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Oliver Kinnane, for the IGBC (Draft 0.1)

Whole Life Carbon in Construction and the Built Environment Ireland

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About this report

This report is produced by the *Building in a Climate Emergency Research Group,* UCD School of Architecture, Planning and Environmental Policy, for the Irish Green Building Council.

It reports work in progress, and hence this report is in draft. Presented results need to be quantified and checked using and against other sources before they can be presumed as validated. The scope of work will be expanded further to encompass as many subsections as possible of the built environment. It should be noted that the data used in this report is not primary data. It is taken from other sources and not generated by these researchers.

Future work will include a more detailed breakdown of built environment sectors which will require the analysis of other data sets and assumptions. All results will be subjected to uncertainty analysis. A multi-methodological analysis will be undertaken and comparison of the gap between top-down and bottom-up methodologies made.

The project team from the Research Group include:

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Scoil na hAiltireachta, na Pleanála agus an Pholasaí Chomhshaoil UCD

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Acronyms

BE. Built Environment

BER. Building Energy Rating

CSO. Central Statistics Office

EC. Embodied Carbon

EPA. Environmental Protection Agency

GHG. GreenHouse Gas

NDP. National Development Plan

NRP. National Retrofit Programme

OC. Operational Carbon

SEAI. Sustainable Energy Authority of Ireland

European Climate Foundation

Laudes Foundation

IKEA Foundation

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Key Findings

Overview

Construction and operation of the Irish built environment accounts for ~22 $MtCO_2e$ of annual emissions in a standard year.

15.7 $MtCO_2e$ of emissions were due to building operation and 6.9 $MtCO_2e$ related to embodied carbon in 2018.

Works outlined in the National Development Plan will increase the embodied carbon total by ~10% per year.

GHG emissions associated with the operation of the residential sector account for the largest share of BE related emissions.

Overall GHG emissions are predicted to follow a downward trend but embodied emissions are forecasted to increase.

Overview

This project aims to quantify the emissions related to the construction sector in Ireland and the built environment more generally. The project has two primary objectives:

1. To quantify the current annual emissions related to construction and operation of the built environment, and,

2. To project future emissions related to the built environment, for a range of scenarios.

The first of these objectives aims at estimating the current annual impact of the built environment, or baselining its impact. The second aims at estimating the future impact of the built environment, and highlights gaps and necessary sectors to target over coming years as we progress toward the goal of net-zero by 2050.

The impact of the built environment, its operation, and to a greater extent its construction are currently poorly quantified. The high-level national climate emissions inventories do not relate data directly to the construction sector. The inventories instead report emissions related to sectors such as Agriculture, Transport, Energy Industries, Manufacturing, Residential, Public services, etc. Many of these encompass emissions related to the built environment.

Similarly the inventories are only concerned with territorial emissions occurring within Ireland and not the emissions due to construction materials and products that occur elsewhere but are imported into Ireland. Ireland imports a high amount of building materials including processed metals, bricks as well as energy for building operation.

Undefined construction sectors emissions makes it difficult to assess the impact of the Irish construction industry on climate emissions.

This report presents a preliminary evaluation of the impact of the built environment accounting for GHG emissions across a range of sectors, some of which are evaluated in greater detail than others. Similarly varying levels of data exist for different sectors.

An initial estimate of GHG emissions in 2030 is made, given current and projected trends. In future iterations of this report this matter will be given significantly more attention and estimates will be better linked to expected policy and technical near term innovations.

Quantified totals are presented in million tonnes carbon dioxide equivalent (MtCO2e) throughout. This study is based on data from a number of primary sources include the EPA, CSO and SEAI who have monitored emissions, construction activity and energy related to the built environment in detail.

A climate emergency has been declared by the Irish government. Ambitious and legally binding targets have been defined. This presents a new context for analysis of the GHG emissions associated with the operation and construction of the built environment. Speedy and forceful action is required to reduce its impact. A first step is to accurately quantify it.

The Built Environment and the National Context

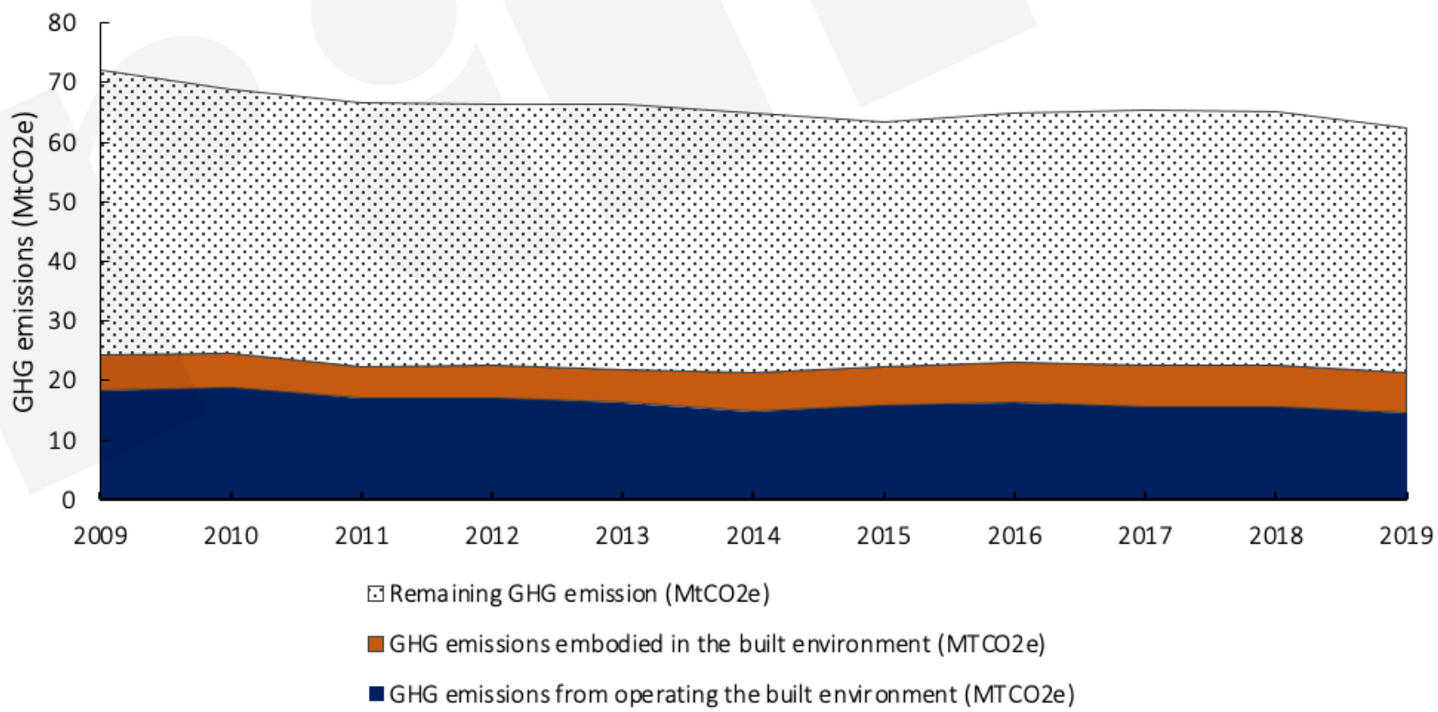
The Irish built environment is estimated to account for > 30% of the overall GHG emissions in a standard year. This includes emissions resulting from the energy required for the operation (~20% of overall emissions) and the construction of the built environment (~10% of overall emissions).

Ireland's GHG consumption based emissions in 2019 were 62.4 Mt CO2eq, a decrease of 4.2% from 2018. Overall GHG related emissions reduced by 5.3% in the period 2010 to 2018 (69 to 65 MtCO2e).

GHG emissions due to the built environment have decreased in line with, and at the same rate as, overall national emissions.

For the benchmark year of 2018 the Irish built environment was estimated to account for 22.6 MtCO2e, or 35% of all national GHG emissions. This includes emissions related to the operation (15.7 MtCO2e) of the built environment and emissions related to capital construction, or embodied in materials and products used in the construction of the built environment (6.9 MtCO2e).

These estimates are based on a combination of data from Ireland's national inventory of carbon (EPA) and national energy balance database (SEAI), as well as other data from the Central Statistics Office (CSO) and the Global Carbon Project dataset.



National GHG emissions and those associated with the operation and construction of the built environment. Data from [6,8,18,21]

On the methods and totals calculated for the built environment

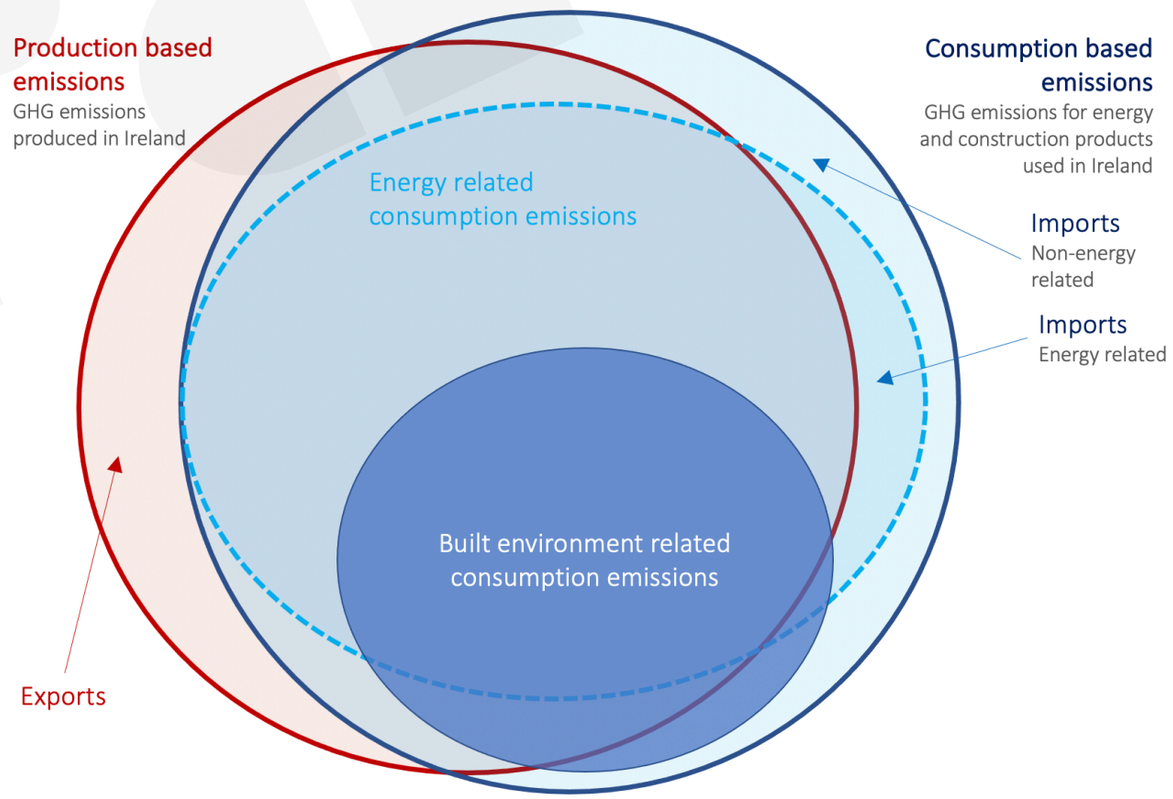
Emission totals are quantified and reported for 2009 to 2018/19. 2018 is given particular attention. It is taken as the benchmark year, and assumed as a standard year; pre Covid related disruption to the industry and a decade after the economic crisis of 2008. It is also the year used as the baseline for which future reductions to 2030 and 2050 are compared against.

