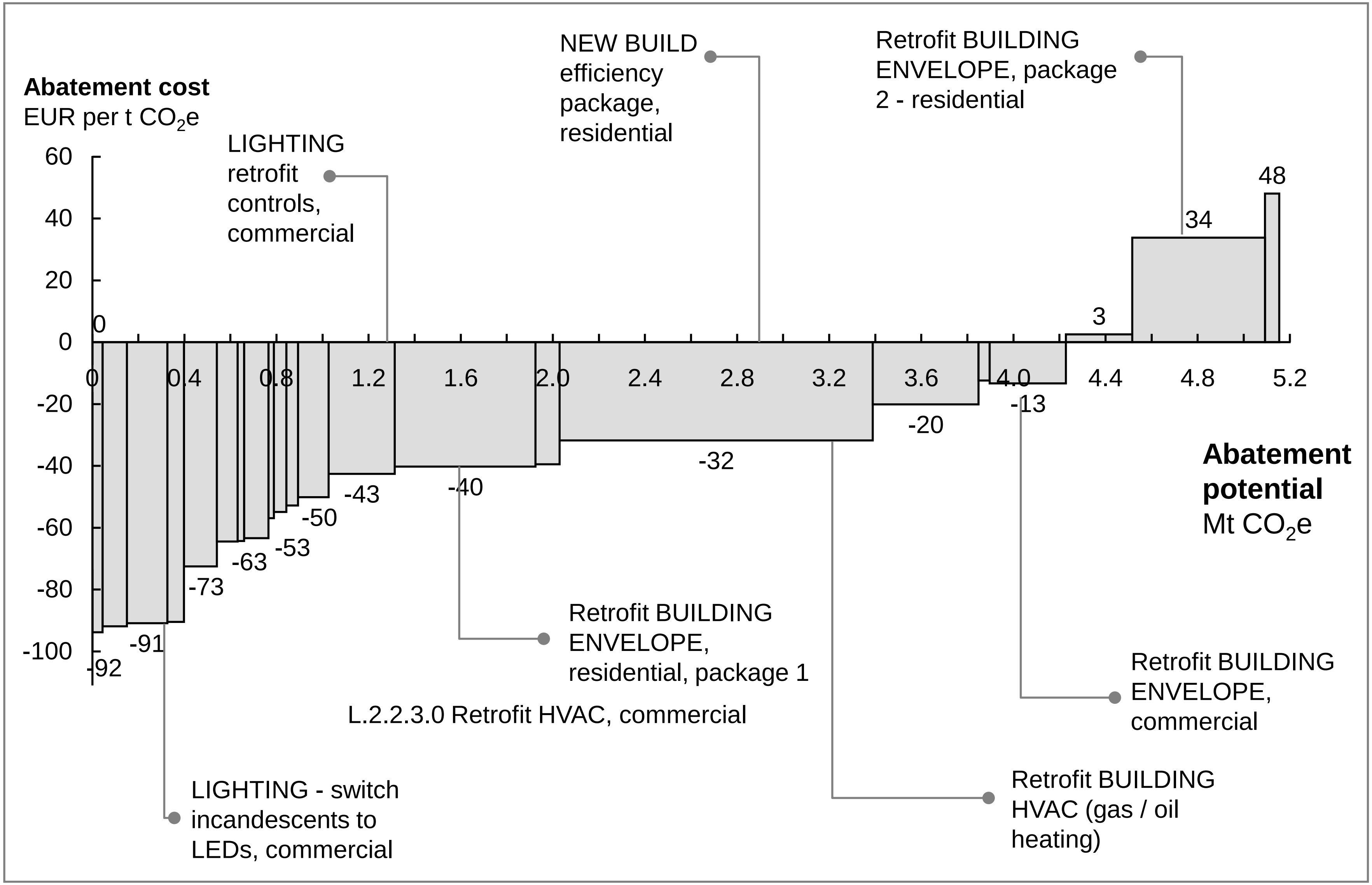


1 Direct emissions only
2 Indirect emissions accounted for in the power sector

SOURCE: Ireland GHG Abatement Cost Curve

Buildings sector abatement cost curve

Societal perspective; 2020



Buildings sector abatement cost curve table (1/2)

Societal perspective; 2020

	Abatement potential (Mt CO_2e)	Price (€ /Mt CO_2e)
ELECTRONICS - consumer, residential	0.04	-94
LIGHTING - switch incandescents to LEDs, commercial	0.11	-92
LIGHTING - switch incandescents to LEDs, residential	0.18	-91
LIGHTING new build controls, commercial	0.07	-91
APPLIANCES - residential	0.14	-73
ELECTRONICS - office, commercial	0.09	-65
APPLIANCES - refrigerators, commercial	0.03	-64
Retrofit HVAC - electric resistance heating to electric h	0.11	-63
LIGHTING - switch CFLs to LEDs, residential	0.02	-57
Retrofit HVAC maintenance – residential[1]	0.05	-55
LIGHTING - switch CFLs to LEDs, commercial	0.13	-50

1 Includes behavioural element

Buildings sector abatement cost curve table (2/2)

Societal perspective; 2020

	Abatement potential (Mt CO_2e)	**Price** (€/Mt CO_2e)
Retrofit HVAC controls, commercial	0.05	-53
LIGHTING retrofit controls, commercial	0.29	-43
Retrofit HVAC, commercial	0.10	-40
Retrofit BUILDING ENVELOPE, residential	0.61	-40
Aggregated NEW BUILD efficiency package, residential	1.34	-20
Retrofit HVAC - gas/oil heating, residential	0.46	-20
LIGHTING - T12 to T8/T5, commercial	0.05	-12
Retrofit BUILDING ENVELOPE, commercial	0.33	-13
Aggregated NEW BUILD efficiency package, commercial	0.29	3
Retrofit BUILDING ENVELOPE, package 2 - residential	0.58	34
WATER HEATING - replacement of electric, commercial	0.06	48

Total 5.1 **Average** -€6

SOURCE: Ireland GHG Abatement Cost Curve

Contents

Sector summary

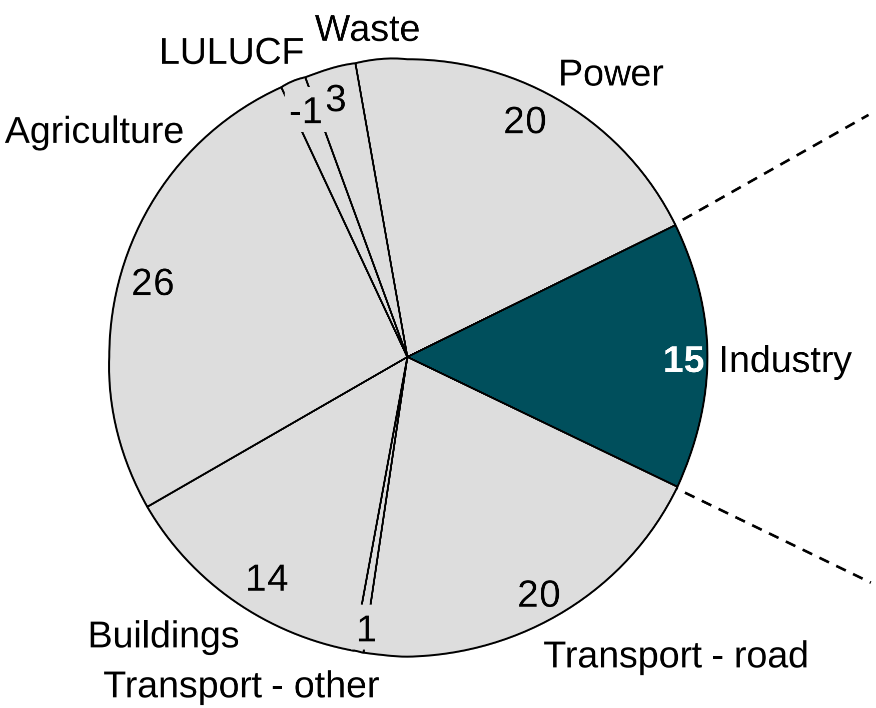
Business-as-usual reference scenario, 2030	▪ Cement industry emissions totalled **3.8 Mt CO_2e** in 2005[1] – **5%** of total Irish emissions – **67%** due to process emissions (from producing clinker) – BAU emissions **rise at annual rate of 0.25%** from 2005 to 2030, to **4.0** Mt ▪ Cement production forecasts are projected in three phases – Constant through 2010 – In line with house completion forecasts from 2010 to 2020 – From 2020 to 2030, at previous decade's CAGR for house completions ▪ Key drivers: **clinker content** and **emissions intensity of kiln fuels** ▪ Other industry emissions totalled **10.7 Mt CO_2e** in 2005 (6.7 direct, 4 indirect)
Abatement opportunities	▪ Total cement opportunity: **1** Mt – Abatement volume limited by existing efficiencies at relatively new Irish plants – **Clinker substitution** (by limestone and blast furnace slag): **0.6** Mt – **Alternative fuels** (e.g. waste, biomass): **0.4** Mt ▪ Other industry opportunities: **1** Mt – Motor systems efficiencies affect indirect emissions, are reflected in the power sector
Implications	▪ Cement opportunities depend on inputs from other industries, so cross-sectoral coordination and planning is critical (i.e. production facilities for alternative fuels, and licenses to burn them; import availability of slag and other materials; specifications for cements with lower clinker content; transportation and processing requirements) ▪ Market dynamics among the three main producers can define uptake rates ▪ Most cement abatement levers have negative cost per tonne of CO_2e abated – From -€48 / t for limestone substitution, to €2 / t for alternative fuels - biomass ▪ Significant abatement opportunities for other industries exist in ETS and non-ETS

1 Based on IPCC inventory for process emissions, and model assumptions regarding energy use
Source: UNFCCC emissions inventory, Ireland GHG Abatement Cost Curve

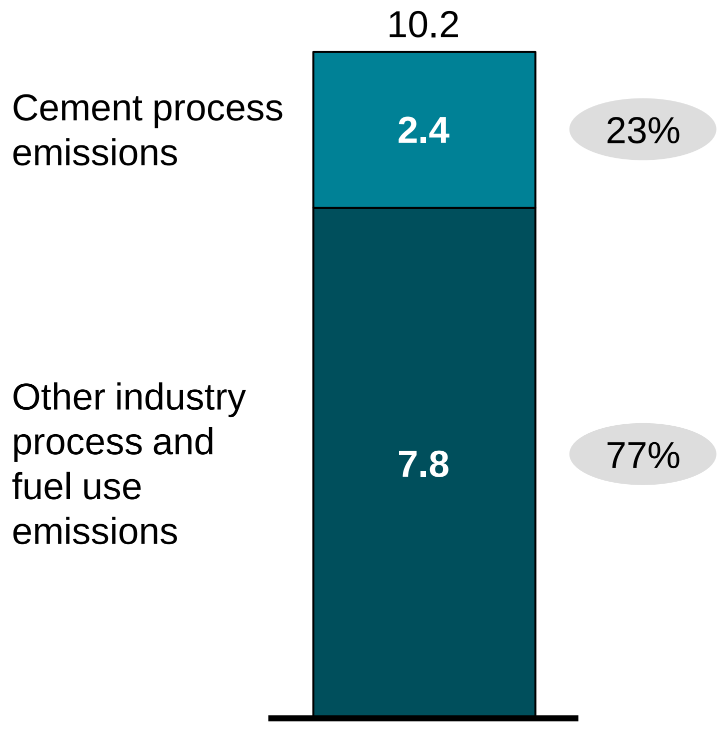
Industry contributed 15% of total Ireland 2007 emissions

2007 total Ireland GHG emissions, %

100% = 68.2 Mt CO_2e



Breakdown of 2007 GHG industry emissions, Mt CO_2e



* Emissions accounted for in power sector

Source: EPA UNFCCC emissions inventory, Ireland GHG Abatement Cost Curve

BAU cement projections are based on production levels

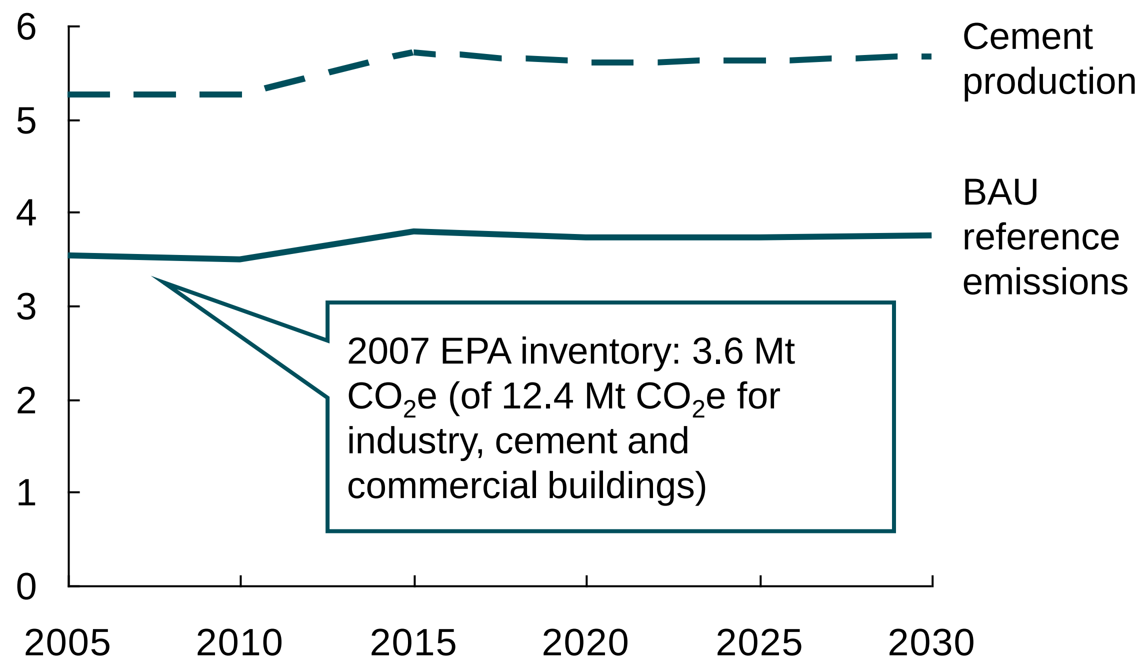
Description of BAU reference scenario

BAU reference scenario includes:

- 5.25 Mt cement produced in 2005, projected using Ireland house completion forecasts
- Domestic production assumed to displace imports due to 2008 capacity increase at Platin
- Increased use of clinker substitution materials
- Maintained current levels of alternative fuels for process heating needs

Projected Ireland GHG emissions from cement

Mt CO_2e and cement



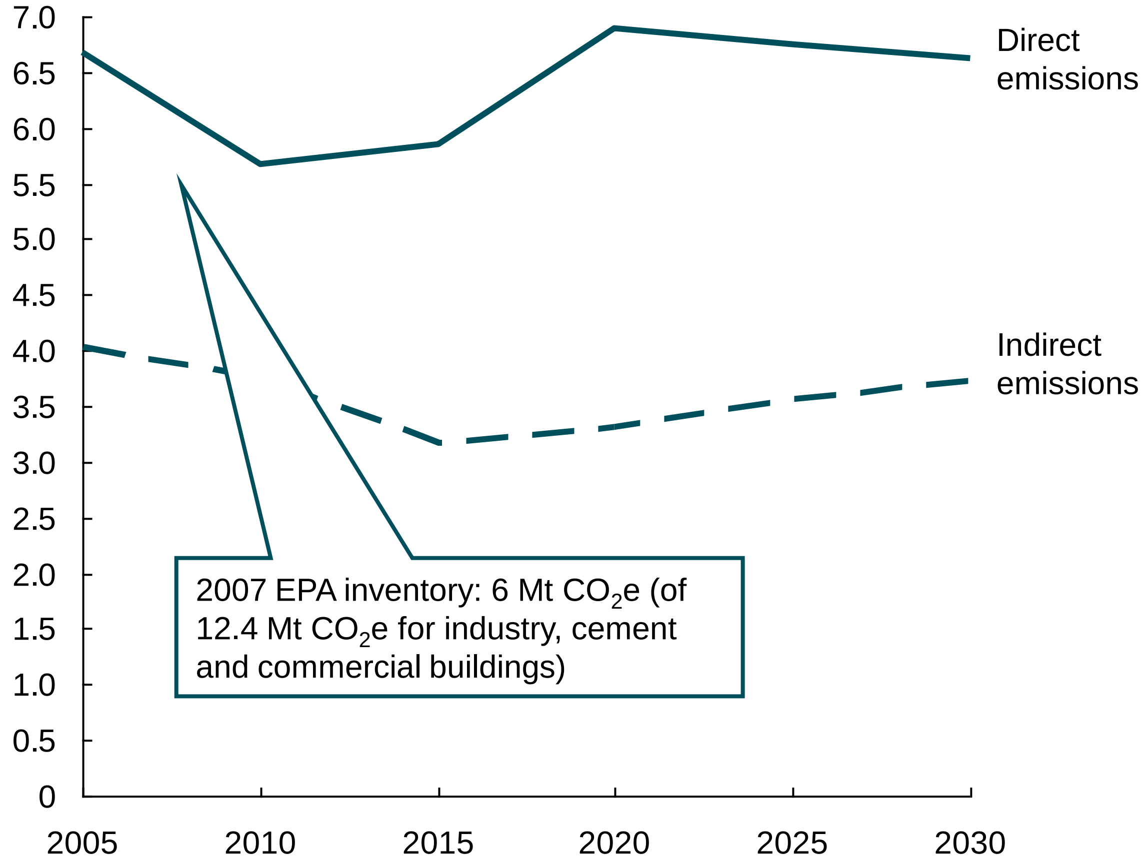
Source: International Cement Review, 7th Edition 2006; ESRI; Ireland GHG Abatement Cost Curve; EPA Ireland projections 2008

BAU projections for other industrial sectors

Description of BAU reference scenario

- BAU direct emissions reference scenario includes:
  - Total industry direct emissions – cement direct emissions
  - Growth rates proportional to industry electricity consumption estimates from National Energy Forecasts
- BAU indirect emissions reference scenario includes:
  - Total industry electricity consumption – cement electricity consumption
  - Growth rates proportional to industry electricity consumption estimates from National Energy Forecasts

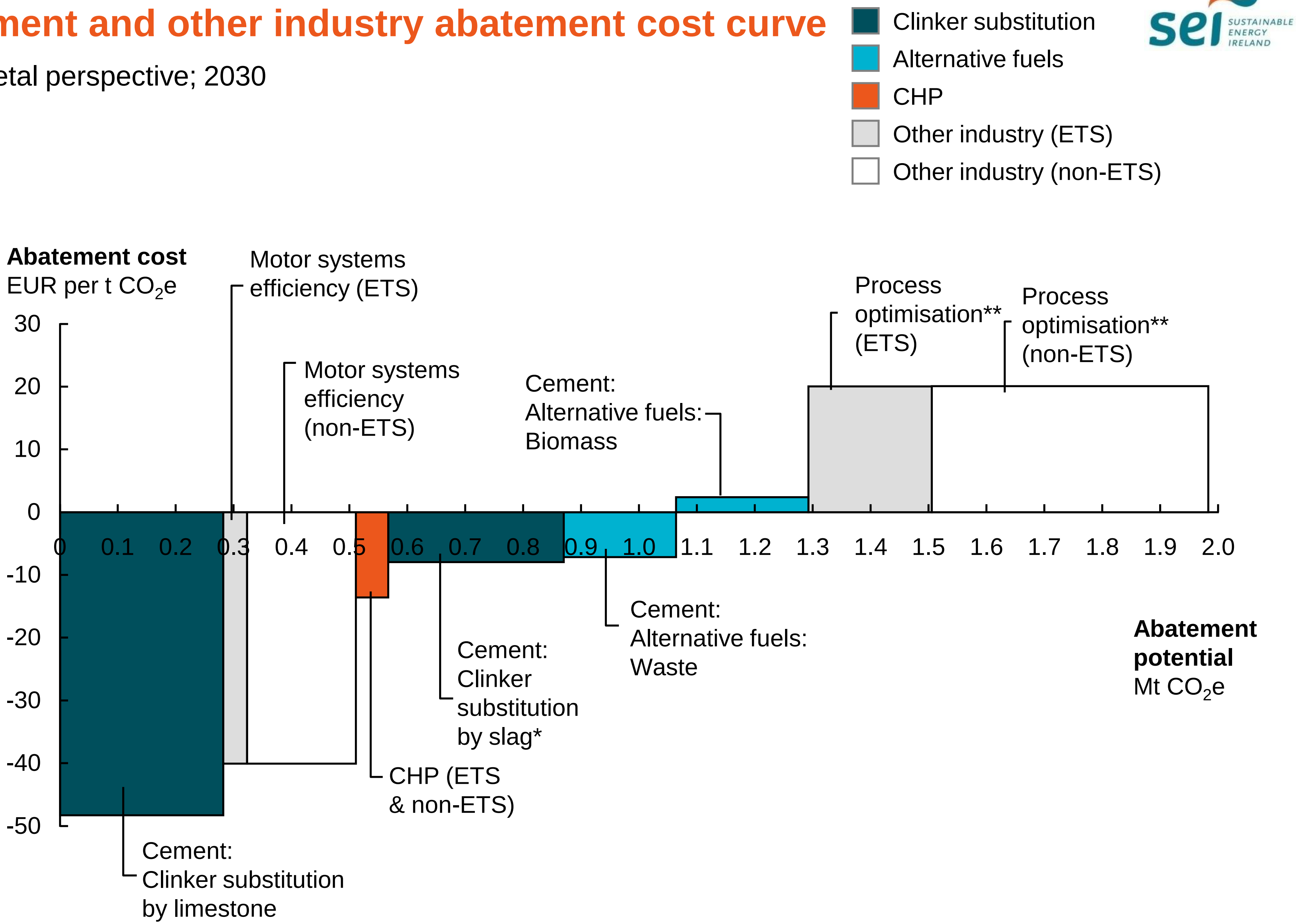
Projected Ireland GHG direct emissions from other industrial sectors
$MtCO_2e$



Source: Ireland GHG Abatement Cost Curve; EPSSU

Cement and other industry abatement cost curve

Societal perspective; 2030



* Assumes material availability. Does not account for emissions from transportation or effects in other national markets.
** Uses conservative high cost estimate from global cost curve analysis.
Source: Ireland GHG Abatement Cost Curve

Description of key levers

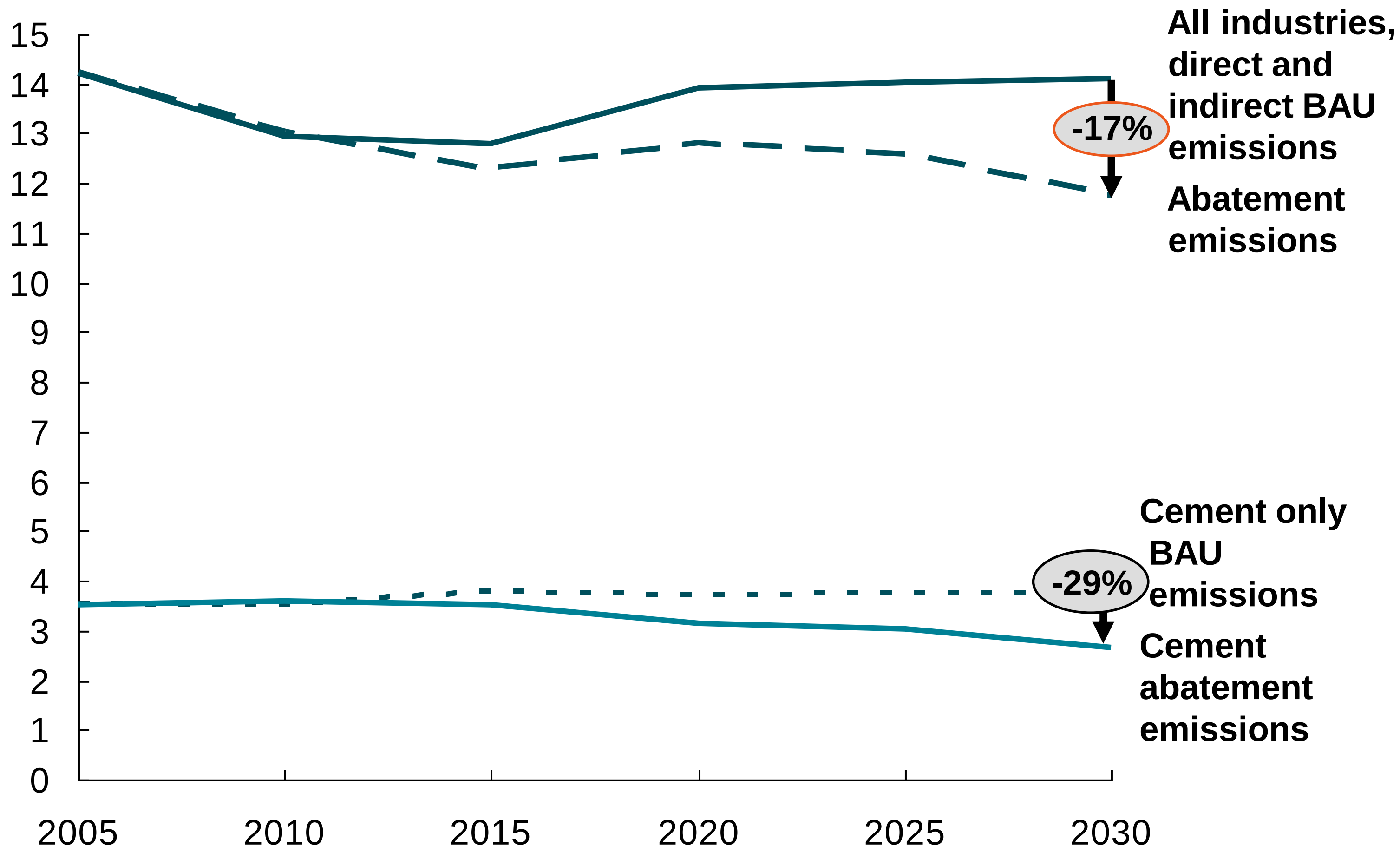
Abatement opportunities in cement and other industry, 2030

