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Trinity College Dublin Decarbonisation Strategy

Summary report

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Glossary

AHU – Air Handling Unit
ASHP – Air Source Heat Pump
BMS – Building Management System
BeMS – Building Energy Management System
CAPEX – Capital Expenditure/ Costs
CHW – Chiller Water
COP – Coefficient of Performance
CO_2e – Carbon Dioxide Equivalent
CRM – Carbon Reduction Measure
DC – District cooling
DHN – District heating
DHW – Domestic Hot Water
DX – Direct Expansion
EOL- End of Life
EUI – Energy Use Intensity
EUB – Energy Use Breakdown
FCU – Fan Coil Unit
FY – Financial Year
GHG – Green House Gas
GIA – Gross Internal Area
GWP- Global Warming Potential
HH – Half hourly
HVAC – Heating, Ventilation, & Air Conditioning
LED – Light-emitting diode
LT – Low Temperature
LTHW – Low Temperature Hot Water
MCA - Multi-criteria analysis
MEP – Mechanical, Electrical, & Plumbing
NIA – Net Internal Area
NZC – Net Zero Carbon
NPV – Net Present Value
O&M – Operation and Maintenance
PC – Post Completion
PIR – Passive Infrared
POU – Point Of Use
PPA- Power Purchase Agreement
PV – Photo Voltaic
RIAI – Royal Institute Architects Ireland
SBTi – Science Based Targets Initiative
SCOP – Seasonal Coefficient of Performance
SEER – Seasonal Energy Efficiency Rating
SEAI - Sustainable Energy Authority of Ireland
TCD – Trinity College Dublin
TRV – Thermostatic Radiator Valves
U-Value – Thermal transmittance
VAV – Variable Air Volume
VfM – Value for Money
VRF – Variable Refrigerant Flow
VRV – Variable Refrigerant Volume
WGBC – World Green Building Council

Contents

EXECUTIVE SUMMARY

Executive summary

Overview

This report outlines a decarbonisation strategy for Trinity College Dublin (TCD), providing a clear roadmap to achieve national SEAI targets and TCD's Net Zero Carbon 2040 goal. The strategy is based on analysis of TCD's varied estate of over 100 buildings and offers an actionable plan to meet the University's climate commitments.

Key Carbon Targets:

- SEAI Target 1: Reduce overall operational carbon emissions by 51% by 2030.
- SEAI Target 2 : Reduce fossil-fuel carbon emissions by 51% by 2030.
- Achieve Net Zero Carbon for operational emissions by 2040.

Key findings

- The majority of carbon emissions are concentrated in a small number of high-priority buildings and clusters, notably TBSI, Island Campus, Dartry, and St James's Hospital Campus.
- The 2030 targets cannot be met without significant investment in heat decarbonisation.
- Many gas boilers are at or near end-of-life. Replacing them with new gas boilers would jeopardize the carbon targets.
- Significant increases in electrical capacity will be required to support the transition from fossil fuels to electrified heating.

Strategy headlines:

The strategy prioritises demand reduction, heat decarbonisation, and targeted investment, focusing first on the highest-emitting assets.

- A suite of low-cost demand reduction measures is identified, including HVAC setpoint adjustments and heating/cooling deadbands, ventilation optimisation, and behaviour change programmes
- Electrification of heat, primarily through the deployment of air source heat pumps and small-scale heat networks, is proposed.
- This is sequenced to align with plant end-of-life, technical feasibility, and capital investment, minimising disruption and maximising value for money.

Investment needed

- Estimated investment to achieve **Target 2 (by 2030): ~€54.3M**
- Total capital investment for **NZC by 2040: ~€115.5M**
- Note a ±30% level of accuracy is advised on these estimates.
- The TCD Estates team will require additional resources to deliver the significant programme of works required.

Key next steps for Trinity College Dublin

- ❑ Review the recommendations set out in this report and develop a detailed implementation plan and programme of works
- ❑ Undertake detailed technical feasibility studies for priority big moves
- ❑ Engage with DNO and progress with site electrical capacity upgrades to support decarbonisation

Strategy to achieve targets

How to meet SEAI Target 1

- The Irish electricity grid is expected to decarbonise significantly by 2030.
- Our modelling indicates that under a baseline (do-nothing) scenario, TCD's operational carbon emissions could fall by approximately 50%, which is close to the SEAI target, but this estimate is subject to uncertainty.
- This projection accounts for energy reductions already achieved (2016/18–2024) and anticipated grid decarbonisation.
- However, grid decarbonisation is outside TCD's direct control and should not be relied upon as the sole strategy.
- Therefore, TCD should not rely on grid decarbonisation to achieve Target 1.
- **Implement demand reduction measures across the estate to deliver a further ~15% savings**, providing a comfortable margin to achieve Target 1.

Recommendation

- [ ] Roll out low- cost demand reduction measures across the estate to ensure the target is met

How to meet SEAI Target 2

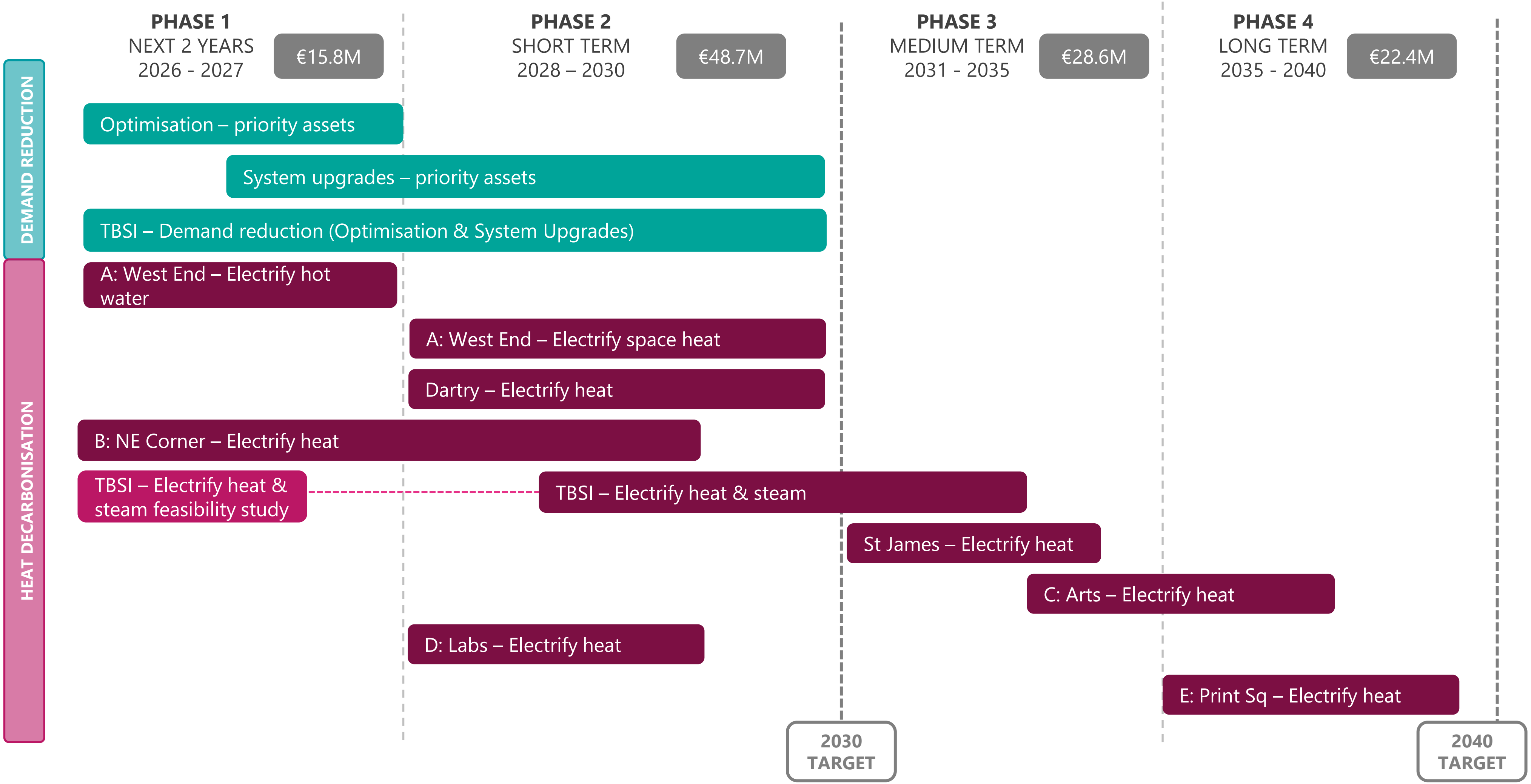
- The fossil-fuel target is intended to encourage electrification, primarily by switching heating from gas to electricity via heat pumps.
- While the electricity grid's carbon intensity is expected to decrease, natural gas will remain carbon-intensive, making continued gas use less sustainable.
- Demand reduction alone will not suffice; **decarbonising heat is essential.**
- Many gas boilers are at or near the end of their service life. Extending their use may be possible in the short term, but replacement is imminent. Replacing with new gas boilers risks missing Target 2 and undermining net zero goals.
- TCD should investigate several heat decarbonisation options. This decarbonisation strategy identifies what are envisaged to be the most cost-effective and easiest to implement approaches, though this may need to be revisited as more detailed technical feasibility and cost assessments are completed.

Recommendation

- [ ] Progress with detailed technical feasibility studies for priority heat decarbonisation moves identified to confirm viability and refine cost estimates.

Implementation timeline

TOTAL EST. COST = €115.5M
±30%



SECTION 1

PROJECT OVERVIEW

Project overview

Background

Trinity College Dublin (TCD), as a publicly funded institution in Ireland, is subject to national green house carbon emissions (GHG) targets. Ireland's Climate Action Plan Act 2021 requires all public sector bodies, including higher education institutions to:

- Reduce greenhouse gas (GHG) emissions by 51% by 2030
- Fossil fuel emission target of 51%
- Improve energy efficiency by 50% by 2030
- Achieve net-zero emissions no later than 2050

In response, TCD has set its own Net Zero Carbon 2040 target, covering operational carbon emissions.

Project outline

To support achievement of this commitment, TCD has engaged Allies & Morrison and Buro Happold to develop a comprehensive strategy for reducing greenhouse gas emissions and improving energy efficiency across the University's central campus and wider estate to develop a decarbonisation strategy. The study aims to address the unique challenges faced by the University, including the diverse age and condition of campus buildings, historic preservation requirements, evolving patterns of use, and the need to balance operational improvements with the core mission of teaching and research.

The study included a series of interrelated analyses, covering energy demand reduction, heat decarbonisation and outline feasibility studies for energy centres to develop an overarching decarbonisation strategy and robust pathway for Trinity College Dublin to meet its climate commitments. Budget costs for the decarbonisation measures have been prepared by a Quantity Surveyor (AECOM) to inform decision making and TCD capital budget planning.

Purpose of report

This report constitutes the final deliverable and presents the outcomes of the Decarbonisation Study. It consolidates the findings, and recommendations from the study into a clear and actionable roadmap. This includes summarising the baseline energy and carbon performance, and the recommended carbon reduction measures, identified and prioritised through multi-criteria analysis that considers cost, carbon impact, technical constraints, and operational impacts. These are presented as a sequence of 'Big Moves'.

This document is ultimately intended to support Trinity College Dublin's leadership and stakeholders in making informed decisions and driving progress towards meeting its carbon targets. Further detailed feasibility and design studies will be required to develop and refine the proposed map.

Study scope

The scope of Decarbonisation Strategy study covers TCD's portfolio assets. This portfolio includes a wide range of building typologies, functions, ages and levels of performance. A summary breakdown of the existing estate in terms of building cluster, floor area, and baseline energy and carbon performance is shown in table 1-1.

As can be seen, the Island campus and TBSI constitute a significant proportion of the University's floor area (~64%) and are responsible for a larger proportion of overall carbon emissions (~76%). Of the remaining clusters, Dartry and St James campus represent a high portion of emissions due to their relatively high fossil fuel use.

Figure 1-1: Proportion of emissions and estate area split by typologies

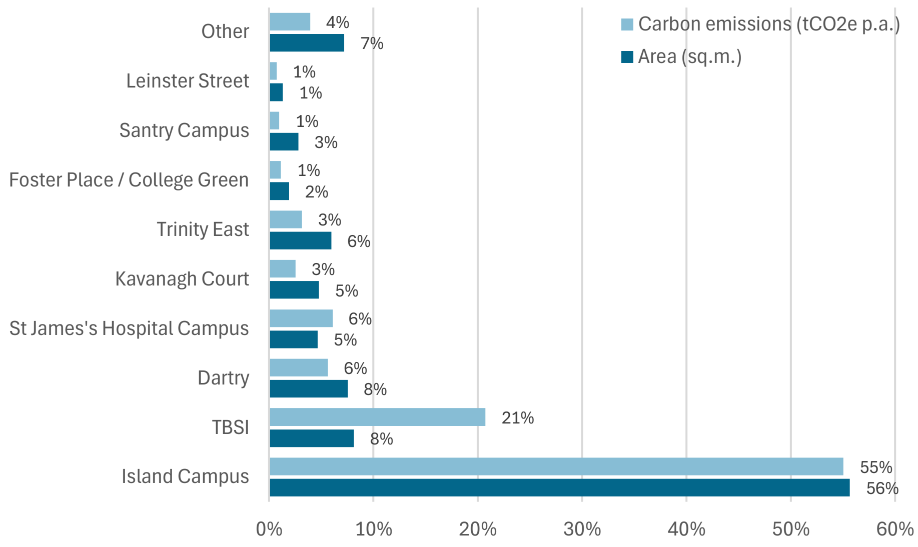


Table 1-1: Overview of TCD's estate

Cluster	No. of buildings	No. of protected buildings	Area	Area	Gas Consumption	Electricity Consumption	Total fuel Consumption	Carbon emissions (2024)	Carbon emissions (2024)
			sq.m.	%	kWh p.a.	kWh p.a.	%	tCO2e p.a.	%
Island Campus	62	14	197,596	56%	21,415,101	20,237,890	54%	9,740	55%
TBSI	1	0	28,849	8%	9,887,954	6,209,407	21%	3,668	21%
Dartry	6	0	26,725	8%	3,815,339	815,955	6%	997	6%
St James's Hospital Campus	5	0	16,551	5%	2,307,134	2,283,937	6%	1,077	6%
Kavanagh Court	1	0	17,000	5%	1,457,818	569,400	3%	449	3%
Trinity East	10	0	21,187	6%	774,212	1,515,678	3%	560	3%
Foster Place / College Green	2	0	6,801	2%	554,866	334,610	1%	202	1%
Santry Campus	3	0	9,962	3%	466,193	297,967	1%	174	1%
Leinster Street	2	0	4,699	1%	310,109	240,548	1%	127	1%
Other	13	0	25,598	7%	1,625,718	1,374,156	4%	697	4%
Total	**105**	**14**	**354,968**	**100%**	**42,614,445**	**33,879,548**	**100%**	**17,691**	**100%**

Decarbonisation targets

SEAI Targets for Public Institutions (Ireland)

Under Ireland's Public Sector Climate Action Mandate, administered by the Sustainable Energy Authority of Ireland (SEAI), all public bodies, including universities, hospitals, and government agencies, are required the following targets:

- 51% reduction in energy-related greenhouse gas (GHG) emissions by 2030
- 51% reduction in thermal (heating and transport) related GHG emissions by 2030
- 50% improvement in energy efficiency
- Achieve net zero status by 2050

These targets are legally binding and form part of Ireland's national climate action strategy. Achieving them requires public institutions to implement long-term strategic planning, secure resources and investment, and adopt energy management programmes. Public bodies must also produce annual Climate Action Roadmaps detailing their progress and planned actions and publish annual energy statements describing measures taken to improve energy performance.