CO_2 emissions are typically measured on the basis of 'production'. This accounting method – which is sometimes referred to as 'territorial' emissions. This report instead reports 'consumption based emissions', thereby adjusting emissions for trade. Imported construction products for the built environment thereby account for the emissions in the country in which they were imported. Exported products result in a subtraction of emissions.

Ireland is a net importer of materials, products and energy used in the built environment. Thereby it is a net importer of GHG emissions. Hence consumption based emissions are greater than production based emissions.

Data for production based emissions is primarily sourced from reports developed by the EPA Ireland. They maintain a GHG carbon inventory database [6] with yearly updated totals. Data is documented for 4 primary sectors (Energy, Agriculture, Waste and Industrial processes) and 46 IPCC-defined sub-sectors, some of which are fully or partly associated with the built environment. Building energy consumption data is provided by the SEAI [18]. Supplementary data is obtained from the CSO. Correction factors are used to convert production to consumption figures where consumption based data is not available.

Later versions of the model will account for trade in greater detail.



Conceptual diagram of production and consumption related emissions

Emissions from the Built Environment

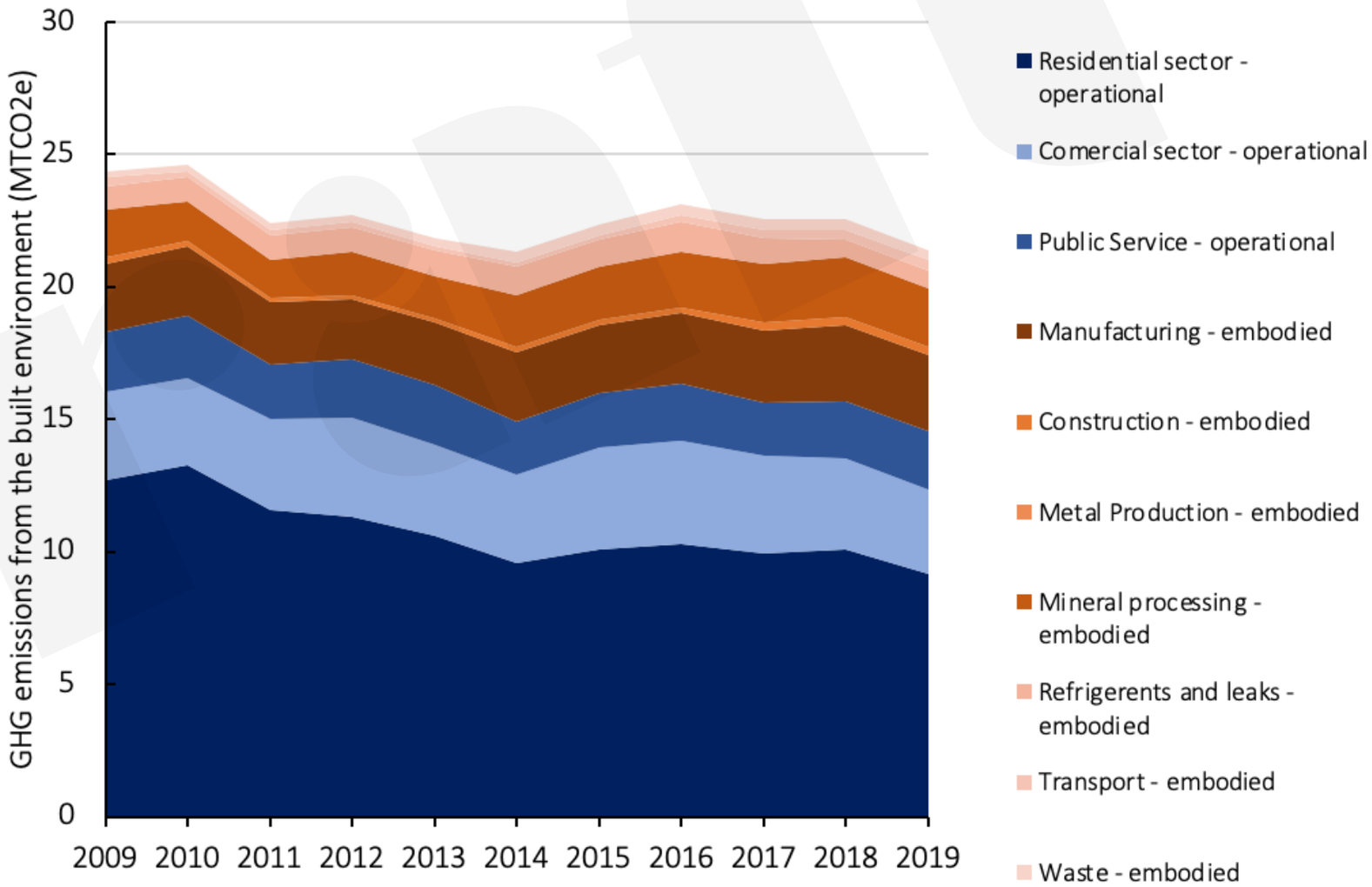
Built environment emissions are categorised into embodied and operational carbon related categories and associated sub-categories for materials, processes and type of operational carbon.

Total BE related emissions trended significantly downward in the early part of the last decade following the economic crash and resulting reduced activity, but also due to improvements in the carbon intensity of electricity. They rebounded somewhat in the middle of the decade but have trended downwards again in years since.

In the baseline year of 2018 operational related emissions account for 70% of all BE emissions, and 24% of national emissions.

In the same year, 2018 capital or embodied related emissions accounted for 30% of all BE emissions, and 11% of national emissions.

In the context of BE emissions operational carbon from the residential sector dominates, accounting for 45% of the built environment related emissions and 15% of overall emissions in 2018.



GHG emission subcategories for embodied and operational carbon. Data from [6,8,18,21]

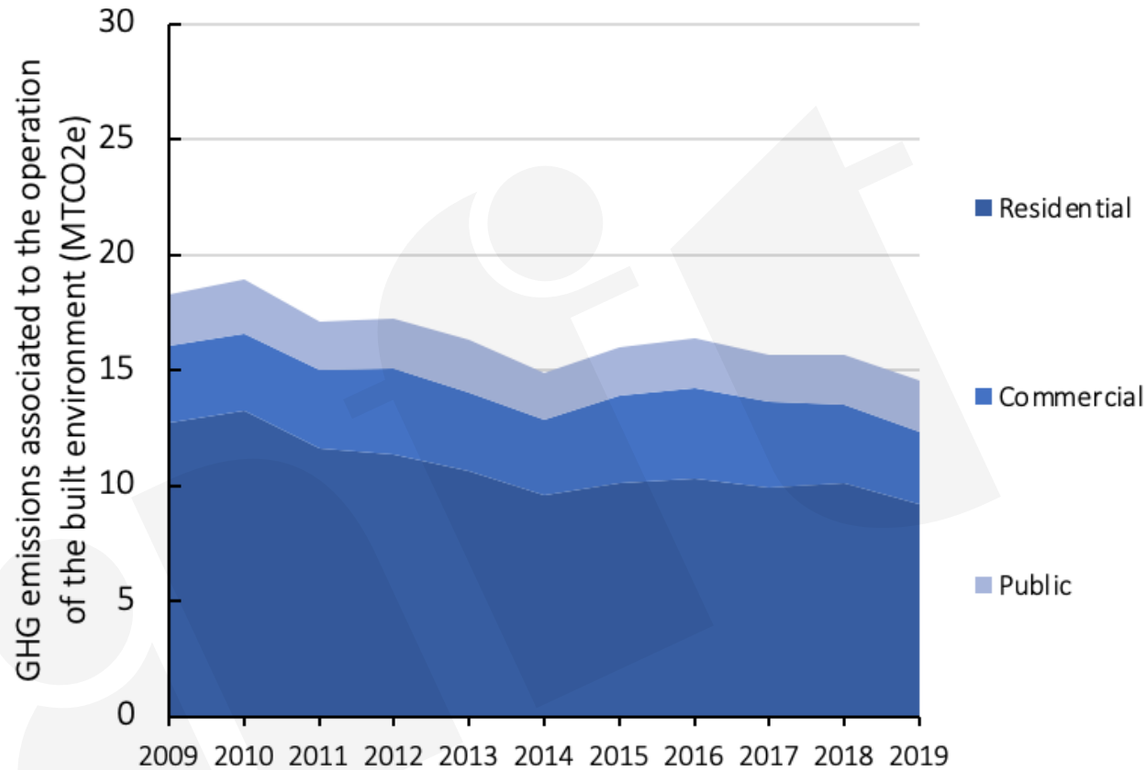
Operational Emissions

GHG emissions resulting from the operation of buildings in use represents approximately 1/4 of all national emissions. Emission totals have tended downward since the beginning to the end of the last decade due primarily to the reduction in the carbon intensity of the electricity grid.

Operational emissions from the residential sector represents two thirds of all operational emissions. This high proportion results from the sectors large requirement for energy.