Lever	Abatement potential, $MtCO_2e$	Cost of lever, € / tCO_2e	BAU implementation, 2030	Abatement case implementation, 2030	Implementation description
Process optimisation	0.69	20.05	0%	100%	% of industrial sites taking optimisation steps
Cement: clinker sub by slag	0.30	-7.97	0%	7%	% of clinker replaced by slag
Cement: clinker sub by limestone	0.28	-48.29	7%	10%	% of clinker replaced by limestone
Motor systems efficiency	0.23	-40.06	10%	100%	% of industrial sites taking motor systems efficiency steps
Cement: alt. fuels - bio	0.23	2.40	0%	25%	Biomass as % of total fuel use
Cement: alt. fuels - waste	0.19	-7.14	5%	20%	Waste as % of total fuel use
CHP	0.06	-13.60	0%	15%	% of total electricity usage generated by CHP
Total	1.98				

Source: Ireland GHG Abatement Cost Curve

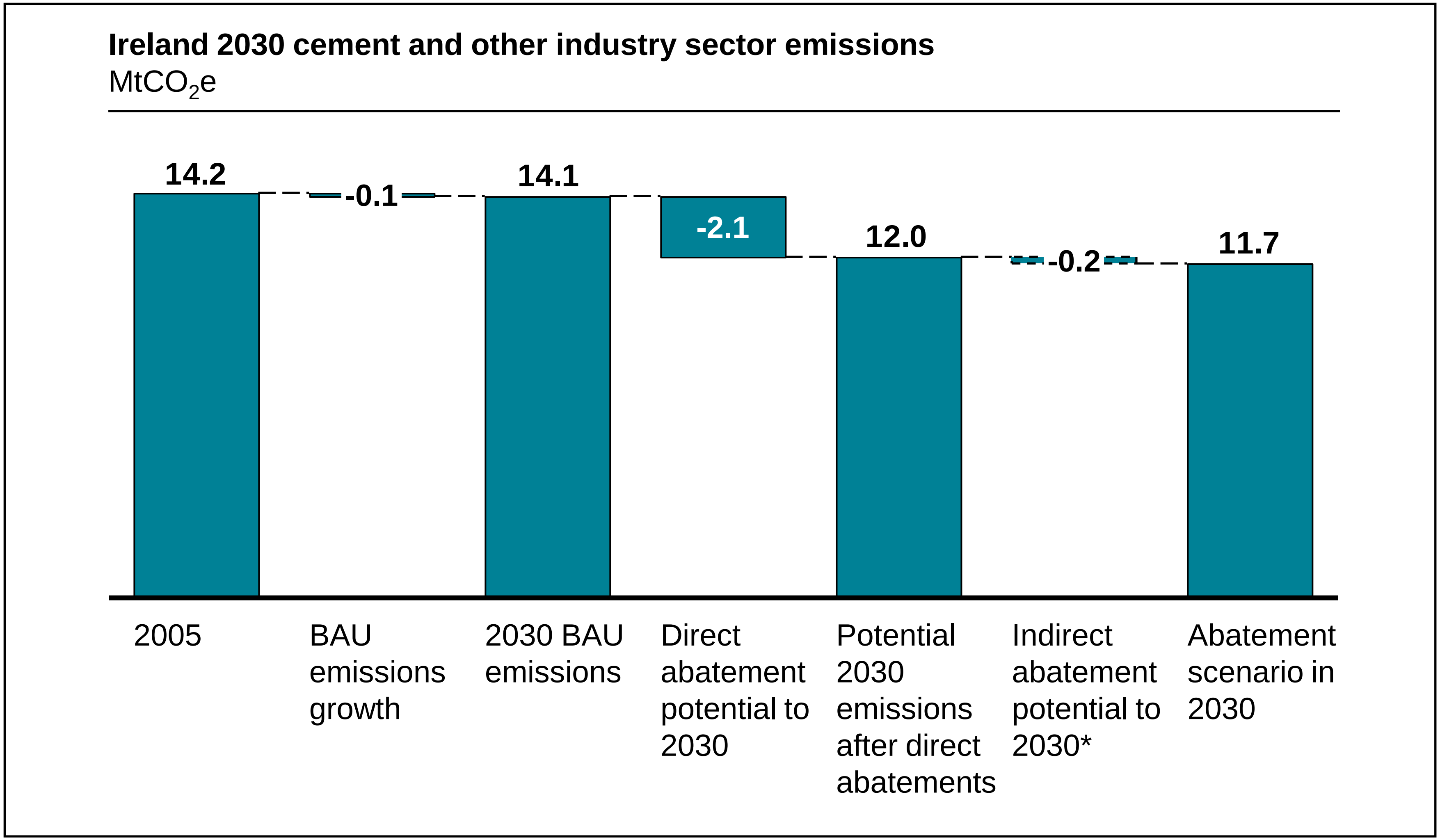
Cement and other industry sector emissions projections

MtCO$_2$e per year



Source: Ireland GHG Abatement Cost Curve

Cement and other industry sector abatement cost curve



* Emission reduction occurs in power sector but abatement driven in industry

Source: Ireland GHG Abatement Cost Curve

Contents

Sector summary

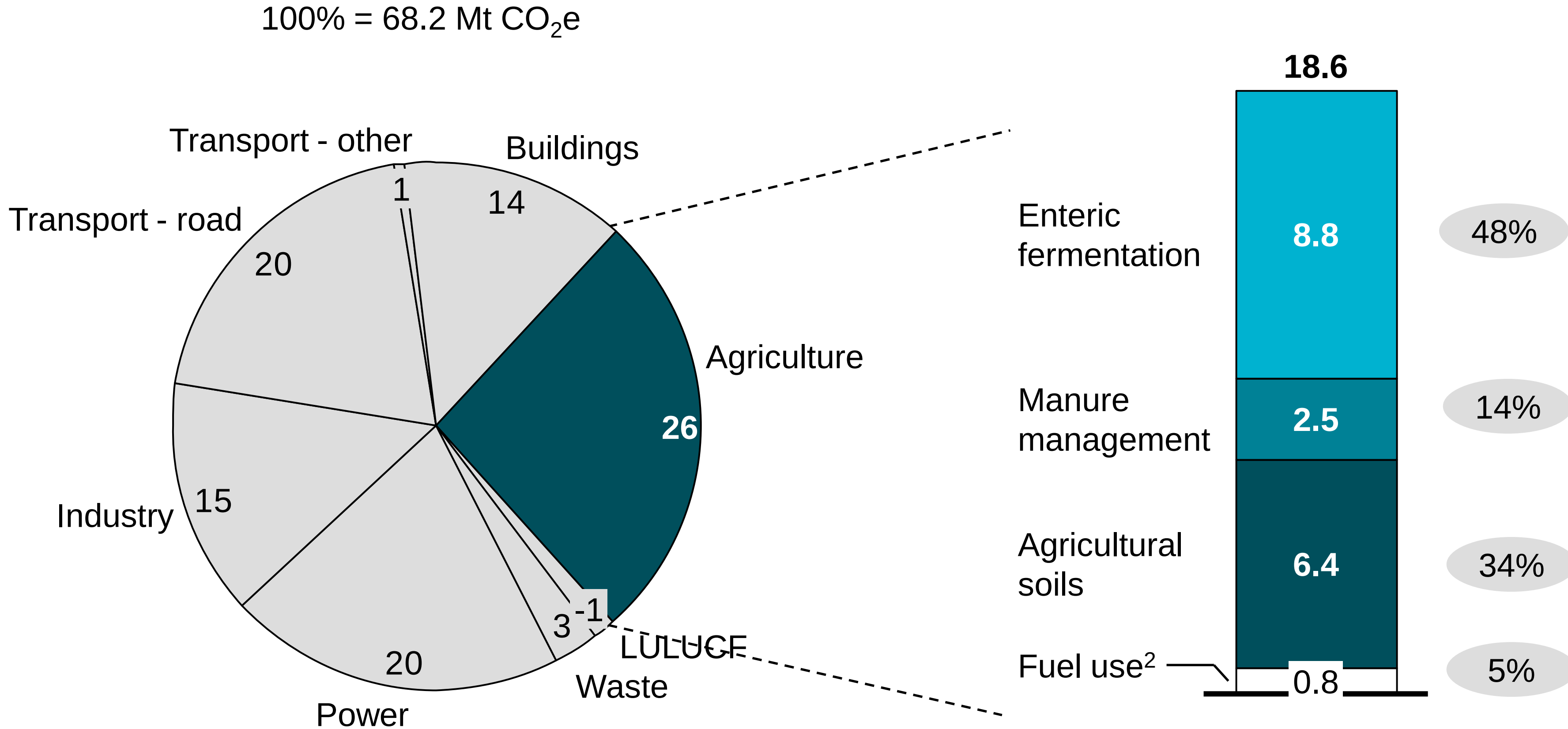
Business-as-usual reference scenario, 2030	▪ Agriculture emissions totalled **18.6 Mt CO_2e** in 2007: **27%** of Ireland total ▪ BAU forecasts emissions **fall at annual rate of 0.34%** from 2007 to 2020, to **17.8 Mt** – Emissions assumed constant from 2020 to 2030 ▪ Key drivers: – **Livestock** caused 76% of 2007 total; cattle numbers to fall by 11% – **Fertiliser** caused 20% of 2007 total; nitrogen fertiliser application to fall by 5%
Abatement opportunities	▪ Total identified abatement opportunities: **0.6 Mt** – Biggest opportunity: 0.28 Mt, from **grassland nutrients (slurry) and management (clover)**, at costs ranging from -€65 to €9 per tonne of CO_2e abated – **Livestock** levers have 0.3 Mt potential, at negative cost, due to increased animal productivity and less expense on food
Implications	▪ **Limited abatement opportunity** results from regional variations in soil conditions and farming practices, according to Teagasc and the Department of Agriculture – Therefore **only low implementation rates are possible** ▪ **Research is necessary** – High levels of **uncertainty** around new technologies, e.g. livestock vaccines ▪ **Permanence and MRV** (measuring, reporting & verifying) are challenges in agriculture, requiring strong incentives and regulatory intervention – Emissions tracked by levels of inputs/outputs (e.g. fertiliser sales, head of cattle), meaning no “credit” is currently given for abatement achieved via farming practises – Current accounting systems mean that many abatements pursued by farmers, such as forestry or microgeneration of power, are “credited” in other sectors and therefore more difficult to incentivise ▪ Ireland’s **unique mix of agricultural activities and resources** positions the sector for a potential global leadership role

SOURCE: Ireland GHG Abatement Cost Curve

Agriculture contributed a 26% of total 2007 GHG emissions

2007 total Ireland GHG emissions, %

Breakdown of 2007 GHG agriculture emissions[1], Mt CO_2e



1 Calculations use GWP conversion factors of 21 for CH_4 and 310 for N_2O
2 Included in BAU projections, but not subject to any abatement reductions

SOURCE: EPA UNFCCC emissions inventory

Business-as-usual forecasts include recent and anticipated policy developments from Irish and EU level

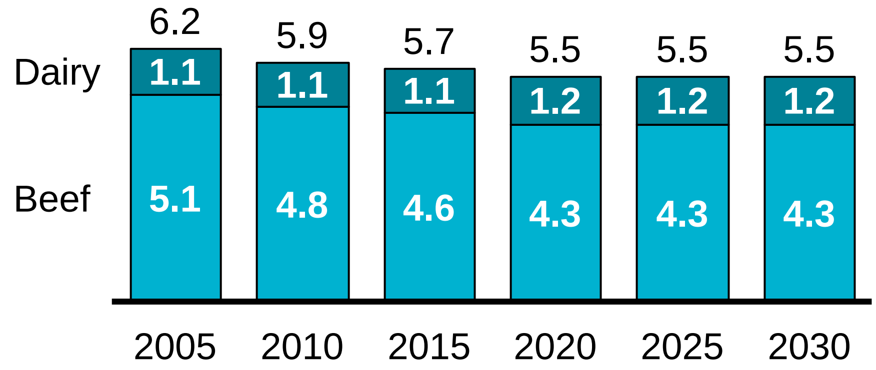
NOT EXHAUSTIVE

Policy drivers

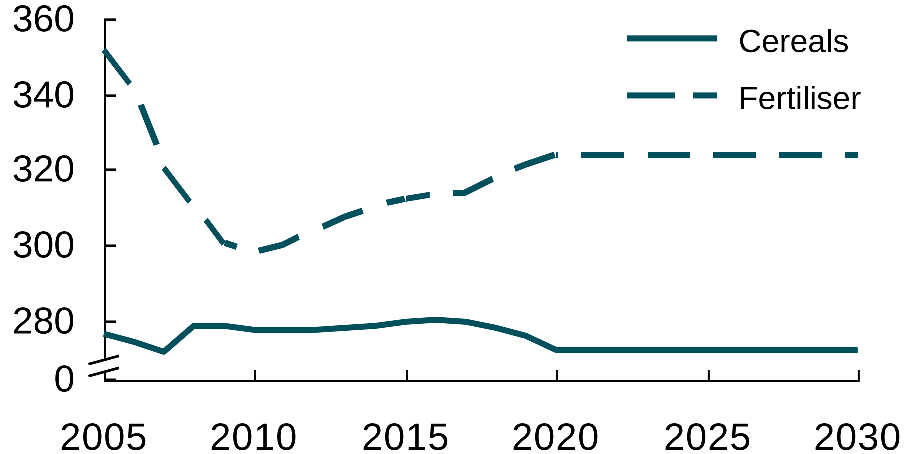
- CAP reform
- Nitrates directive
- Milk quotas
- Biofuel schemes
- Future policy changes…

Emissions drivers

Cattle, millions

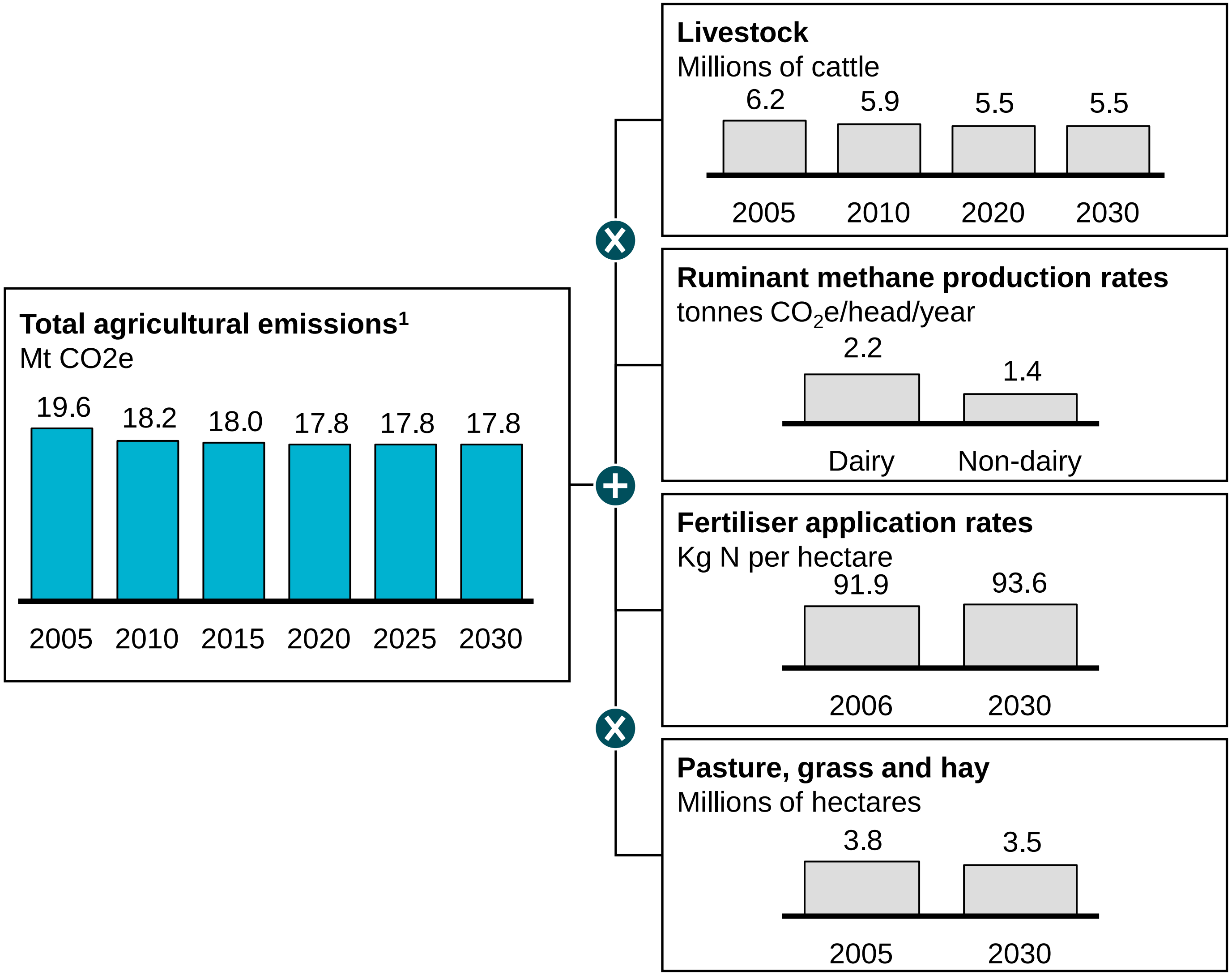


Fertiliser, tonnes N
Cereals area (wheat, barley, oats), ’000 ha



Declining emissions are driven by livestock and land

NOT EXHAUSTIVE

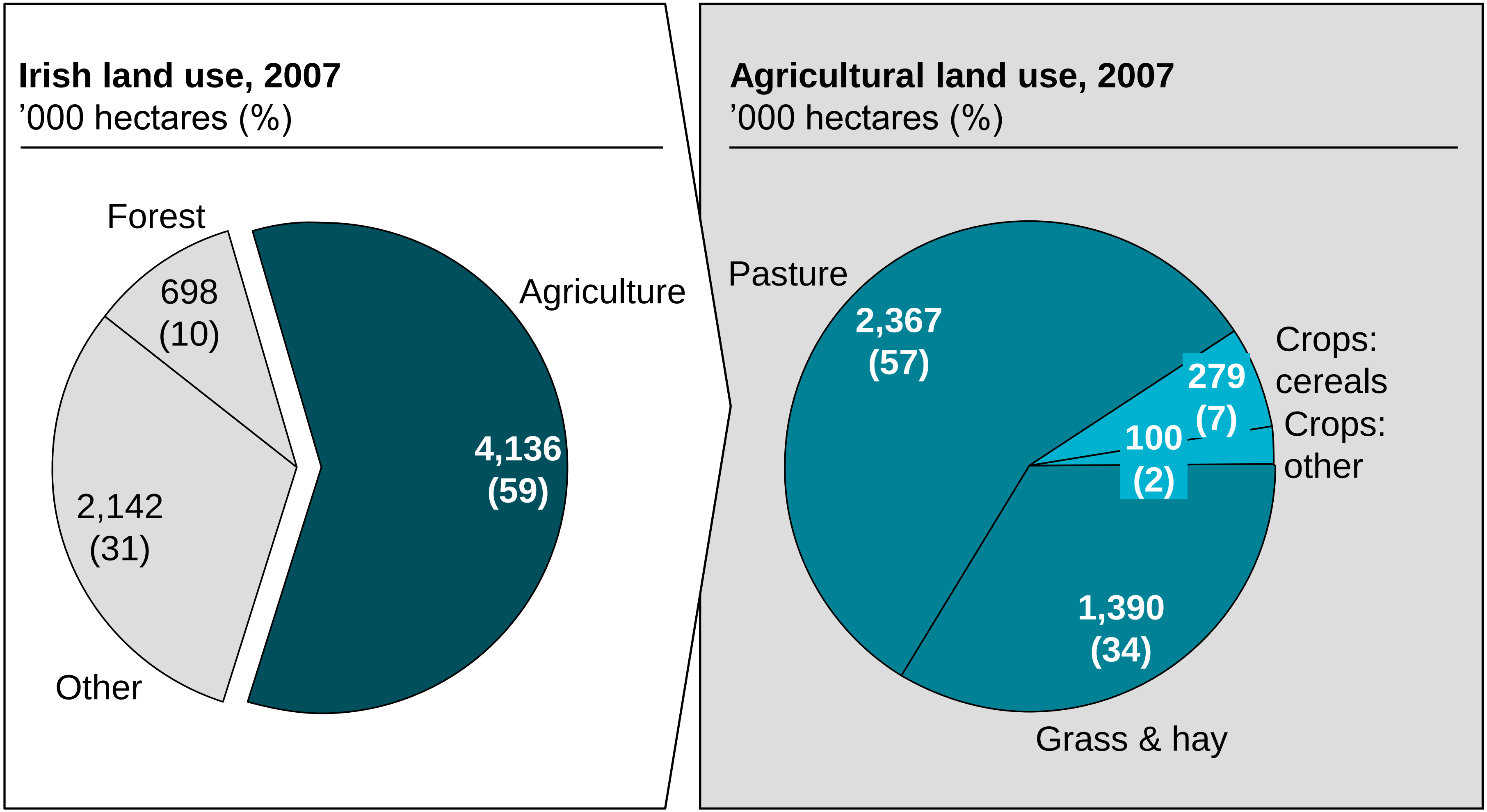


Source

- Teagasc (full forecasts include sheep and pigs)
- UNFCCC National Inventory Report
- Calculated by dividing Teagasc forecasts for total N application by CSO agricultural land area (below)
- CSO (projected to 2030 at 2000-07 CAGR)

1 Calculation may not sum precisely; some inputs chosen for illustrative purposes

Grasslands account for more than 90% of agricultural land use



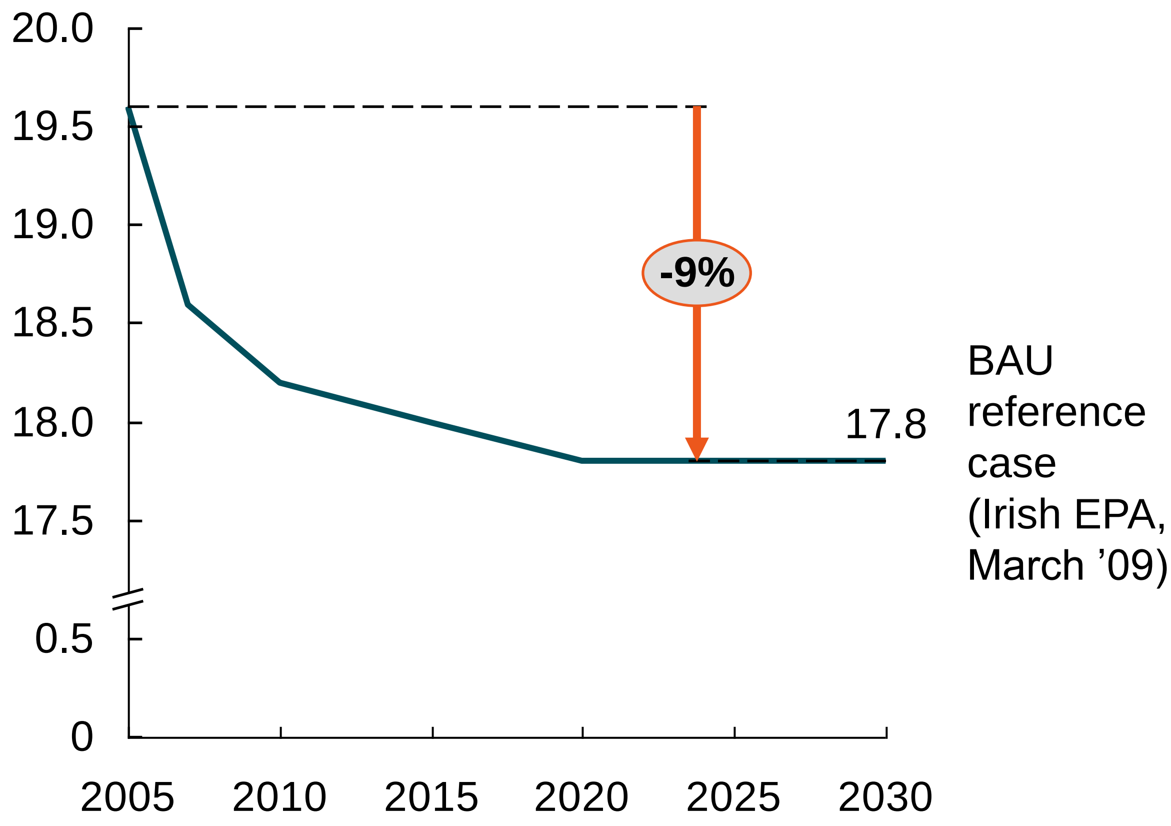
Business-as-usual projections show a decline in agriculture emissions

Description of BAU reference case

- Reference case uses latest forecasts from EPA and Teagasc, and will project to 2030
- Trends include:
  - Fluctuations in livestock numbers and fertiliser use
  - Effects of prices, demand and legislation
- BAU emissions are assumed constant from 2020 to 2030 due to high uncertainty in agricultural policies