In response to the overall SEAI requirement of net zero by 2050, TCD have set a target year of 2040.

national carbon emission target (indirect EU mandate)		TCD target
target 1	**target 2**	**target 3**
Reduce overall greenhouse gas (GHG) emissions by 51% by 2030	Reduce overall greenhouse gas (GHG) emissions by 51% by 2030	Achieve Net-Zero Carbon by 2040 Trinity have set the above target in response to the mandated target of achieving net zero carbon by 2050

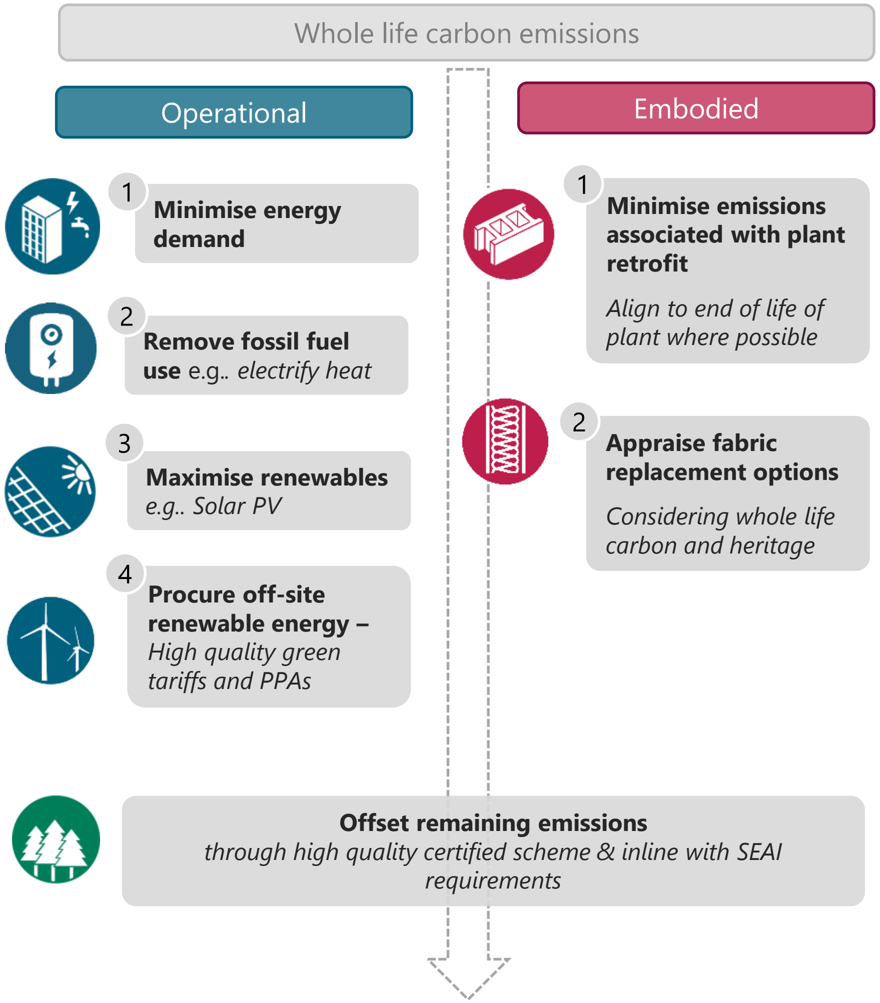
Figure 1-2: Summary of TCD's decarbonisation related targets

Best practice approach

It is recommended that TCD follow a best practice approach to achieving net zero carbon. This study has followed current industry best practice including SEAI and the World Green Building Council's (WGBC) definition for operational carbon emissions.

This net zero carbon approach is to minimise **operational emissions** as far as possible by reducing energy demand, electrifying assets by removing fossil fuel, and installing solar PV across available roof area. Once operational emissions are reduced as far as possible residual emissions should be mitigated through green energy procurement and investment in high-quality carbon offsets.

Embodied carbon emissions should be considered for any new buildings and efforts should be made to reduce these by setting best practice targets from industry bodies such as RIAI for new construction projects. The final post-construction embodied carbon should be recorded so this can be offset in the future alongside any other residual operational emissions once TCD has established its carbon offsetting approach inline with SEAI recommendations.

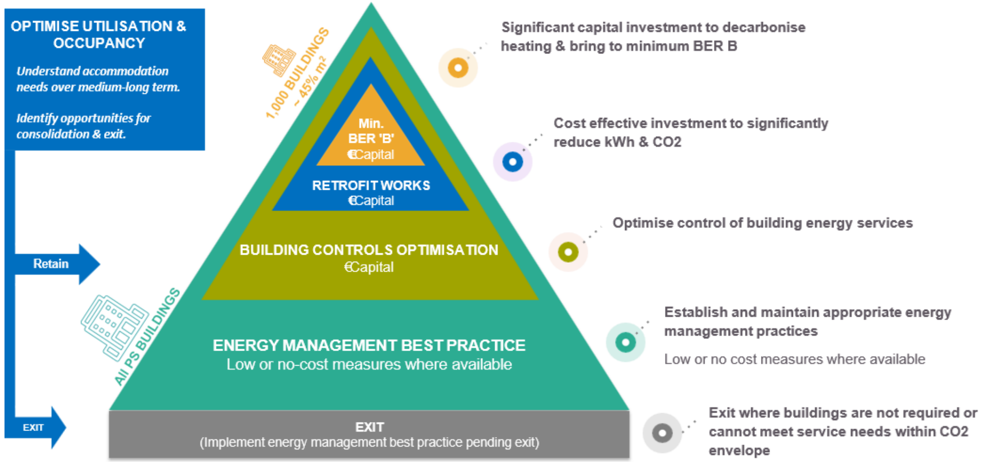


SEAI pyramid approach

Figure 1-3 shows the SEAI's pyramid approach to decarbonisation. This provides a structured, strategic framework for portfolio decarbonisation, prioritising actions based on cost-effectiveness and impact. At its foundation, **Energy Management Best Practice** focuses on low- or no-cost measures such as monitoring, targeting, and behavioural changes to reduce energy consumption. Above this, **Building Controls Optimisation** introduces cost-effective interventions to improve the efficiency of heating, ventilation, and other building services. The next tier, **Retrofit Works**, requires significant capital investment to upgrade building fabric and systems, aiming to achieve a minimum Building Energy Rating (BER) of B. At the top of the pyramid, **Optimising Utilisation** and Occupancy ensures that space is used efficiently, identifying opportunities for consolidation or exit where buildings cannot meet service needs within the defined carbon envelope. This hierarchy ensures that resources are allocated effectively, starting with measures that deliver the greatest return on investment before progressing to more capital-intensive solutions.

The Decarbonisation Strategy has attempted to align the recommended key moves and energy savings measures to the SEAI's approach where possible.

Figure 1-3: SEAI's pyramid approach to portfolio decarbonisation



SEAI requirements[1] state that no new fossil fuel systems should be installed in new buildings or major renovation projects. There are several exceptions including if fossil fuel use is required for backup or peak load or when no technically viable non-fossil fuel alternative exists. In this case the fossil fuel use should be restricted to <10% of annual heating load.

Due to this, where appropriate for decarbonisation options, ASHPs have been sized for 90% of annual load with gas boiler back up at 10%.

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1. *SEAI, Public Sector Climate Action Roadmap Guidance 2025 v1.0*

Project structure

The Decarbonisation study has followed a four-stage process set out in figure 1-4:

1. **Baseline review** of available energy and carbon performance data. Review planned new buildings and removals aligned to developing masterplan proposals. Develop a building matrix based on available information summarising baseline condition of assets. Establish energy end-use breakdowns based on available sub metering data, bottom-up calculations and benchmarking.
2. **Develop decarbonisation options** for demand reduction and heat decarbonisation for priority assets. These are based on findings from site visits, energy analysis, and discussions with TCD estate's team. The potential impact of options are then modelled in terms of both operational energy and carbon.
3. **Net Zero decarbonisation pathway. T**he identified options were consolidated into a series of 'key moves' which TCD could implement to achieve the decarbonisation targets. Energy and carbon savings undertaken as well as opportunities and constraints review including assessment of structural, spatial, and operational constraints.
4. **Implementation Roadmap** showing the prioritised order of the key moves based on multicriteria analysis. Cost analysis undertaken to understand what sit he most cost-effective strategy to achieved decarbonisation target. Key recommendations, actions, and next steps to achieve net zero are set out.

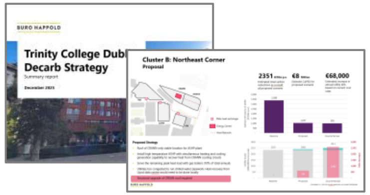
Figure 1-4: Overview of project approach

STAGES	KEY TASKS
1 Baseline data review	• Baseline energy & carbon performance • Review assets – typology, age, HVAC system, fabric, listed status • Review existing heat & hot water plant sizes • Identify anchor heat loads and heat recovery opportunities
2 Decarbonisation Options	• Site visits & energy analysis to identify decarb options and energy savings • Extrapolate measures to other priority buildings based on typology, HVAC etc • Develop heat demand profiles for clusters • Estimate heat pump sizing and size of energy centre
3 Net Zero pathway	• Consolidate decarb options into series of key moves • Develop decarbonisation strategies for priority assets • Estimate energy & carbon emissions savings • Set out how to implement key moves to meet 2030 and 2040 net zero targets • Information to Cost Consultant for cost estimates
4 Implementation roadmap	• Assessment & prioritisation of key moves • Recommended order of delivery based on multicriteria analysis • Cost analysis of options • Set out next steps for moving to delivery

Study outputs

The study includes analysis at both a strategic and asset level. The key outputs of these are intended for use by different stakeholders and are summarised below.

Implementation roadmap
Strategic level



- **Report PDF (*this document*) providing summary of key moves, with carbon and cost impact from 2026 – 2040.**
- Executive summary intended for communicating headlines to key stakeholders
- Preferred Net Zero pathway against TCD/SEAI targets
- Prioritised list of the 'big move' decarbonisation projects and high-level implementation timeline
- Estimated capital costs and utility cost savings for decarbonisation projects
- High-level decarbonisation strategies for priority assets
- Next steps for implementation TCD

Energy savings measures
Asset level

- **Energy savings excel spreadsheet listing specific energy savings measures for key assets**
- Identification of energy reduction measures via energy analysis, site visits, BMS review, and discussions with TCD decarbonisation manager.
- Measures specific to key assets with assumptions to extrapolate to similar assets.
- Savings are referenceable with precedent studies included where applicable.
- Bottom-up calculations for energy end used breakdowns for priority assets
- Interfaces with SEAI Gap-to Target tool for reporting

SECTION 2

BASELINE PERFORMANCE

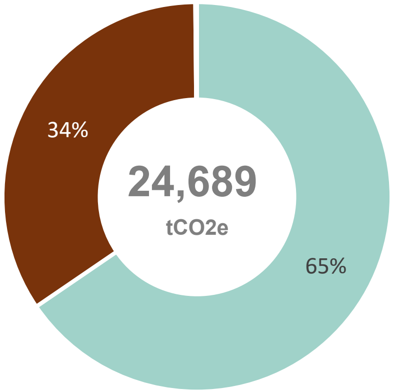
SEAI Baseline energy & carbon emissions (2016-18)

Baseline performance

This pie chart and table summarise TCD's baseline energy related operational carbon emissions (e.g.. scopes 1 & 2) associated with the University's estate (105 buildings included this study). In the baseline year (i.e. the average of 2016-18), TCD reported an annual consumption of 78,840,296 kWh across electricity, natural gas and vehicle fleet. Out of this, 52% of consumption is attributed to natural gas with 48% of consumption is attributed to grid electricity input.

Carbon emissions

As can be seen, operational carbon emissions are broadly split between grid electricity and thermal emissions (including natural gas and vehicle fleet). These emissions have been estimated using the 2016-18 carbon factors for grid electricity and natural gas. Whilst the forecast decarbonisation of the Irish Grid is likely to reduce the GHG emissions associated with electricity over the coming years, natural gas emissions are anticipated to remain broadly constant. Therefore, removal of gas-fired plant from buildings is a key part of the decarbonisation strategy for the University.



		Absolute consumption (2016-28)		GHG emissions (2016-18)	
Scope	**Emissions category**	**kWh p.a.**	**%**	**tCO_2e p.a.**	**%**
1	Gas	41,418,602	52%	8,487	49.2%
1	Vehicle fleet	65,634	>1%	35	>1%
2	Grid electricity	27,284,596	49%	16,166	50.7%
	Total	**78,840,296**	**100%**	**24,689**	100%

Figure 2-1: Table and pie chart summarising TCD's 2016-18 operational carbon emissions baseline for SEAI reporting.

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Portfolio consumption to date

Data source

Annual energy consumption and associated GHG emissions from baseline year 2016-18 to 2024 were taken from the SEAI Gap to Target tool shared by TCD.

Energy consumption to date

TCD's current energy consumption shows notable changes compared to the 2016–2018 baseline period. Electricity consumption has decreased by approximately 2,500 MWh, whilst thermal energy consumption has increased by around 2,000 MWh. Although there have been some energy savings projects implemented over recent years e.g.. lighting upgrades that may account for the reduction in electricity, it is unclear why fossil fuel consumption has increased.

Carbon emissions to date

Overall, TCD has achieved a reduction of ~27% in total emissions to date. Whilst implemented energy savings initiatives are likely to have contributed to this reduction, the majority can be attributed to the decarbonisation of the national electricity grid. Electricity-related carbon emissions have fallen significantly, with an estimated reduction of 7,000 tCO_2e compared to the baseline year. However, an increase in thermal consumption has contributed an increase 410 tCO_2e in emissions.