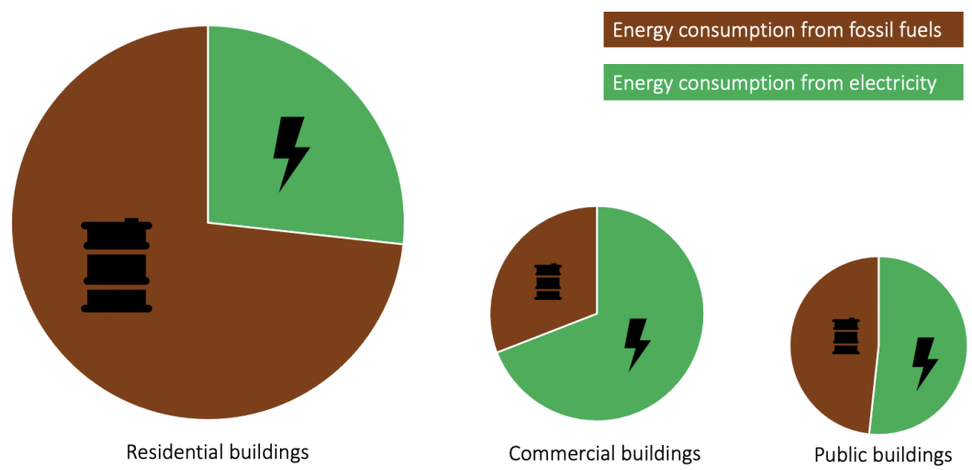
Operational carbon from the commercial sector in contrast represents ~20% of all operational emissions while the final energy consumption of public services equates to ~15%.

These totals are quantified from national energy balance data sheets [18].



Above. GHG emissions for the operation of the built environment [18,21]

Below. Fuel distribution for final energy consumption of different building sectors (2018)

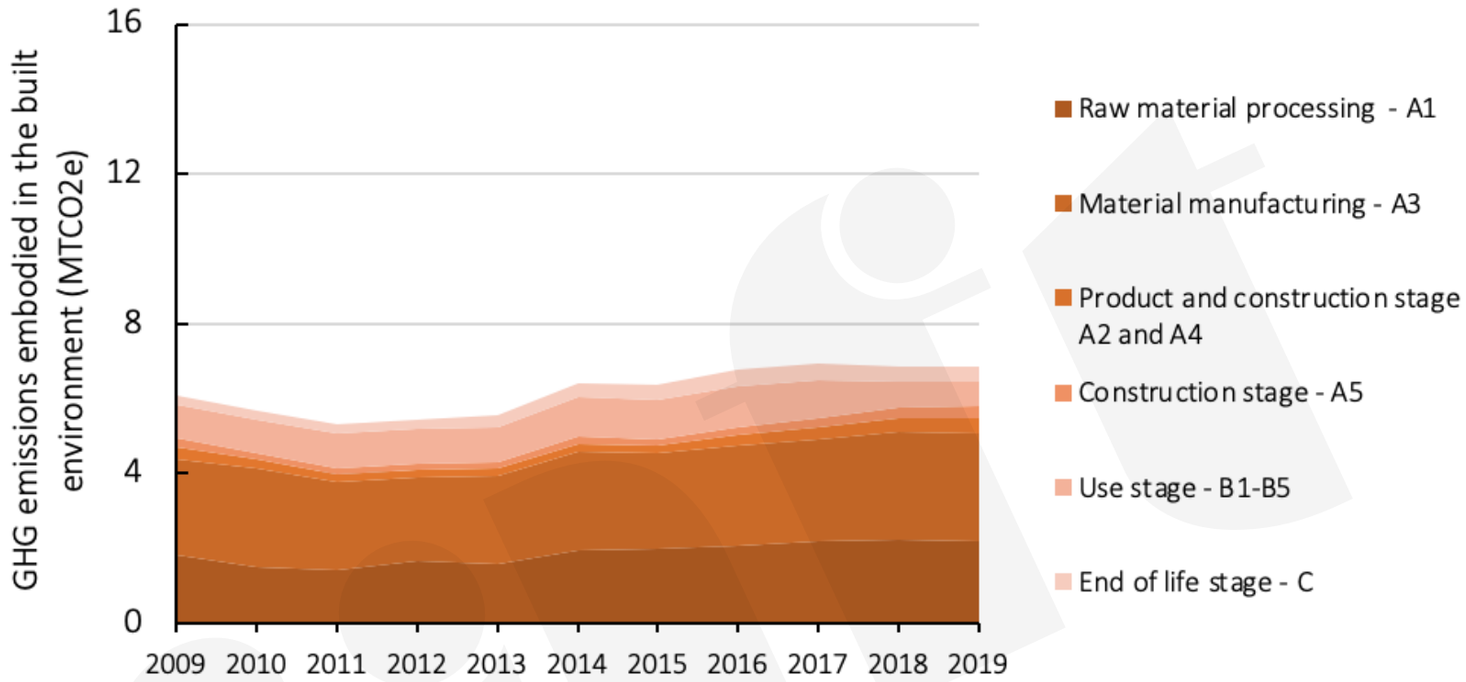


Embodied Emissions

Emissions embodied in the built environment include emissions from the processing of raw materials, manufacturing of products both on and off site as well as the emissions associated with the maintenance and end of life of the materials and products used in the built environment.

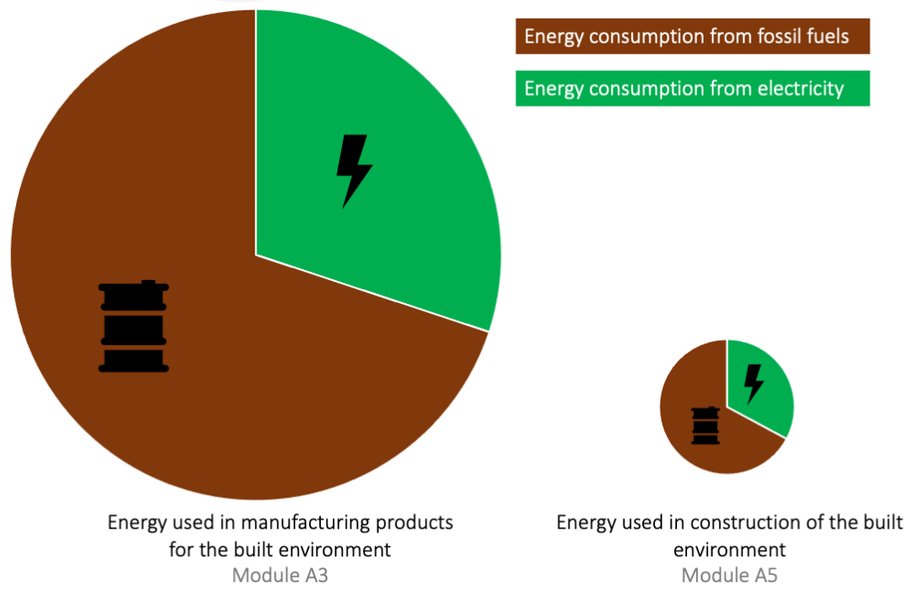
Since 2011 the embodied carbon has steadily increased. Operational carbon emissions will decrease in line with a reduction in the carbon intensity of electricity resulting in a proportional increase in the embodied carbon related emissions.

This is an initial analysis and embodied related emissions requires further investigation and more detailed examination of available data and corroboration with other data sources. Some of the sectors overlap as some data is included from different sources that are not clearly distinguished. This will be filtered out in later iterations.



Above: GHG emissions broken down by life cycle module (as per EN 15978) [6]*

Below: Fuel ratio for final energy consumption of modules A3 and A5



Carbon intensity of electricity

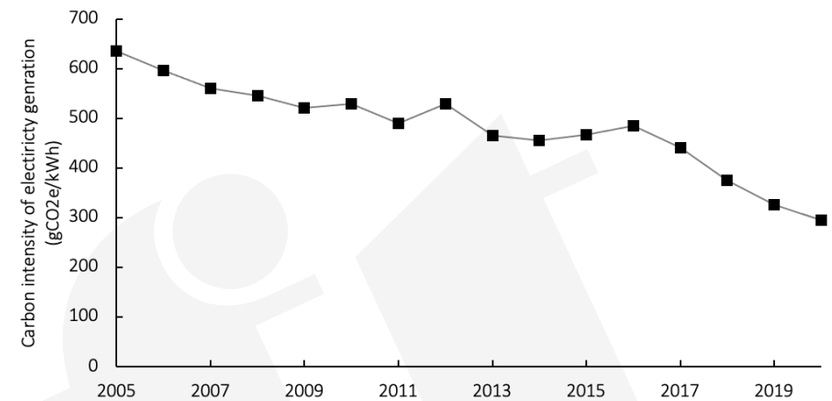
Factors affecting the carbon intensity of the built environment include the proportion and carbon intensity of electricity, and the fuel mix for different sections of the built environment. These impact the GHG emissions of both buildings in operation and the construction of buildings and infrastructure.

Electricity decarbonisation has been significant between 2005 and 2018, with a 40% reduction in carbon intensity achieved primarily as a result of significant expansion of wind capacity. The carbon intensity has fallen from 635 gCO2/kWh in 2005 to to 375 gCO2/kWh in 2018. It has continued on a downward trend to 324 gCO2/kWh in 2019.

Despite this, the latest data shows that the CO_2 emissions intensity of Ireland's energy supply is 20% higher than the European average.

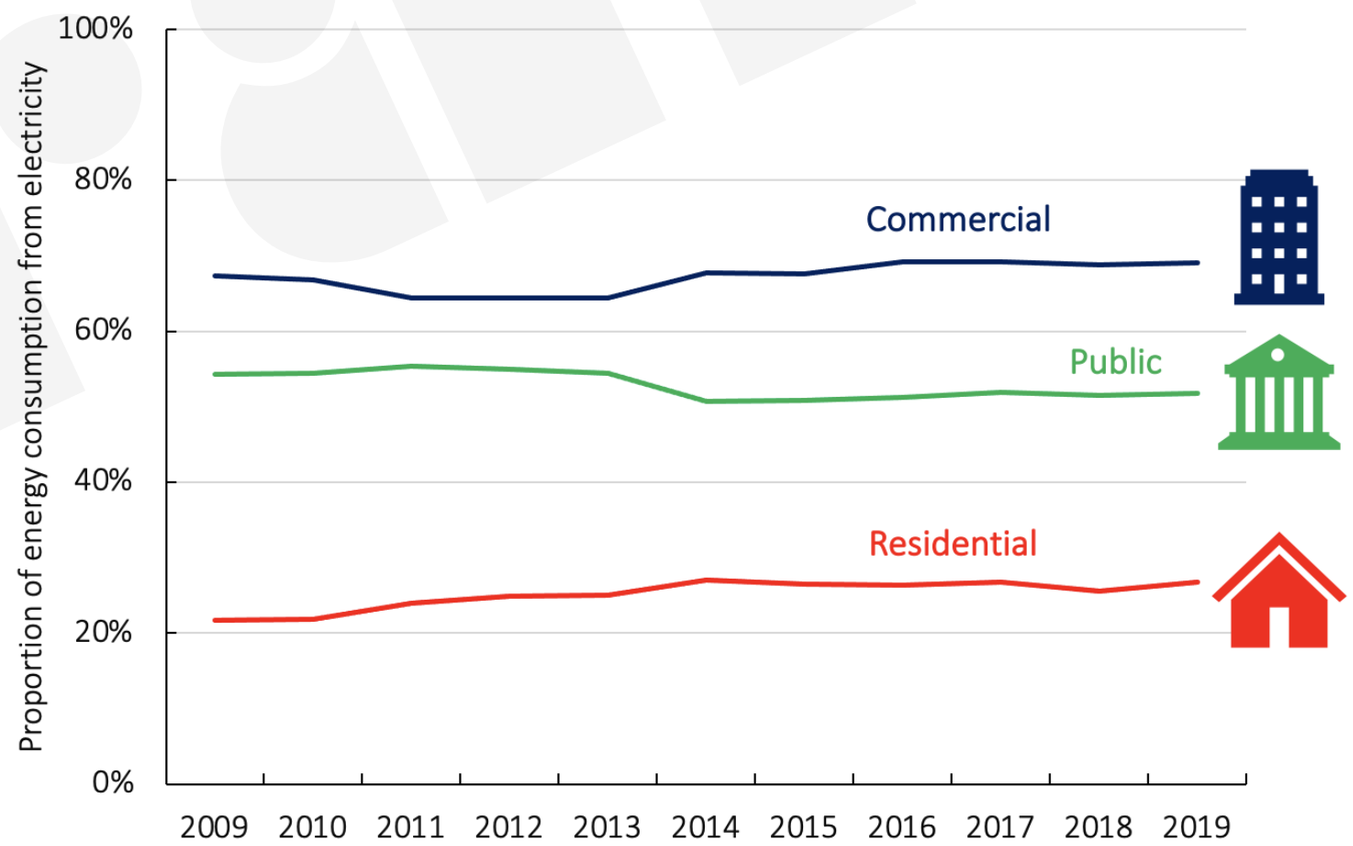
However, the impact of the improvement is pronounced on the operational related emission output.