Projected Ireland GHG emissions

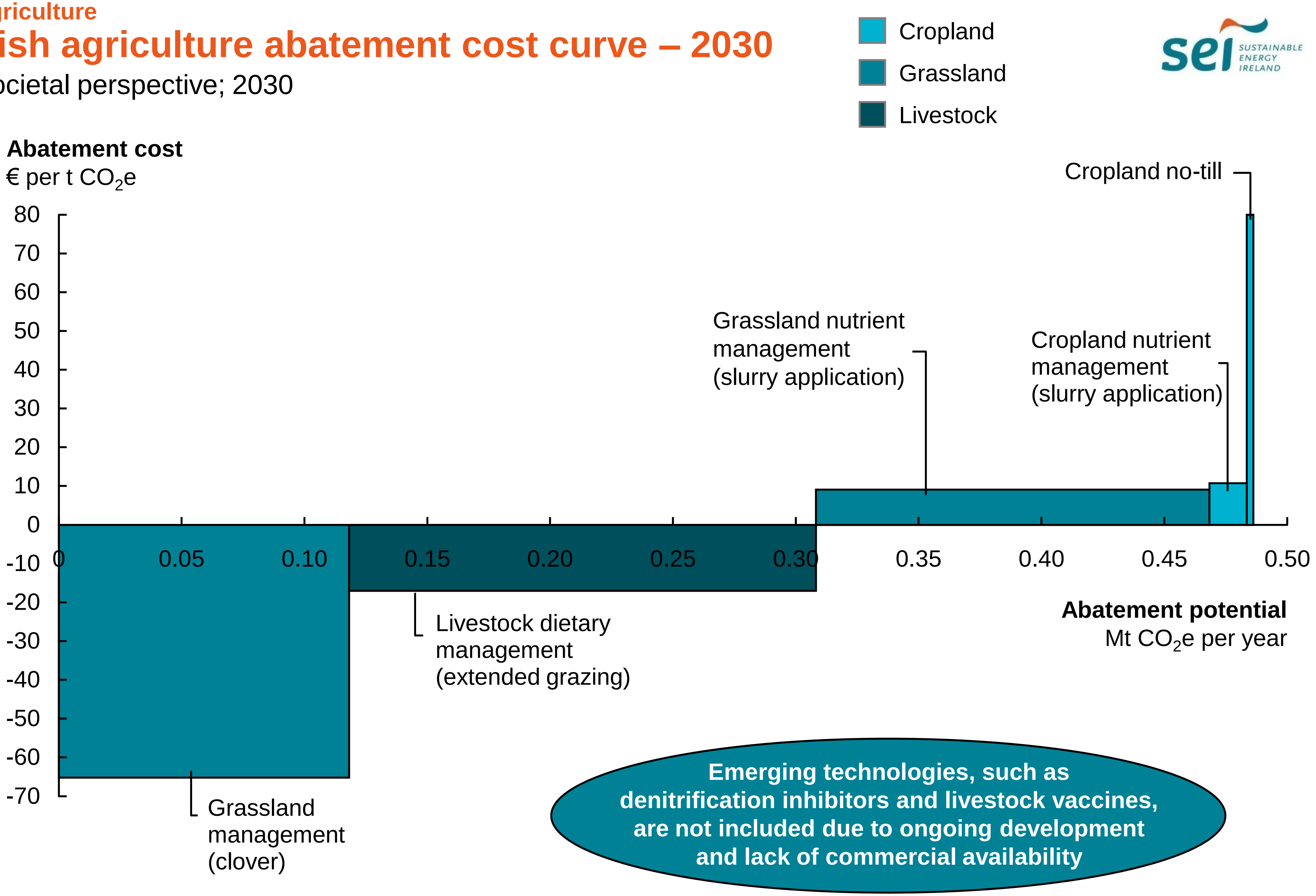
Mt CO_2e



1 Follows Irish EPA forecasts (March ’09 revision) to 2020, assumes constant emissions to 2030

Irish agriculture abatement cost curve – 2030

Societal perspective; 2030



Description of agriculture levers

Top abatement levers in Irish agriculture, 2030

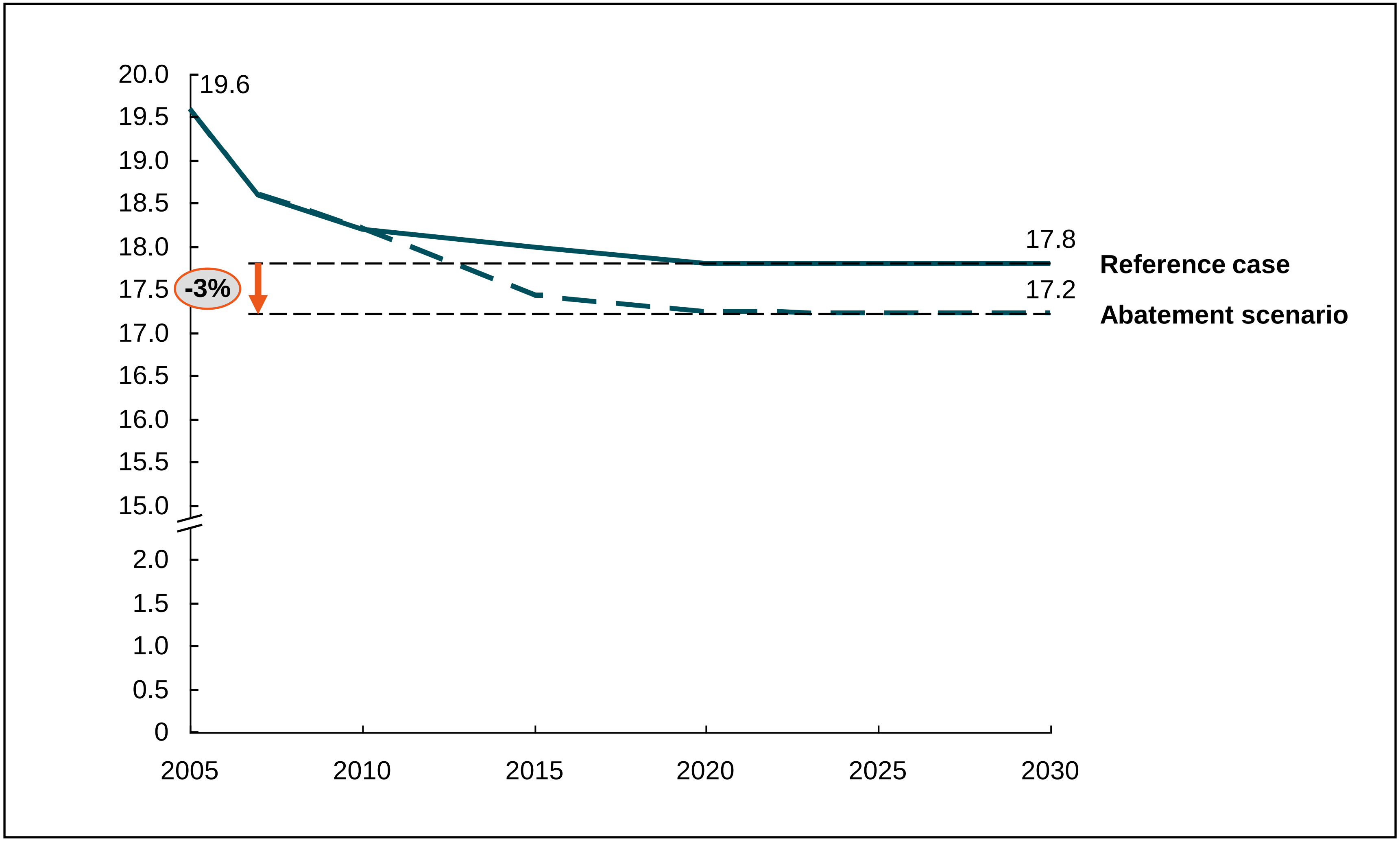
Lever	**Abatement potential,** $MtCO_2e$	**Average cost of lever,** €/t CO_2e	**BAU implementation, 2030**	**Abatement case implementation, 2030**	**Emissions reduction potentials**[2]
Grassland	0.28	-22.46	▪ Management (clover): 1% ▪ Nutrients (slurry): 33%	▪ Management (clover): 10% ▪ Nutrients (slurry): 50%	▪ 0.46 t CO2e / ha / yr from grazing and clover ▪ 0.33 t from nutrients
Livestock	0.19	-17.05	▪ Increased grazing: 5%	▪ Increased grazing: 60% beef, 100% dairy	▪ 4.76% emissions reduction from 35 extra grazing days
Cropland[1]	0.02	21.21	▪ Tillage: 0% no-till, 10% reduced & residue mgt ▪ Agronomy: 5% ▪ Nutrients (slurry): 10%	▪ Tillage: 4% no-till, 25% reduced & residue mgt ▪ Agronomy: 25% ▪ Nutrients (slurry): 30%	▪ 0.25 from no-till ▪ 0.33 from reduced till ▪ 0.6 from agronomy (cover crops) ▪ 0.28 t from nutrients
Total	0.39	-18.48			

1 Levers for reduced till & residue management, and for agronomy, are not included in cropland totals or cost curve results due to high cost per t CO_2e
2 Teagasc, Department of Agriculture, expert interviews

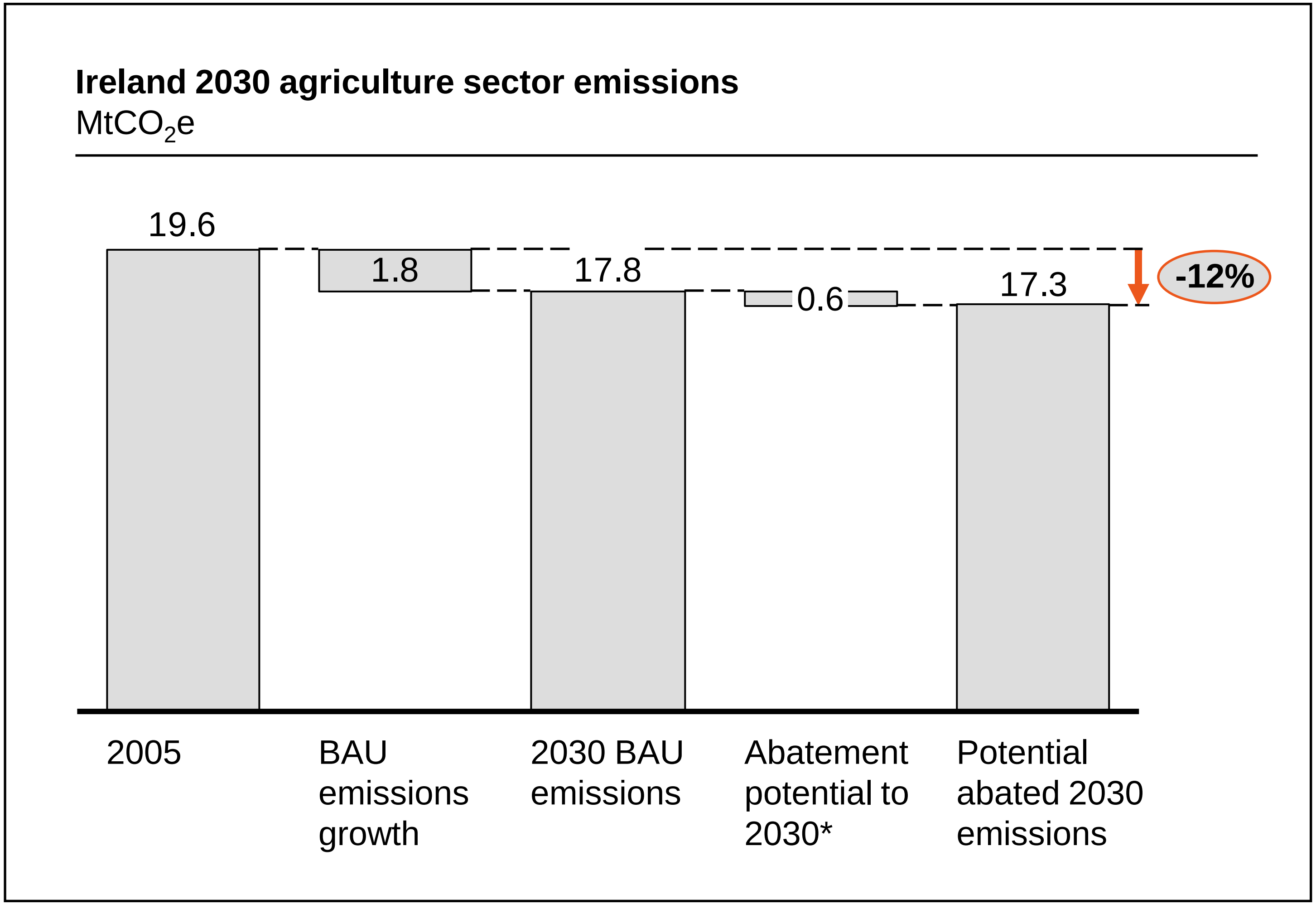
SOURCE: Ireland GHG Abatement Cost Curve

Sector emissions projections

$MtCO_2e$ per year



Agriculture sector abatement cost curve



Contents

Sector summary

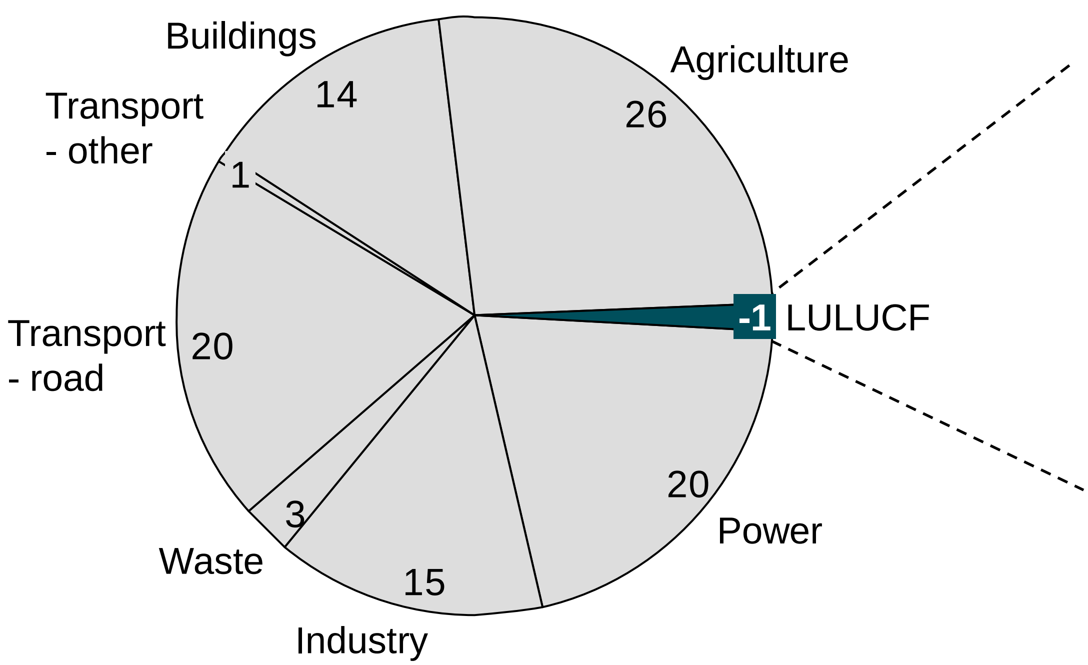
Business-as-usual reference scenario, 2030	▪ LULUCF emissions totalled **-1 Mt CO_2e** in 2007 ▪ Forestry acted as a carbon sink, absorbing **-1.5 Mt** ▪ BAU forecasts an increase in negative forestry emissions from 2007 to 2020, to **-4.4 Mt** – This trend plateaus and then reverses in 2030 due to historic planting activity ▪ Key drivers: afforestation rate, currently 8 kha / year
Abatement opportunities	▪ Total identified abatement opportunities: **3.7 Mt** – Biggest opportunity: 3.0 Mt from afforestation at cost of €30 per tonne of CO_2e abated – Organic soils restoration has 0.6 Mt potential, at cost ranging from €27 to €201 (includes 0.3 Mt potential from restoring farmed peatland at high cost)
Implications	▪ **Further research is necessary** – High levels of **uncertainty** around organic soils restoration ▪ **Permanence and MRV** (measuring, reporting & verifying) are challenges in LULUCF, requiring strong incentives and regulatory intervention ▪ Due to the age profile of planted forest, **future sequestration potential is subject to past afforestation rates**, which must be increased in order to sustain the current carbon sink ▪ Restoration is **assumed to meet the ecologically sensitive requirements** of Special Areas of Conservation, Areas of Scientific Interest, and national parkland; and to have **no impact on agricultural output** due to >10% declines that are forecast in grazing animal numbers

Source: Ireland GHG Abatement Cost Curve

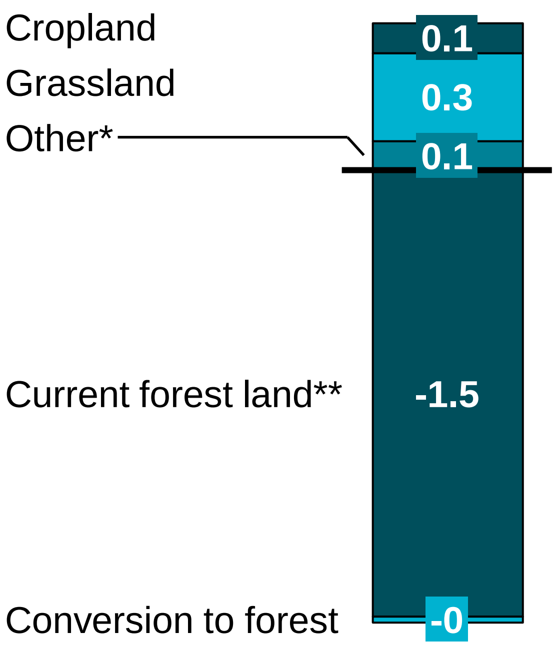
Forestry contributed a 1.5 Mt reduction in 2007 GHG emissions while land-use change added 0.5 Mt

2007 total Ireland GHG emissions, %

100% = 68.2 Mt CO_2e

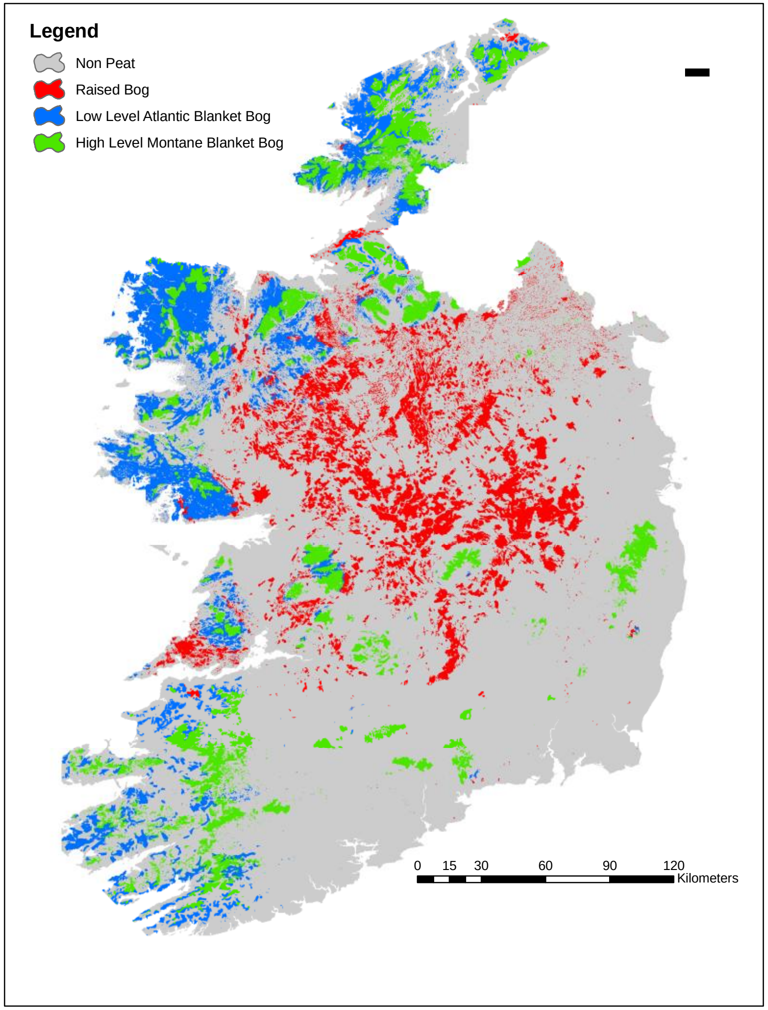


Breakdown of 2007 LULUCF GHG emissions, Mt CO_2e



* Includes wetlands and settlements
** May vary from Kyoto Protocol reporting
Source: EPA UNFCCC emissions inventory; Expert interviews

Peatland is estimated to cover between 14% and 25% of Ireland's land area



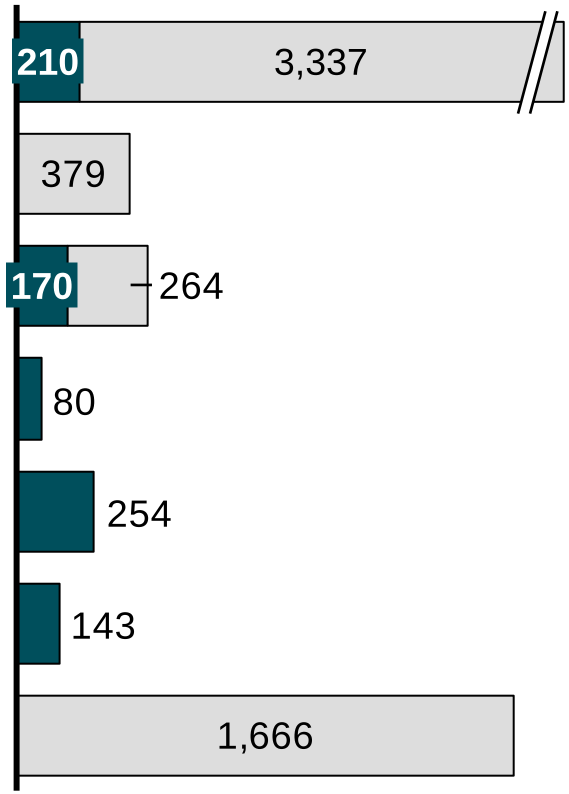
- **Recent research has determined that peatland covers more area than previously thought**
  - From 950,000 to 1.7m hectares
  - 'New' peatland is due to counting of small drumlin-based areas, which are not included in abatement analysis
- **Bogs are predominantly located in the midlands and west**
  - Around 400,000 hectares are either intact or not in significant economic use

* Image courtesy of Connolly and Holden, "Updating maps of peat soil extent in Ireland: a GIS rules-based mapping approach," 2008

Source: Connolly and Holden, 2008; National Forest Inventory; CSO

Restoration of impacted peatland has the potential to contribute significantly to abatement efforts

Irish peatland distribution, 2007
’000 hectares

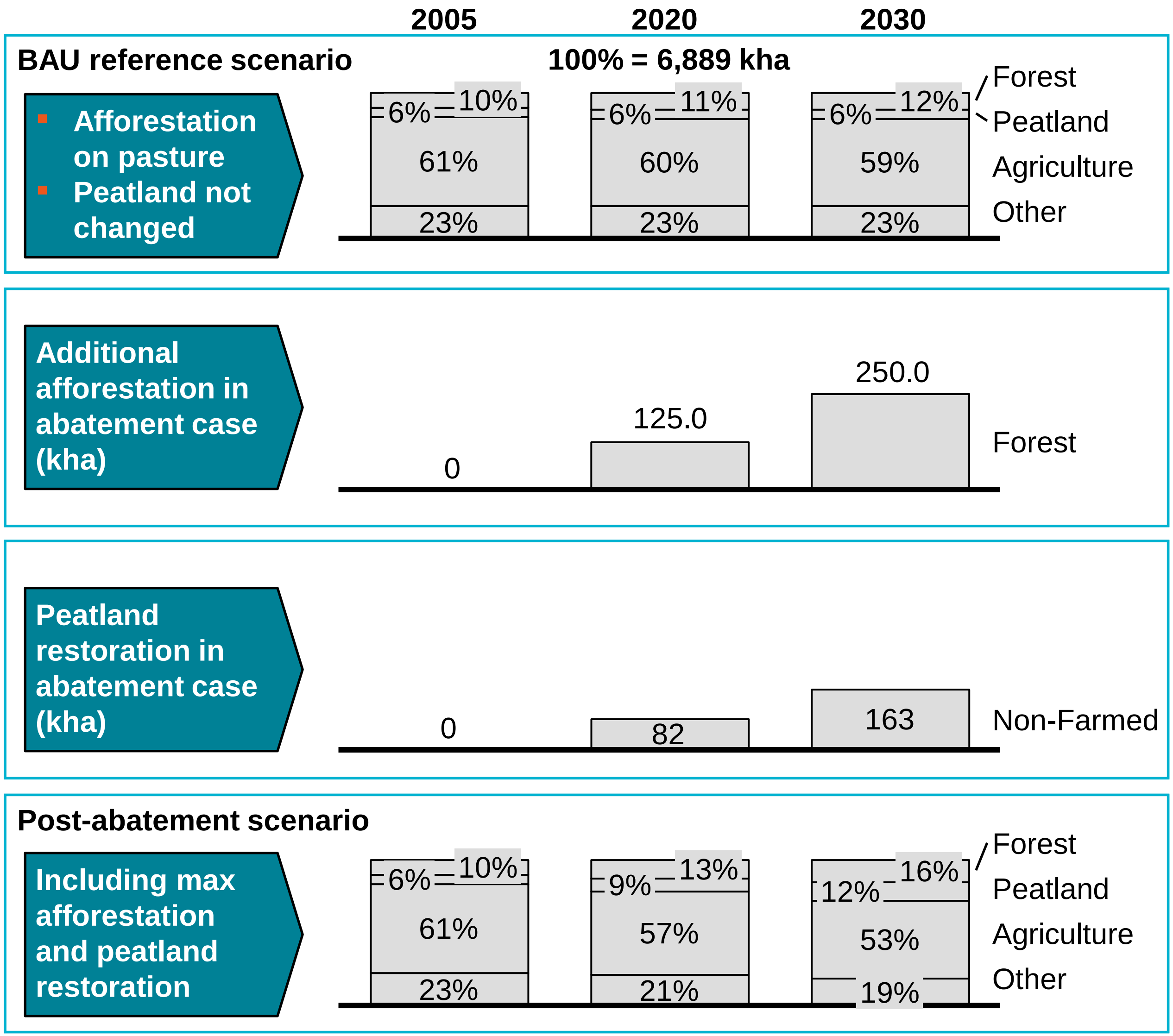


	Description	% of peatland eligible for 2030 restoration
Grassland	Pasture, hay and silage	75%
Cropland	Cereals, vegetables, fruit, horticulture	n/a
Forest	Principally commercial forestry	0%
Bord na Mona	40 kha actively harvested	0%
Other impacted peat	Remainder after other uses and intact	75%
Intact peat	15% of total peatland	0%
Other land	Developed land, roads, bodies of water, etc.	n/a