Carbon emissions summary 2024

Total emissions = 18,107 tCO_2e (~49% gas, ~51% electricity)

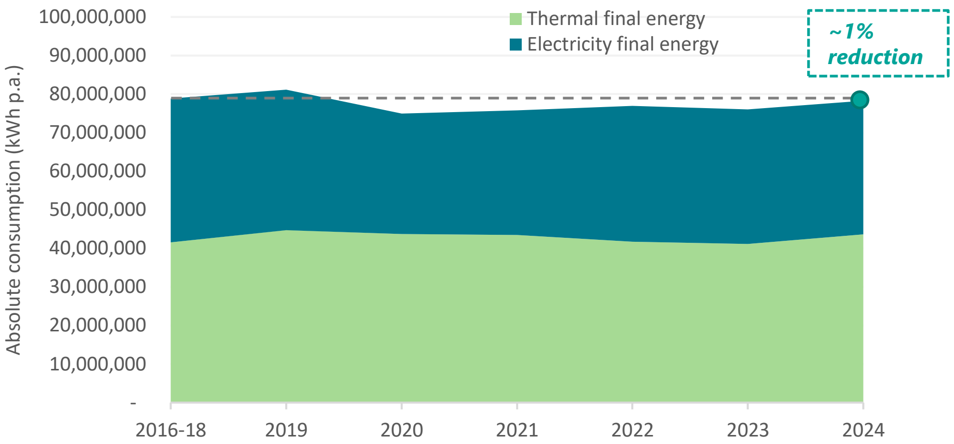


Figure 2-2: Portfolio energy consumption from baseline to 2024

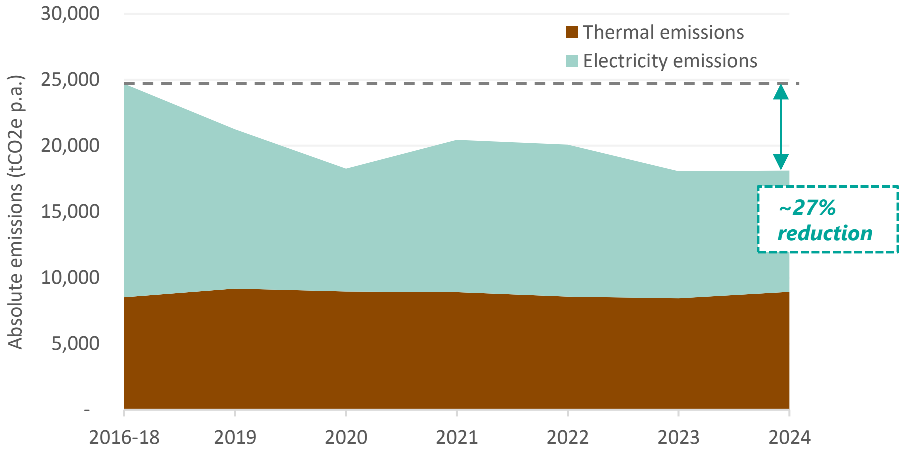


Figure 2-3: Portfolio carbon emissions from baseline to 2024

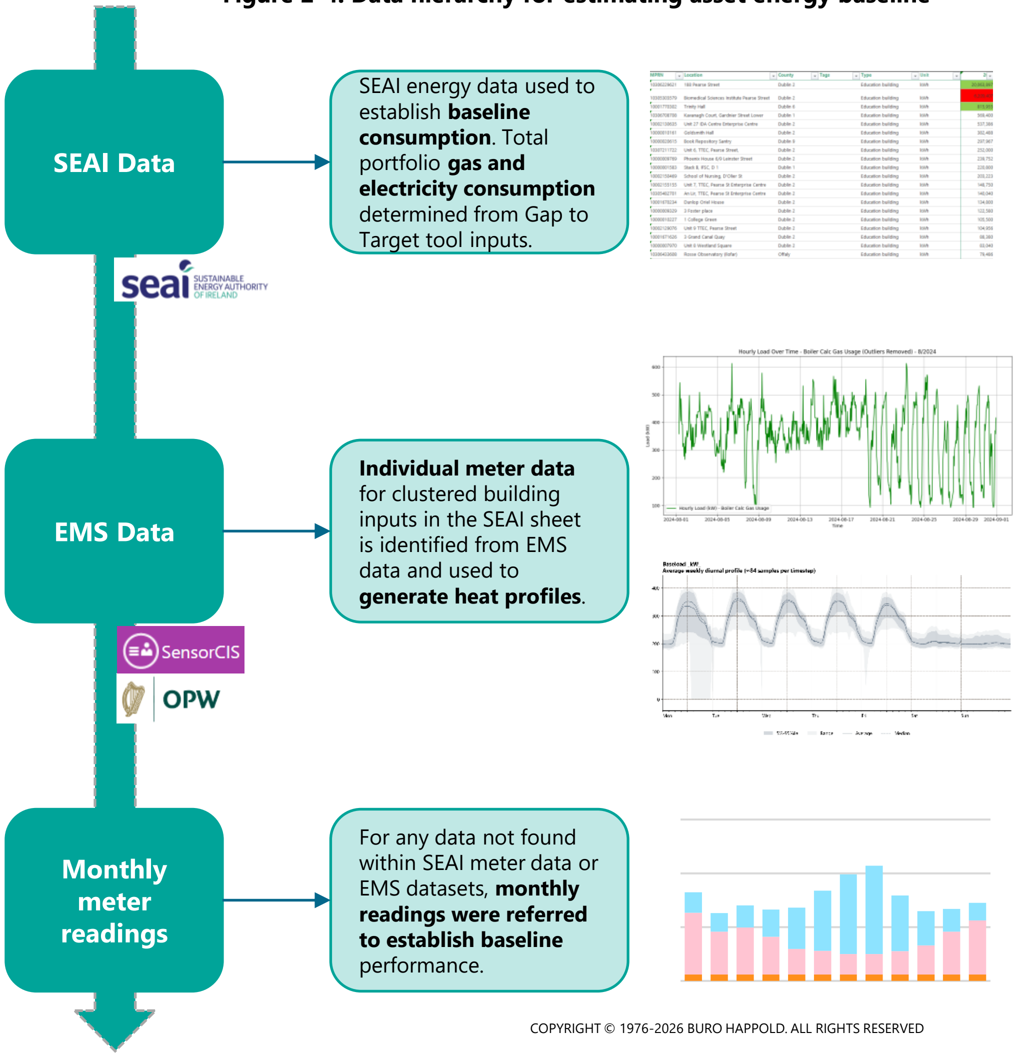
Building performance

Establishing baseline performance for key assets

This study has reviewed the available energy performance data for key assets to identify potential energy savings measures and to understand where TCD should focus investment to reduce operational carbon emissions. Note, not all buildings have separate fiscal electricity and gas metered data so a hierarchal approach for establishing baseline performance was taken, summarised in figure 2-4.

1. **SEAI data**: The baseline gas (included in thermal consumption) and electricity consumption of individual assets has been acquired from the SEAI annual sheet that logs annual consumption for the estate.
2. **Energy Management System (EMS) Data**: For assets where individual gas and electricity data was not available within the SEAI data, EMS data has been used for the year 2024. Where data on the EMS was incomplete for 2024, additional consumption data from 2025 has been used to ensure a complete year.
3. **Monthly meter readings:** Monthly meter readings for gas and electricity are manually collected by the TCD Estates team for key assets/ meters. These readings were used to establish baseline consumption for assets not covered by the EMS and to inform energy end use breakdowns.
4. **Industry benchmarks:** For selected assets, CIBSE energy performance benchmarks were used to estimate energy consumption.

Figure 2-4: Data hierarchy for estimating asset energy baseline



Building performance

Figure 2-5 shows the baseline energy consumption for key TCD assets. The study focuses on Priority Assets which make up ~90% of operational carbon emissions.

TBSI accounts for **~26%** of current total carbon emissions
Other notable buildings are:

- Dartry – 5%
- St James – 4%
- Lloyd – 4%
- Sports 4%
- Crann – 4%

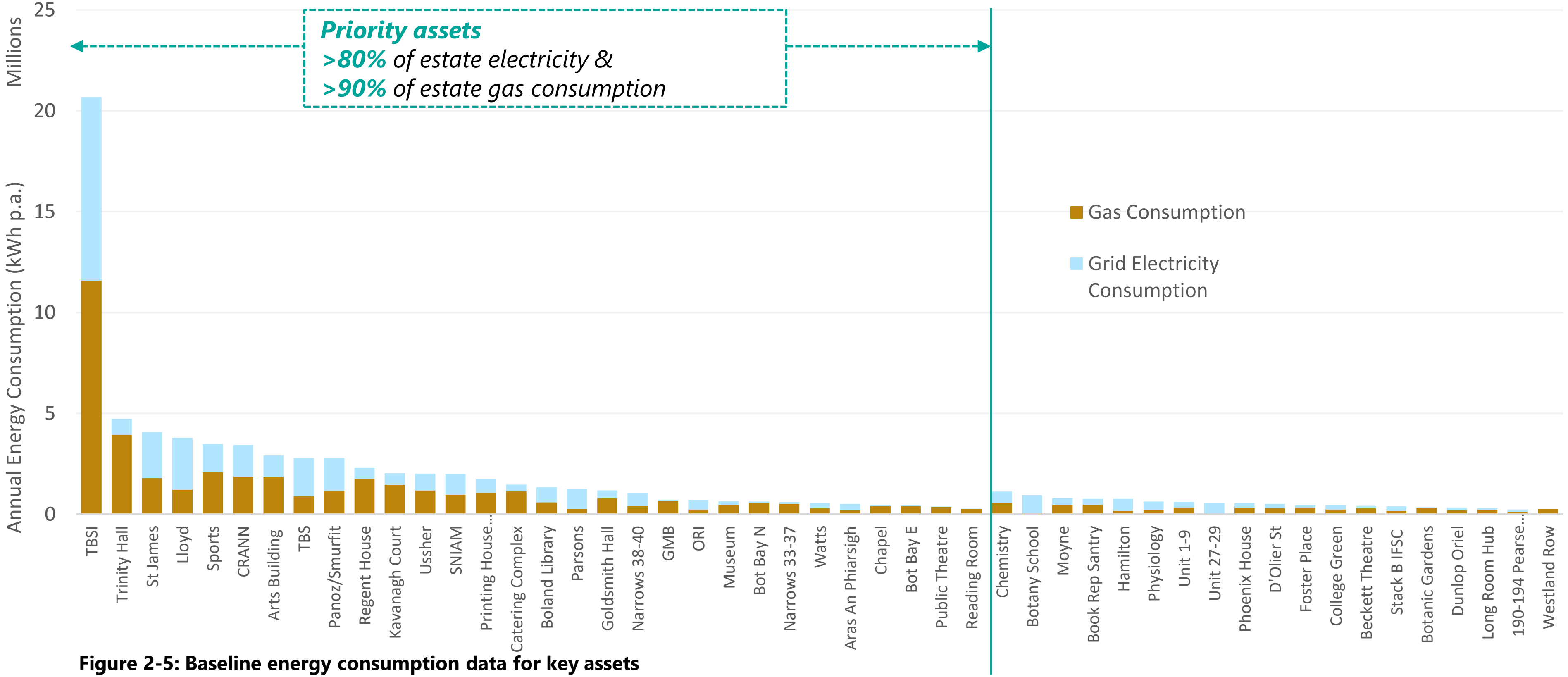


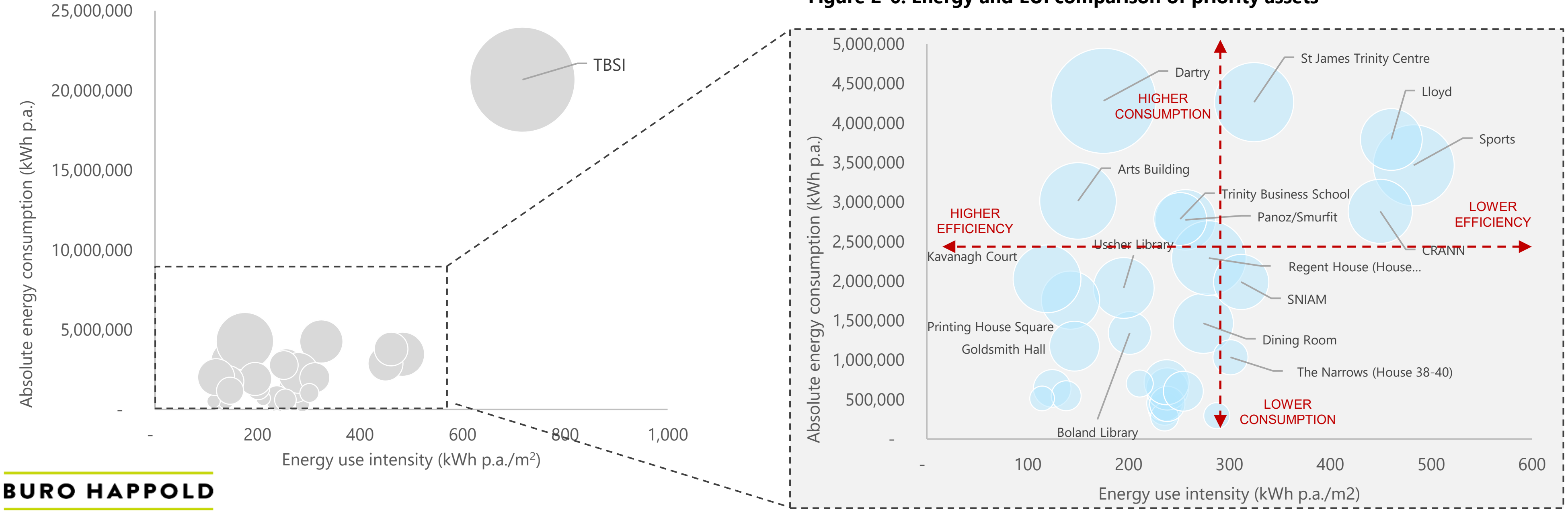
Figure 2-5: Baseline energy consumption data for key assets

Building performance

In addition to absolute energy consumption, the energy-use intensity (EUI) of assets has also been considered. This can provide an overview of how efficiently a particular building is operating. The chart below plots absolute energy consumption against EUI with the size of the bubbles indicating overall fossil fuel carbon emissions. This shows that, as well as having the highest absolute consumption, TBSI also exhibits the highest EUI.

Among the remaining assets, Sports, CRANN, and Lloyd show relatively high EUI, indicating potentially lower operational efficiency – although allowance should be made for the different typologies of the buildings in this data set. Dartry and St James's Trinity Centre are also significant energy consumers overall, primarily due to their high gas demand, which results in high fossil fuel emissions. These buildings should be a key focus for decarbonisation.