The impact on emissions related to construction material is not as pronounced as many rely on fossil fuel sources and/or imported construction products often from countries with higher fossil fuel reliance.



Above. Historical carbon intensity of electricity [22]

Below. Proportion of energy from electricity by building type



Forecasting to 2030

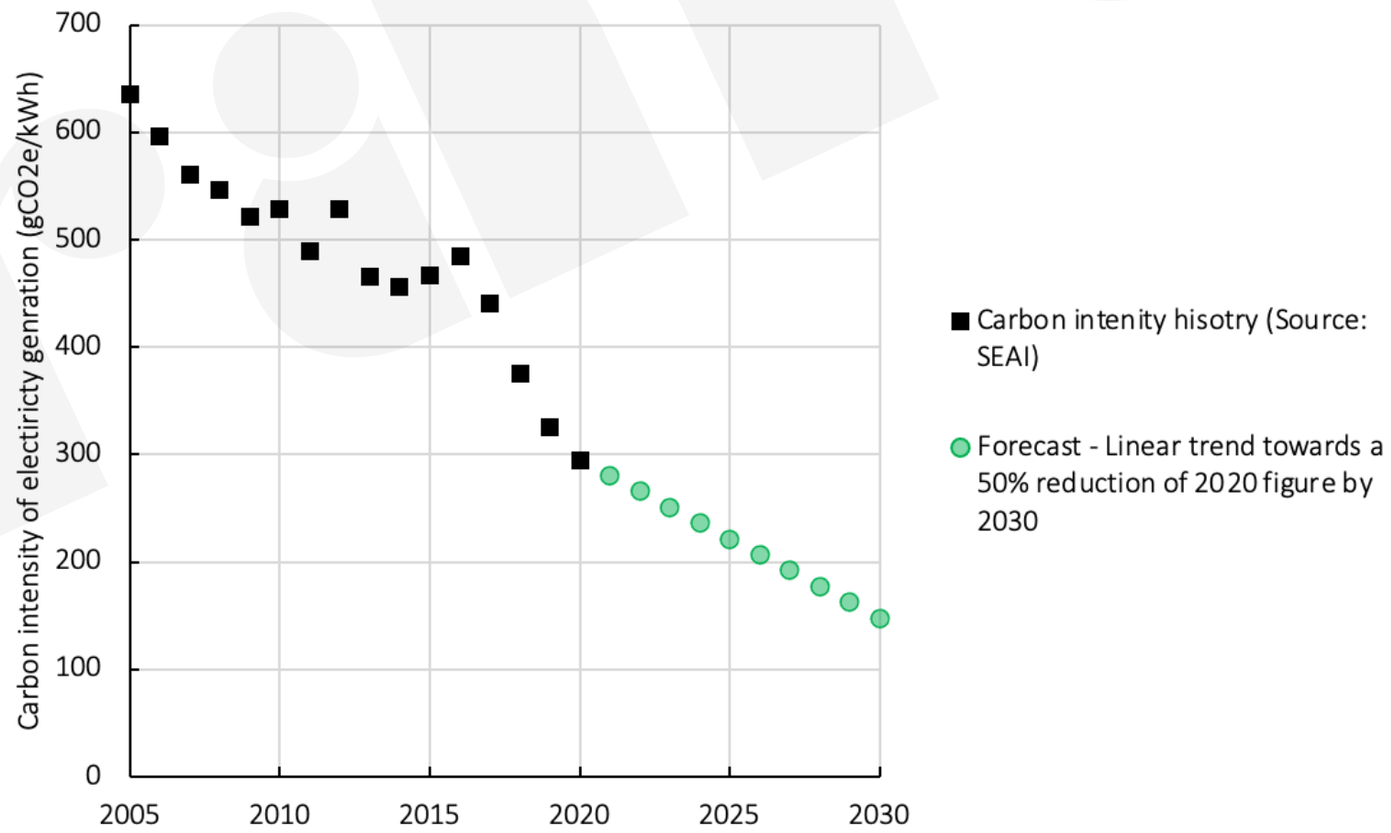
Throughout this report GHG emission projections associated with the BE are made to 2030 for a range of stated approximations and assumptions. Although the absolute value of these projections are made with a low level of confidence, the trends are broadly reliable as they are based on recent and continuous trends.

In certain sectors of the built environment the range of strategies to reduce impact are already well defined. Hence, for residential, for example, projections comprise proposed increasing rates of retrofit. It also includes the transition of space heating provision from fossil fuel to electricity power and the associated reduced and reducing GHG emissions due to decarbonisation of the electricity grid.

This project assumes all sectors equally do their share to reach the 51% reduction in GHG emissions from 2018 levels. Assuming this, the GHG budget for 2030 for the BE would be ~11 MtCO2e as will be later explained in greater detail.

The carbon intensity of electricity is key to improvements already made, and to future improvements. A 50% reduction in the carbon intensity of Irish electricity from 2020 to 2030 would result in electricity with a carbon intensity of 147.5 gCO2/kWh. Continuing on that trajectory would bring the carbon intensity to net zero by 2040.

Later versions of the model will account for varied levels of renewable penetration including ambitious targets proposed in the NDP, including 4GW onshore wind, 5GW offshore, and 2.5GW solar.



Historic and forecast carbon intensity of electricity to 2030

Residential

Key Points

GHG emissions related to residential operational energy accounts for 45% of all built environment related emissions.

>50% of the housing stock is expected to be B rated or better by 2030

Operational carbon is expected to decrease by ~30% to 2030.

Embodied carbon is expected to reach a maximum of 3.7 MtCO2/year at the height of construction.

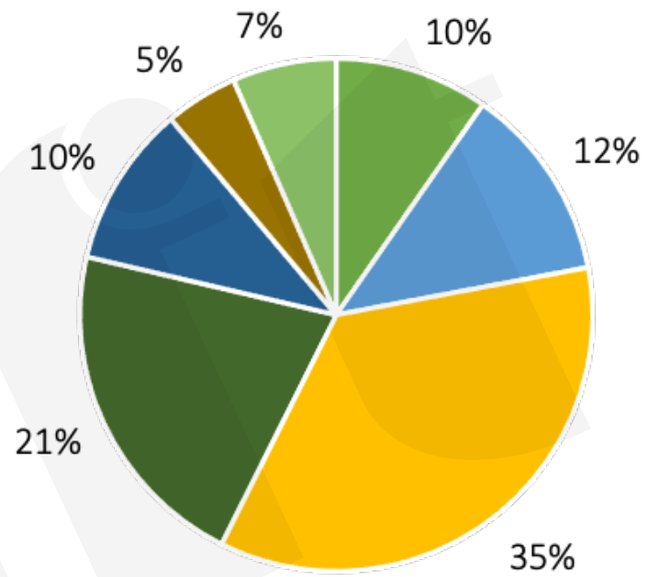
Residential Sector

The residential sector is the largest emission impacting sector both in construction and in operation.

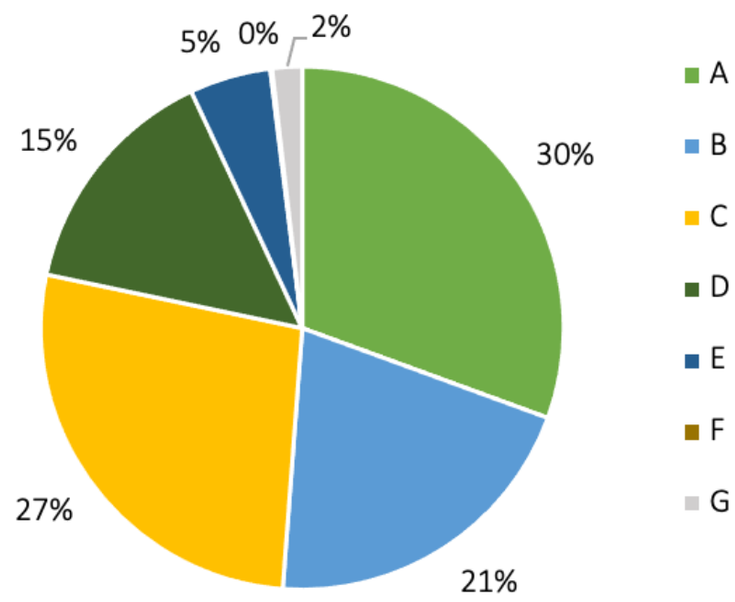
Operational carbon from the residential sector accounts for just less than half of overall built environment related emissions. Residential, quantified by floor area granted permission in a year, is typically 100 to 170 per cent higher than the combined total of the other sectors.

In the baseline 2018 year, the operational related GHG emissions totalled 10.3 MtCO2e for regulated load. The embodied GHG related emissions came to 1.04 MtCO2e. These numbers are calculated using a variety of methods. Embodied emissions will be further investigated in later iterations of this report.