- Only ‘Other impacted peat’ and ‘Grassland peat,’ covering more than 400 kha, are considered eligible for restoration
- ‘Other impacted peat’ is assumed to have no economic use besides small-scale turf-cutting

Source: National Forest Inventory, CSO

Afforestation and peatland restoration cause slight changes in the Irish land-use mix



- Full implementation of abatement measures accelerates a marginal shift away from pasture, and reassigns degraded bog as peatland
- Incremental afforestation of 12.0 kha / year assumed to start in 2010, for total rate of 20 kha / year
- Abatement numbers for each year are cumulative

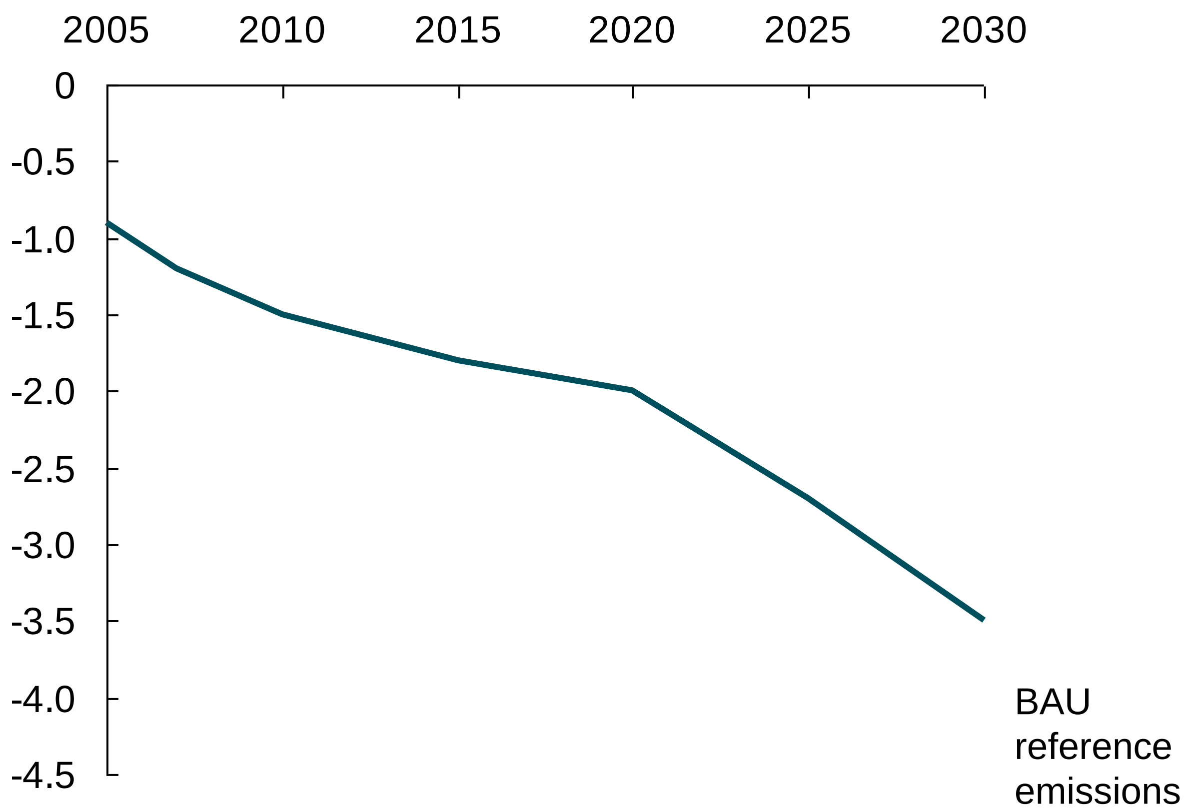
Source: FAOSTAT, CSO, NPWS, expert interviews

LULUCF BAU forecast based on 2007 emissions from forestry

Description of BAU reference scenario

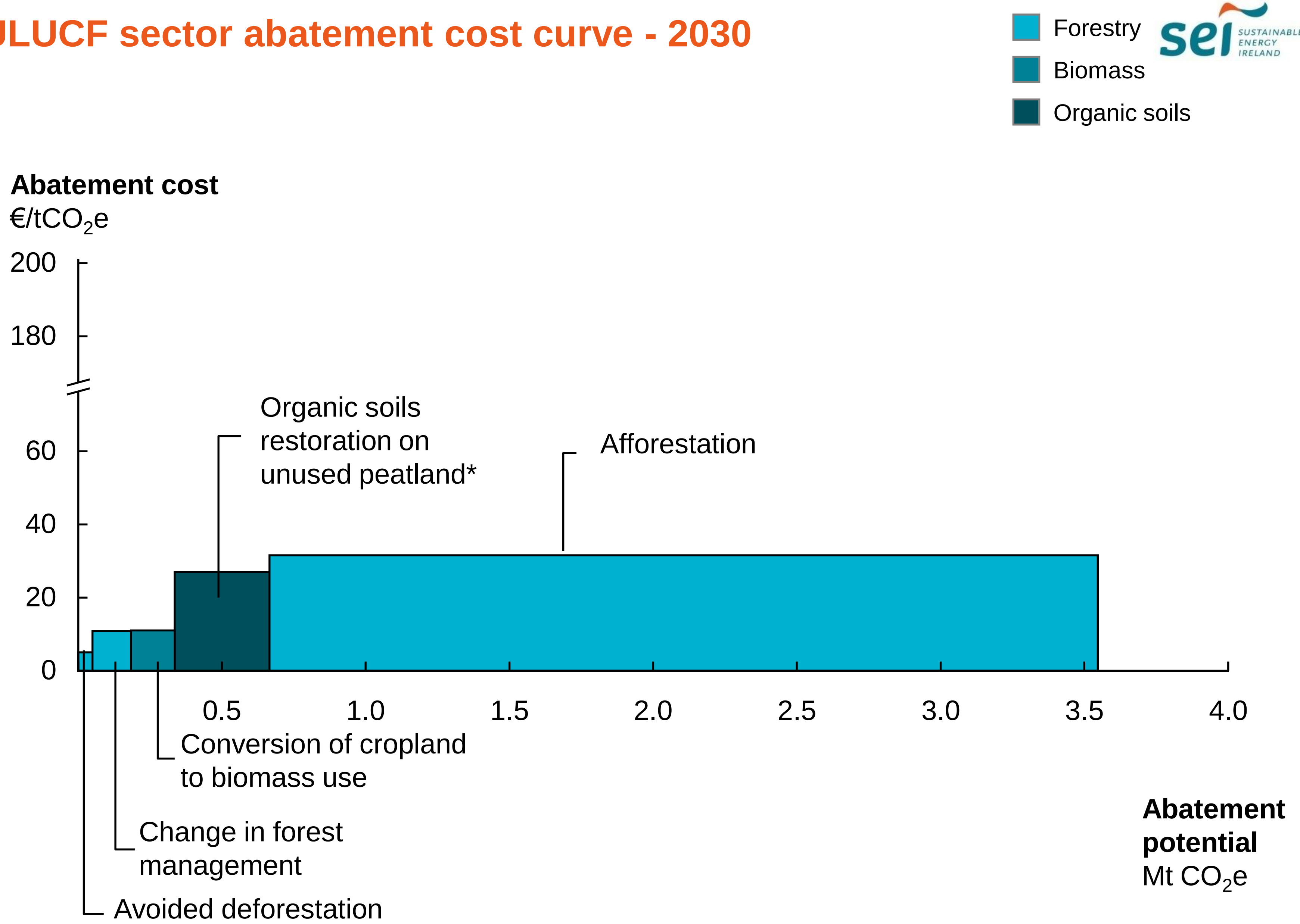
- Uses afforestation rate of 8,000 hectares / year, and the harvesting scenario cited as most probable by COFORD/FERS
- Sequestration rates are forecast to plateau after 2030 and drop thereafter, due to the timing of when trees have previously been planted

Projected Ireland GHG emissions from LULUCF
Mt CO_2e



Source: COFORD, FERS, UNFCCC, Ireland GHG Abatement Cost Curve

LULUCF sector abatement cost curve - 2030



* Peatland that does not support significant economic activity – excludes peatland that is afforested or held by Bord na Mona

** Contingent on 20,000Ha/annum of land being available for afforestation – further research is required to verify this assumption

Source: Ireland GHG Abatement Cost Curve

Description of LULUCF levers

Top abatement levers in Irish LULUCF, 2030

Lever	**Abatement potential,** $MtCO_2e$	**Average cost of lever,** €/t CO_2e	**BAU implementation, 2030**	**Abatement case implementation, 2030**	**Emissions reduction potentials**
Afforestation	3.0	30.00	▪ 8,000 ha / year	▪ 20,000 ha / year	▪ 11.3 t CO_2 / ha / year ▪ 556 t / ha (over 50 years)
Organic soils	0.3	27.23	▪ 0%	▪ 75%*	▪ Rewetted bog becomes carbon sink absorbing 2.0 tCO_2e / ha / yr
Biomass on cropland	0.2	11.01	▪ 0 ha / year	▪ 1,000 ha / year	▪ 8.85 t CO_2 / ha / year
Forest management	0.1	10.75	▪ 0 ha / year	▪ 50,000 ha / year	▪ 2.69 t CO_2 / ha / year
Avoided deforestation	0.1	5	▪ 500 ha / year deforested	▪ 400 ha / year deforested	▪ 0.05 Mt CO_2 total potential savings
Total	3.7				

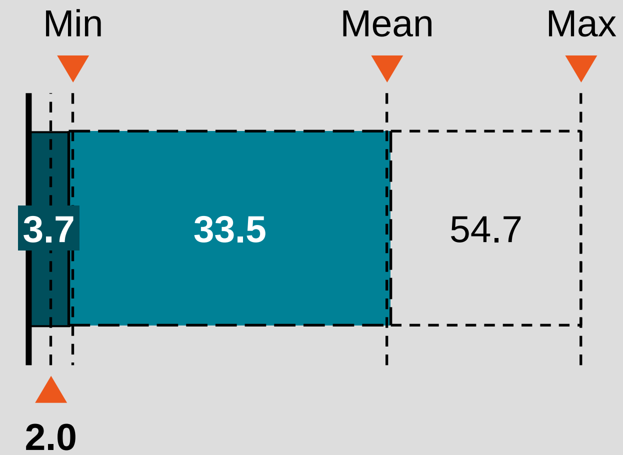
* Scaled back from 90% to account for unsuitable areas on bog perimeters, due to impact on adjacent land that is in use

Source: Ireland GHG Abatement Cost Curve

Organic soils: global overview

- **Restoring organic soils represents a very large abatement opportunity globally, at low cost**
  - 1.14 Gt of CO_2e abatement in 2030
  - 3% of total abatement, one of top ten levers
  - Cost of €4.5 / t CO_2e
- **Broad range of scientific estimates of potential CO2e absorption per hectare**
  - Intergovernmental Panel on Climate Change provides a wide range of estimates for absorption potential in cool climates (mean = 33.5 t / ha / yr)
  - Reviewed by leading climate change experts
- **Uncertainty due to unpredictable impact of various environmental factors**
  - Temperature, soil chemistry, underlying geology
  - Extent and age of damage / draining
  - Difficulty in reflooding in a uniform fashion
- **Abatement gains are due to once-off carbon sinks that can take decades to reach saturation**
  - Uncertain how inventories account for this

IPCC estimates of CO_2e absorption by restored organic soils in cool climates
t CO_2 / ha / yr



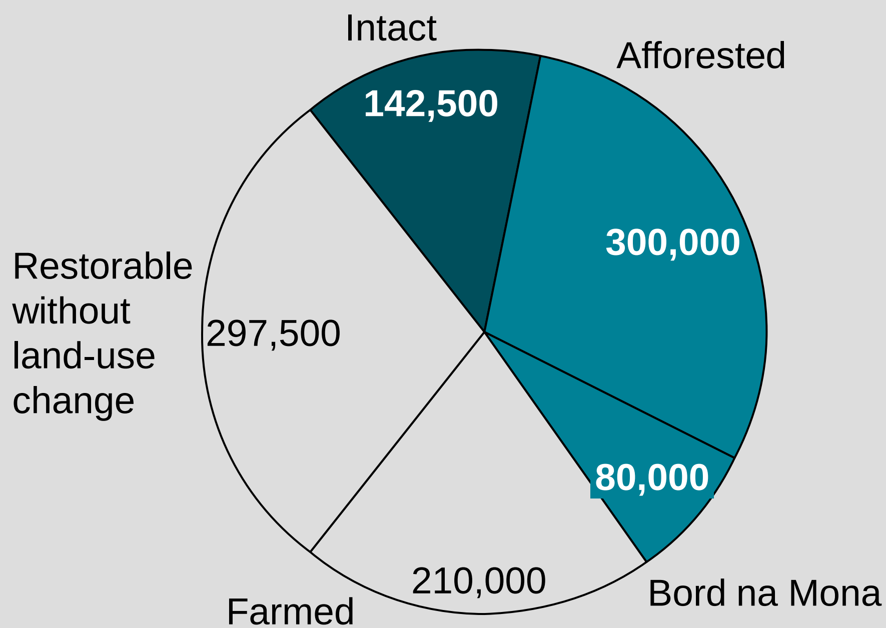
Estimate for Irish cost curve*: 2.0 t CO_2e / ha / yr

* Estimate by the Department of Agriculture, Fisheries and Food. Figure is consistent with Freibauer *et al* (2004) as quoted in IPCC AR4.

Organic soils: Irish overview

- **A unique feature of the Irish landscape**
  - Peatland = 14% of total land area, ~1m ha, almost all has been impacted
  - Lower cost than elsewhere because less bog has been converted to cropland
- **Using a conservative sequestration estimate (2 t / ha / yr) subject to ongoing developments in Irish research**
  - Some scientific opinion suggests that negative potential remains a short- or medium-term possibility due to CH_4 emitted by microbes in peat
- **Costs attributable to equipment and labour**
  - Blocking drainage ditches, raising water table, seeding native flora
  - Monitoring fluxes of CO_2 and CH_4
  - Restoring peat from grassland includes cost of 100-year use of the land
- **Current research should provide more specific numbers by early 2010**
  - Bogland project, UCD
  - Coillte, Bord na Mona

Distribution of organic soils in Ireland
Hectares



- Analysis includes restoring bog that has been converted to pasture and grassland
  - Forecast declines in grazing animal numbers will facilitate this process
  - Cost calculations provide for land acquisition that may be necessary

Contents

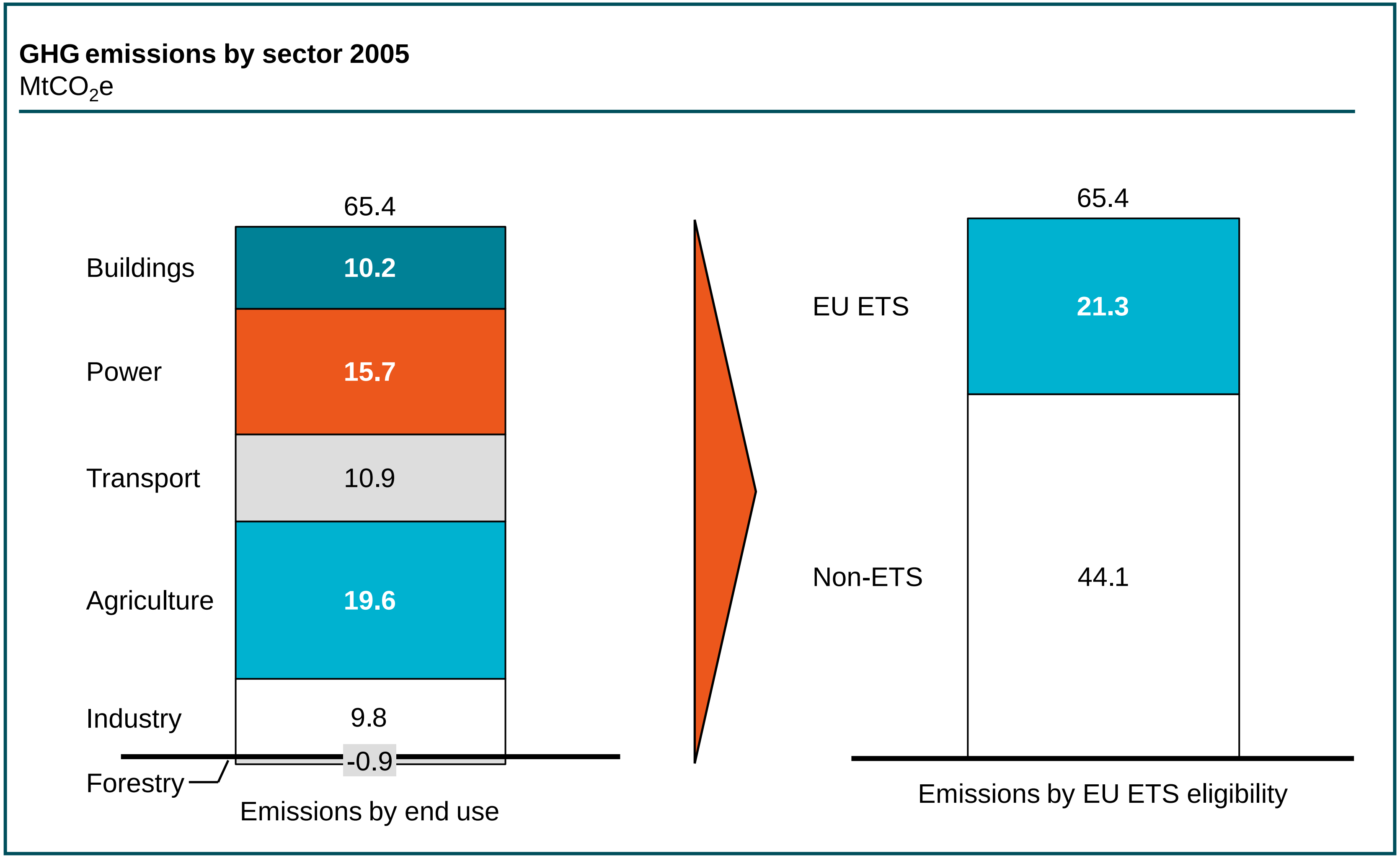
Scenarios covered

- **A** ETS/non-ETS split
- **B** Oil price sensitivity
- **C** Investor cost sensitivity
- **D** Behavioural lever estimation

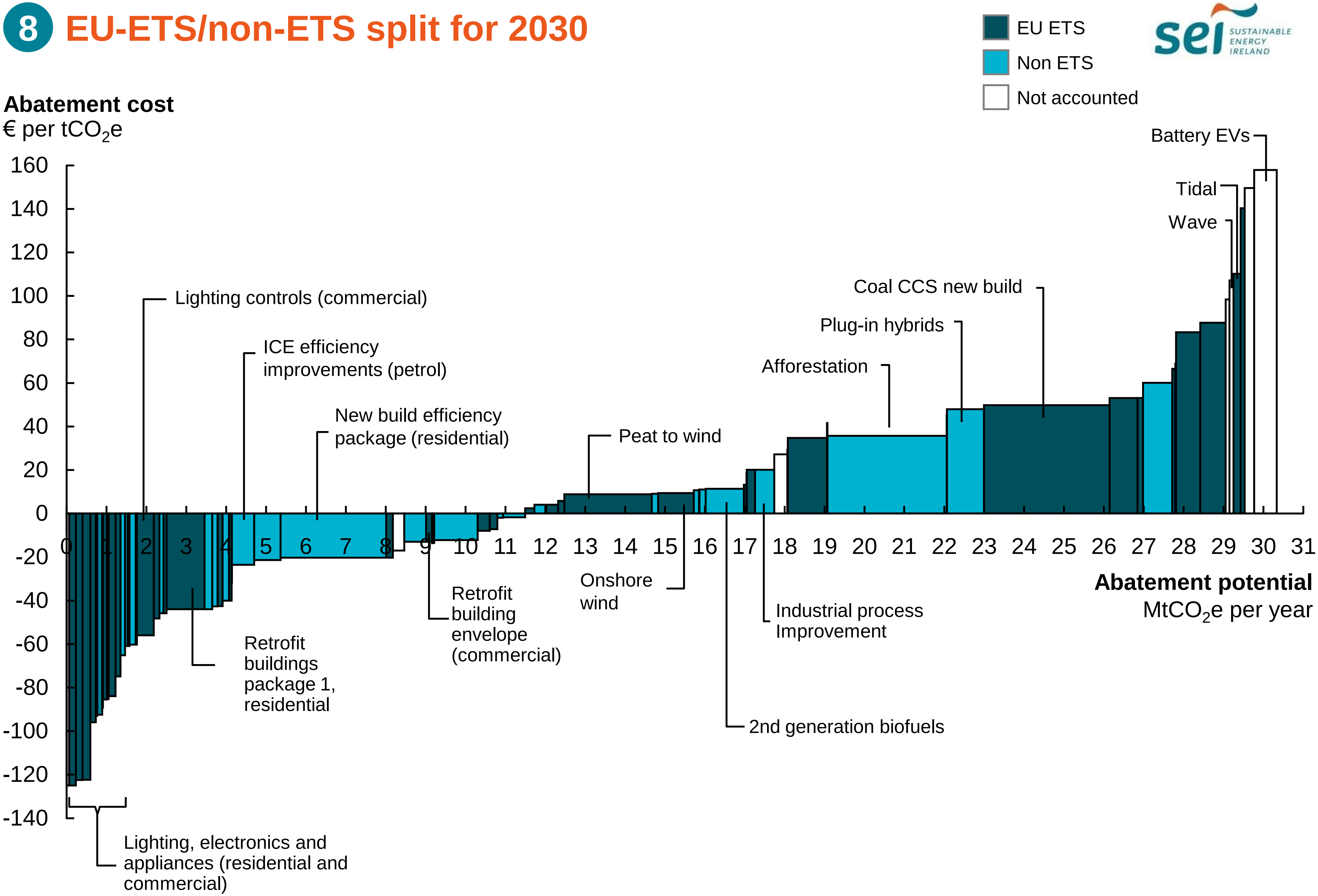
- Nuclear scenario (covered in power sector)

SOURCE: EPA UNFCCC 2005 GHG inventory; Ireland GHG Abatement Cost Curve; SEI Energy in Industry

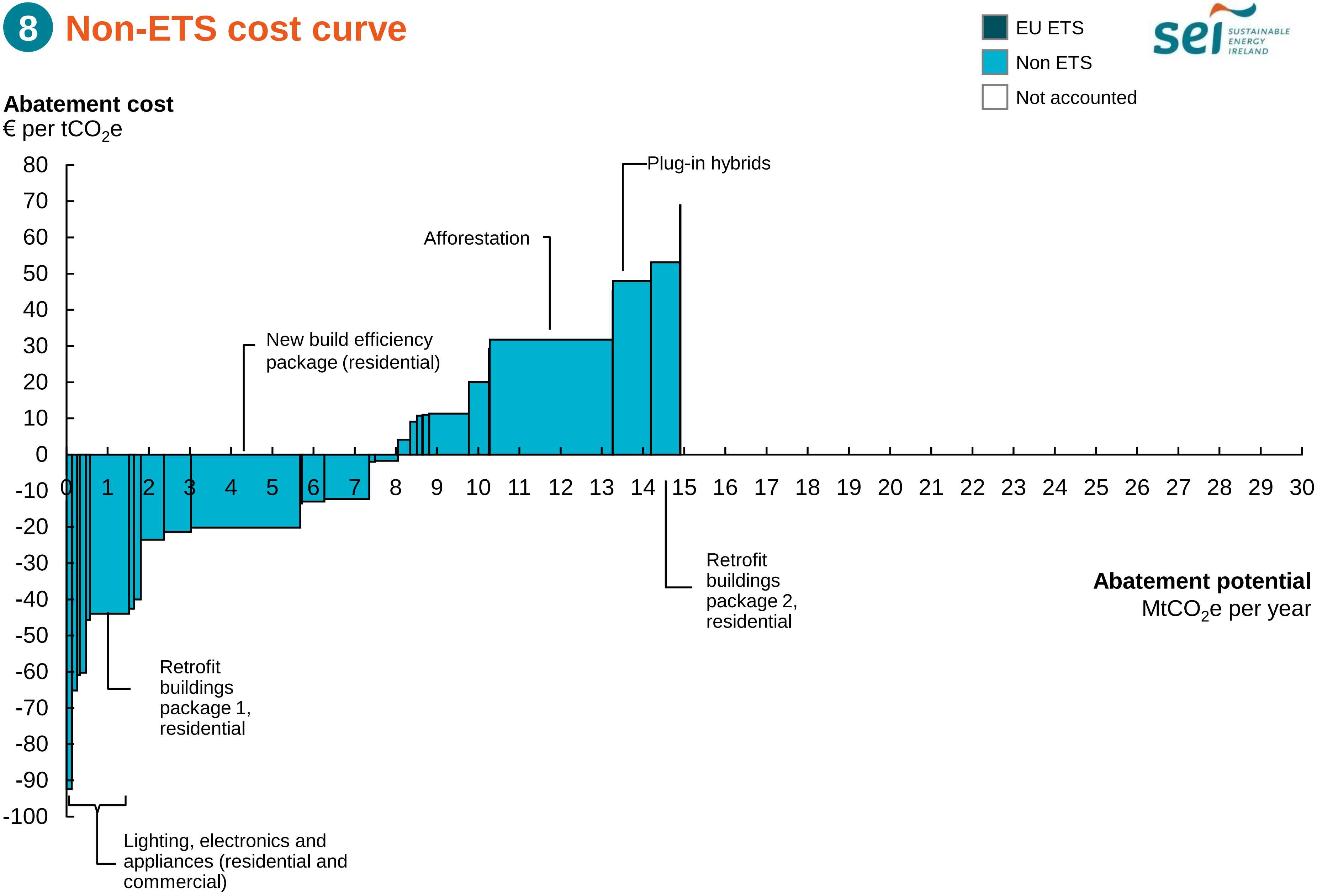
The EU-ETS sector contributes 33% of emissions