Figure 2-6: Energy and EUI comparison of priority assets



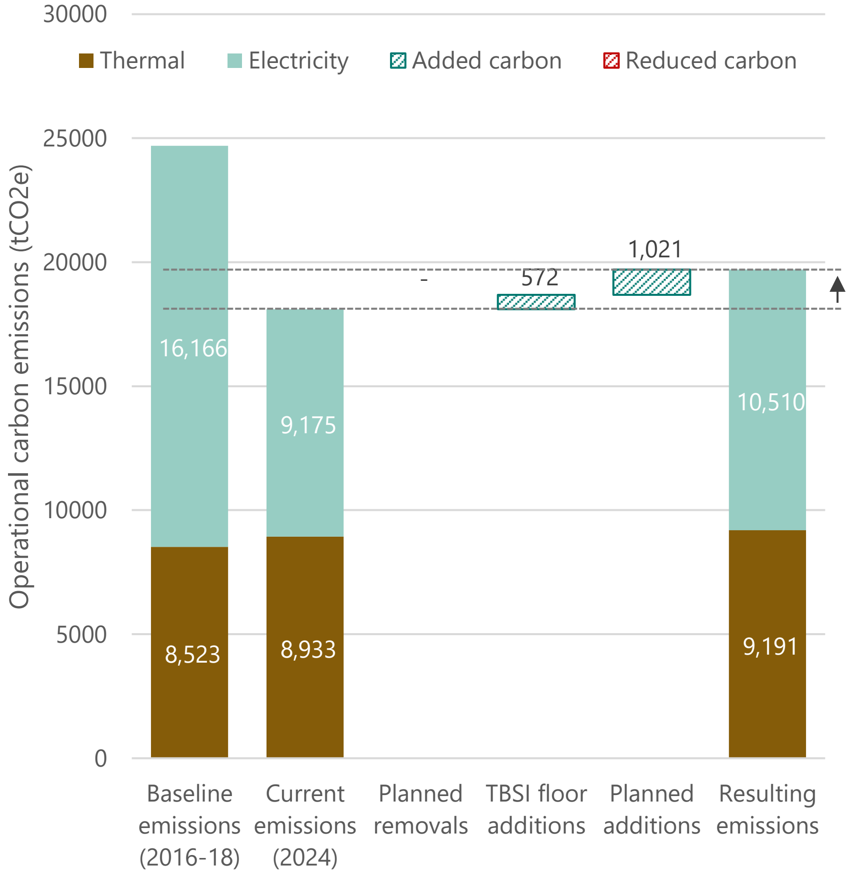
Impact of planned additions to the estate

Impact of changes to TCD portfolio

The reintegration of the Trinity Centre/TBSI floors into the portfolio could potentially increase total emissions by ~572 tCO_2e. In addition, the new projects scheduled to come online in the coming years are projected to add another ~1,021 tCO_2e.

Overall, these portfolio changes are estimated to increase carbon emissions by ~1,593 tCO_2e, based on 2024 grid electricity emission factors. Assuming all new builds are fully electric, the associated carbon emissions will decline as the grid continues to decarbonise.

This impact of grid decarbonisation on portfolio emissions is illustrated on the next page, showing that the effect of integrating all-electric new builds will have a relatively low negative impact on TCD's carbon reduction targets. However, it remains essential to minimise building energy consumption by adopting sustainable design and construction practices to reduce end-use energy intensities.



1,593 tCO_2e

Est. increase in total carbon emissions compared against 2024 emissions.

258 tCO_2e

Est. increase in thermal carbon emissions compared against 2024 emissions.

Figure 2-7: Summary of carbon emissions impact of planned asset additions and removals

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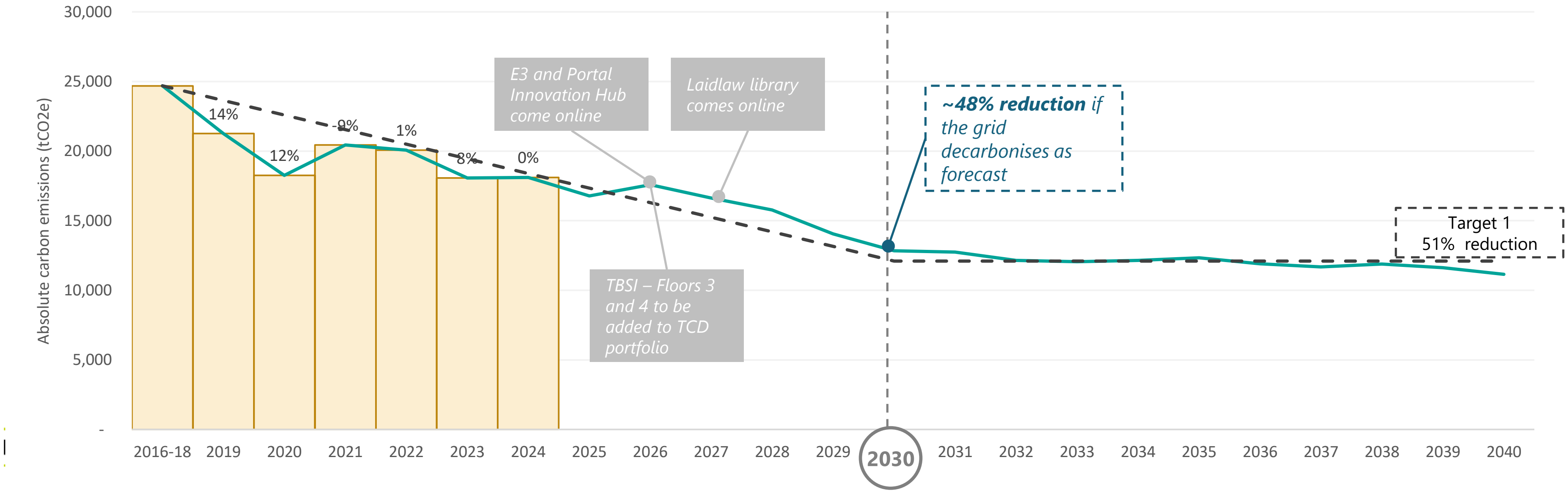
Baseline emissions pathway

Figure 2-8 shows the baseline operational carbon emissions pathway for the portfolio. This is based on forecast carbon emissions factors for the Irish electricity grid from SEAI and an assumed static carbon emissions factor for natural gas. The chart includes new developments and removals outlined on the previous page. As can be seen:

1. Operational carbon emissions are estimated to reduce significantly due to the forecast decarbonisation of the Grid. This is could potentially result in a reduction in operational carbon emissions of ~48% by 2030
2. However, from 2030 emissions reductions begin to plateau. This emphasises that the University will need to remove gas from buildings to be able to achieve further significant reductions.
3. There is likely to be only a minor increase in emissions related to new developments coming online by 2030. This is because these developments will be energy efficient and electric only.

Figure 2-8: Baseline 'do nothing' carbon emissions pathway



SECTION 3

DECARBONISATION OPTIONS

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Decarbonisation projects

The decarbonisation strategy is underpinned by a set of projects to decarbonise heat and reduce energy and associated carbon emissions. The projects have been identified based on energy data analysis, discussions with TCD and, and site visits. The energy and carbon savings for projects have been estimated through simplified energy modelling and bespoke bottom-up energy calculations. The projects are grouped under the following categories:

1. **Demand reduction**
   - **Optimisation** – Low-cost measures that can be implemented relative easily with minimal building side intervention. However, they may require extensive stakeholder engagement.
   - **System upgrades –** Measures that improve technology or systems already in the building e.g.. lighting or chiller upgrades. Theses are more intrusive and incur higher capex. This can potentially be mitigated by waiting until end of life of current equipment, and/or aligning with other proposed works
2. **Heat decarbonisation** – Measures focused on decarbonising heat generation i.e. replacing gas boilers with electric boiler or heat pumps – but without major changes to building side operation e.g.. no changing of heat emitters.
3. **Deep retrofit** – Extensive building refurbishment measures that involve significant disruption and possible decant require as well as incurring significant capital cost. This includes major HVAC refurbishment, heat emitter and pipework upgrades and fabric improvements.

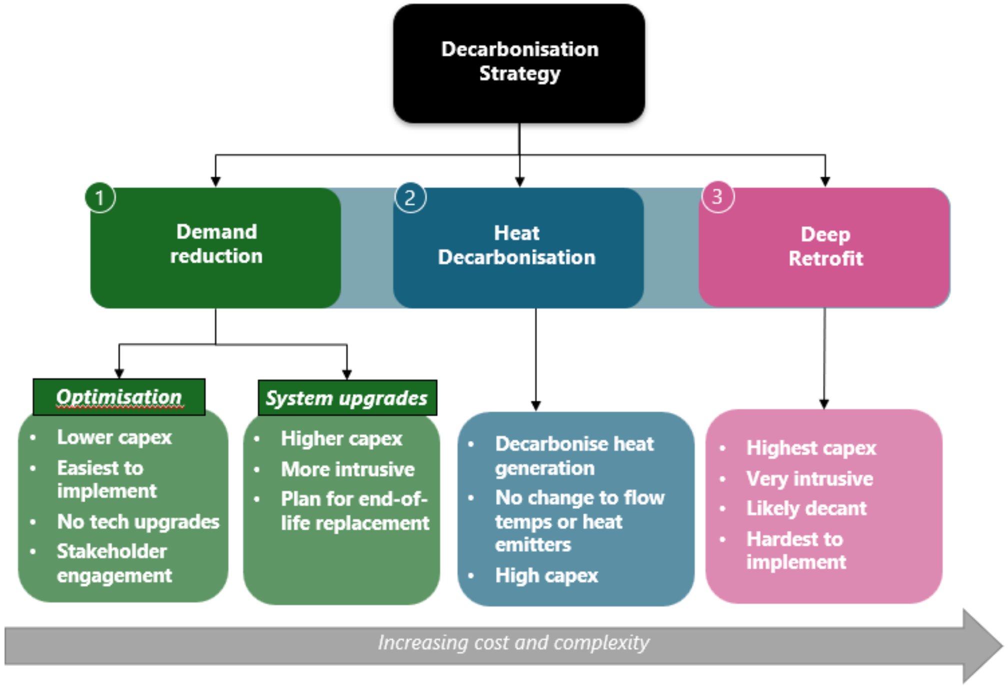


Figure 3-1: Categorisation for decarbonisation projects

Note that only Demand Reduction and Heat Decarbonisation projects have been identified for the key assets during this project. Extensive fabric improvements beyond draught proofing are not considered. The key driver for this is to maximise cost effectiveness and minimise embodied (lifecycle) carbon impacts.

Identification of projects

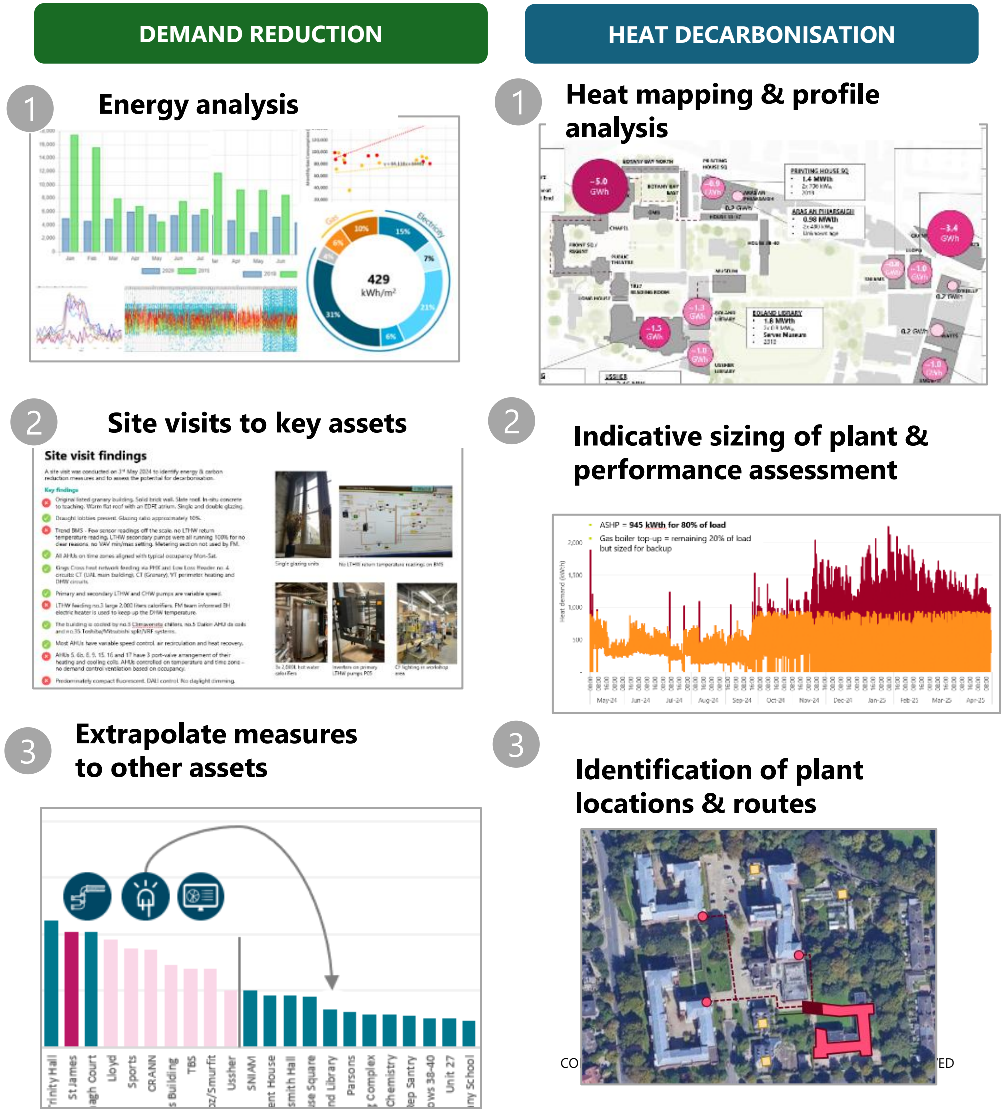
To identify and evaluate potential energy and carbon reduction measures the team conducted site visits to a representative sample of priority buildings, allowing them to directly assess opportunities for improvement. This included a review of the BMS and analysis of available energy data to identify potential controls issues, sub-optimal system performance and other energy wastages.

Based on these visits, a 'long-list' of possible measures was developed, which included interventions such as controls improvements, HVAC system adjustments, installation of heat pumps, and renewables. This also considered the suitability of using heat networks for identified 'clusters' of buildings based on heat mapping analysis (see summary in figure 3-3 overleaf).

For each measure, the potential energy and carbon savings were estimated, drawing on industry benchmarks, bottom-up calculations and data from previous projects to ensure robust analysis of saving. High-level capital and operational cost estimates were also prepared for each option.

A multicriteria analysis was used to prioritise the long list of proposed measures to various criteria, including carbon savings, cost, technical complexity, ease of implementation, and other relevant considerations.