Operational related emissions are quantified based on building energy ratings, extrapolated to the wider housing stock. This base data is taken from the SEAI's national BER database [18] and checked against total occupied dwelling CSO figures for 2018-2021. Data from the Central Statistics Office (CSO) [21] is further processed by Aecom [2] and the government's Build [11] report.



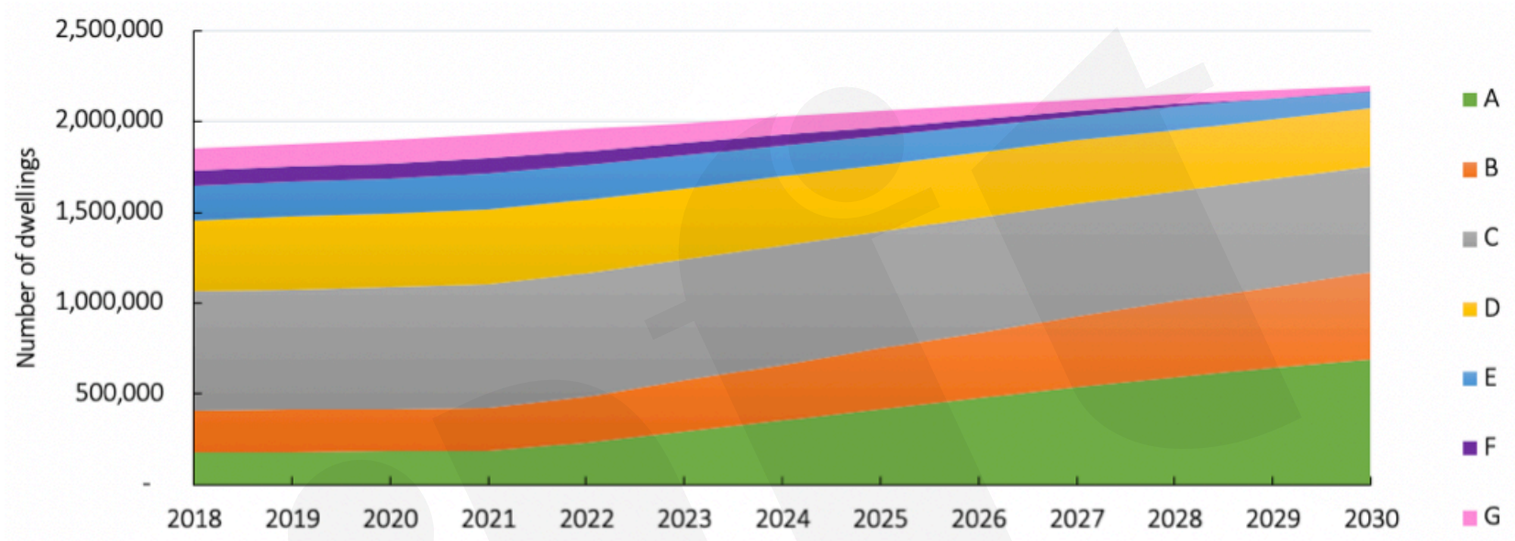
Current (2021) % of building stock by BER category



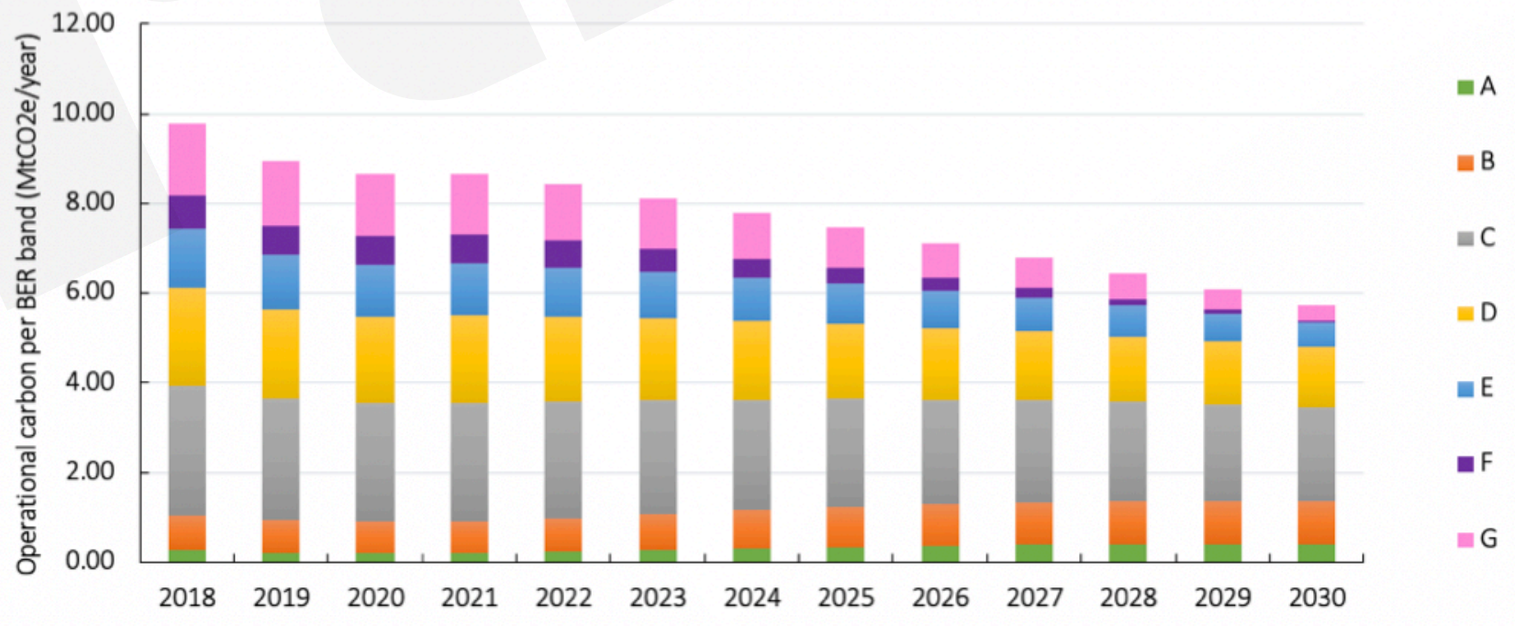
Forecast (2030) % of building stock by BER category

Residential OC Projections to 2030

Operational carbon is predicted to decrease by ~30% to 2030. National policy aims to achieve a domestic housing stock with >50% of homes rated B or better (>50kWh/m2/yr). The projections shown for operational carbon assume this is achieved, with additional homes added in line with predicted growth and as defined by the National Development Plan. Retrofit rates defined in the National Retrofit Programme are assumed. It is assumed all new builds and retrofit are equipped with electric heating or heat pump technology and that the carbon intensity of the grid's electricity is decreased in line with the projections forecast. New homes are assumed to be built at 32,500 new homes per year until 2027 followed by 25,000 per year until 2030 as per NDP. All new homes are expected to be A rated. Retrofit rates of 20,000 in 2021, 30,000 in 2022 and 50,000 from 2023 onwards are assumed, with 50% B and 50% A rated.



Projected increase in residential units to 2030 and their proposed building energy rating.



Projected operational carbon for residential sector to 2030

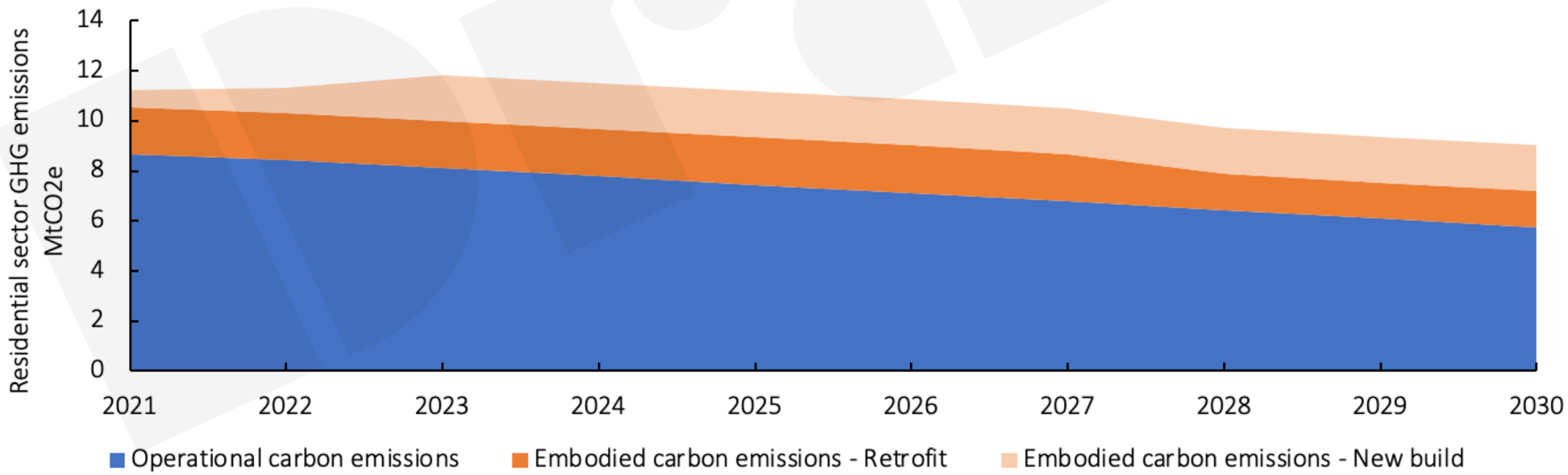
Residential EC Projections to 2030

An increase in embodied carbon from 2.5 MtCO2e/yr currently to 3.7 MtCO2e/yr at peak construction is projected based on the NDP.

The share of EC as a % of the overall GHG emissions associated with the residential sector is expected to increase from 22% in 2021 to 36% by 2030.

This forecast is based on simple projections of the m2 of area to be built and retrofit and associated embodied carbon figures per m2.

Later projections will investigate what strategies are best and should be pursued to reduce the embodied carbon portion while at the same time ensuring a reduction in residential sector operational emissions.



Non-Residential

Key Points

GHG emissions from non-residential construction is ~2.7 $MtCO_2e$ with ~1.4 $MtCO_2e$ due to commercial building

Emissions due to operation of the non-residential sector in 2018 was 36% of overall operation related emissions

Operational carbon associated to non-residential buildings is expected to decrease by 51% to 2030.