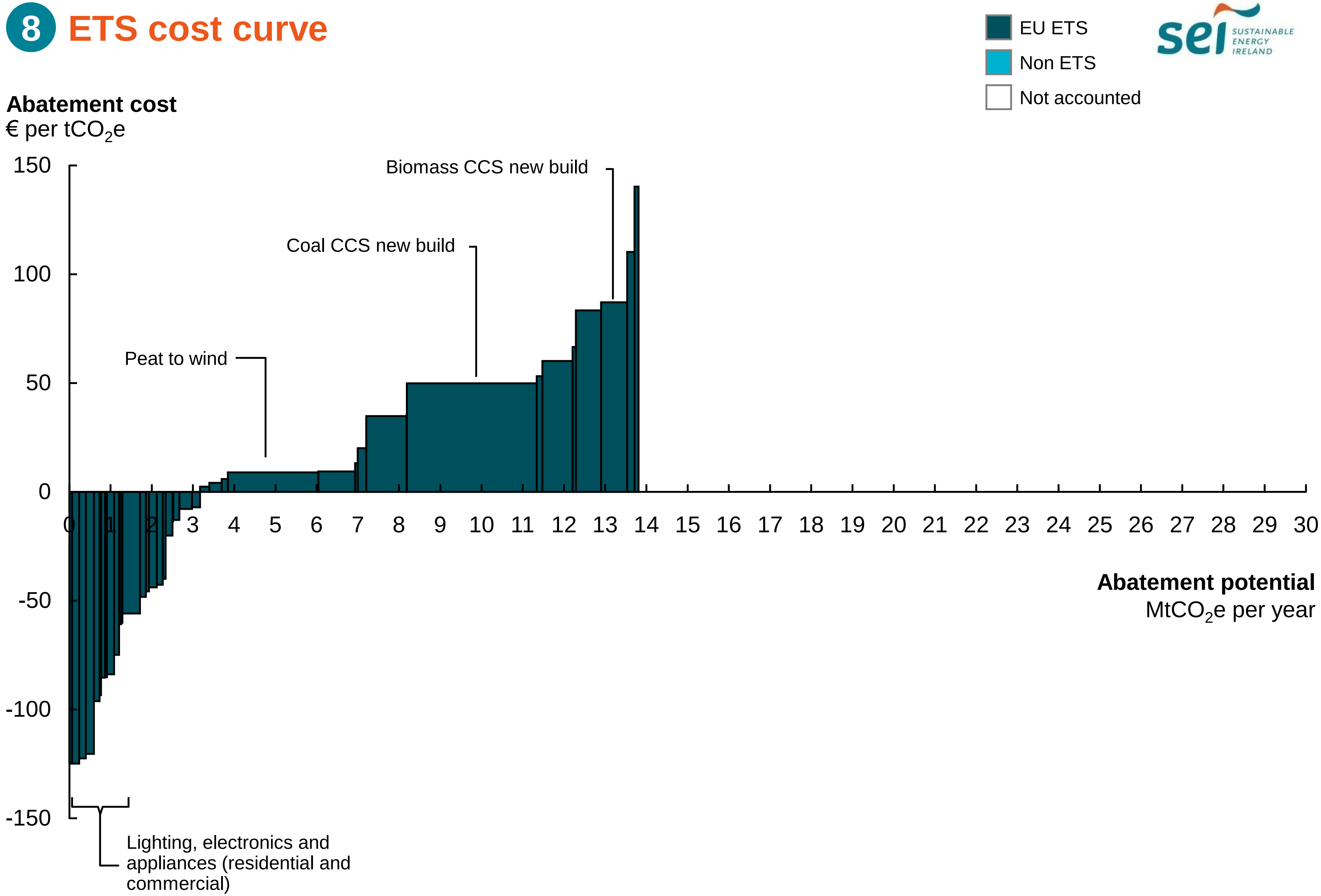
8 EU-ETS/non-ETS split for 2030



8 Non-ETS cost curve

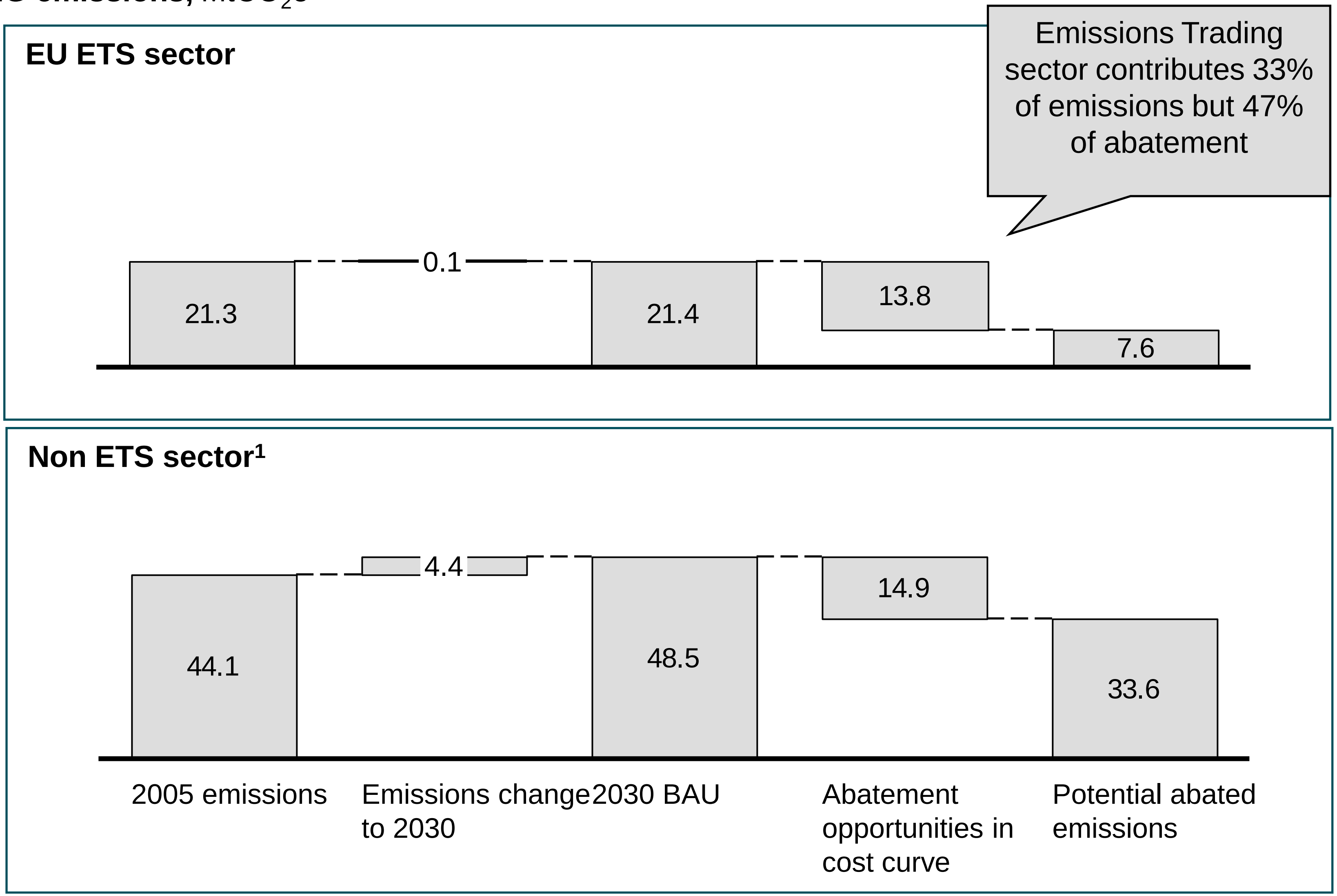


8 ETS cost curve



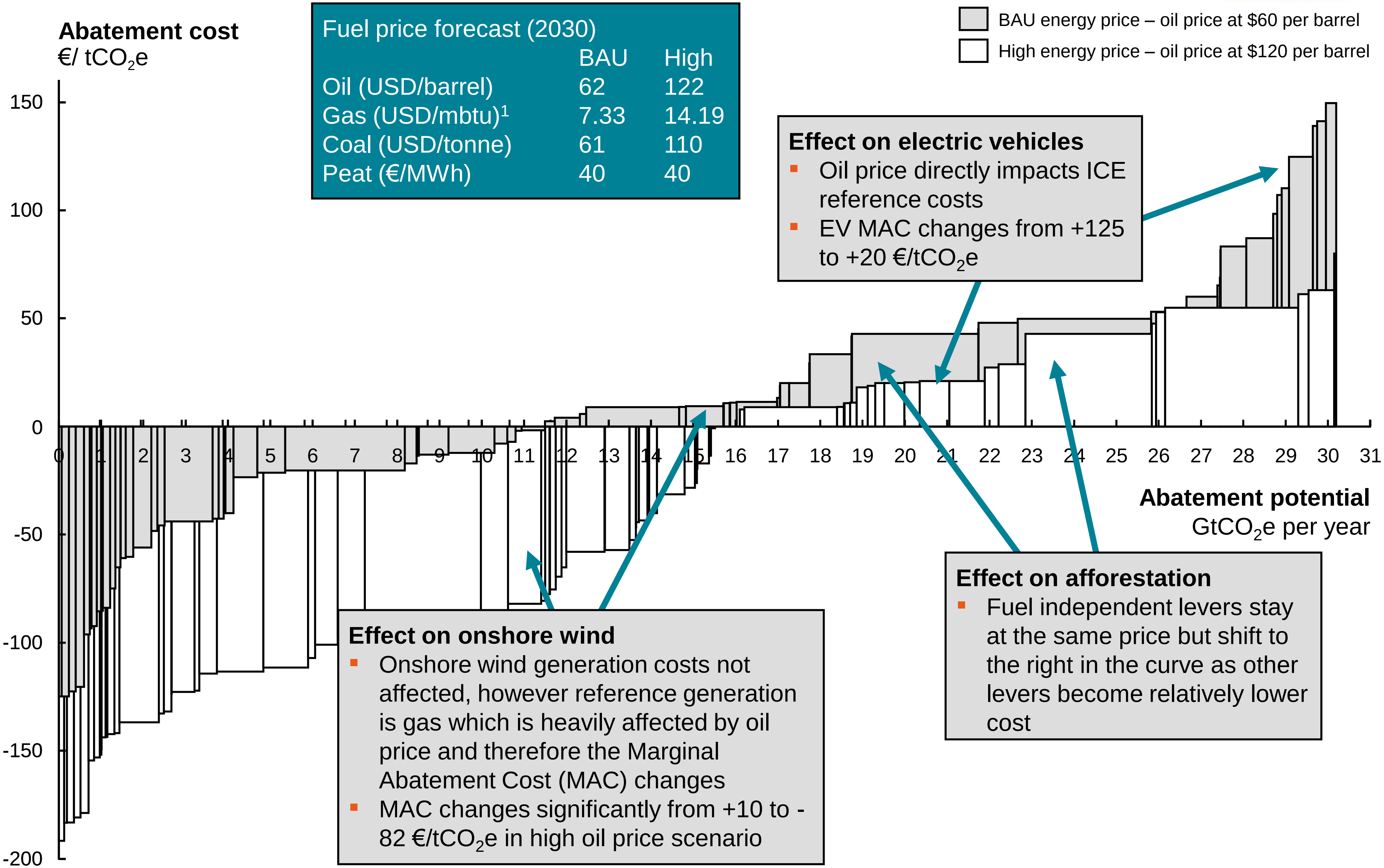
A Overview of EU-ETS/non-ETS sectors

GHG emissions, $MtCO_2e$



1 Does not include 'not-accounted' for levers

B Effect of high energy prices (oil price at $120 a barrel)



Fuel price forecast (2030)

	BAU	High
Oil (USD/barrel)	62	122
Gas (USD/mbtu)[1]	7.33	14.19
Coal (USD/tonne)	61	110
Peat (€/MWh)	40	40

Effect on electric vehicles
- Oil price directly impacts ICE reference costs
- EV MAC changes from +125 to +20 €/tCO_2e

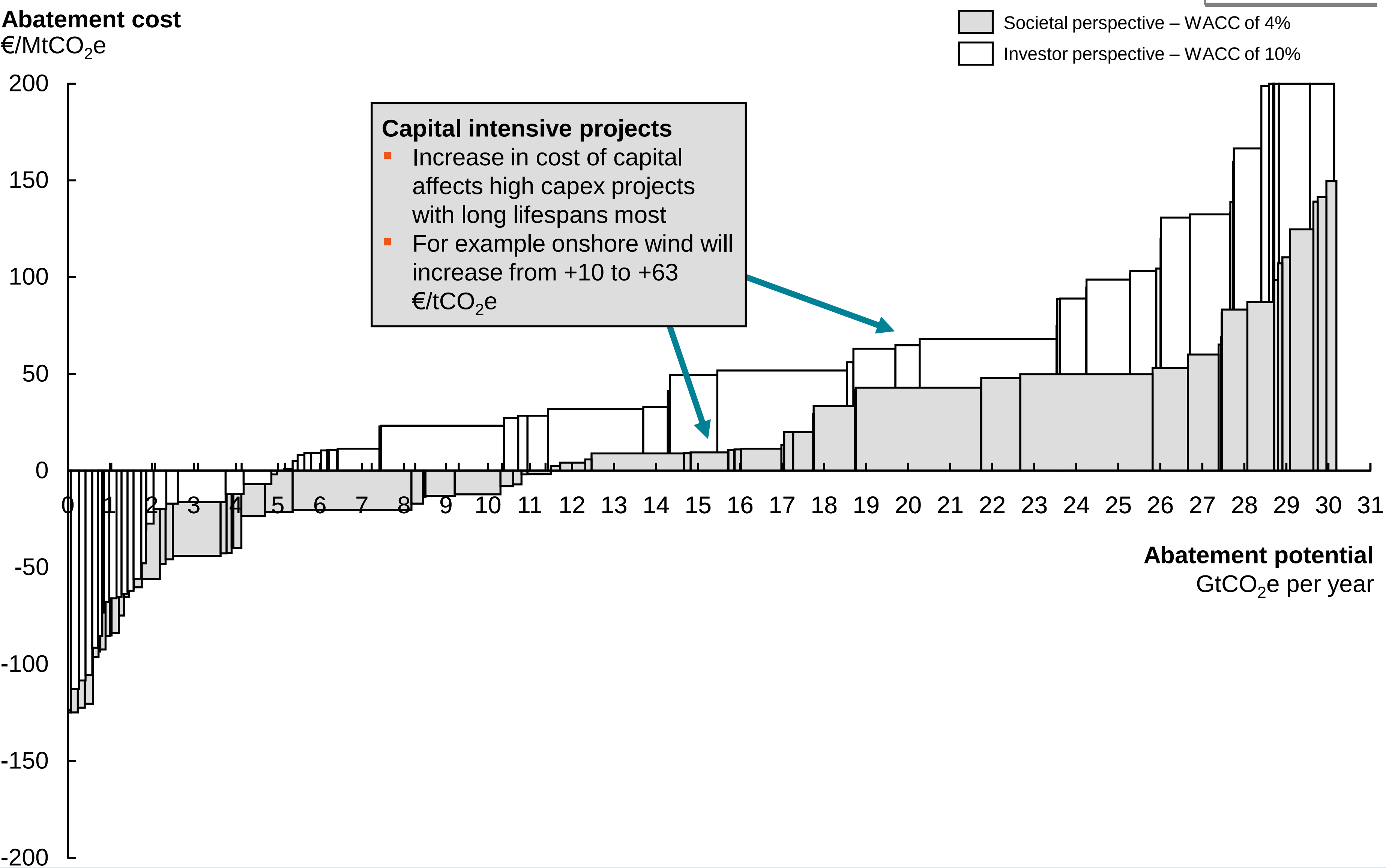
Effect on onshore wind
- Onshore wind generation costs not affected, however reference generation is gas which is heavily affected by oil price and therefore the Marginal Abatement Cost (MAC) changes
- MAC changes significantly from +10 to -82 €/tCO_2e in high oil price scenario

Effect on afforestation
- Fuel independent levers stay at the same price but shift to the right in the curve as other levers become relatively lower cost

1 Includes gas transport costs from UK to Ireland

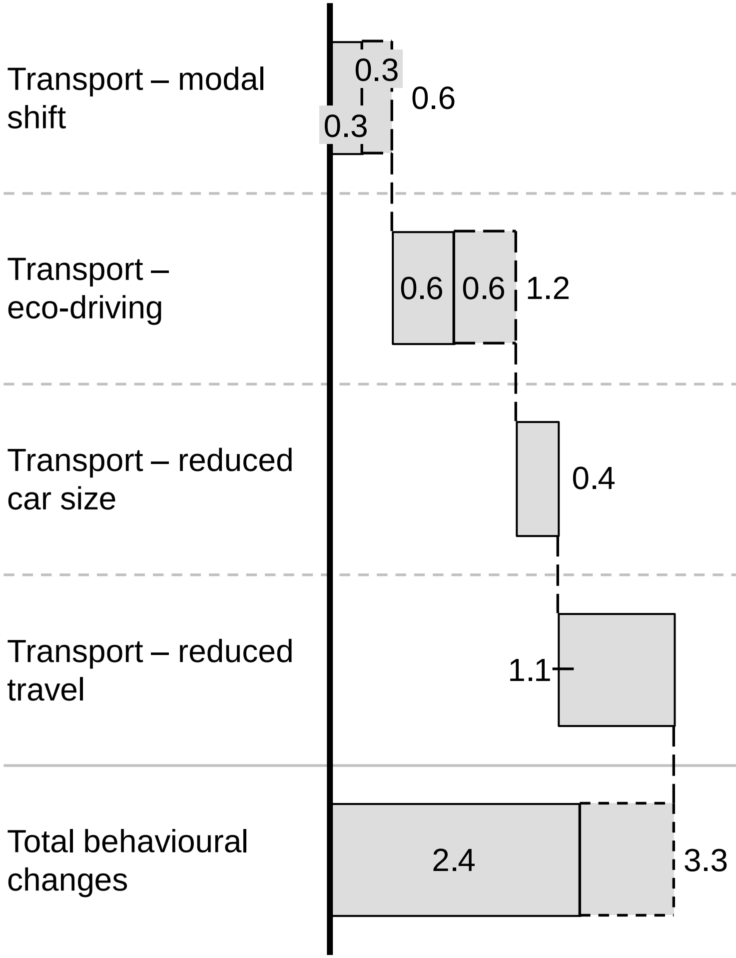
Ⓒ Effect of investor decision perspective on cost curve

ILLUSTRATIVE



D Examples of potential behavioural changes beyond technical abatement measures (1/2)

$MtCO_2e$ per year; 2030



Calculation assumptions[1]

Transport – modal shift:
- 5-10% shift to public transport, cycling or walking
- Applied only to private vehicles

Transport – eco-driving:
- 5-10% reduction in fuel consumption through improved driving (e.g., change gears at lower revs, smooth acceleration and braking, decrease use of air conditioning, reduce idling, maintaining proper tyre pressure)

Transport – reduced car size:
- 50% of vehicles bought at one class smaller than currently leading to average savings of ~10gCO_2e/km
- Applied only to private vehicles

Transport – reduced travel:
- 10% road transport use reduction
- Also applied to commercial vehicles through improved route planning and more efficient use of vehicle capacity

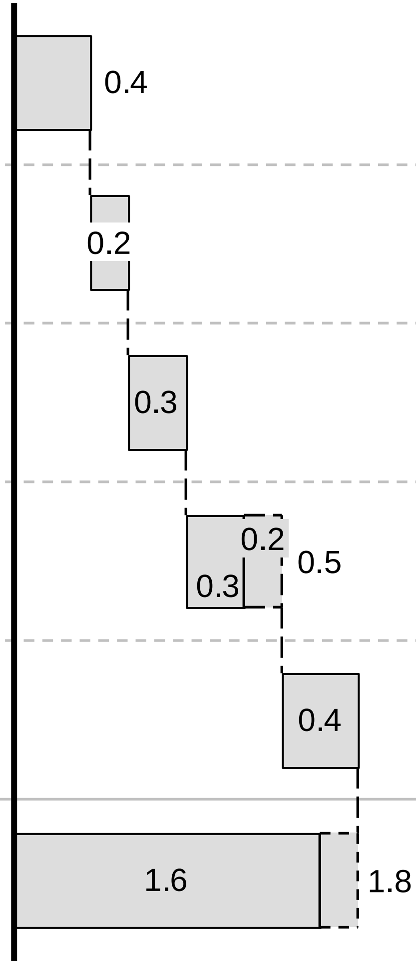
2.4 – 3.3 $MtCO_2e$ of abatement may be achievable from the transport and agriculture sectors

1 Behavioural effects accounted for after implementation of all other levers
2

SOURCE: Ireland GHG Abatement Cost Curve, Global GHG Abatement Cost Curve v2.0

Examples of potential behavioural changes beyond technical abatement measures (2/2)

$MtCO_2e$ per year; 2030



	Calculation assumptions[1]
Buildings – reduced room temp (-2C)	-2°C change in HVAC equivalent to ~12% reduction in energy use
Buildings – reduced electricity use	20% reduction in lighting, appliances, water heating and electronics
Buildings – reduced floor space of new builds	20% decrease in average size of new builds
Buildings – alternate building materials	Replacement of 10-20% of cement use in buildings with alternate materials
Spill-over effects to industry sector	Cement: -15% (from floor space reduction in buildings)
Total behaviourial changes	

Buildings behavioural levers could lead to a reduction of 1.6-1.8 $MtCO_2e$ for a total of 3.0 – 4.1 $MtCO_2e$ across the selected behavioural levers

1 Behavioural effects accounted for after implementation of all other levers

SOURCE: Ireland GHG Abatement Cost Curve, Global GHG Abatement Cost Curve v2.0

Contents

How is a marginal abatement cost curve built?