Figure 3-2: Overview of method use to identify decarbonisation projects



Heat mapping
Island Campus

BOILER HOUSE A
- **3.8 MW_{th}**
- 2x 1.9 MW_{th} boilers
- Over end of life
- **Serves existing heat network at West End**
- 90/80°C
- Est gross eff = 80%

PRINTING HOUSE SQ
- **1.4 MWth**
- 2x 706 kW_{th}
- 2019
- 80/70°C
- Est gross eff = 85%

ARAS AN PHIARSAIGH
- **0.98 MWth**
- 2x 490 kW_{th}
- Unknown age
- 80/70°C
- Est gross eff = 85%

SNIAMS
- **0.6 MWth**
- 2x 300 kW_{th}
- 1998 - over end of life
- 80/70°C
- Est gross eff = 80%

LlOYD
- **1.7 MW_{th}**
- 2x 850 kWth
- 2005 - at end of life
- 80/70 ° C
- Est gross eff = 85%

CRANN & SPORTS
- **2.9 MW_{th}**
- 2x 1.45 MW_{th}
- 2005 - **at end of life**
- 80/70°C
- Est gross eff = 85%

O'REILLY
- **0.3 MWth**
- 2x 150 kWth
- 2022 - new
- 80/70°C
- Est gross eff = 90%

WATTS
- **1.7 MWth**
- 2x 850kWth
- 1992 – over end of life
- 80/70°C
- Est gross eff = 80%

BOLAND LIBRARY
- **1.8 MWth**
- 2x 0.9 MW_{th}
- **Serves Museum**
- 2010
- 80/70°C
- Est gross eff = 90%

ARTS BUILDING
- **2.16 MW_{th}**
- 1.1 MW_{th} & 1.06MW_{th}
- 2000 & 2014
- 80/70°C
- Est gross eff = 85%

USSHER
- **2.16 MW_{th}**
- 1.1MW_{th} & 1.06MW_{th}
- 2000 & 2014
- 80/70°C
- Est gross eff = 85%

PANOZ & SMURFIT
- **1.65 MWth**
- 1x 1650 kWth
- Unknown age
- 80/70°C
- Est gross eff = 85%

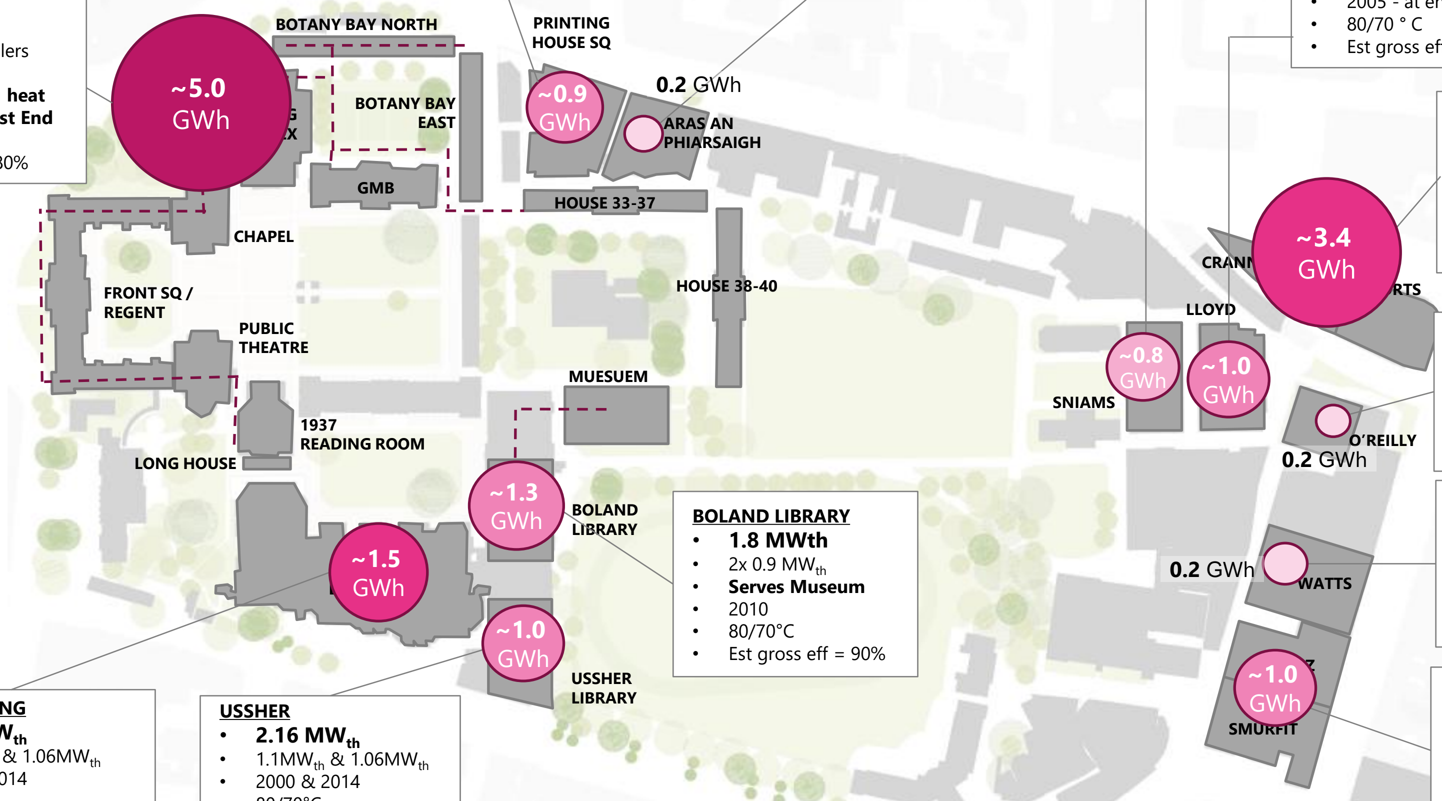


Figure 3-3: Heat mapping and heat generation plant review at Island Campus

Cluster overview
Island Campus

The buildings were initially grouped by the TCD Estates team into the five clusters shown below. Heat mapping and analysis confirmed this approach, and these clusters are referred to throughout the strategy.

Cluster	Name	No. of buildings	Total area (m^2)	Total heat demand (MWh p.a.)	%
A	West End	9	26,818	4,894	29%
B	NE Corner	5	32,165	5,382	31%
C	Arts	4	41,711	3,800	22%
D	Labs	2	14,780	1,221	7%
E	Printing Sq	4	22,644	1,857	11%
	Total ->	**24**	**138,118**	**17,154**	**100%**

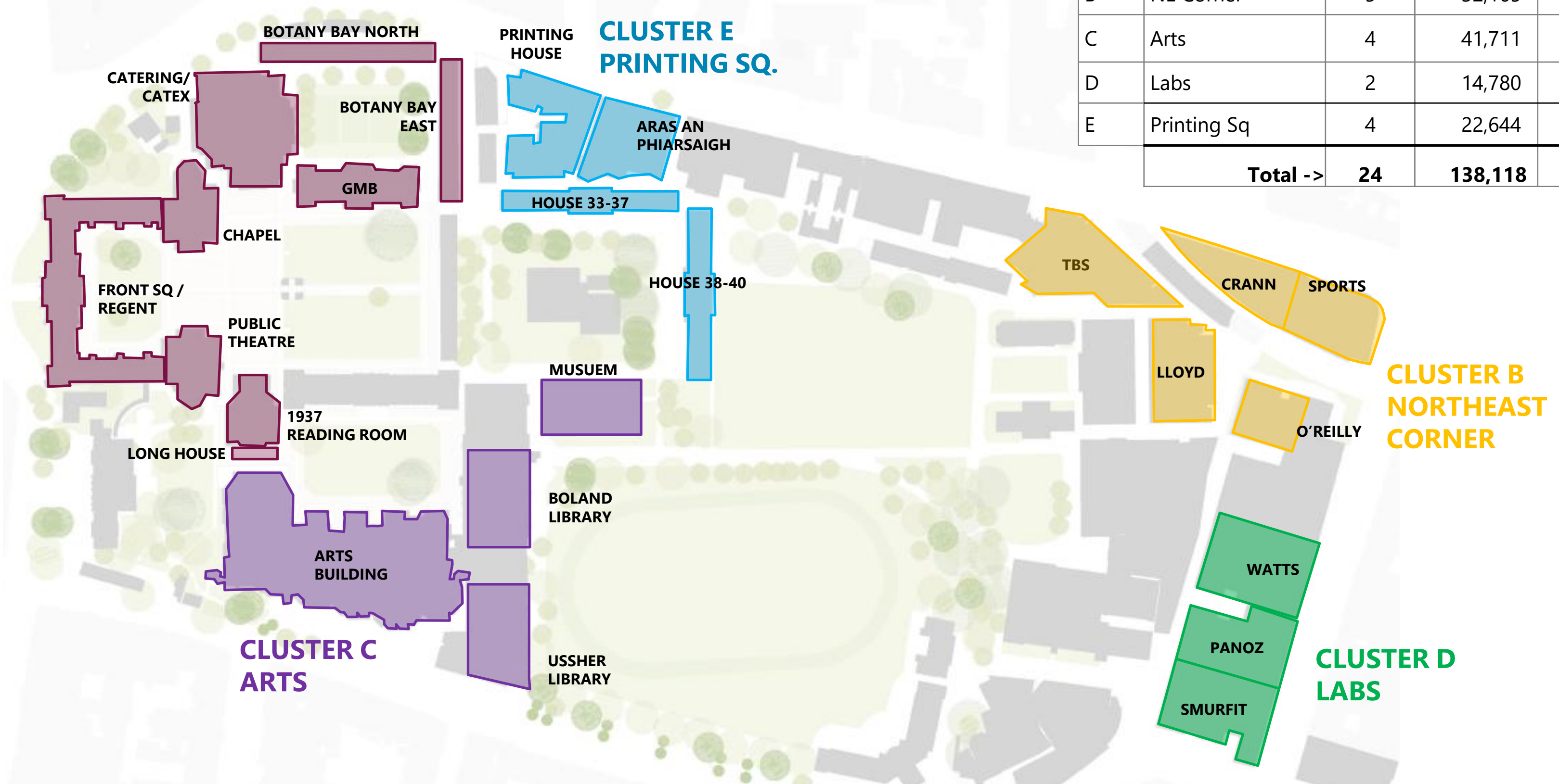


Figure 3-4: Summary of identified building clusters at Island Campus (clustering provided by TCD Estates Team)

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Heat decarb options

The following approach and assumptions were made when developing heat decarbonisation options for the five clusters on the Island Campus and other key assets in the estate.

- Estimate heating and cooling hourly profiles using EMS data. Where this data does not exist, use benchmark assumptions.
- Estimate required ASHP plant size to serve 90% of the annual heat profile (to align to SEAI requirement).
- Top up gas boiler plant for remaining 10% of load but sized to serve total peak load.
- ASHPs based on Pure Thermal high temperature heat pumps 150kWth units
- ASHPs are mounted externally
- Pipework/ Distribution losses assumed to be 10%
- Thermal Stores - allowance 10l per kWth installed load
- Flow/ Return temp 80°C/70°C
- Assumed space allowance within existing plantroom for boiler and plate heat exchangers, pressurisation units and expansion vessels
- Develop indicative size requirements for energy centre based on above.
- Review options for locating plant either on roofs, within proposed new development, or in new purpose-built energy centre.
- Estimate electrical infrastructure requirements

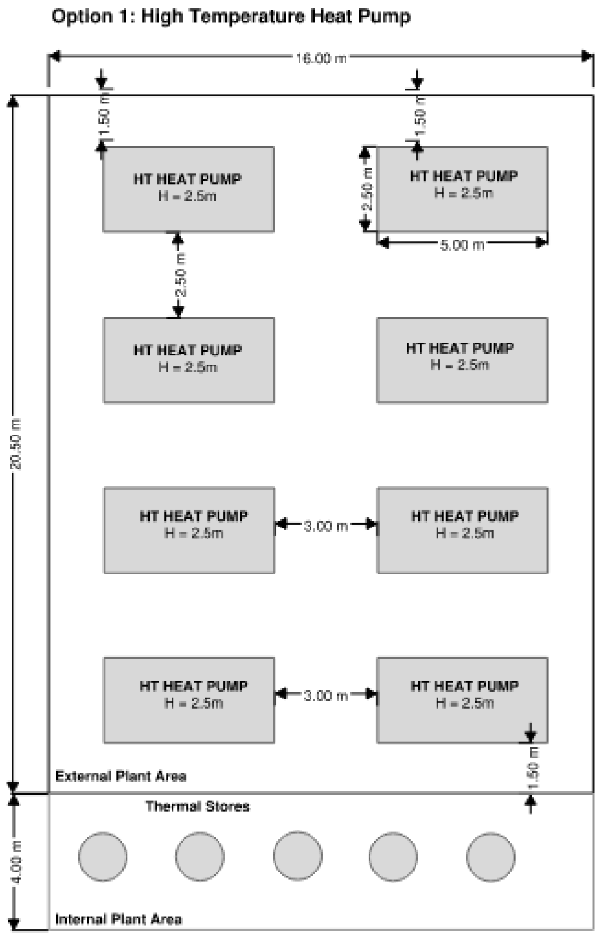


Figure 3-5: Example sketch sizing of energy centre for Cluster A.

Demand reduction measures

Overview

A set of demand reduction measures have been identified for the project via site visits, energy analysis, review of current TCD projects in the gap-to-target tool, and discussion with TCD Estates Team. Site visits were conducted for a sample of key assets including: TBSI, Sports, CRANN, Lloyd, Panoz/ Smurfit, Dartry, and St James. Walkthroughs of plant rooms and review of the BMS were carried out for the majority of other priority assets. Identified measures were then extrapolated to other similar buildings based on typology, HVAC strategy, and findings from the BMS review.

Figure 3-6 shows a selection of the key measures from Optimisation and System Upgrades that are being recommended. Details of the energy savings measures can be found in Appendix D and the Energy Savings calculation spreadsheet (Appendix C, see Energy Savings Calculation page for summary).

Energy savings calculations

Energy savings are estimated for each measure recommended for a building. Measures are specific to TCD, are referenceable, and precedents are provided. Energy savings calculations are a mixture of HVAC 1^{st} principles, bottom-up estimations, and benchmarks and are applied to an energy end use breakdown for each asset (see following page).