Construction of the residential sector is projected to increase at a greater rate then the non-residential sector

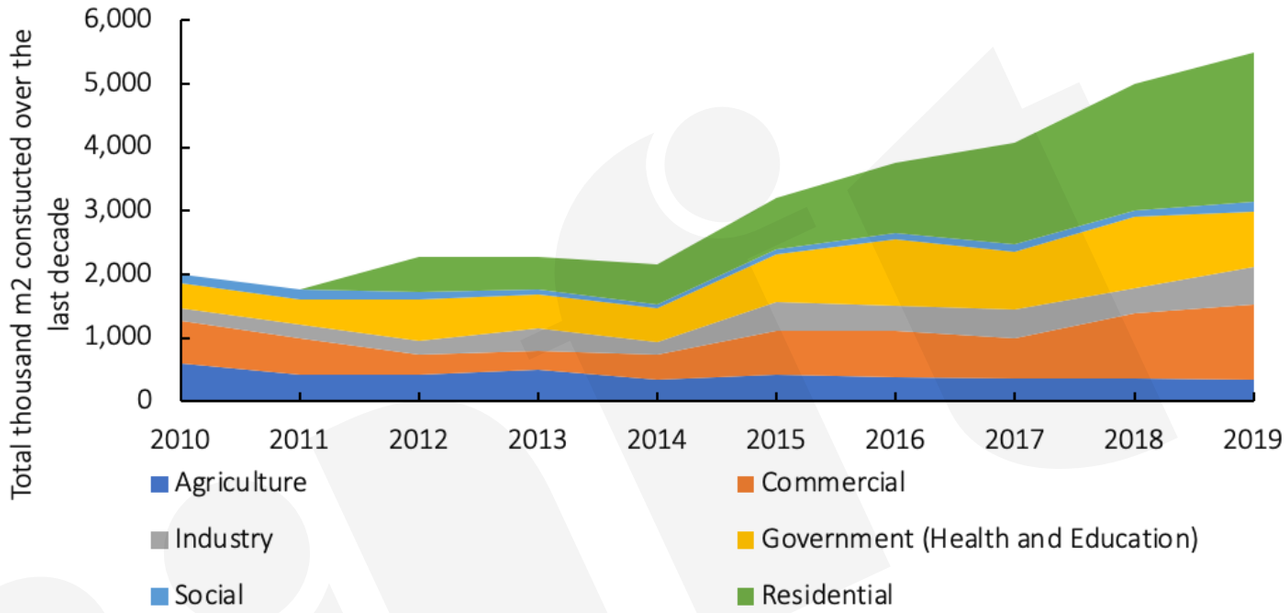
Non-Residential

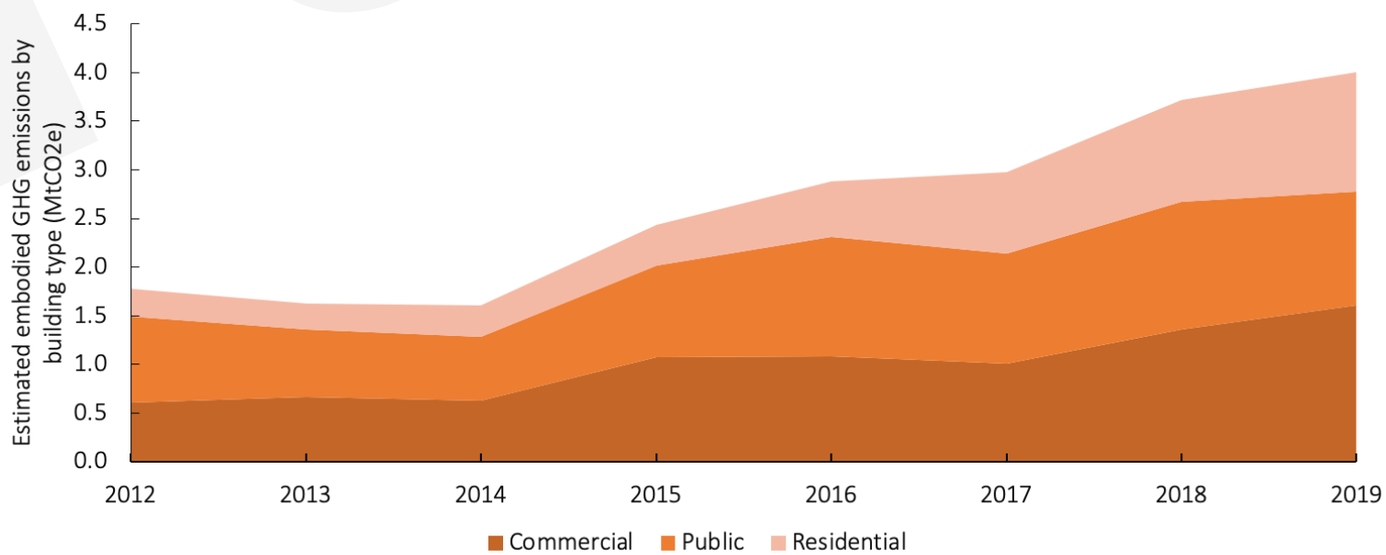
Non-residential construction is increasing in Ireland. Since 2012 the annual embodied carbon emissions associated to the non-residential sector has almost doubled.

Non residential operation emissions equated to 5.6 MtCO2e in 2018 or 36% of all operational emissions.

In the benchmark year of 2018 non-residential construction accounted for 2.7 $MtCO_2e$, of which 1.4 $MtCO_2e$ was related to commercial property and 1.3 $MtCO_2e$ to public property.

These numbers are quantified based on applications granted for planning permission and as such may vary relative to final built property. This graphs are developed using results extrapolated from data processed by Aecom [2] using CSO data.





Infrastructure

Key Points

Embodied emissions associated with infrastructure could account for up to ~2.8 MtCO2e/yr calculated using a top-down approach.

NDP includes approx. 850km of new road projects. Using a bottom-up approach the embodied carbon of transport projects is estimated at ~0.74 MtCO2e/yr.

Wind energy to expand by 4GW onshore and 5GW offshore by 2030, with 2.5GW of solar. EC of energy projects estimated at 3.9 MtCO2e to 2030.

Disparity exists between bottom-up and top-down approaches to infrastructure quantification that will be further investigated.

Infrastructure

The method of quantification of the embodied emissions related to infrastructural works presents unique challenges. This is particularly due to the poorly defined and accounted for material usage in the wider urban and infrastructural context.

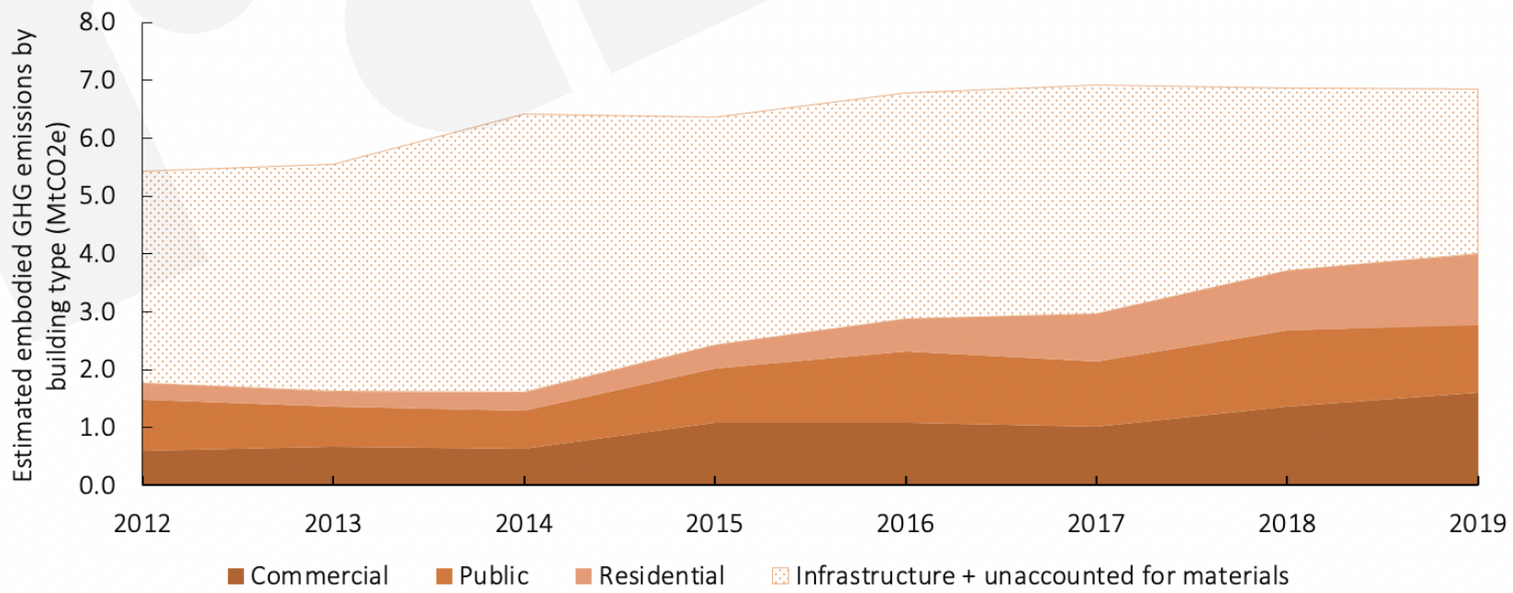
Two approaches are used in this project. In a broad-ranging, top-down approach the baseline figure for embodied emissions related infrastructure can be quantified as the difference between those emissions related to all materials used in Ireland in a given year, and the total for building related emissions.

However, this is likely to include errors as unaccounted for materials may not necessarily be used in infrastructural works. Hence this category is presented here as Infrastructure + unaccounted for materials.

Infrastructure and unaccounted for materials account for 2.8 $MtCO_2e$ and this is used as a baseline figure, with the outlined uncertainty.

The National Development Plan (see subsequent 4 pages) outlines a scheme of expenditure on large scale infrastructure in Ireland over the coming 10 years. This encompasses billions of euro of investment and will necessitate high levels of embodied carbon (EC) through material extraction, manufacture, transport, and construction activities. This project aims to as accurately as possible quantify this embodied carbon impact and hence a bottom-up approach is applied, drawing on embodied carbon quantities documented for specific projects and extrapolating these for other proposed projects. A bottom-up approach risks underestimation of total emissions. Although it is a detailed accounting exercise, it may result in exclusion of material for ancillary works, wastage, or unaccounted for activity.

While this work remains at a nascent stage, large discrepancies currently exist between the top-down and bottom-up approaches, and between embodied emissions associated to infrastructure.



Estimated embodied GHG emissions for infrastructure based on the difference between total material quantities and building kgCO2 per meter squared of permitted floor area [11, 21].