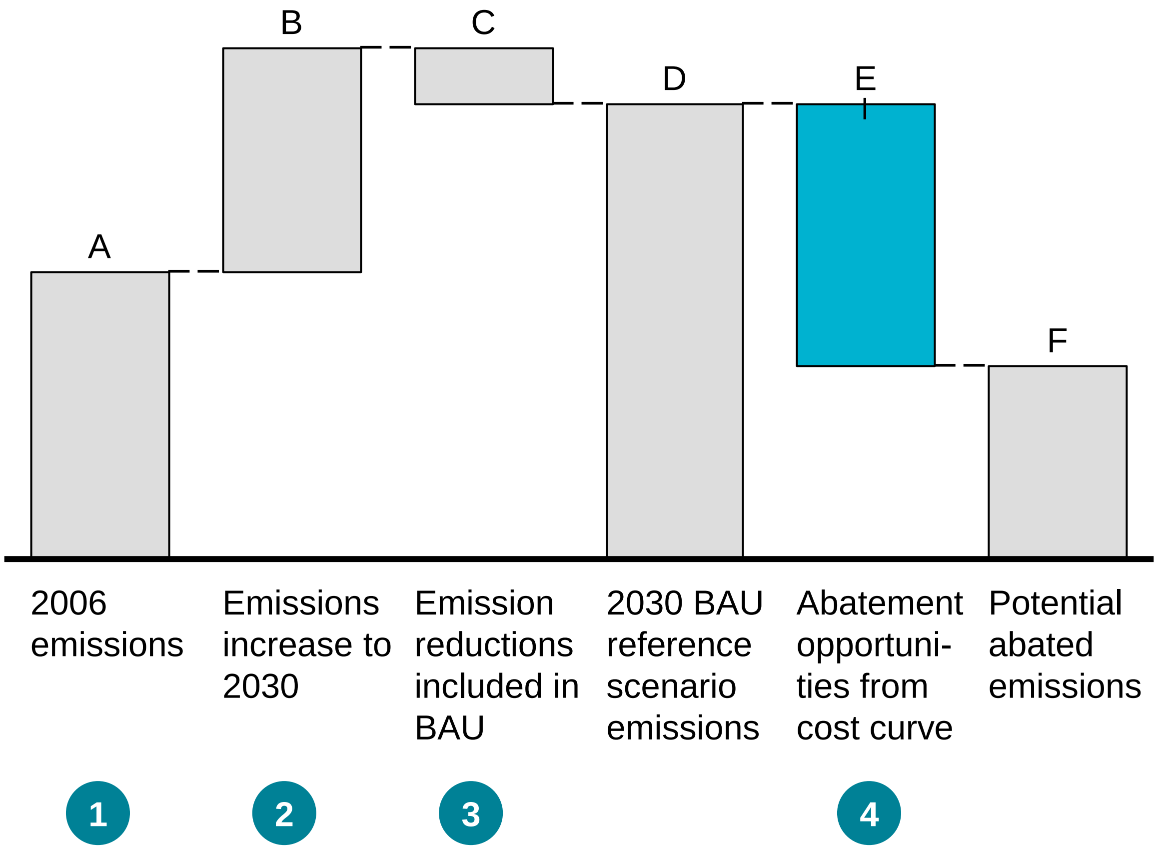
FOR DISCUSSION

Detailed on next page

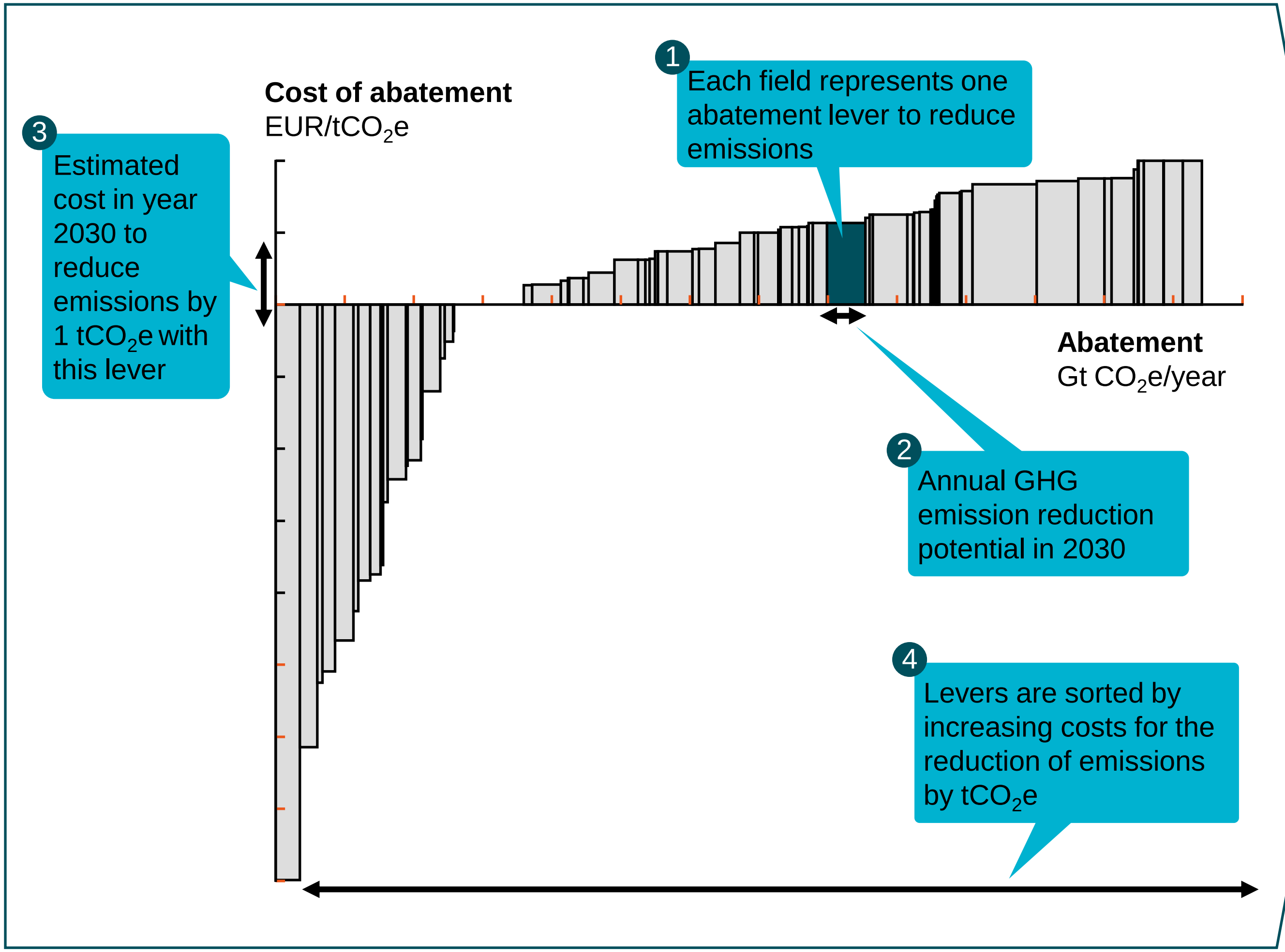
BAU reference scenario methodology

1. Allocate Ireland 2006 emission inventory to sectors
2. Determine emissions increase due to key sector drivers to calculate emissions projections to 2030
3. Determine emission reductions included in the BAU such as on-going trends (e.g. efficiency improvements) and specific proposals with high likelihood of success (e.g. specific legislation not including general targets)
4. Evaluate additional abatement potential and costs relative to BAU reference scenario

BAU reference scenario emissions
Mt CO_2e



How do you read a marginal abatement cost curve?



- The cost curve displays abatement potential, and corresponding cost, for each abatement lever relative to a "BAU reference scenario"
- The merit order is applied based on the cheapest measures in 2030 in EUR/tCO_2e

How are the costs calculated?

$$\text{Marginal abatement cost} = \frac{[\text{Full cost of } CO_2e \text{ efficient alternative}] - [\text{Full cost of reference solution}]}{[CO_2e \text{ emissions from reference solution}] - [CO_2e \text{ emissions from alternative}]}$$

Full cost **includes…**

- Operating costs, incl. personnel/materials costs
- Investment costs calculated with economic amortization period and capital costs (like a repayment of a loan)
- Possible cost savings generated by the actions (e.g., energy savings)

Full cost **does not include…**

- Transaction costs
- Communication/information costs
- Subsidies or explicit CO_2 costs
- Taxes
- Consequential impact on the economy (e.g., advantages from technology leadership)

Other assumptions

- Abatement cost for new technologies are consistently compared to the specific cost and emission intensity of displaced alternatives
- Full costs could be negative, i.e., indicating a net benefit deriving from the use of the alternative
- Technology is phased in on a new and replacement basis

SOURCE: Ireland GHG abatement cost curve

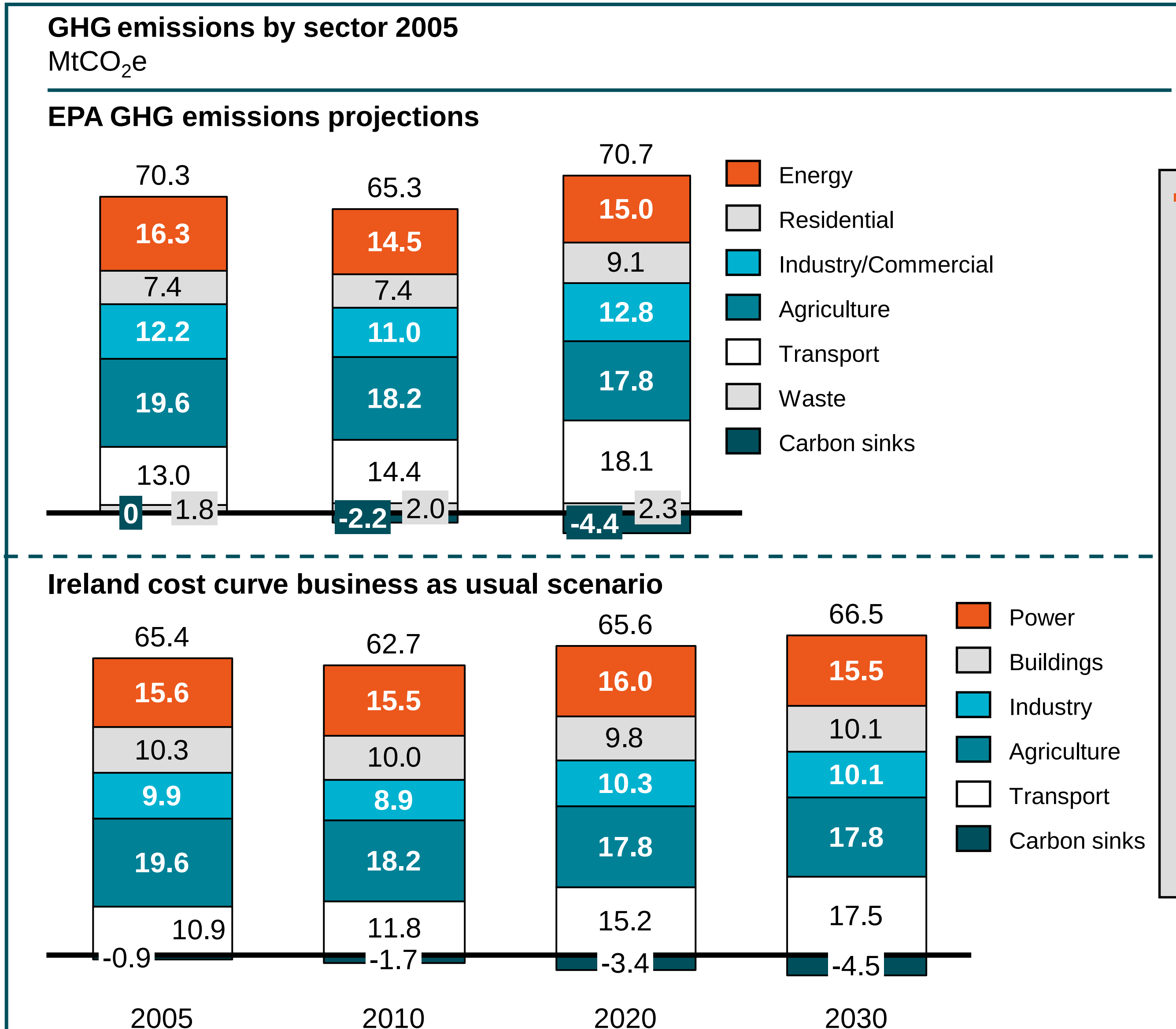
Review of key points on the abatement cost curve

Cost curve methodology	Description
Point in time perspective	▪ The cost curve is defined for a given year ▪ Gives a picture of technical abatement potential in that year related to the reference (Business As Usual) scenario ▪ The potential abatement is dependent on actions taken between 2010 and the given year ▪ The Ireland cost curve will use 2020 and 2030 as output years
Societal perspective	▪ Cost curve is based on a “societal” or “cost to economy” perspective rather than a “decision maker” perspective ▪ Cost of capital used is in line with financing of public projects (4% real)[1]
Abatement cost	▪ Cost of reducing one tonne of CO_2e relative to the reference BAU scenario ▪ Is levelised cost including investment and opex and subtracting savings (e.g. from reduced energy consumption) ▪ Does not include transaction costs, taxes, subsidies, communication/information costs or broader economic benefits (e.g. technological leadership)
Technical potential	▪ Cost curve assesses economic potential of technical measures under 60 €/tonne ▪ Technologies that are currently available or under development are included ▪ Behavioural abatement opportunities are not included

1 Base case modelling with effect of decision-maker cost of capital discussed afterwards

SOURCE: Ireland GHG abatement cost curve

Comparing the EPA emissions projections and the cost curve



- Ireland cost curve covers a subset of the EPA emissions with key differences being:
  - Waste not included in cost curve
  - Cost curve energy sector includes only power generation
  - In cost curve, industry sector covers other energy industries and industry portion of Industry/commercial numbers
  - Cost curve buildings sector includes residential and commercial buildings
  - Cost curve transport sector covers only road transport

SOURCE: EPA UNFCCC 2005 GHG inventory; Ireland GHG Abatement Cost Curve

Glossary

2nd generation biofuels – low-carbon fossil-fuel replacements, made from non-food sources such as switchgrass (e.g. not maize)
CAGR – compound annual growth rate
CCS – carbon capture and storage
CO2e – carbon dioxide equivalent
Direct emissions – CO2e emitted 'on site,' e.g. by burning fuel or processing raw materials in a residential/commercial building or industrial site
Envelope packages 1 and 2 – bundles of home insulation products
ETS – (European Union) emissions trading scheme
EVs – electric vehicles
Gasoline bundles 1-3 – ranges of efficiency improvements for traditional petrol-based engines
GDP – gross domestic product
GHG – greenhouse gas
Gt – gigatonne (1 billion tonnes)
GWh – gigawatt-hour (1,000,000 kWh)
GWP – global warming potential. Conversion factors for CO2, CH4 and N2O are 1, 21 and 310, respectively
HDV – heavy-duty vehicle
HESS – SEI's Home Energy Saving Scheme
HVAC – heating, ventilating and air-conditioning
ICE – internal combustion engine
Indirect emissions – CO2e emitted as a result of electricity consumption
kWh – kilowatt-hour
LDV – light-duty vehicle
Load factors – percentage usage for power stations
LULUCF – land-use, land-use change, and forestry. A UNFCCC emissions category
MAC – marginal abatement cost
MDV – medium-duty vehicle
Mt – megatonne (1 million tonnes)
MWh – megawatt-hour (1,000 kWh)
N2O – nitrous oxide. GWP = 310
T5-T12 lighting – range of fluorescent light bulbs
TWh – terawatt-hour (1,000,000,000 kWh)
UNFCCC – United Nations
WACC – weighted average cost of capital

Contents

Methodology for calculating potential

Required N+R generation

- Occur due to plant retirements or increased demand
- N+R generation is calculated from equation below:

Total required N+R generation (TWh)	=	Increase in BAU generation demand relative to previous period (TWh)	+	Demand change from other sector models (TWh)	+	Total plant retirements forecast for period (TWh)

- A specific selection order is used to decide what levers are used to fill required N+R generation
- Each lever is limited by a maximum available volume potential (MWh)
- As there is excess onshore wind potential then newer technologies are prioritised in the selection order (to ensure the curve is not filled with only onshore wind)
- Selection order
  - 1. Wave (available for 2030)
  - 2. Tidal (available for 2020)
  - 3. Offshore wind
  - 4. Onshore wind
- If required N+R generation cannot be filled by abatement levers, it is assumed that the plant type operating at marginal cost (gas) fills this demand

Specific generation alternatives

- Peat co-firing of biomass occurs at all three of Ireland's peat plants from 2015–25
- Peat plants are retired in 2025 and replaced by onshore wind
- Coal CCS built at the Moneypoint site to replace the retiring plant
- Nuclear scenario – built at the Moneypoint site to replace the retiring plant instead of a coal CCS plant

Power calculation methodology

Overall

- Reference generation is based on the plant/fuel being replaced relative to the BAU reference scenario
- Abatement potential based on new and replacement (N+R) of retiring plants
- Demand reduction affects projected imported generation before reducing gas generation
- Two types of abatement opportunity: excess demand and specific scenarios

Volume

$$\textbf{Potential abatement volume } (tCO_2e) = \textbf{Power generation volume } (MWh) \times \left(\textbf{Ref } \mathbf{CO_2} \textbf{ intensity } (Mt\ CO_2e/MWh) - \textbf{Lever } \mathbf{CO_2} \textbf{ intensity } (Mt\ CO_2e/MWh) \right)$$

Cost

$$\textbf{Abatement cost } (€/tCO_2e) = \frac{\textbf{Cost of abatement generation } (€/MWh) - \textbf{Cost of reference generation } (€/MWh)}{\textbf{Reference generation emission intensity } (tCO_2e/MWh) - \textbf{Abatement generation emission intensity } (tCO_2e/MWh)}$$

Power reference generation assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Combined cycle gas turbine (CCGT)	**Overall**				
	▪ Reference case will be new build CCGT gas plant				Validated with industry expert
	▪ Grid can accommodate less flexible generation				Validated with industry expert
	▪ BAU assumes new build plants projected for completion are Whitegate, Aghada, Quinn and another 400MW plant				ESRI – Baseline Scenario
	Volume				
	▪ CO_2 intensity, tonne/MWh	0.39	0.38	0.37	NERA: Market Simulation Data and Model Validation, P. 36 ($MtCO_2e$/GJ) / efficiency
	▪ Load factor, %	65	65	65	CER, Impact of High Levels of Wind Penetration in 2020 on the SEM, P.29
	▪ Efficiency (HHV), %	52	53	54	IEA WEO 2008 – converted to HHV efficiency
	Cost				
	▪ Capital costs, €/MW	677	677	677	Best New Entrant 2006
	▪ Fuel costs – reference scenario, €/MWh	32.2	37.2	38.2	IEA WEO 2007/2008 + additional transport costs (€0.9/MWh) divided by efficiency
	▪ Fuel costs – high oil price scenario, €/MWh	n/a	66.0	71.8	
	▪ Operations and Maintenance				UK Department of Trade and Industry, 'The Energy Challenge', P.194/95
	– Variable, EUR/MWh	3	3	3	
	– Fixed, EUR/MW	10,200	10,200	10,200	
	▪ Economic lifespan, years	25	25	25	Expert interviews

Power reference generation assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Open cycle gas turbine (OCGT)	**Overall** ▪ Used in the calculation of additional capacity costs for renewable technologies – Onshore wind – Offshore wind – Wave ▪ Additonal 200MW installed as part of BAU				ESRI – Baseline Scenario
	Volume				
	▪ CO_2 intensity, tonne/MWh	0.58	0.58	0.58	All-Island Grid Study Workstream 2A, P.13
	▪ Load factor, %	10	10	10	Assumption based on industry interviews
	▪ Efficiency (HHV), %	31	31	31	All-Island Grid Study Workstream 2A, P.13 converted to HHV efficiency
	Cost				
	▪ Capital costs, €/MW	400	400	400	All-Island Grid Study Workstream 2A, 13
	▪ Fuel costs, €/MWh	54.1	63.1	67.2	IEA WEO 2007 UK + additional transport costs (€0.9/MWh) divided by efficiency
	▪ Operations and Maintenance – Variable, EUR/MWh – Fixed, EUR/MW	 2 8,000	 2 8,000	 2 8,000	Assumptions based on expert interviews
	▪ Economic lifespan, years	25	25	25	Expert interviews

Power reference generation assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Coal plant	**Overall** ▪ Used as the reference scenario for coal CCS and nuclear				
	Volume				
	▪ CO_2 intensity, tonne/MWh	0.86	0.77	0.72	NERA: Market Simulation Data and Model Validation, P. 36 ($MtCO_2e$/GJ) / efficiency
	▪ Load factor, %	85	80	70	Assumption based on high wind penetration by 2030
	▪ Efficiency, %	40	45	48	Expert interviews
	Cost ▪ Capital costs, m €/MW	1.981	1.981	1.981	All-Island Grid Study Workstream 2A, P.13
	▪ Fuel costs – reference scenario, €/MWh	17.1	13.3	13.1	IEA WEO 2007
	▪ Fuel costs – high oil price scenario, €/MWh	n/a	26.6	23.5	IEA WEO 2008
	▪ Operations and Maintenance – Variable, EUR/MWh – Fixed, EUR/MW	 2 35,000	 2 35,000	 2 35,000	Assumptions based on expert interviews All-Island Grid study Workstream 2A, P.13
	▪ Economic lifespan, years	30	30	30	All-Island Grid study Workstream 2A, P.13

Power reference generation assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Peat plant	**Overall** ▪ Used as the reference scenario for 'peat to wind' lever and co-firing with biomass				
	Volume				
	▪ CO_2 intensity, tonne/MWh	1.06	1.06	1.06	NERA: Market Simulation Data and Model Validation, P. 36 ($MtCO_2e/GJ$) / efficiency
	▪ Load factor (%)	84	84	84	All-Island Grid Study Workstream 2A, P.13
	▪ Efficiency (%)	36	36	36	National Energy Forecasts
	Cost ▪ Capital costs, m (€/MW)	1.69	1.69	1.69	All-Island Grid Study Workstream 2A, P.13
	▪ Fuel costs (€/MWh)	40	40	40	Industry expert interviews
	▪ Operations and Maintenance – Variable (EUR/MWh) – Fixed (EUR/MW)	 2 55,000	 2 55,000	 2 55,000	 Industry expert interviews All-Island Grid study Workstream 2A, P.13
	▪ Economic lifespan (years)	30	30	30	All-Island Grid study Workstream 2A, P.13

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Coal co-firing biomass	**Overall** ▪ Assumed that 115MW of biomass could be co-fired at Moneypoint ▪ Assumes that this would occur in 2025 when a new plant with CCS is built				SEI – 'Co-firing with biomass'
	Volume				
	Emissions intensity, t CO_2e/MWh	0	0	0	
	Maximum volume, MW	N/A	115	115	SEI – 'Co-firing with biomass, P.43
	Load factor, %	N/A	70	70	Assumption – based on high wind penetration by 2025
	Cost				
	Fuel costs, €/MWh	N/A	65	62	Interview with industry player and industry expert price projection
	Operations and maintenance, €/MWh	N/A	2	2	Interview with industry player
	Capital expenditure, €/MW	N/A	125,470	125,470	UK Department of Trade and Industry, 'The Energy Challenge', P.194/95 - £100,000 £/MW converted to EUR

Power abatement lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Onshore wind	**Overall**				
	▪ No wind generation is spilt and load factors do not decrease with additional capacity due to technology improvements				Validated with industry players
	▪ Two tiers of wind are included (0, <3GW, 3GW+) to account for higher capacity costs				Assumption
	Volume				
	Emissions intensity, tCO_2e/MWh	0	0	0	
	New build maximum limit, MW/year	400	400	400	Assumption based on Eirgrid previous capacity projections – Generation Adequacy Report 2009–15
	Low penetration load factor, %	32	32	32	CER 'Impact of High Levels of Wind Penetration in 2020 on the SEM', P.29
	High Penetration load factor, %	28	28	28	Expert interviews
	Cost				
	Capital costs in €/MW	1.3	1.22	1.11	All-Island Grid Study P.16 current cost (2005) + capex reduction rate from expert interviews
	Operations and Maintenance, €/MW	51,900	36,700	29,100	All-Island Grid Study Workstream 1, P.38, + reduction rate from expert interviews
	Economic lifespan, year	20	20	20	All-Island Grid Study Workstream 2A, P.16
	Incremental capcacity costs due to high wind penetration[1], €/MWh				
	▪ Tier 1: 0–4,000MW	13	13	13	Capacity costs calculated by estimating the cost of providing an equivalent non-running gas plant (average of CCGT and OCGT) for the difference in capacity credit between a conventional plant and windfarm.
	▪ Tier 2: 4,000MW +	15.4	15.4	15.4	Tier 1: Capacity credit used – 3,000MW Tier 2: Capacity credit used – 5,000MW All-Island Grid Study 2A, P.21

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Offshore wind energy	**Overall** ▪ Assumed that Arklow bank project is completed by 2020 ▪ Assumed that another 500MW windfarm is built by 2030 ▪ Relatively low penetration is assumed due to continued attractiveness of onshore wind				Interviews with industry players suggest that 500MW is the minimum size to ensure that a windfarm is profitable
	Volume Emissions intensity, t CO_2e/MWh	0	0	0	
	Maximum volume, MW	30	500	1000	Assumption based on expert interviews
	Load factor	40%	40%	40%	Expert interviews
	Cost Economic lifetime	20	20	20	All-Island Grid study, Workstream 2A, P.13
	Capital costs, m €/MW	2.5	1.96	1.88	Current price estimate + capex reduction rate applied from expert interviews
	Operations and maintenance, (000's), €/MW	104	75.4	64.8	All-Island Grid Study + Workstream 1, P.38 Note: € 104,000/MW / (load factor x hours) + projected cost decreases from expert interviews
	Incremental capacity costs due to high level penetration, €/MW ▪ 0–4,000 MW ▪ 4000 + MW	15 17.2	15.1 17.2	15.4 17.2	See onshore wind lever

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Peat co-firing biomass	**Overall** ▪ All of Ireland's peat plants can co-fire with up to 30% biomass ▪ Assumes that all 3 peat plants convert to co-firing by 2015 and plants are closed in 2025				SEI – 'Co-firing with biomass'
	Volume				
	Emissions intensity, t CO_2e/MWh	0	0	0	
	Maximum volume, MW	N/A	105	0	30% of total peat capacity (351MW) – Powerplatts 2009
	Load factor, %	N/A	84	0	All-Island Grid Study 2A, P.13
	Cost				
	Fuel costs, €/MWh	N/A	65	0	Interview with industry player and industry expert price projection
	Operations and maintenance, €/MWh	N/A	2	0	Interview with industry player
	Capital expenditure, €/MW	N/A	17,241	0	Assumption based on interview with industry player

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Tidal energy	**Overall** ▪ A total volume of 113 MW of accessible tidal energy exists for Ireland ▪ Technological challenges not as great as wave ▪ A pilot study of 35 MW completed in 2020 ▪ Assumed that all 113 MW implemented by 2030				All-Island Grid study, Workstream 1, P.234
	Volume Emissions intensity, t CO_2e/MWh	0	0	0	
	Installed capacity, MW	0	35	113	All-Island Grid Study – Workstream 1, P.234 Assumed all ROI projects implemented by 2030
	Load factor	N/A	27%	27%	JHR Hampson C. Eng Call for evidence to House of Lords 2008 – Select Committee on Economic Affairs
	Cost Total generation cost, €/MWh	N/A	102.9[1]	102.9	All-Island Grid study – Workstream 1, P.234 Table A92 Note: Average cost (€/MWh) calculated for all ROI projects at a cost of capital of 8%, number recalculated to have a cost of capital at 4%
	Operations and maintenance, €/MWh	N/A	15.8	15.8	Economic viability of a simple tidal stream energy capture device DTI Project No: TP/3/ERG/6/1/15527/REP
	Capital expenditure, €/MWh	N/A	87.1	87.1	Estimate – total minus O&M

1 Total average cost is assumed across all installations. Installations built initially will have higher capital and operations costs

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Wave energy	**Overall** ▪ Assumed that only one large wave installation is completed by 2030 ▪ Tawnaghmore site chosen as this installation ▪ Technology is likely to still face significant technical challenges in 15-20 years time				
	Volume				
	Emissions intensity, t CO_2e/MWh	0	0	0	
	Maximum volume, MW	0	0	154	All-Island Grid Study, Workstream 1, P.214, Table A8.8
	Load factor	N/a	N/a	35%	Expert interviews
	Cost				
	Capital costs, m €/MW	N/A	N/A	2.4	World Energy Outlook power generation cost assumptions
	Operations and maintenance, (000's) €/MW	N/A	N/A	144	World Energy Outlook Power generation cost assumptions
	Additional capacity costs, €.MWh	N/A	N/A	7.70	For given load factor, assumed to be half the capacity costs of equivalent wind project interviews – see onshore wind lever high penetration