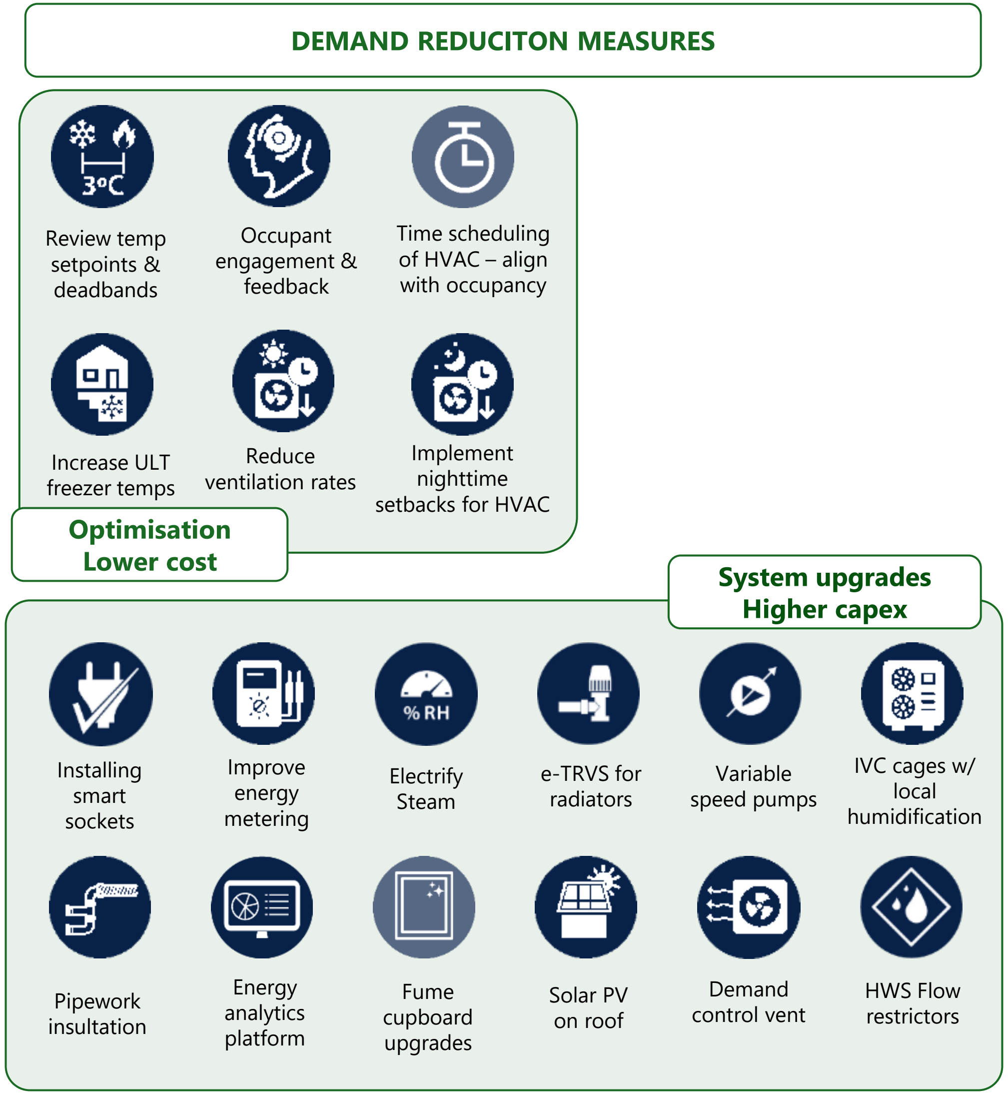


Figure 3-6: Examples of Optimisation and System Upgrades measures in the project

Energy end-use breakdowns

Energy savings calculations are underpinned by an energy demand end use breakdown that has been estimated for each of the ~30 priority assets. The end use breakdown is developed using a combination of available sub metering data, bottom-up estimations based on installed load or other design assumptions, HVAC 1st principles calculations, energy analysis load disaggregation and engineering assumptions.

Developing an end use breakdowns enables energy savings measures to be applied to the end use(s) that they impact to provide a more accurate estimation of the potential energy savings. The end use breakdown for each asset can be found in the Energy Savings Calculation sheet.

Figure 3-7 shows an example end use breakdown for TBSI. The categories shown here are consistent across all assets.

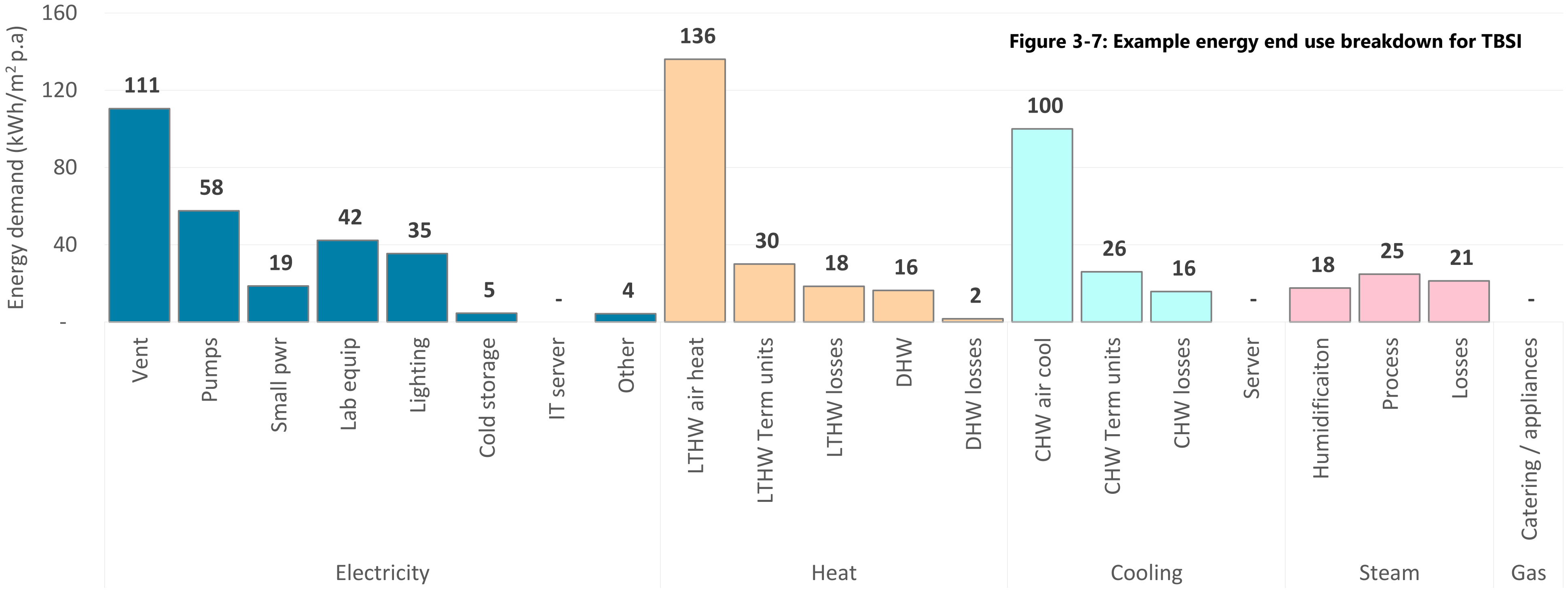
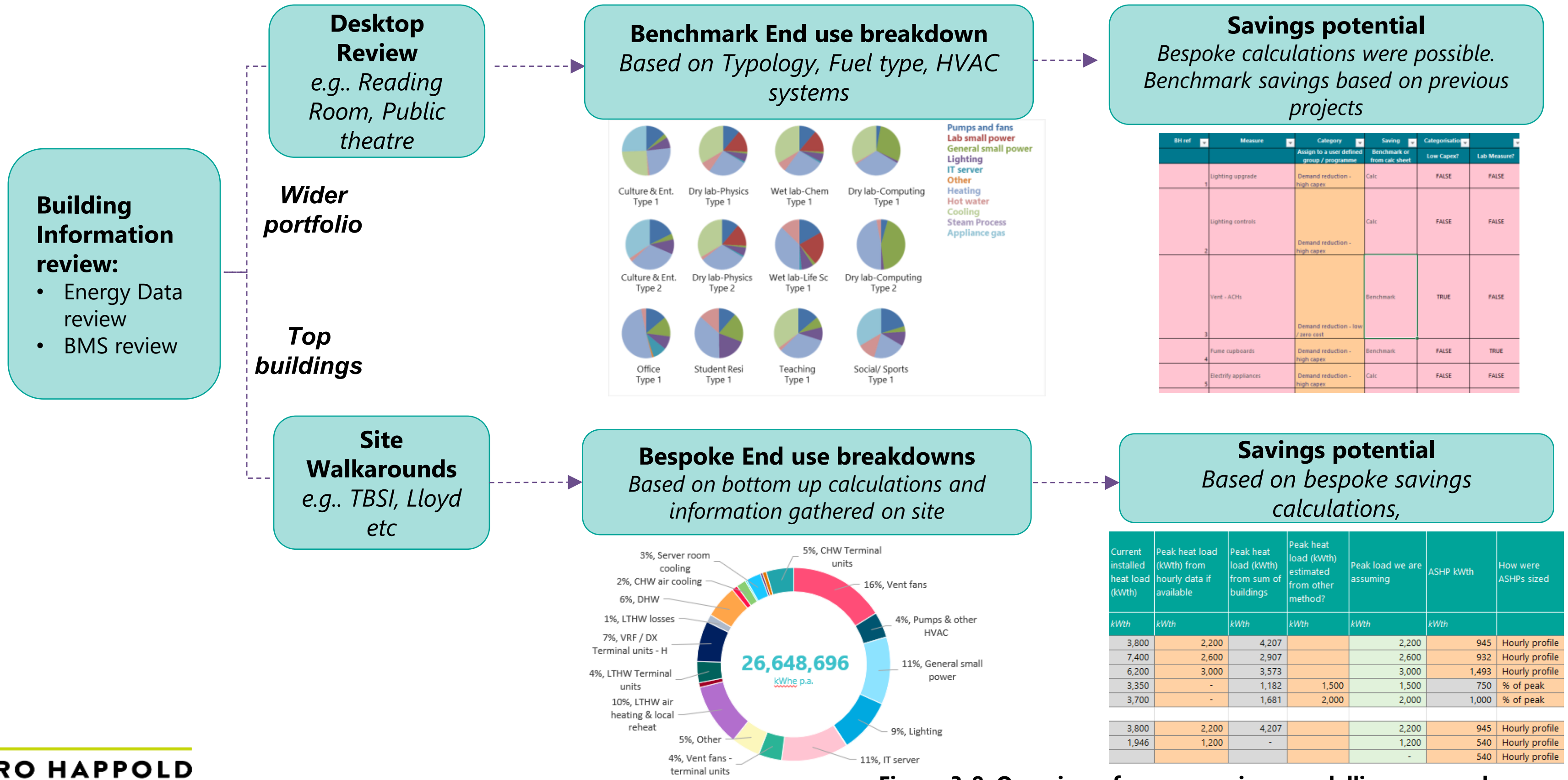


Figure 3-7: Example energy end use breakdown for TBSI

Energy savings modelling approach

Figure 3-8 provides an overview of the energy savings modelling approach for the priority assets and highlights how the approach differs between assets where a site visit has taken place and others where a desktop review approach was used.



BH ref	Measure	Category	Saving	Categorisation	
		Assign to a user defined group / programme	Benchmark or from calc sheet	Low Capex?	Lab Measure?
1	Lighting upgrade	Demand reduction - high capex	Calc	FALSE	FALSE
2	Lighting controls	Demand reduction - high capex	Calc	FALSE	FALSE
3	Vent - ACHs	Demand reduction - low / zero cost	Benchmark	TRUE	FALSE
4	Fume cupboards	Demand reduction - high capex	Benchmark	FALSE	TRUE
5	Electrify appliances	Demand reduction - high capex	Calc	FALSE	FALSE

Current installed heat load (kWth)	Peak heat load (kWth) from hourly data if available	Peak heat load (kWth) from sum of buildings	Peak heat load (kWth) estimated from other method?	Peak load we are assuming	ASHP kWth	How were ASHPs sized
kWth	kWth	kWth	kWth	kWth	kWth	
3,800	2,200	4,207		2,200	945	Hourly profile
7,400	2,600	2,907		2,600	932	Hourly profile
6,200	3,000	3,573		3,000	1,493	Hourly profile
3,350	-	1,182	1,500	1,500	750	% of peak
3,700	-	1,681	2,000	2,000	1,000	% of peak
3,800	2,200	4,207		2,200	945	Hourly profile
1,946	1,200	-		1,200	540	Hourly profile
				-	540	Hourly profile

Figure 3-8: Overview of energy savings modelling approach

Energy savings calculations

A key output of this process is a supporting Energy Savings calculation spreadsheet in Excel format. This provides the underpinning calculations and energy savings estimates for the Decarbonisation Strategy. The figure below provides an overview of the summary table from the Energy Savings calculation sheet with key criteria highlighted. This output is designed to interface with the SEAI's Gap to Target tool for ease of reporting.

REF
Unique code for measure

BUILDING
where the measure has been identified

CATEGORY
Gap to Target tool category i.e.: Energy Efficiency, Heat Decarb or Solar PV

PRECEDENTS
Examples of where measure has been implemented before and savings achieved

THERMAL SAVING
Estimated energy saving (kWh p.a.)

ELEC SAVING
Estimated energy saving (kWh p.a.)

Ref	Measure	Building	Description	Category (G2TT)	Calculation methodology	Precedents / references	Confidence	Thermal saving (kWh p.a.)	Elec saving (kWh p.a.)	Est CAPEX	Est OPEX saving

MEASURE
Name of savings measure

DESCRIPTION
Overview of what the measure is

CALC METHODOLOGY
Overview of and how savings estimated. References to studies / guidance documents to support methodology included.

CONFIDENCE
Subjective score 1- 5 (5 high) to indicate confidence in savings calculation – i.e. Lighting generally high as LED savings well established, but a behaviour change saving would be low

EST. CAPEX
Capital cost estimate for the measure

EST. OPEX SAVING
Operational energy savings for the measure

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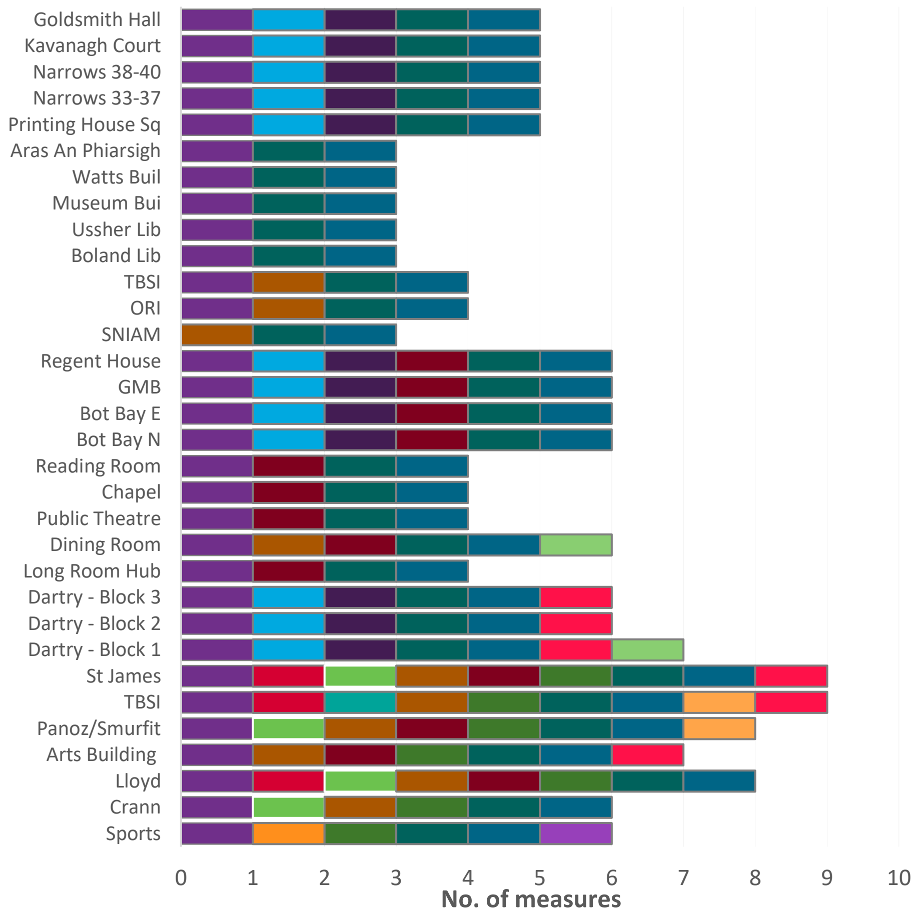
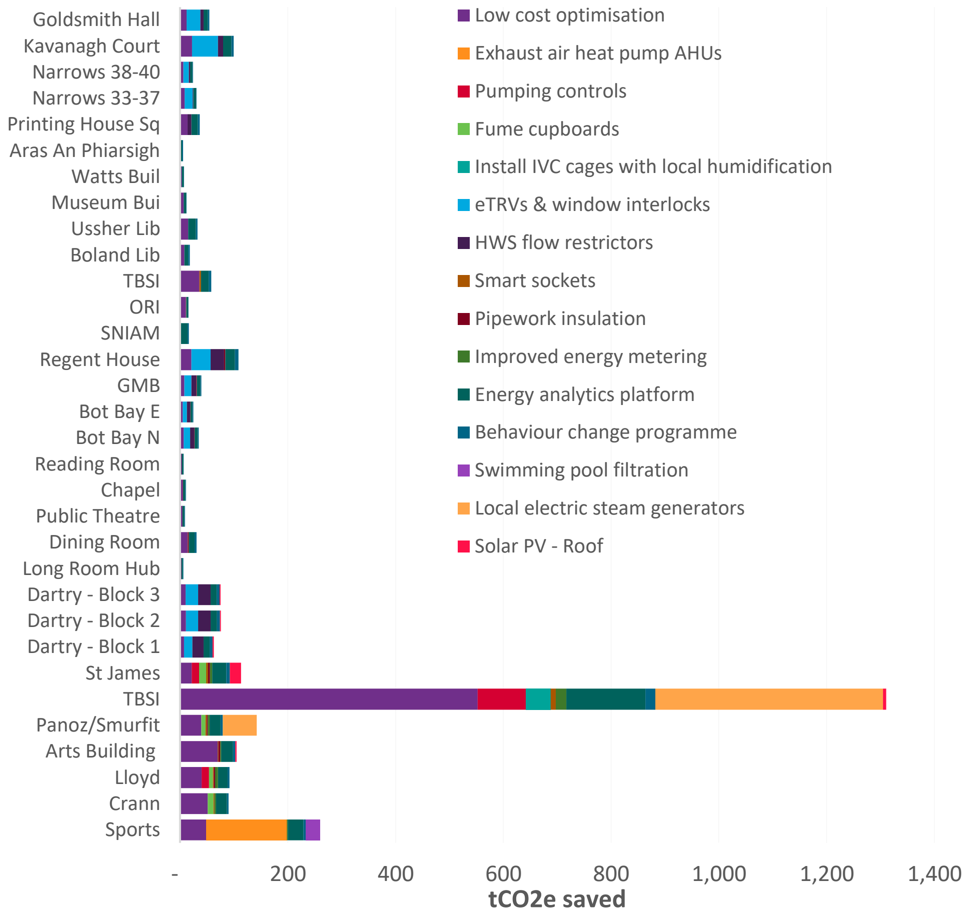
Energy savings measures