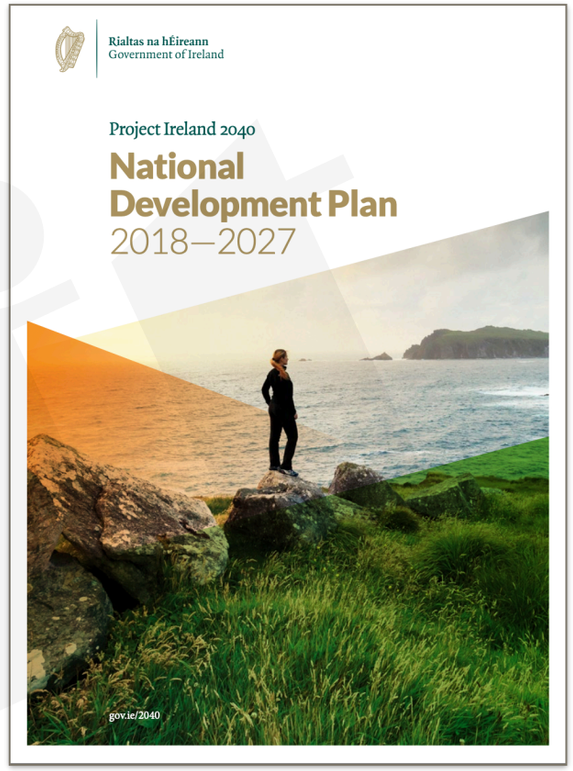
National Development Plan

The National Development Plan (NDP) 2021-2030 was launched on 4th October 2021. The plan is a revision of the NDP 2018-2027, undertaken as a provision of the Programme for Government, 2020. The review aligns the plan with the National Planning Framework, which seeks balanced regional development, clustered and compact growth, and improved connectivity.

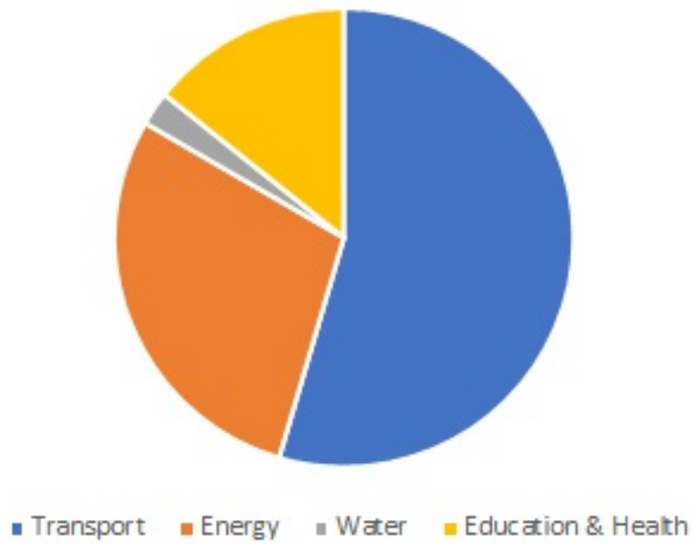
The NDP is not intended as a definitive list of all investment projects under the lifetime of the plan. However, it includes references to projects for which significant planning has already taken place. The plan commits a historically high 5% of GNI (Gross National Income) to capital spending. This amounts to €165 bn over the life of the plan. The revised NDP places an emphasis on climate action. Each of the measures in the plan was subject to an assessment of its climate and environmental impact across a range of measures from Climate Mitigation to Air Quality [23]. The resulting grade category, from A (strongest) to C (weakest) is displayed next to each measure throughout the plan. The plan also contains references to government targets for renewable energy and energy retrofitting.

The NDP's focus on investment covers a broad range of areas from broadband to biodiversity. The infrastructure elements of the plan include road-based and public transport, water services and flood relief works, energy generation, port developments, and public buildings including schools and hospitals. The infrastructure projects of the NDP represent a major construction programme involving billions of euro of investment each year for the lifetime of the plan. This scale of construction will necessitate high levels of embodied carbon (EC) through material extraction, manufacture, transport, and construction activities.

The total EC associated with the NDP was calculated using a range of mostly bottom-up methods, and includes projects that have been developed to a sufficient stage to allow carbon estimates to be applied.



Above. Ireland's National Development Plan launched in 2018 [9]
Below. EC of main NDP sectors



Evaluating the impact of the National Development Plan | Methodology

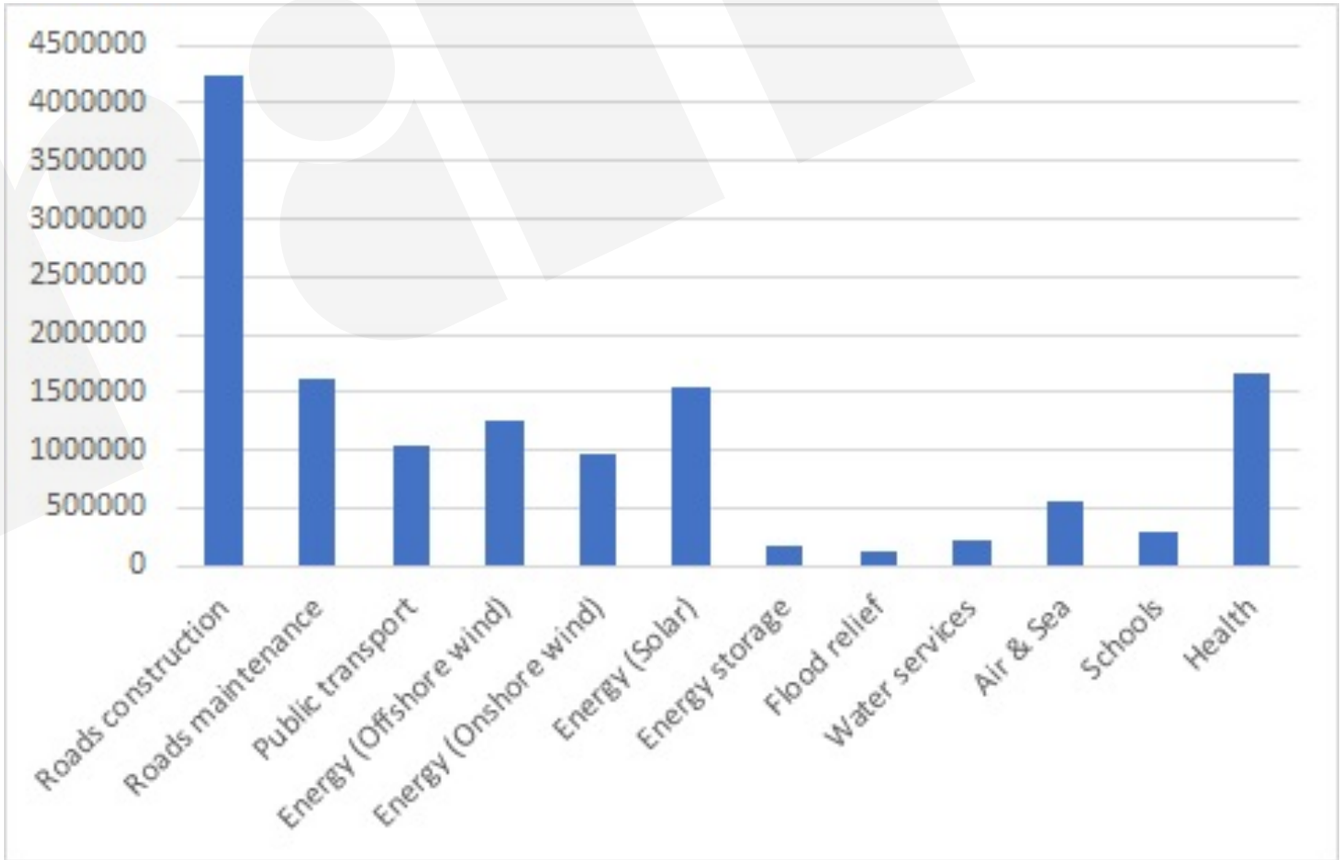
The quantification of the embodied carbon impact of the NDP is undertaken in a mostly bottom-up manner. GHG emissions are calculated for individual projects, with results extrapolated to similar scaled projects in the sector.

A bottom up approach is valid when the list of projects if of sufficient detail (for example the roads projects). In other areas (such as water services projects) insufficient data resulted in a top-down approach being adopted, wherein overall budgets for a sector give estimates for the number of projects and resulting carbon figures.

The bottom-up method risks underestimation, as the full complexity of differentials between projects can not be assessed accurately. Conversely, top-down methods can result in overestimation, as large numbers imply greater numbers of projects than occur in reality. The study uses both with caution to create the embodied carbon estimates.

Although the NDP is wide ranging and includes significant works, it should be noted that it does not include all construction projects that will be publicly funded in the timeframe of the plan. Also, many projects mentioned in the plan are as yet not detailed enough to allow carbon factors to be applied.

Projects included in the NDP fall under a number of main categories including road transport, public transport, air & sea infrastructure, energy, water services, flood relief, education, and health. While most of the funding for this investment is from exchequer resources, some sectors mentioned in the NDP, such as wind power generation, will be largely privately financed.



Initial estimates of GHG emissions (in $MtCO_2e$) of project categories within the NDP using a mostly bottom-up approach

Evaluating the impact of the National Development Plan | Results I

Transport

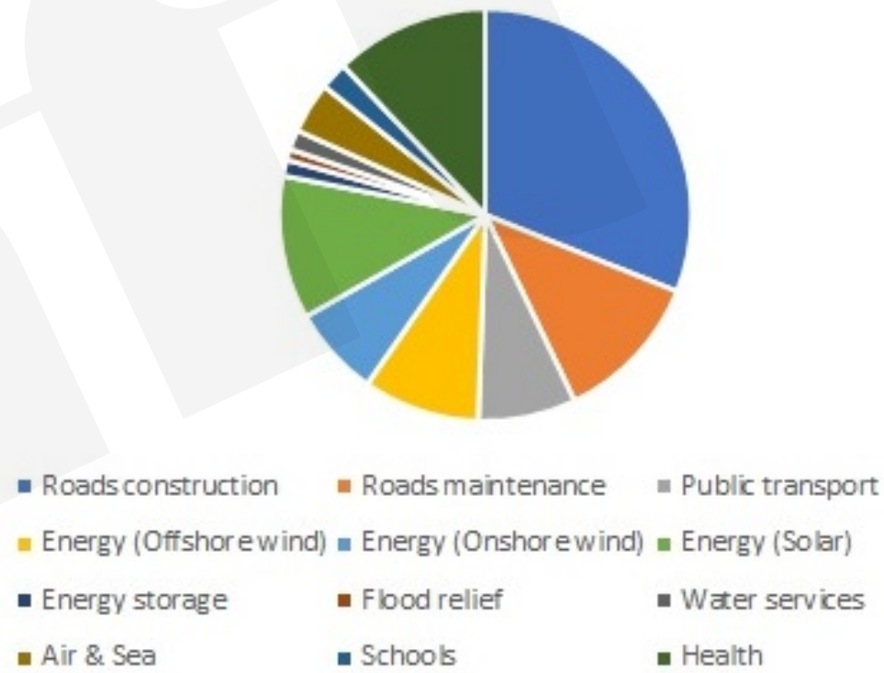
The largest individual sector is the roads programme. Approx. 850km of new roads are included in the plan, with a calculated embodied carbon total of 4.24MtCO2e. The NDP lists all roads currently in development, including projects in design development stage. The EC figure for roads includes the M20 Cork to Limerick motorway. The final design of this link is to be confirmed, with an upgrade of the N20 and/ or rail alternatives under consideration. Similarly, the Galway City Ring Road is included in the NDP, and so is included in the calculation. The project is currently under review by An Bord Pleanála.