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Coal CCS new build	**Overall** ▪ Lever based on a scenario where 900MW coal CCS is installed to replace current Moneypoint plant in 2025 ▪ Scenario considers Kinsale gas field as the CO_2 storage site				SEI/EPA: Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland
	Volume Emissions intensity, % of equivalent coal emissions	N/A	N/A	20%	SEI, CO_2 capture and storage in Ireland, P.6, Table 2
	Maximum volume, MW	0	0	900	SEI/EPA: Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland
	Load factor	N/A	N/A	70%	Assumption – based on high wind penetration in 2025
	Cost Economic lifetime	N/A	N/A	30	All-Island Grid study Workstream 2A, P.13 – coal plant
	Capital costs, m €/MW	N/A	N/A	3.21	Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland, P.69 Note: € 2,893 m/900MW
	Operations and maintenance ▪ Fixed , €/MW ▪ Variable, €/MWh	N/A N/A	N/A N/A	37,800 2.8	Expert interviews
	Fuel costs, €/MWh	21.4	16.1	15.7	World Energy Outlook 2007 divided by efficiency[1]
	Transport and storage costs, €/t CO_2e	N/A	N/A	17	Expert interviews, based on purely hypothetical route from Moneypoint to Kinsale

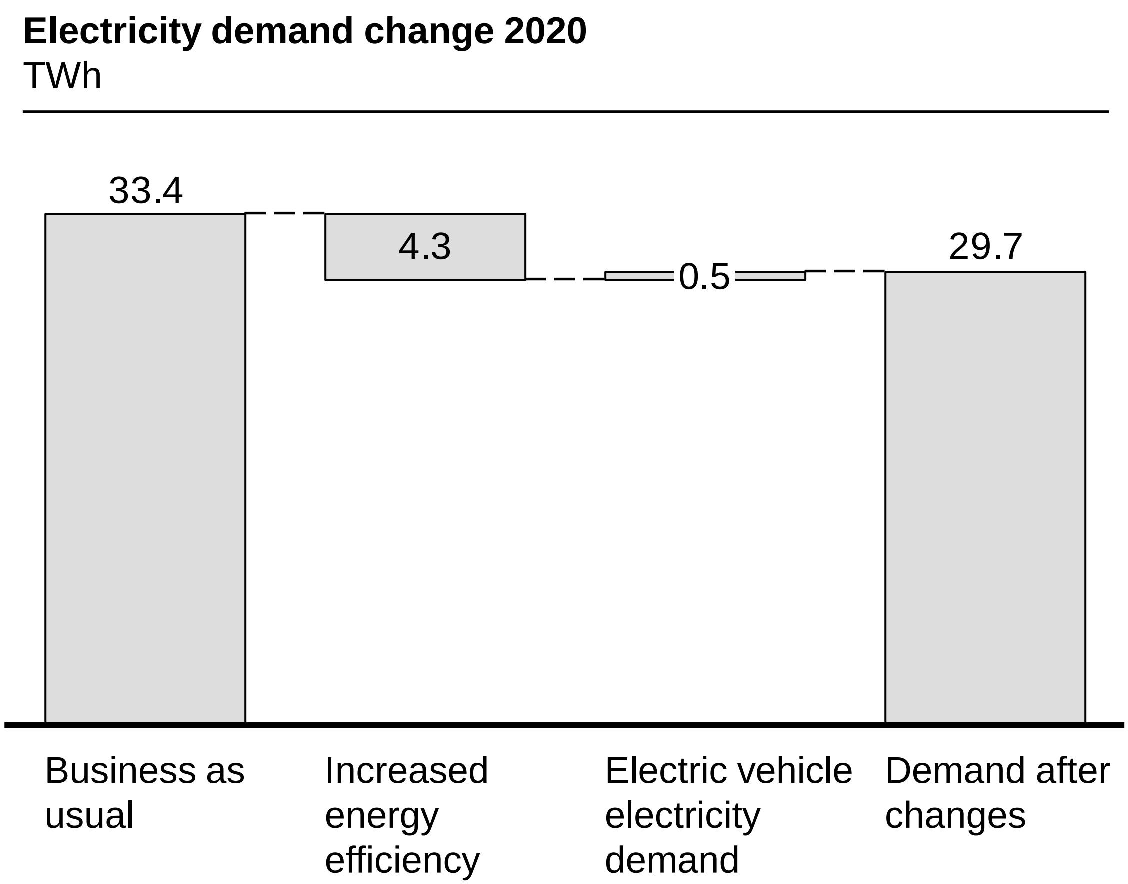
1 Assessment of the Potential for Geological Storage of CO2 for the Island of Ireland assumes coal price of $90/tonne, IEA forecast for 2030 is $61/tonne

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Nuclear	**Overall** ▪ Lever dependent on current legislation changing to permit nuclear power ▪ Scenario assumes that nuclear plant replaces the current Moneypoint plant in 2025				Expert interviews
	Volume				
	Emissions intensity, t CO_2e/MWh	0.01	0.01	0.01	Interviews with industry players
	Maximum volume, MW	0	0	600	Interviews with industry players
	Load factor,%	75	75	75	Validated with industry players assumes relatively low load factor due to high levels of wind capacity
	Efficiency, %	34	35	37	Expert interviews
	Cost				
	Economic lifetime	40	40	40	Expert interviews
	Capital costs[1], m €/MW	3	2.9	2.8	Expert interviews
	Operations and maintenance, €/MWh	16.5	16.5	16.5	Expert interviews
	Fuel costs, €/MWh	5	4.77	4.62	Expert interviews

1 Includes decommissioning costs and waste removal costs that are assumed to be 10% of construction costs

Demand change due to energy efficiency and electric vehicles

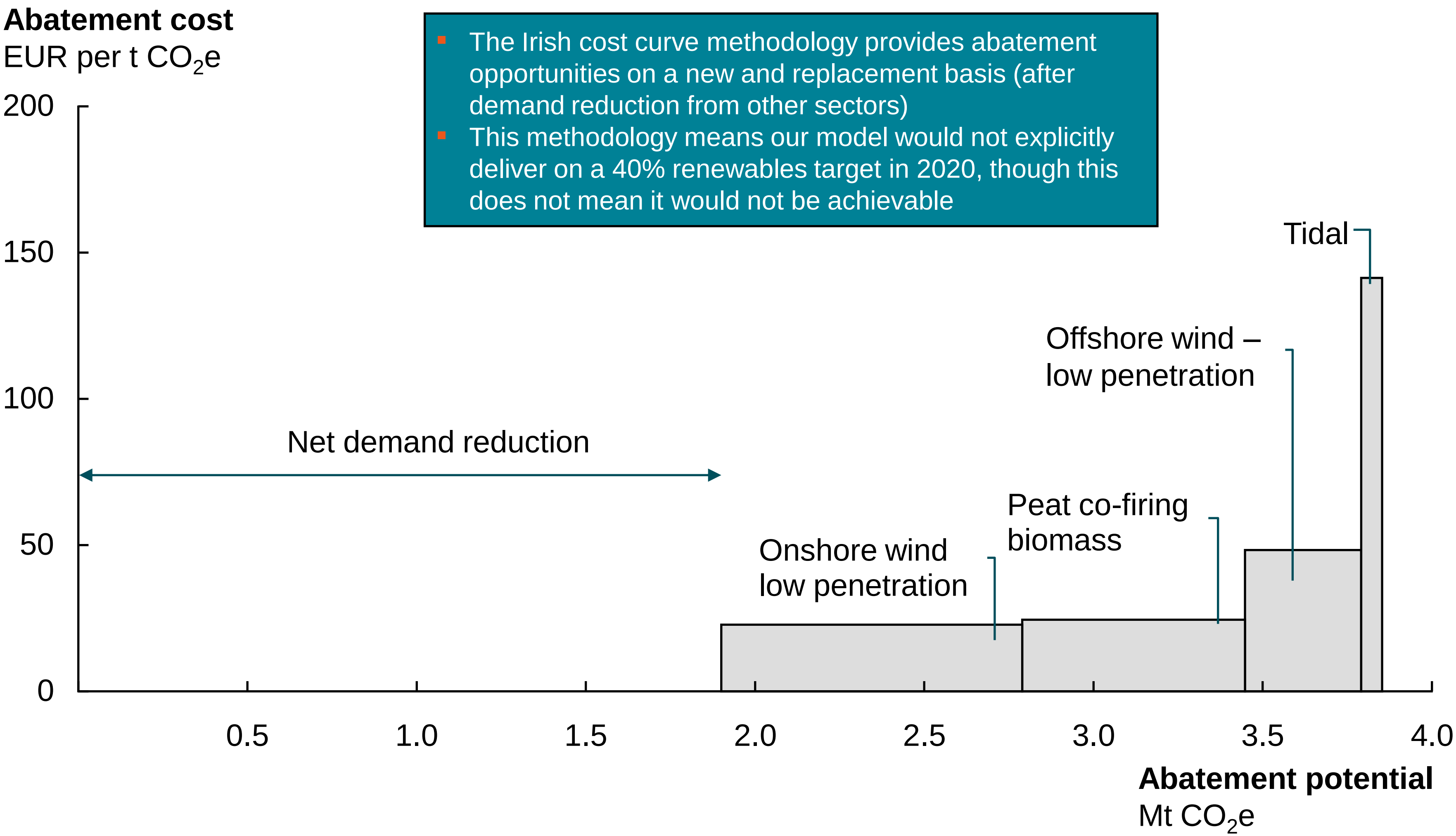


SOURCE: Ireland GHG Abatement Cost Curve

1 Power sector abatement cost curve – 2020

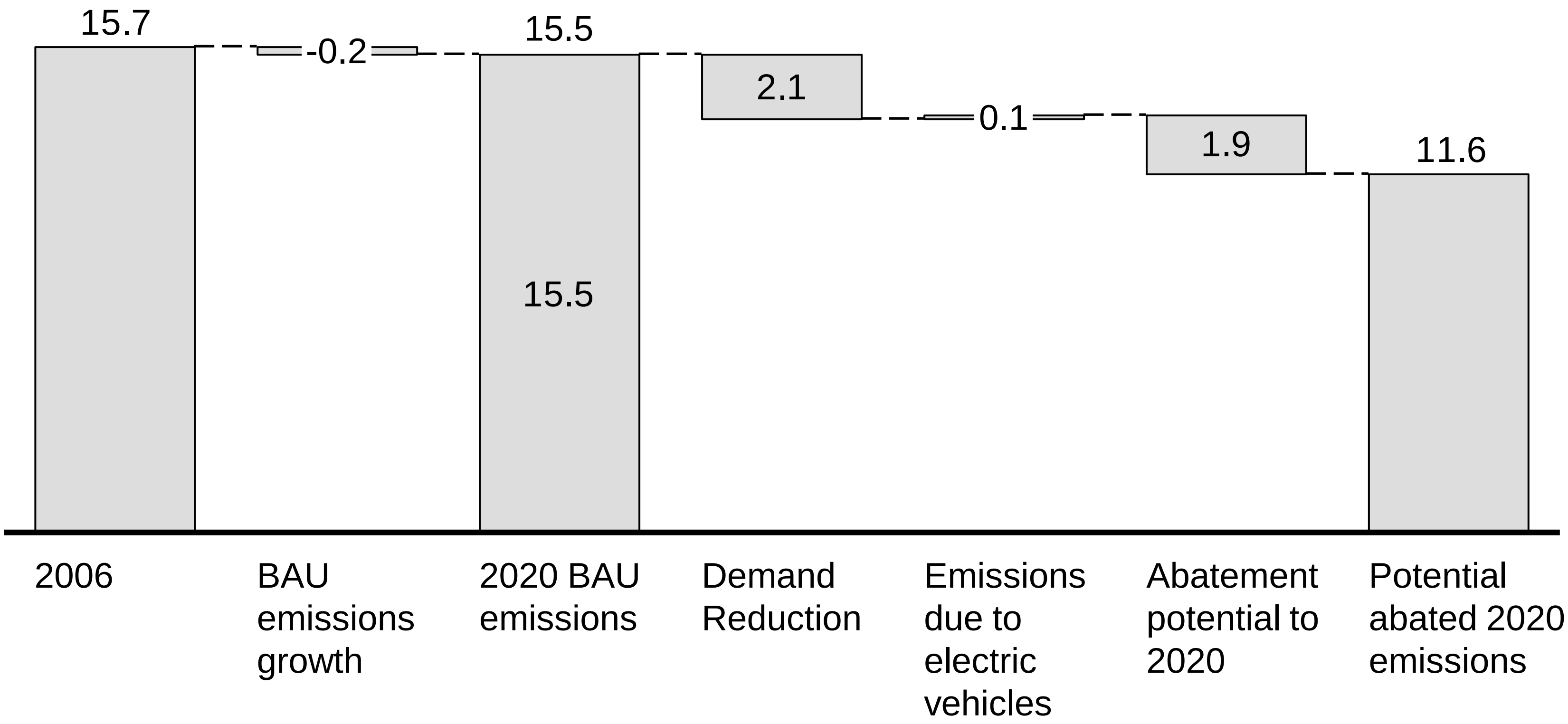
Societal perspective

- The Irish cost curve methodology provides abatement opportunities on a new and replacement basis (after demand reduction from other sectors)
- This methodology means our model would not explicitly deliver on a 40% renewables target in 2020, though this does not mean it would not be achievable



1 Abatement potential for 2020

Ireland 2020 power sector emissions
Mt CO_2e



SOURCE: Ireland GHG Abatement Cost Curve

Contents

Sales penetration mix

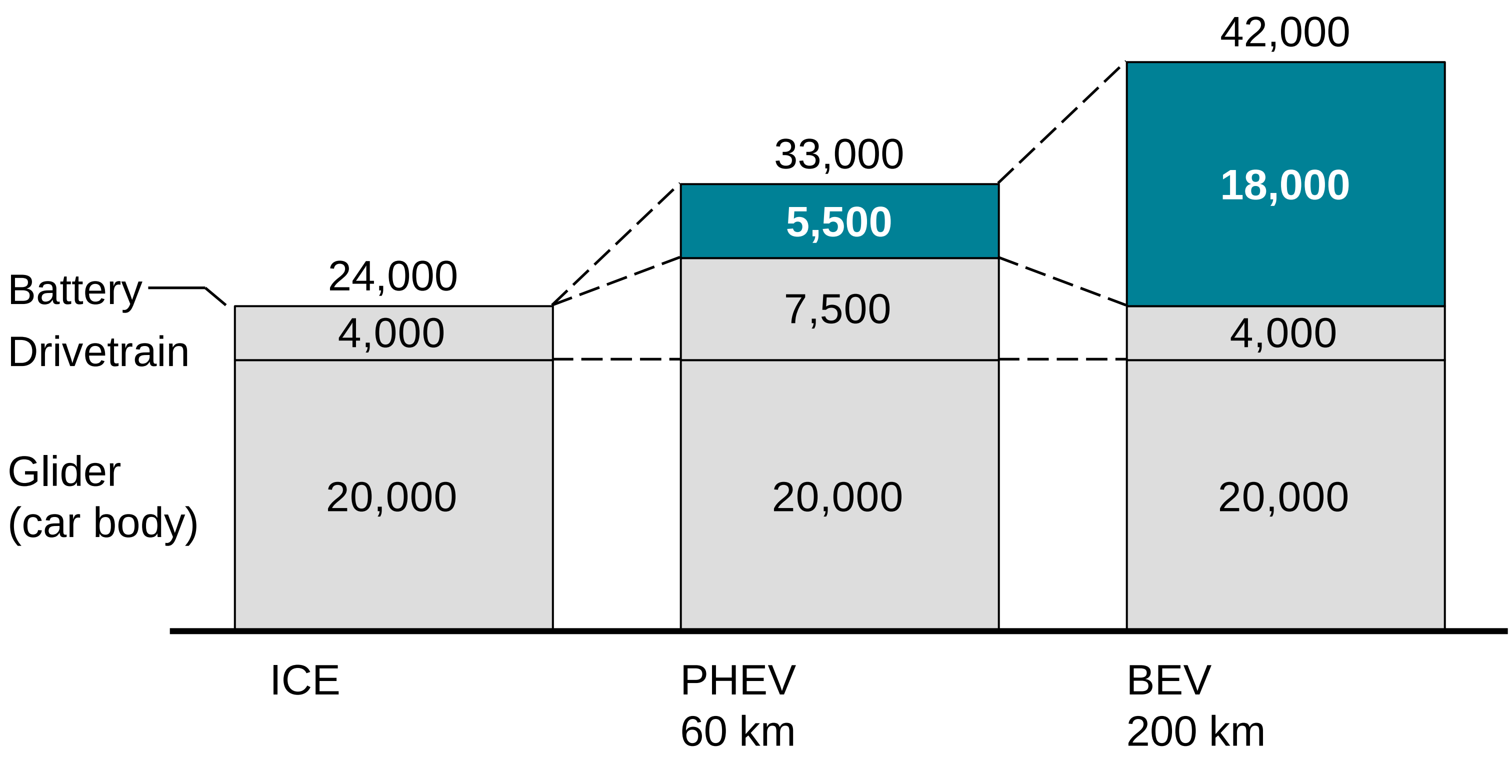
LDV, %

Sales penetration of abatement levers	2005	2010	2015	2020	2025	2030
Gasoline Bundle 1	0	3	25	20	0	0
Gasoline Bundle 2	0	2	13	9	0	0
Gasoline Bundle 3	0	0	7	25	20	0
Gasoline Bundle 4	0	0	0	16	40	52
Gasoline Full Hybrid	0	0	3	8	18	25
Gasoline Plugin Hybrid	0	0	7	15	15	15
Electric Cars	0	0	3	8	8	8
Diesel Bundle 1	0	12	30	24	0	0
Diesel Bundle 2	0	4	15	13	0	0
Diesel Bundle 3	0	0	7	20	13	0
Diesel Bundle 4	0	0	0	29	64	68
Diesel Full Hybrid	0	0	3	8	15	20
Diesel Plugin Hybrid	0	0	0	3	8	10
Compressed Natural Gas	3	1	1	1	1	2

Increased cost of electric vehicles is driven by the battery costs

ROUGH ESTIMATES

Approximate cost breakdown for VW Golf equivalent in 2013
Dollars



Source: Rocky Mountain Institute; McKinsey analysis

BAU reference assumptions

BAU	Details and assumptions	Values 2005	2020	2030	Source
	Emissions (LDV)				
	Fuel economy – Petrol (L / 100km)	9.64	9.02	9.02	IEA energy statistics (Ireland assumed same fuel consumption as UK – validated with Irish interviews – Dept of Transport, Comhar)
	- Diesel (L / 100km)	7.76	7.23	7.23	
	Emissions - Petrol (gCO2e / km)[1]	172	152	152	
	- Diesel (gCO2e / km)	208	194	194	
	Emission intensity				
	- Petrol (gCO2e / L)	2422	2422	2422	
	- Diesel (gCO2e / L)	2683	2683	2683	

Sales penetration	Lever	Values 2005	2020	2030	Source
	LDV Gas bundle 1 (%)	0	3	3	Expert interviews
	LDV Gas bundle 2 (%)	0	2	2	
	LDV Gas bundle 3 (%)	0	0	0	
	LDV Gas bundle 4 (%)	0	0	0	
	LDV Diesel bundle 1 (%)	0	12	12	
	LDV Diesel bundle 2 (%)	0	4	4	
	LDV Diesel bundle 3 (%)	0	0	0	No BAU reference case abatement through MDV and HDV ICE bundles
	LDV Diesel bundle 4 (%)	0	0	0	
	LDV Gas full hybrid (%)	0	0	0	
	LDV Gas plug in hybrid (%)	0	0	0	
	LDV Electric vehicle (%)	0	0	0	
	Bioethonal Generation 1 (%)	0	1	1	
	Bioethonal Generation 2 (%)	0	0	0	
	Biodiesel Generation 1 (%)	0	1	1	
	Biodiesel Generation 2 (%)	0	0	0	

1 Drive cycle emissions for new car sales in 2005, increased by 30% to account for on the road conditions and increased emissions of the fleet relative to new sales – this is consistent with Irish average fuel consumption estimates by Authentic

Electric vehicles abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Extra cost when compared with ICE and PHEV is driven by battery expense
- CO2e intensity of electricity is average of the post abatement average and the marginal fuel (wind)
- Aggressive government 10% fleet penetration target by 2020 is achieved (7% PHEV, 3% EV) with 20% penetration in 2030
- Stock and flow model used with a vehicle life (and battery life) of 15 years

Lever	Details and assumptions	Values 2005	2020	2030	Source
Electric vehicles	**Abatement**				
	Penetration (% sales)	0	8	15	Assuming 10% fleet penetration EV target by 2020, expert interviews (20% in 2030)
	CO2e intensity of electricity (CO2e / MWh)	N/A	0.24[1]	0.15[1]	Power sector outputs
	KWh per km	N/A	0.25	0.25	Expert interviews
	Emissions (GCO2e / km)[2]	N/A	117	75	Based on above assumptions
	Cost				“
	Incremental vehicle cost driven by battery cost (€ / vehicle)	N/A	8000	6000	Various – see acknowledgements section
	Cost of electricity (EUR / kWh) Avoided fuel cost – 67% during night time)	N/A	0.024	0.024	Power sector outputs

1 Discounted societal electricity cost and reduced electricity CO2 intensity reflects the assumption of predominantly night-time charging of batteries
2 On the road emissions rather than test emissions

SOURCE: Deutsch Bank: Electric cars: plugged in; Natixis: Car makers/SRI

Plug in hybrids abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Extra cost over ICE is driven by battery and multiple drivetrains (electric and ICE)
- CO2e intensity of electricity is average of the post abatement average and the marginal fuel (wind)
- Aggressive government 10% fleet penetration target by 2020 is achieved (7% PHEV, 3% EV) with 20% penetration in 2030
- Stock and flow model used with a vehicle life (and battery life) of 15 years

Lever	Details and assumptions	Values 2005	2020	2030	Source
Plug in hybrids	**Abatement**				
	Penetration (% sales)	0	15	25	10% EV target, expert interviews
	CO2e intensity of electricity (CO2e/Mwh)	N/A	0.24	0.15	Power sector outputs
	Kwh per km	N/A	0.25	0.25	Expert interviews
	% time driving electric	N/A	66	66	Expert interviews
	Fuel economy (l/100km)	N/A	5.02	5.02	TNO Institute of Environmental Sciences, California EPA, press search, expert interviews
	Emissions (GCO2e/km)[1]	N/A	118	90	
	Cost				
	Incremental vehicle cost driven by battery cost (less than EV) and drivetrain duplication (EUR/vehicle)	N/A	4600	3200	Various – see acknowledgements section
	Cost of electricity (EUR/ kWh) (avoided fuel cost - 67% during night-time)	NA	0.024	0.024	Power sector outputs

1 On the road emissions

Full hybrids abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Stock and flow model used with a vehicle life of 15 years

Lever	Details and assumptions	Values 2005	Values 2020	Values 2030	Source
Full hybrids	**Abatement**				
	Penetration (% sales)	0	8	25	Expert interviews
	Emissions (GCO2e/km)[1]	N/A	121	121	TNO Institute of Environmental Sciences, California EPA, press search, expert interviews
	Cost				
	Incremental vehicle cost (EUR / vehicle)	N/A	2535	1848	Rocky Mountain Institute

1 On the road emissions

Biofuel abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Ireland assumed to import most of our biofuel needs
  - Therefore global biofuel prices assumed
- 2nd Generation begins to displace 1st Generation after 2025
- Biofuel abatement potential considered for petrol-fueled LDV category only

Lever	Details and assumptions	Values 2005	2020	2030	Source
Biofuel	**Abatement**				
	Ethanol generation 1				
	- Emissions (gCO_2e / joule)	N/A	26	26	National renewable energy laboratory (NREL) "Biofuels – a vision for 2030 and beyond" Expert interviews
	- Penetration (%)	0	7	3	
	Ethanol generation 2				
	- Emissions (gCO_2e / joule)	N/A	25	25	
	- Penetration (%)	0	7	20	
	Cost				
	Ethanol generation 1 (EUR / L)	0.228	0.228	0.228	National renewable energy laboratory (NREL)
	Ethanol generation 2 (EUR / L)	0.243	0.243	0.243	

LDV ICE bundle 1 abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Stock and flow model used with a vehicle life of 15 years
- Applies to passenger cars only

Lever	Details and assumptions	Values 2005	2020	2030	Source
LDV Gasoline bundle 1	**Abatement** Emissions - Petrol (gCO_2e / km)[1] - Diesel (gCO_2e / km)[1] Sales penetration - Petrol (%) - Diesel (%)	 N/A N/A 0 0	 189 171 20 24	 N/A N/A 0 0	TNO Institute of Environmental Sciences (NL), California EPA, press search, expert interviews Expert interviews
	Cost Incremental cost (€ / vehicle) - Petrol - Diesel	 N/A N/A	 239 1158	 N/A N/A	TNO report, California EPA, press search, expert interviews

1 On the road emissions

LDV ICE bundle 2 abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Stock and flow model used with a vehicle life of 15 years
- Applies to passenger cars only

Lever	Details and assumptions	Values 2005	2020	2030	Source
LDV Gasoline bundle 2	**Abatement**				
	Emissions				
	- Petrol (gCO_2e / km)[1]	N/A	164	N/A	TNO Institute of Environmental Sciences (NL), California EPA, press search, expert interviews
	- Diesel (gCO_2e / km)[1]	N/A	156	N/A	
	Sales penetration				
	- Petrol (%)	0	9	0	Expert interviews
	- Diesel (%)	0	13	0	
	Cost				
	Incremental cost (€ / vehicle)				
	- Petrol	N/A	866	N/A	TNO report, California EPA, press search, expert interviews
	- Diesel	N/A	1400	N/A	

1 On the road emissions

LDV ICE bundle 3 abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Stock and flow model used with a vehicle life of 15 years
- Applies to passenger cars only

Lever	Details and assumptions	Values 2005	2020	2030	Source
LDV Gasoline bundle 3	**Abatement** Emissions - Petrol (gCO2e / km)[1] - Diesel (gCO2e / km)[1] Sales penetration - Petrol (%) - Diesel (%)	 N/A N/A 0 0	 149 136 25 20	 N/A N/A 0 0	TNO report, California EPA, press search, expert interviews Expert interviews
	Cost Incremental cost (€ / vehicle) - Petrol - Diesel	 N/A N/A	 1393 1856	 N/A N/A	TNO report, California EPA, press search, expert interviews