The chart on the left provides an overview of the different measures being applied to each of the priority assets. As can be seen, there is generally between three to nine measures being applied to the assets. The chart on the right shows the estimated carbon impact of those measures. As can be seen the bulk of the estimated carbon savings is associated with measures at TBSI.





Impact on performance

Figure 3-9 shows the impact of the demand reduction energy savings measures on the priority assets in the study. The bars show the building side energy use for electricity, heat (thermal), and cooling (thermal) with the overall percentage reduction achieved for each asset.

As can be seen these assets are estimated to have energy use savings in the range of 6-31% depending on which measures have been applied in the modelling.

See Appendix C for a sense check of the overall energy savings.

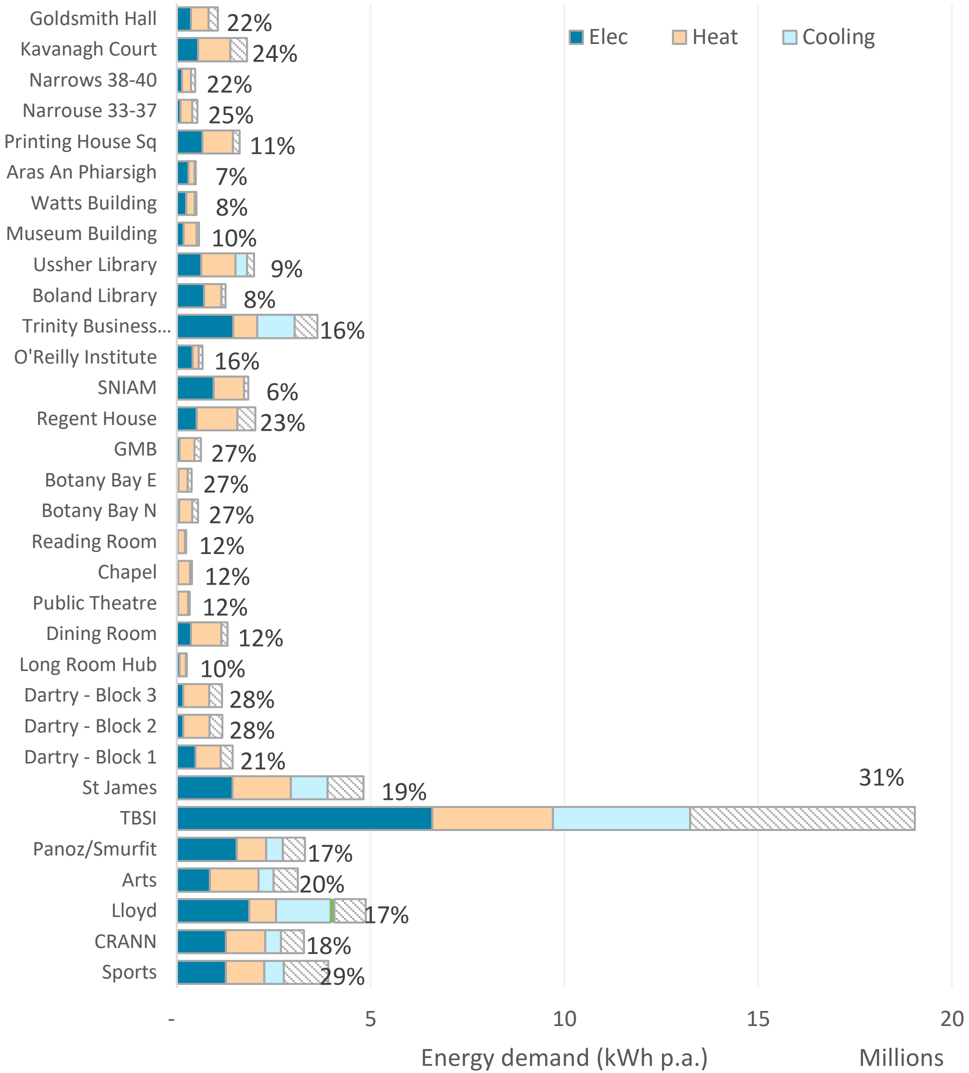


Figure 3-9: Estimated energy demand savings for each asset

Key decarbonisation moves

The long-list of options has been consolidated into a series of key moves that are recommended to enable TCD to achieve their decarbonisation targets. The key moves are split into demand reduction and heat decarbonisation and are shown opposite. A brief overview is provided here with further details in Appendix A.

Consolidation (any planned disposals & additions)

Energy and carbon emissions associated with planned new builds and disposals aligned to the masterplan, as well as parts of TBSI coming back into the TCD portfolio.

Programme of Optimisation measures

Indicative duration: 2 years

Low-cost control adjustments including ventilation rate reduction, improved time scheduling of plant, heating & cooling setpoints, and integration of temperature deadbands where no heating or cooling is required. These measures generally do not require additional technology or systems to be installed.

Programme of System Upgrades

Indicative duration: 4 years

Higher cost demand reduction measures which require implementation of new systems or technologies for example switching from 3-port to 2-port control and variable speed pumping, AHU upgrades, eTRVs, hot water flow restrictors, and improved energy metering.

demand reduction

- Consolidation (planned disposals & additions)
- Optimisation & System Upgrades at TBSI
- Optimisation measures for Priority Buildings – lower cost
- System upgrades for Priority Buildings – higher cost

heat decarbonisation

- Cluster A: West End - Electrify hot water
- Cluster A: West End - Electrify space heat
- Cluster B: NE Corner - Electrify heat
- Cluster C: Arts – Electrify Heat
- Cluster D: Labs - Electrify Heat
- Cluster E: Printing Sq - Electrify Heat
- Dartry - Electrify heat
- St James - Electrify heat
- TBSI – Electrify heat

Key decarbonisation moves

Cluster A: West End - Electrify hot water (step 1)

Preferred scenario: Local CO_2 heat pumps for DHW load

Indicative duration: 2 years

Install individual CO_2 heat pumps (with electric immersion back up) to serve hot water for buildings with high heat demand in the cluster (e.g.. student residential). This will enable the main gas boilers in Boiler House A to be switched off in summer to reduce total heat demand, and it will reduce the overall size of ASHPs required to decarbonise the existing heat network, see step 2.

Cluster A: West End - Electrify space heat (step 2)

Preferred scenario: Heat pumps roofs of laundry & boiler house

Indicative duration: 2 years

Replace the existing gas boilers Boiler House A with high temperature ASHPs to serve the remaining heat load. There are spatial restrictions for siting the ASHPs in this cluster, but there is potential to repurpose the existing boiler house and the laundry to accommodate plant serving a lower percentage of the heat load than other clusters, with the remaining load being served by electric or gas boilers.

Cluster B: NE Corner - Electrify heat

Preferred scenario: Heat pumps on CRANN roof

Indicative duration: 3-4 years

Contains energy intensive buildings including Sports, CRANN, and Lloyd. New plant room built on roof of CRANN with high temperature ASHPs sized to deliver heat via small scale DHN to these buildings as well as ORI and possible future connection for TBS. Potential for polyvalent heat recovery heat pumps on both CRANN and Lloyd to provide simultaneous heating and cooling (being explored as part of the focused analysis of Cluster B). Electrify steam networks with direct electric steam generators.

Cluster C: Arts – Electrify Heat

Preferred scenario: Centralised plant room in carpark adjacent to Arts

Indicative duration: 3 years

New centralised plant enclosure located in carpark to south of Arts with high temperature ASHPs sized for heat load via small scale DHN to Arts, USSHER, Boland and the Museum.

Cluster D: Labs - Electrify Heat

Preferred scenario: Install heat pumps on Watts roof

Indicative duration: 2 years

New centralised plant located on roof of Watts with high temperature ASHPs designed to serve Panoz/ Smurfit and Watts. Electrify steam network in Panoz with direct electric steam generators.

Key decarbonisation moves

Cluster E: Printing Sq - Electrify Heat

Preferred scenario: Centralised plant room in carpark adjacent to Narrows

Indicative duration: 2 years

New centralised plant enclosure located in carpark to east of Narrows. High temperature ASHPs provide heat to Aras An Phiarsigh, Printing House Sq., and the two Narrows blocks via mini-DHN.

Dartry - Electrify heat

Preferred scenario: Install heat pumps on available roof space

Indicative duration: 2 years

New ASHPs for space heating and CO_2 heat pumps for DHW load located on available flat roofs of the three blocks or alternative option for a centralised energy centre in proposed new development or stand-alone structure with small scale DHN.

St James - Electrify heat

Indicative duration: 2 year

Preferred scenario: Centralised plant room in carpark or new building

New centralised plant located in the proposed new development in the car park or located in the existing roof boiler house for Phase 2/3. High temperature ASHPs sized to serve all phases of St James and new development (which would operate on lower flow temperatures).

TBSI – Electrify heat & steam

Indicative duration: 2 years

Preferred scenario: Heat recovery heat pumps on roof with new chillers

Significant year-round cooling load. New polyvalent simultaneous heat recovery heat pump array located where cooling towers currently are. Existing chillers, absorption chiller, and gas CHP all removed. New air cooled turbocor chillers located on flat roof on east end of building. Electrify steam networks with direct electric steam generators.

SECTION 4

DECARBONISATION PATHWAY ANALYSIS

40

Prioritisation of key moves

Multi-criteria analysis (MCA) has been used to provide a prioritisation assessment for the key moves based on their specific opportunities and constraints. The purpose of this is to provide TCD with a recommended implementation order that could achieve the decarbonisation targets considering not only capital costs and carbon savings but other constraints such as disruption, plant end of life, and electrical infrastructure.

The prioritisation assessment considered the criteria shown in table 4-1. The criteria are a combination of quantitative data from analysis and objective scoring on a scale of 1 to 5 (with 5 high). Criteria have been weighted by Buro Happold (Figure 4-1). The assessment provides an overall percentage performance score for each option which can then be used to inform prioritisation.

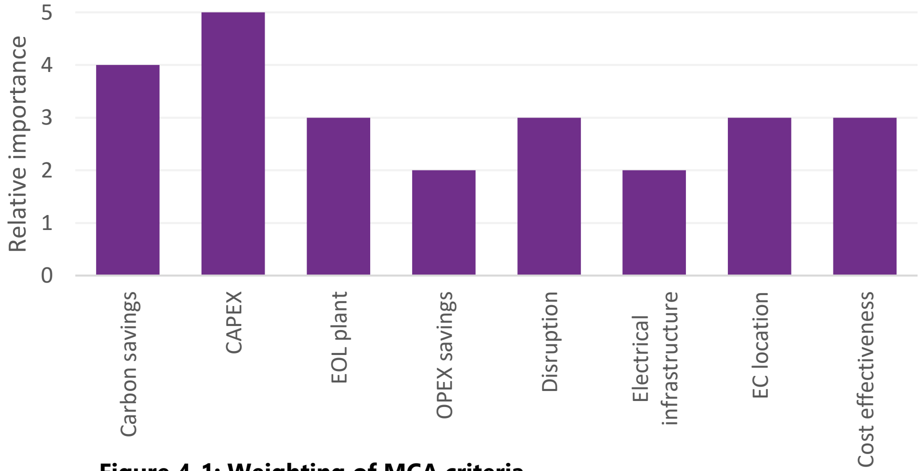


Figure 4-1: Weighting of MCA criteria

A summary of the MCA scoring is provided in Appendix A along with a Radar Chart (opposite) to provide a visual summary of performance. This example is for West End – Heat pumps. The grey dotted line is the average score for all key moves. The further the line is to the outer edge the better the move performs for that category.