Public transport projects assessed for the calculation include the Dublin metro (including tunnel, raised, and at-grade sections, with 15 stations) and Cork Light Rail (with a proposed length of 17km). Commuter rail projects for Cork and Galway, along with refurbishment works on railway terminals, have not been detailed sufficiently for inclusion in the calculation. Sea port projects include upgrades at Ringaskiddy, Dublin Port, and Shannon-Foynes. Total embodied carbon of public transport projects and ports is 1.59MtCO2e.

Water & flood relief

The NDP commits to the delivery and development of water and wastewater services over the lifetime of the plan. From 2021-2025, €6bn is budgeted for water services investment, focusing on water supply, water conservation, and future-proofing. The largest project is the expansion of the Ringsend Wastewater Treatment Plant, which will add capacity for an additional 400,000 people. The combined embodied carbon of water services projects is 0.21 MtCO2e.

Flood relief schemes are planned for several towns and cities, with works typically including flood walls and embankments, drainage works, bridge strengthening and replacement, new bridges, dredging of water channels, debris traps, and public realm improvements. The combined embodied carbon for flood relief schemes is 0.11 MtCO2e.



Above: Embodied Carbon of all NDP sectors

Evaluating the impact of the National Development Plan | Results II

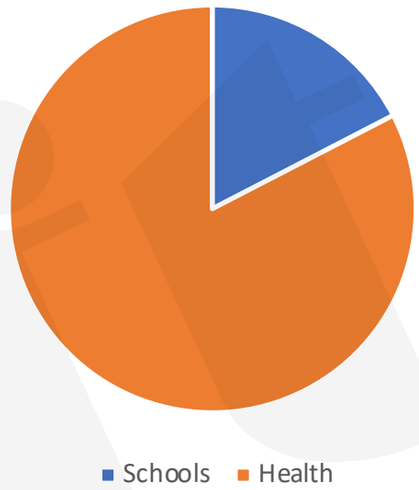
Energy

The NDP calls for an increase of 5GW of offshore wind by 2030, with an additional 4GW of onshore wind, and 2.5GW of solar. These figures contribute to the government's aim for 80% renewable electricity generation by 2030. Applying estimates for tCO2e per wind turbine, the embodied carbon for offshore development is 1.25MtCO2e, with 0.96MtCO2e for onshore wind. Solar is estimated at 1.53MtCO2e. Energy storage is mentioned in the NDP without specific targets. Energy Storage Ireland reported in 2020 that 2.3GW of projects are in development. An EC figure of 0.17MtCO2e was calculated for this volume of storage.

Public buildings (education and health projects)

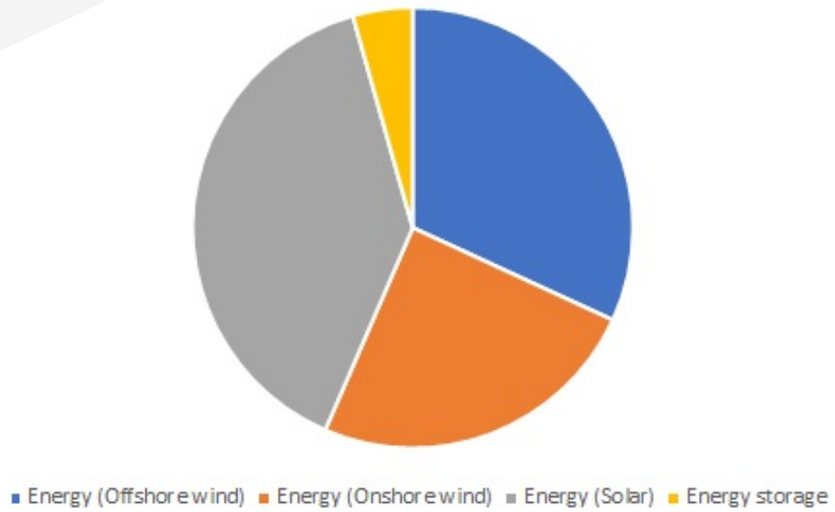
The NDP notes 1200 school building projects are planned under the government's two school building programmes- the Additional Accommodation Programme and the Large Scale Projects Programme. It is envisaged that between 150-200 school building projects will be completed annually each year to 2025. This school building programme is focused on the post-primary sector, where pupil numbers are forecast to peak in 2024-2025. The embodied carbon of the school building programme is 0.29MtCO2e

The health capital budget includes the completion of the National Children's Hospital, acute bed capacity projects nationwide, the primary care centre construction programme, and the replacement and refurbishment of community nursing units. The heterogenous mix of projects meant the health projects embodied carbon total was calculated in an approximate method resulting in an overall embodied carbon figure of 1.65MtCO2e.



Above. EC of education and health projects

Below. EC of energy projects



Toward net-zero

Key Points

GHG emissions from the built environment are projected to decrease in 2030 primarily due to a decrease in operational carbon.

Operational carbon is estimated to decrease by approximately 43% to 2030, led by a reduction in the residential sector.

No discernible decrease is projected in embodied emissions related to the built environment.

Based on current analysis it is projected the built environment will be ~40% above 2030 GHG emission targets.

Toward net-zero

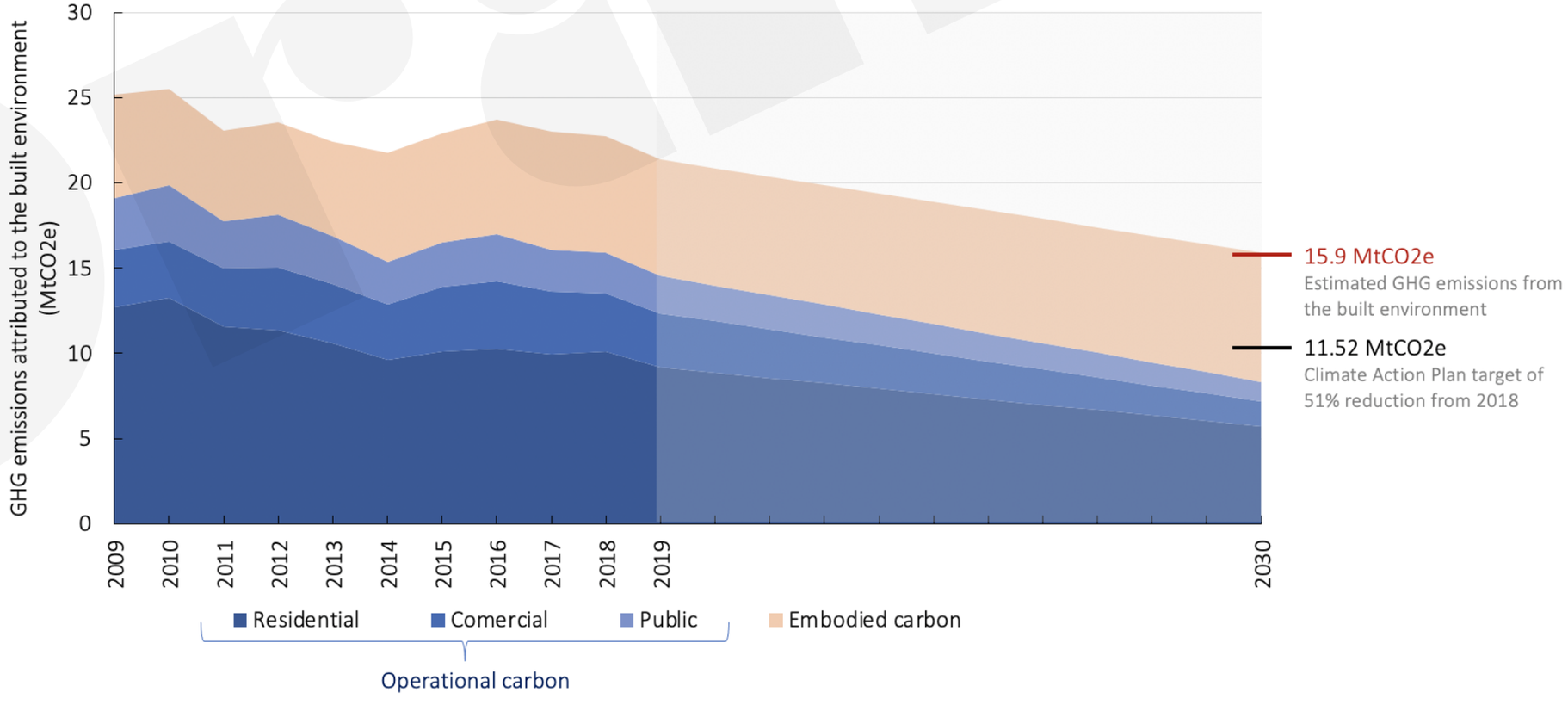
An initial estimate of built environment GHG emissions to 2030 is calculated using a broad top-down methodology, that needs refinement. Reiterations of these projections will include greater detail and nuance, while scenarios will be defined that will account for different policy, technology rollouts and innovations.

For the graphic shown, residential operational carbon is projected to decrease significantly based on an assumed 50% reduction in grid emissions, and an assumption that all new, and newly retrofit housing, will be electrically powered. This projection also accounts for an increase in housing stock inline with NDP and retrofit plans.

Commercial and public sectors are assumed to grow and enhance efficiency in line with the residential sector, although with the added savings deriving from their greater proportion of electricity power. Future embodied carbon is calculated here by assuming a continuation of the growth trend in embodied carbon emissions observed over the past decade while also accounting for the reduction due to the improvement in the carbon intensity of electricity relevant to a portion of nationally produced construction products.

It is projected the built environment will be 4.8 MtCO2e above the 2030 targets, as calculated using the defined methodology.

National reduction targets associated with the built environment will not be achieved through operational carbon emissions reductions alone. Later versions of this report will investigate scenarios to reduce built environment related emissions and particularly embodied emissions.



Projected Built Environment GHG emissions to 2030

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