1 On the road emissions

LDV ICE bundle 4 abatement opportunities assumptions

Overall methodology

- Technological learning curve assumed
- Stock and flow model used with a vehicle life of 15 years
- In abatement case all sales in 2020 are either Hybrid, electric or ICE bundle 4
- Applies to passenger cars only

Lever	Details and assumptions	Values 2005	2020	2030	Source
LDV Gasoline bundle 4	**Abatement**				
	Emissions				
	- Petrol (gCO2e / km)[1]	N/A	134	134	TNO report, California EPA, press search, expert interviews
	- Diesel (gCO2e / km)[1]	N/A	126	126	
	Sales penetration				Expert interviews
	- Petrol (%)	0	16	52	
	- Diesel (%)	0	29	68	
	Cost				
	Incremental cost (€ / vehicle)				
	- Petrol	N/A	2013	1563	TNO report, California EPA, press search, expert interviews
	- Diesel	N/A	2139	1661	

1 On the road emissions

Contents

Sector background

- Buildings includes energy use in both residential and commercial buildings
  - Residential buildings include both single family homes and apartment buildings
  - Commercial/public buildings include warehousing, food service, education, lodging, malls, offices and hospitals

- Emissions in the reference case include only direct emissions (i.e. those fuels burned onsite e.g. coal) with indirect emissions (from electricity) accounted for in the power sector. However abatement opportunities include those arising from indirect emissions (e.g. lighting) and thus the abatement potential includes both indirect and direct abatement potential
  - The indirect abatement potential assumes abatement based on the marginal pre abatement electrical emissions intensity
  - The majority of abatement opportunities in the buildings sector are at negative or very low life-cycle cost
  - Many of the negative cost abatement opportunities are not realised under business as usual due to misaligned incentives (e.g. principal agent issues), high perceived consumer discount rates and programme costs

- Abatement opportunities fall into six broad categories
  - New build efficiency opportunities
  - Retrofit building envelope
  - High efficiency lighting and lighting controls
  - Energy efficient electronics and appliances
  - Retrofit water heating
  - Retrofit HVAC (Heating, ventilation and air conditioning systems)

- All abatement measures considered in this sector assume no impact on end-user comfort; behavioural changes would yield additional abatement potential

General assumptions

BAU	Details and assumptions	Values 2005	2020	2030	Source
Residential	**Floorspace (million m2)**	161	198	215	MGI
	Fuel				Baseline – 'National energy forecasts'
	- Electricity (million MWh)	8	10	11	
	- Gas (million MWh)	7	8	8	
	- Oil (million MWh)	14	18	19	
	- Coal (million MWh)	3	1	0	
	- Other (million MWh)	3	2	1	
	End use of electricity				SEI "Energy in the residential sector"
	- Space heating (%)	14	N/A	N/A	
	- Space cooling (%)	0	N/A	N/A	
	- Water heating (%)	23	N/A	N/A	
	- Lighting (%)	18	N/A	N/A	
	- Appliances (%)	20	N/A	N/A	
	- Other (%)	13	N/A	N/A	
	- Cooking (%)	12	N/A	N/A	
Commercial	**Floorspace (million m2)**	83	92	115	Scaled down from communities.gov.uk
	Fuel				
	- Electricity (million mWh)	9	11	12	SEI Baseline – 'National energy forecasts' (trends continued to 2030)
	- Gas (million mWh)	4	9	12	
	- Oil (million mWh)	8	1	0[1]	
	- Coal (million mWh)	0	0	0	
	- Other (million mWh)	0	0	0	
	End use of energy				
	- HVAC and water heating	50	50	50	
	- Other	50	50	50	

1 No decrease assumed after 2025 (2025 figure 0.3 mWh)

Residential lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
New build efficiency package	**Volume**				▪ BER; Interviews, SEI, Dept of Environment, CIF, Dalkia
	▪ Assumes passive house standard (kWh / m2)	N/A	40	40	
	▪ Penetration (% of new builds that year)[1]	0	90	90	
	Cost				
	▪ Cost premium on new buildings (EUR / m2)[2]	N/A	230	230	
Retrofit building package, level 1 and level 2	**Volume**				▪ BER; Interviews, SEI, Dept of Environment, CIF, Dalkia
	▪ Level 1 retrofit energy efficiency improvement (kWh)	25	25	25	
	▪ Penetration (%)	0	40	80	
	▪ Package 2 retrofit (kWh)	25	25	25	
	▪ Penetration (%)	0	28	59	
	Cost				
	▪ Level 1 retrofit cost (EUR / m2)	35	35	35	
	▪ Level 2 retrofit cost (EUR / m2)	77	77	77	

1 Penetration begins with 15% in 2010 increasing to 90% in 2020

2 Based on data from DCENR for cost premium for building at 60 kWl/ m2 vs 150 kWl/m2, and extrapolated for additional 20 kWl/m2 improvement to 40 kW/m2

Residential lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Retrofit HVAC, residential	**Volume**				▪ Energy Star; ▪ Vendor interviews ▪ Penetration estimates from LBNL ▪ DOE / EERE ▪ Expert interviews
	▪ Savings potential for standard gas / oil heaters through improved technology and proper sizing - not included in other heating opportunities (%)	19	19	19	
	▪ Additional penetration in abatement case (%)	0	50	70	
	▪ Savings potential for electric heat pump compared to electric resistance heating (%)	50	50	50	
	▪ Additional penetration in abatement case (%)	0	61	52	
	▪ HVAC maintenance savings potential from proper duct insulation and proper maintenance (%)	15	15	15	
	▪ Additional penetration in abatement case (%)	0	17	63	
	Cost				
	▪ Premium for high efficiency gas / oil model that covers 130 sq. meter house (EUR)	500	500	500	
	▪ Premium for HE heat pump model that covers 130 sq. meter house (EUR)	2000	2000	2000	
	▪ Duct insulation / maintenance for 130 sq. meter house(EUR)	630	630	630	
Retrofit water heating systems	**Volume**				▪ ACCEE; Eco-hot water report for EC; Frost and Sullivan (US); NREL ▪ Vendor interviews; Fuji Keizai
	▪ Maximum solar capacity is installed by 2030. 10% solar penetration, with remainder using most efficient technology (heat pump or HE gas)	See details and assumptions			
	Cost				
	▪ Solar water prices drop at 2.3% CAGR, based on historic improvement form 1984-2004 (EUR)	4800	3300	2600	

Residential lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
New and retrofit lighting systems	**Volume**				
	▪ lumens / W:				▪ IEA; Daiwa; Rubenstein, et al
	– Incandescent	12	12	12	
	– CFL	60	60	60	▪ Calculations from power sector
	– LED	75	150	150	
	▪ Reference case CFL penetration (%)	13	27	43	
	▪ In abatement case, assume full remaining share of incandescents switch to LEDs, and full remaining share of CFLs switch to LEDs				
	▪ Lighting control systems				
	▪ Savings potential in new build (%)	50	50	50	
	▪ Savings potential in retrofit (%)	29	29	29	
	▪ Penetration (%)	0	22	36	
	Cost				
	▪ Cost for new build (EUR / m2)	3	3	3	
	▪ Cost for retrofit is (EUR / m2)	11	11	11	
New and "retrofit" appliances and electronics	**Volume**				
	▪ HE consumer electronics saving potential (%)	38	38	38	▪ ACEEE; LBNL; Data received directly from Energy Star programme; UN, CEA
	▪ Package of certified appliances savings potential (%)	35	35	35	
	▪ Penetration (%)	0	41	57	▪ Industry data 2007 and 2008; McKinsey work on power packs / consumer electronics
	Cost				
	▪ Electronics: price premium for small devices (EUR)	1	1	1	▪ IEA
	▪ Appliances: price premiums for HE devices (%)	12	12	12	

Commercial lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
New build efficiency package	**Volume**				
	▪ Savings potential (kWh / m2)	60	60	60	▪ BER; Interviews, SEI, Dept of Environment, CIF, Dalkia
	▪ Penetration (%)	0	81	90	
	Cost				
	▪ Cost premium on new builds (EUR / m2)	35	35	35	
Retrofit building package	**Volume**				▪ BER; Interviews, SEI, Dept of Environment, CIF, Dalkia
	▪ Savings potential assumed 20% improvement in energy efficiency (from an average of ~250 kWh / m2)	50	50	50	
	▪ Penetration (%)	0	40	80	
	Cost				
	▪ Cost premium on new builds (EUR / m2)	45	45	45	

Commercial lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Retrofit HVAC systems and controls	**Volume** ▪ HVAC system retrofit savings potential (%) ▪ HVAC controls potential(%) ▪ Penetration (%)	 13 15 0	 19 15 46	 20 15 85	▪ EIA, LBNL ▪ Vendor interviews ▪ Industry and academic expert interview ▪ University of Texas; vendor interviews
	Cost ▪ Premium for every 5 tonnes (~17000 W) of capacity installed (EUR) ▪ Cost for retrofit control system in 1700 m2 building	 500 5000	 500 5000	 500 5000	
Retrofit water heating systems	**Volume** ▪ Assume that maximum solar capacity is installed by 2030 (%) ▪ No fuel shift, but shift to most efficient technology within fuel type (condensing gas or electric heat pump) for remainder	 0	 10	 20	▪ ACCEE; Eco-hot water report for EC; Frost and Sullivan (US); NREL ▪ Vendor interviews; Fuji Keizai
	Cost ▪ Solar water heater learning rate based on 18% improvement in solar technology from 1950-2000 (EUR)	 4800	 3300	 2600	• Energy Information Administration (2004)

Commercial lever assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
New and retrofit lighting systems	**Volume** ▪ Reference case CFL penetration (%) ▪ In abatement case, assume full remaining share of incandescents switch to LEDS, and full remaining share of CFLs switch to LEDs. ▪ Lighting control systems – Savings potential in new build (%) – Savings potential in retrofit (%) – Penetration (%) **Cost** ▪ Cost for new build (EUR / m2) ▪ Cost for retrofit is (EUR / m2)	13 50 29 0 3 11	27 50 29 22 3 11	43 50 29 36 3 11	▪ IEA; Daiwa; IEA presentation ▪ Rubenstein, et al ▪ Calculations from power sector
New and "retrofit" appliances and electronics	**Volume** ▪ Savings potential in office electronics (%) ▪ Savings potential in commercial refrigerators (%) ▪ Penetration (%) **Cost** ▪ Price premium per item for high efficiency charging devices and reduction in standby loss (EUR) ▪ Premium for every 0.65 sq. meter of high efficiency refrigeration area (EUR)	48 17 0 1.5 19	48 17 33 1.5 19	48 17 43 1.5 19	▪ LBNL ▪ Energy Star calculators; McKinsey document on power packs / charging

Contents

Cement calculation methodology

Overall

- Reference generation is based on the clinker or fuel being replaced relative to the BAU reference scenario
- Abatement potential of individual levers is calculated based on differential between overall industry emissions in reference case and abatement case

Volume

Potential abatement volume for lever X (tCO_2e) = **Total reference case emissions** (tCO_2e) - **Abatement case emissions for lever X** (tCO_2e)

Cost

$$\textbf{Abatement cost}\ (€ / tCO_2e) = \frac{\textbf{Cost of production with abatement}\ (€ / \text{tonne}) - \textbf{Cost of production under reference case}\ (€ / \text{tonne})}{\textbf{Reference case emission intensity}\ (tCO_2e / \text{tonne}) - \textbf{Abatement case emission intensity}\ (tCO_2e / \text{tonne})}$$

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Clinker substitution by limestone and flyash	**Overall** ▪ Assumes all available flyash is already used ▪ Assumes no limestone capacity constraints	--			--
	Volume				
	Total cement production (Mt)	5.25	5.59	5.66	Euroconstruct, projected at ESRI house completion rates
	BAU substitution by limestone & flyash (%)	14	14	14	Irish industry experts
	Abatement substitution by limestone & flyash (%)	20	20	20	Irish industry experts
	Current usage of available flyash by cement (%)	100	100	100	Irish industry experts
	Flyash from coal-fired powergen (t/MWh)	0.0692	0.0692	0.0692	OECD industry estimate
	Cost				
	Flyash unit cost (€ / t)	1.5	1.5	1.5	Irish industry experts
	Limestone unit cost (€ / t)	1.5	1.5	1.5	Irish industry experts
	Flyash handling capacity cost (€ / tonne)	10	10	10	OECD industry estimate
	Flyash transport unit cost (€ / tonne)	13.5	13.5	13.5	OECD industry estimate
Clinker substitution by slag	**Overall** ▪ Assumes no capacity constraints – Current imports are sufficient to cover demand if abatement implementation had been achieved in 2005 ▪ Transportation costs not included	--			--
	Volume				
	Total cement production (Mt)	5.25	5.59	5.66	Euroconstruct, projected at ESRI house completion rates
	BAU clinker substitution by slag (%)	0	0	0	Irish industry experts
	Abatement clinker substitution by slag (%)	0	7	7	Irish industry experts
	Cost Euro per Tonne imported	- 20	20	20	Industry representatives

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Alternative fuels: Waste	**Overall** ▪ Assumes no capacity or licensing constraints in 2030	--			--
	Volume BAU use of alternative fuels: fossil waste (%) BAU use of alternative fuels: MBM (%) Abatement use of alternative fuels: all waste (%)	0 2 2	0 5 20	0 5 20	Irish industry experts Irish industry experts Irish industry experts
	Cost Fuel handling capacity cost (€ / tonne)	200	200	200	OECD European estimate
Alternative fuels: Biomass	**Overall** ▪ Assumes no capacity or licensing constraints in 2030	--			--
	Volume BAU use of alternative fuels: biomass (%) Abatement use of alternative fuels: biomass (%)	0 0	0 15	0 25	Irish industry experts Irish industry experts
	Cost Biomass cost (€ / gigajoule)	6.95	6.95	6.95	Bord na Mona

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Waste heat recovery	**Overall** ▪ Assumes no capacity for implementation given modern equipment in newly built Irish plants	--			--
	Volume Incremental possibility of waste heat recovery	0	0	0	Irish industry experts
	Cost Waste heat recovery capacity cost (€ / tonne clinker)	12.9	12.9	12.9	Global industry research
Post-combustion CCS	**Overall** ▪ Assumes no capacity for implementation given minimal probability of constructing a new plant in Ireland before 2030	--			--
	Volume BAU use of CCS (%) Abatement use of CCS (%)	0 0	0 0	0 0	Irish industry experts
	Cost Capacity cost (€ / t clinker)	600	300	200	Global industry research

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Process optimisation	**Overall** ▪ Assumes uniform distribution of improvements across industries	--			--
	Volume Incremental improvement from full implementation (%) Implementation rate (%)	0 0	5 100	15 100	Global industry research
	Cost Implementation cost (€ / tonne CO_2e)	20	20	20	Global industry research
Motor systems efficiency	**Overall** ▪ Assumes uniform distribution of improvements across industries	--			--
	Volume Energy savings from full implementation (%)	10	10	10	Global industry research
	Cost Implementation cost, € / MWh	50	50	50	Global industry research

Assumptions

Lever	Details and assumptions	Values 2005	 2020	 2030	Source
CHP	**Overall** ▪ Assumes uniform distribution of improvements across industries ▪ Assumes 80% thermal efficiency	--			--
	Volume Savings in direct power spend with CHP (%) Implementation rate (%) Lifespan of average install (years)	 20 0 15	 20 10	 20 15	 Irish industry experts
	Cost Capital costs, m € / MW Operations and Maintenance, € / MWh	 1.2 7.30	 1.2 7.30	 1.2 7.30	 Irish industry experts US EPA - $10 /MWh converted to EUR

Contents

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Cropland: no-till, reduced till	**Overall** ▪ Low implementation is achievable in Ireland due to stony soils and small size of individual fields, which require more ploughing ▪ Tillage changes only apply to cereals crops	--			--
Cropland: no-till	**Volume**				
	Cereals area ('000 hectares, excl. fruit & horticulture)	279.8	275.3	270.3	CSO: 2005; Teagasc: cereal rate of decline to 2020; CAGR to 2030
	Potential emissions reduction (t CO_2e / ha / yr)	0.25	0.25	0.25	Teagasc
	Max implementation rate (%)	0	4	4	Teagasc
	Cost Savings on labour, machinery; lost revenue of straw left on land (otherwise sold for mushroom fields), and of lower yields; expense on herbicides and seed				
	Net cost	20	20	20	Teagasc
Cropland: reduced till & residue management	**Volume**				
	Cereals area ('000 hectares, excl. fruit & horticulture)	279.8	275.3	270.3	CSO: 2005; Teagasc: cereal rate of decline to 2020; CAGR to 2030
	Potential emissions reduction (t CO_2e / ha / yr)	0.33	0.33	0.33	Teagasc
	Max implementation rate (%)	10	18	25	Teagasc
	Cost Savings on labour, machinery; lost revenue of straw left on land (otherwise sold for mushroom fields), and of lower yields; expense on herbicides and seed				
	Net cost	100	100	100	Teagasc

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Cropland: agronomy	**Overall** ▪ Cover crops are only valid for certain types of main crops (potato, barley) ▪ Mustard seed is the primary cover crop available ▪ Not relevant in area used for winter crops	--			--
	Volume Cropland area ('000 hectares), excl. winter crops	205.5	202.2	198.5	CSO: 2005; Teagasc: cereal rate of decline to 2020; CAGR to 2030
	Potential emissions reduction (t CO_2e / ha / yr)	0.6	0.6	0.6	Teagasc
	Max implementation rate (%)	2	14	25	Teagasc
	Cost Expense on mustard seed (€ / ha / yr)	130	130	130	Teagasc
Cropland: nutrients	**Overall** ▪ Replacing nitrogen fertiliser with best-practice slurry application (trailing shoe, springtime) ▪ Limited by total national slurry supply ▪ Transportation emissions not included	--			--
	Volume Cropland area ('000 hectares)	279.8	275.3	270.3	CSO: 2005; Teagasc: cereal rate of decline to 2020; CAGR to 2030
	Potential emissions reduction (t CO_2e / ha / yr)	0.28	0.28	0.28	
	Max implementation rate (%)	1.5	15.75	30	Department of Agriculture
	Cost Savings from less fertiliser Savings on slurry storage (€ / ha / yr)	-25	-25	-25	Teagasc, Dept. of Agriculture

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Grassland: management (planting clover as cover crop)	**Overall** ▪ Most grassland is 2-3% clover; must be >20% to be considered clover pasture ▪ BAU implementation rate - 1% of land ▪ Abatement case - non-acidic soils (10% of land)	--			--
	Volume Grassland area ('000 hectares) Potential emissions reduction (t CO_2e / ha / yr) Max implementation rate (%)	 3,409 0.46 1	 2,856 0.46 10	 2,856 0.46 10	CSO: 2005; Teagasc decline in grazing livestock numbers Department of Agriculture Teagasc, McKinsey
	Cost Expense on clover seed (€ / ha / yr) Savings on fertiliser (€ / ha / yr)	 -30	 -30	 -30	 Department of Agriculture
Grassland: nutrients (reducing fertiliser with best-practice slurry application)	**Overall** ▪ Limited by total national slurry supply ▪ Max implementation 50%, remainder for management (clover)	--			--
	Volume Grassland area ('000 hectares) Potential emissions reduction (t CO_2e / ha / yr) Max implementation rate (%)	 3,409 0.33 33	 2,856 0.33 50	 2,856 0.33 50	CSO: 2005; Teagasc decline in grazing livestock numbers Department of Agriculture Teagasc, McKinsey
	Cost Savings from less fertiliser and slurry storage (€ / ha / yr)	3	3	3	Department of Agriculture

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Livestock: dietary management	**Overall** ▪ Increasing outdoor grazing period by 52 days annually (midpoint of estimates by Teagasc and Dept. of Agriculture) ▪ Concentrates already applied to significant portion of eligible cattle so excluded from calculation	--			--
	Volume				
	Total beef cattle (m)	5.1	4.3	4.3	Teagasc
	Emissions factor – beef (t CO_2e / head)	1.4	1.4	1.4	UNFCCC
	Total dairy cattle (m)	1.1	1.2	1.2	Teagasc
	Emissions factor – dairy (t CO_2e / head)	2.23	2.23	2.23	UNFCCC
	Potential emissions reduction (%)	4.76	4.76	4.76	Lovett et al., 2008, revised to midpoint of estimates by Teagasc and Dept. of Agriculture
	Max implementation rate – beef (%)	0	60	60	Dept. of Agriculture
	Max implementation rate – dairy (%)	0	100	100	Dept. of Agriculture
	Cost				
	Savings from increased productivity (€ / head / yr)	-1.35	-1.35	-1.35	Dept. of Agriculture

Contents

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Organic soils	**Overall** ▪ Restorable area excludes land that is owned by Bord na Mona, afforested, or intact ▪ Implementation rate accounts for areas adjacent to residential areas ▪ Permanence may be an issue	--			--
	Volume				
	▪ Total peatland area ('000 hectares)	950	950	950	Connolly et al., 2007
	▪ Intact peatland area (15% of total)	142.5	142.5	142.5	Expert interviews
	▪ Bord na Mona area	80	80	80	Bord na Mona
	▪ Afforested peatland area	300	300	300	Expert interviews
	▪ Farmed peatland area (pasture)	210	210	210	Department of Agriculture
	▪ Potential emissions reduction (t CO_2e / ha / yr)	7.5	7.5	7.5	IPCC, expert interviews
	▪ Max implementation rate (%)	0	38	75	McKinsey
	Cost				
	▪ Technical expense: blocking drainage, applying vegetation (€ / ha / yr) ▪ Annualisation period - restoration horizon (years)	54.45 30	54.45 30	54.45 30	▪ Coillte's Bog Restoration Project, €4.2m budget for 2,571 ha ▪ Comparable to €400/ha cost for restoration and amenity creation at Tullaun ▪ Learning process with repeated efforts would imply lower annual costs
	▪ Cost of farmed peatland for restoration ▪ Annualisation period - ownership of land (years)	347.90 100	347.90 100	347.90 100	▪ IAVI Property Survey, average €/acre for non-residential farmland, 2008: €14,265

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Afforestation	**Overall**				
	▪ Afforestation on pasture land, cropland and peatland	-			Expert interviews
	Volume				
	▪ Avg carbon absorption period (yrs)	50			Approximation based on global estimates
	▪ Avg above ground tree (tCO_2e / ha)	35			National forestry inventory 2007
	▪ Avg below ground tree (tCO_2e / ha)	13			National forestry inventory 2007
	▪ Avg deadwood / litter	16			National forestry inventory 2007
	▪ Avg soil (tCO_2e / ha)	450			National forestry inventory 2007
	▪ Maximum annual afforestation (kha / yr)	20	20	20	Expert interviews
	▪ Current afforestation (kha / yr)	8	8	8	EPA
	Cost				
	▪ Annuity value of Euro3500 planting cost (€ / ha)	163	163	163	Expert interviews
	▪ Pasture land rental cost (€ / ha / yr)	300	300	300	
	▪ Management and monitoring (€ / ha / yr)	0	0	0	
	▪ Annuity value of 500m3 timber sales	-87	-87	-87	
Conversion of cropland to biomass use	**Volume**				
	▪ Maximum annual conversion (ha / yr)	1000	1000	1000	Expert interviews
	▪ Current conversion (ha / yr)	0	0	0	Expert interviews
	Cost				
	▪ Planting cost (€ / ha)	3500	3500	3500	Expert interviews
	▪ Pasture land rental cost (€ / ha / yr)	300	300	300	
	▪ Management and monitoring (€ / ha / yr)	0	0	0	

Assumptions

Lever	Details and assumptions	Values 2005	2020	2030	Source
Avoided deforestation	**Volume** ▪ Current rate of deforestation (ha) ▪ Avoidable deforestation (ha)	 500 100	 500 100	 500 100	 Expert interviews
	Cost ▪ Opportunity cost of timber (€ / ha) ▪ Management and monitoring (€ / ha / yr)	 2000 500	 2000 500	 2000 500	 Expert interviews
Change in forest management	**Volume** ▪ Area available for forest management improvement ('000 ha)	 50	 50	 50	 Expert interviews
	Cost ▪ Once-off improvement cost (€ / ha / year) ▪ Annual improvement cost (€ / ha / year)	 52 23	 52 23	 52 23	 Global research Global research

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Stakeholders and sources

Stakeholders engaged

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Stakeholders engaged

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Stakeholders and sources

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Stakeholders and sources

Stakeholders engaged

- Michael MacCarthy, Liam Kinsella, Kevin Smith, Miriam Cadwell, Gordon Conroy (Department of Agriculture)
- Gary Lanigan (Teagasc)
- Trevor Donnellan (Teagasc)
- Joseph Curtin (IIEA)
- Pete Smith (Univ. of Aberdeen)
- Thomas Ryan, Rowena Dwyer (Irish Farmers' Association)

Sources used

- US EPA Global Antropogenic Non-CO_2e Emissions, 2006
- "The Greening of Irish Agriculture," Irish Institute of European Affairs, various industry expert presentations
- IPCC, Annual Report 4, 2007
- "Greenhouse Gases in Agriculture," Teagasc, various industry expert presentations

Stakeholders and sources

Stakeholders engaged

- Eugene Hendrick, Philip Carr (COFORD)
- Kevin Black (FERS)

- Phillip O'Brien (EPA)
- Laura Burke (EPA)
- Caitriona Douglas, Jim Ryan (NPWS)
- John Reilly, Dermott Kelly, Charlie Shier, Catherine Farrell (Bord na Mona)

- David Wilson (UCD)
- John Connolly (UCD)
- Paul Leahy (UCC)
- Pete Smith (Univ. of Aberdeen)

- Gary Lanigan (Teagasc)

- Michael MacCarthy, Liam Kinsella (Department of Agriculture)

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