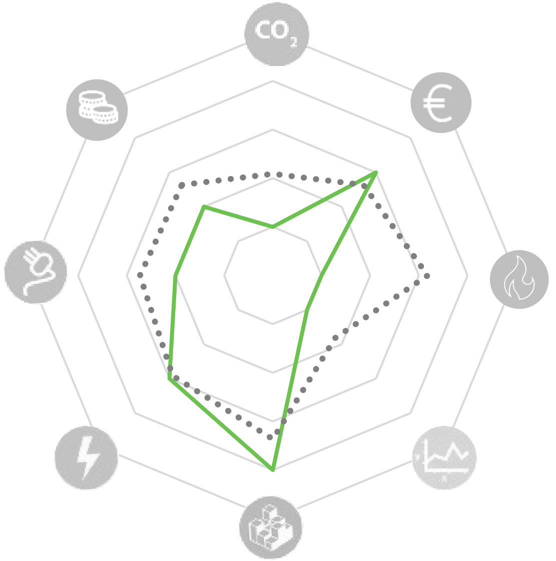


Table 4-1: Summary of criteria used for prioritisation assessment

Criteria	Description	Metric
Carbon savings	*Estimate of tCO_2e saved at 2030 (i.e. includes the impact of grid decarbonisation)*	*tCO_2e p.a.*
Capital cost	*Capital cost estimate for measure*	*€*
Energy cost savings	*Estimate of energy cost savings per year*	*€ p.a.*
Cost effectiveness	*Cost per tCO2e saved at 2030.*	*€ / tCO_2e p.a.*
Disruption / decant risk	*Anticipated disruption rated on scale 1-5 with 1 very low disruption 5 very high and potentially requiring decant whilst works carried out.*	*Scale 1-5 5 best*
EC location & pipework constraints	*General difficulty of implementation rated on scale of 1-5 with 1 very difficult and 5 very easy.*	*Scale 1-5 5 best*
Current EOL of plant	*Summary rating for remaining life of gas fired heating plant rated on a scale 1-5 with 1 beyond EOL and 5 replaced within last 3 years*	*Scale 1-5 5 best*
Electrical infrastructure constraints	*Summary rating for electrical infrastructure constraints rated on a scale 1-5 with 1 very significant constraints and 5 no constraints*	*Scale 1-5 5 best*

Prioritisation scoring

Table 4-2 shows the summary scores for the key moves and provides a recommended order of priority for implementation. Scores are a relative comparison from 0-100%, note that as this is a relative comparison a low score does not necessarily mean that an option should not be pursued. Where a category is scored 1-5, 5 is the best score.

The prioritised order is:

1. Optimsation measures – **83.1%**
2. Systems upgrades – **69.5%**
3. Cluster A: West End electrify hot water - **60.2%**
4. Trinity Hall, Dartry - **44.0%**
5. Cluster B: NE Corner – Sports/ CRANN - **41.2%**
6. Cluster A: West End electrify remaining space heat - **38.0%**
7. TBSI Electrify heat & steam- **37.6%**
8. St James, electrify heat - **35.9%**
9. Cluster E: Printing Square electrify heat - **28.9%**
10. Cluster D: Labs electrify heat - **27.8%**
11. Cluster C: Arts electrify heat - **24.0%**

Table 4-2: Summary scores for Key Moves from MCA analysis

		% score	tCO_2e p.a.	€	Scale 1 to 5 (high)	€ p.a.	Scale 1 to 5 (high)	Scale 1 to 5 (high)	Scale 1 to 5 (high)	€/tCO_2e
	Move	Total score	Est. carbon savings Yr1	Est. capital cost (mid-point)	Current EOL of plant	Operational cost savings	Decant risk/ operational disruption	Electrical infrastructure constraints	EC location & pipework constraints	€ per tonne CO_2e saved
1	Optimisation	83.1%	953	€ 300,000	3	€ 699,000	5	5	5	€ 184
2	Systems upgrades	69.5%	2,385	€ 13,500,000	3	€ 790,000	4	4	5	€ 5,833
3	Cluster A: West End - Electrify DHW	60.2%	447	€ 4,300,000	5	-€ 37,000	4	3	4	€ 8,101
4	Trinity Hall, Dartry	44.0%	694	€ 7,500,000	5	-€ 97,000	2	2	3	€ 10,440
5	Cluster B: Sports/ CRANN	41.2%	2,252	€ 12,200,000	3	-€ 272,000	1	3	2	€ 5,704
6	Cluster A: West End - Electrify heat	38.0%	887	€ 6,400,000	5	-€ 101,000	2	3	2	€ 14,972
7	TBSI electrify heat	37.6%	2,349	€ 20,200,000	4	-€ 300,000	2	3	2	€ 8,481
8	St James	35.9%	675	€ 8,900,000	4	-€ 95,000	3	1	3	€ 15,482
9	Cluster E: Printing Sq	28.9%	532	€ 12,700,000	2	-€ 97,000	4	4	3	€ 24,208
10	Cluster D: Labs	27.8%	531	€ 10,100,000	4	-€ 64,000	2	3	2	€ 18,486
11	Cluster C: Arts	24.0%	1,074	€ 19,400,000	3	-€ 187,000	3	1	3	€ 18,870

Decarbonisation pathway modelling

A recommended decarbonisation pathway has been developed based on prioritised rollout of the key moves. This pathway is contrasted to the Baseline '*Do Nothing*' approach to provide an indication of potential savings. A high-level summary of the decarbonisationn pathway is provided in this table, along with the definition of the 'Do Nothing' baseline.

The key moves are broadly programmed into four phases based on the high-level indication of the project duration highlighted in Section 3. There is a certain amount of flexibility in when key moves can be implemented within phases.

Table 4-3: Summary of modelled pathways

	Baseline - Do Nothing	Decarbonisation pathway
Summary	Shows the 'do nothing' situation. Serves as a comparison to estimate the potential savings of the pathway.	Modelled impact of key moves including demand reduction and heat decarbonisation.
Target 1	Not achieved	Achieved
Target 2	Not achieved	Achieved
Key features	• All planned new development and planned removal of assets • Impact of Irish electrical grid decarbonisation • No demand reduction or heat decarbonisation measures • Like-for-like replacement for fossil fuel heating plant – so the pathway retains significant gas use.	• Impact of new developments and removals • Electrical grid decarbonisation • Demand reduction measures • Heat decarbonisation measures • Measures programmed across four phases • No fabric improvements

Decarbonisation pathway

Figure 4-1 shows the decarbonisation pathway based on implementation of the key moves across the four phases. Note that the carbon reduction for the key moves have been apportioned equally across their assumed duration. Therefore, this pathway should be treated as indicative. Carbon emissions are estimated using the carbon emission factors from SEAI. The savings shown are relative to the baseline year (2016-18).

As can be seen, the decarbonisation pathway can potentially achieve significant savings against the baseline year and the 'do-nothing' situation. At 2030, the pathway could save ~60% increasing to ~78% at 2040 vs the baseline year.

Note the pathway achieves both Target 1 and Target 2 at 2030 whilst the 'do-nothing' situation does not achieve either target

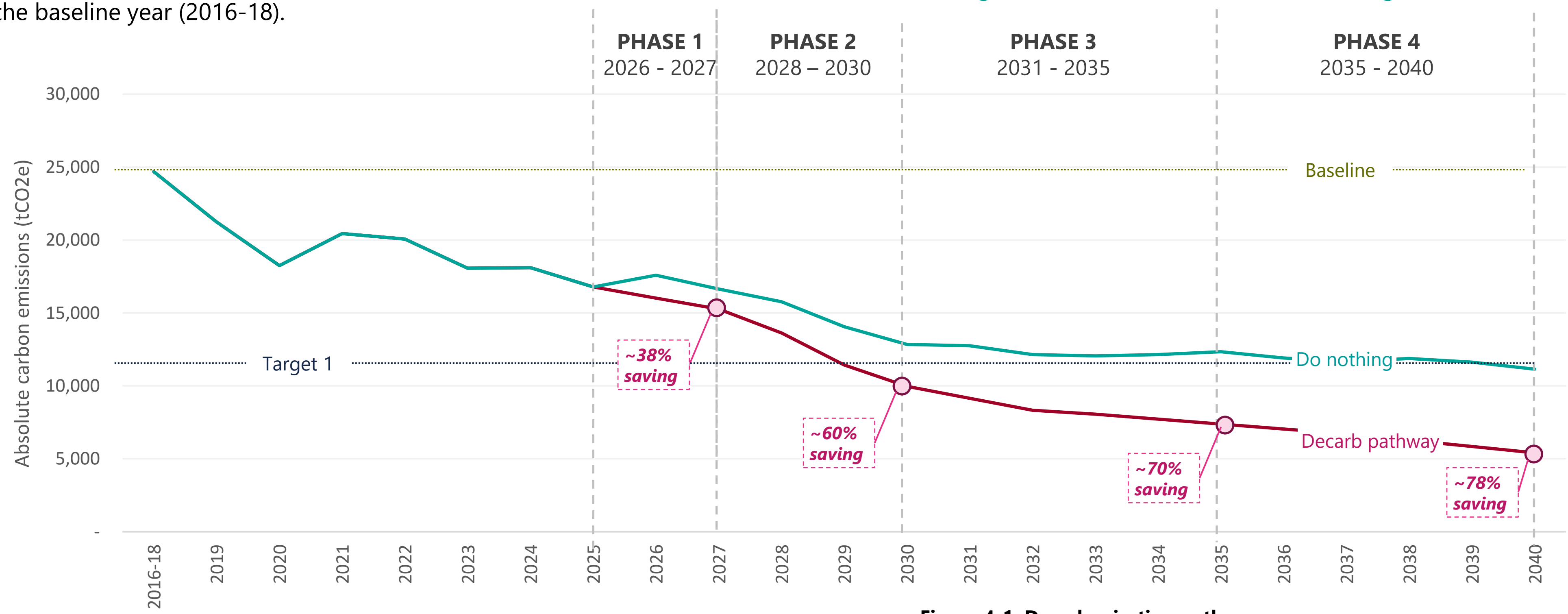


Figure 4-1: Decarbonisation pathway

Waterfall chart

Note cost estimates at this stage are ±30%

This is a waterfall chart for the decarbonisation pathway which shows the percentage carbon saving against the baseline for each of the key moves alongside the estimated capital cost, with the total capital cost shown. This shows year 1 carbon savings (so if measures were implemented now) against a 2024 baseline and accounts for diminishing returns of implementing the measures together (as opposed to in isolation).

As can be seen, Optimisation measures can save ~5% emissions for relatively low capital outlay. System upgrades, Cluster B: Sports/ CRANN, and TBSI heat decarb all provide similar reduction in emissions ~7-12% with TBSI being the more expensive of these options. At least two of these three are required to achieve Target 2 by 2030. Cluster C: Arts is an expensive option which is estimated to only provide ~4% emissions reduction.

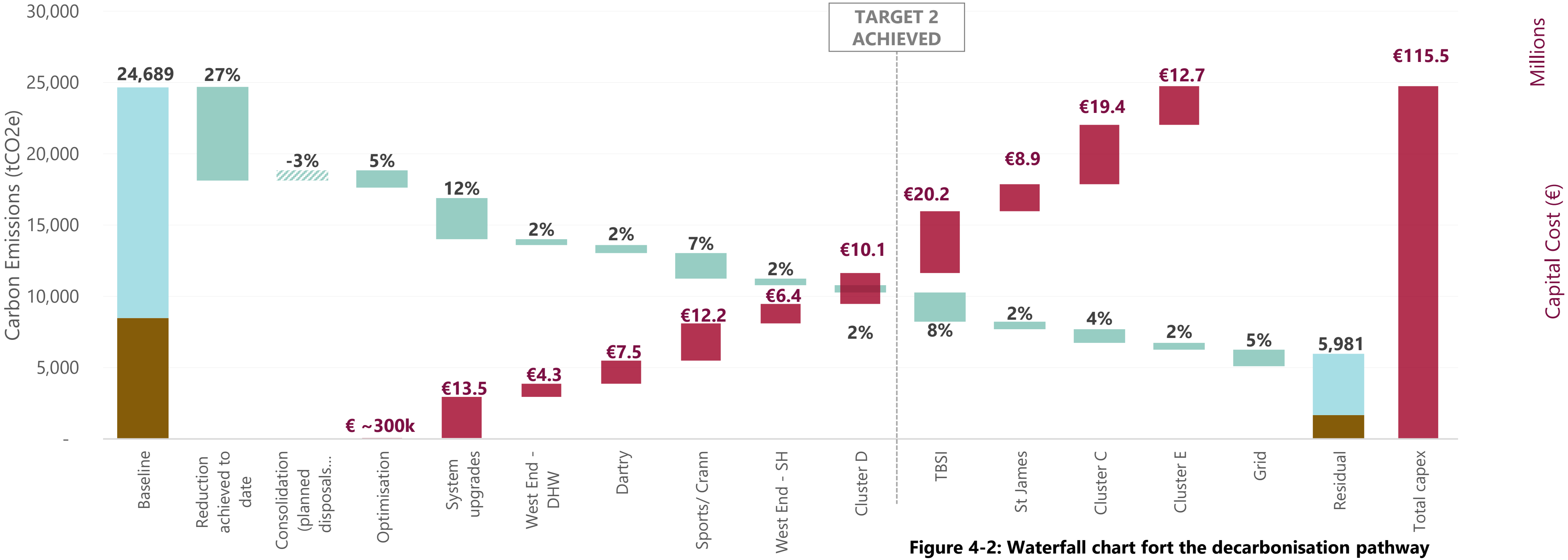


Figure 4-2: Waterfall chart fort the decarbonisation pathway

SECTION 5

COST ANALYSIS

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Capital cost analysis

Overview

A preliminary cost exercise has been undertaken to provide TCD with order-of-magnitude (OOM) capital cost estimates for implementing the decarbonisation strategy. The purpose of this analysis is to:

- Support early-stage capital budgeting
- Inform strategic decision-making
- Provide a preliminary understanding of investment requirements across the estate

A cost list was established for each priority move, and capital cost estimates were developed by AECOM Cost Specialists based on the high-level list of cost items prepared by Buro Happold. (see Appendix E, TCD Decarbonisation Energy Centre Cost Study 2026, AECOM).

Key assumptions

Detailed cost assumptions are provided in Appendix B.

These estimates are pre-feasibility stage and therefore indicative.

As highlighted by AECOM, the estimates carry a typical accuracy of ±30%, reflecting the limited design detail available at this pre-feasibility stage. This level of accuracy is standard for early-stage decarbonisation and infrastructure studies and should not be interpreted as investment-grade costing. A more detailed explanation of this cost uncertainty is provided on the following page.

Cost estimates are presented in December 2025 prices and represent the fully installed cost, including contractor preliminaries, overheads and profit, project contingency, professional fees, and VAT (note that overheads have not been applied to the demand reduction measures due to varied type of projects they relate to, although they do include VAT).

No allowance has been made for future inflation, market escalation, or potential technology learning rates that could reduce costs over time.

Cost uncertainty at this stage

Cost uncertainty

As only central (mid-point) cost estimates were shown in the initial strategy visuals, it is important to interpret these figures correctly. The values presented for each cluster represent the **central cost estimate**, used to provide a consistent basis for comparing options and understanding the overall scale of investment across the estate. These figures should not be interpreted as fixed or final construction costs.

To support transparency and improve interpretation, this report now includes a summary table (next page) showing the full ±30% cost ranges associated with each key move. These ranges reflect the normal level of accuracy for pre-feasibility, order-of-magnitude cost exercises and provide a clearer view of the potential variability at this stage. For example, an indicative cost of €10 million should be considered as sitting within a probable range of approximately €7–13 million.

Why this uncertainty is normal at this stage

The ±30% accuracy band is standard for pre-feasibility stage costing because many aspects of the strategy remain to be defined or validated. In particular:

- ***Designs are not yet developed***, including plantroom locations, pipework routing, structural interventions, utilities interfaces and construction sequencing.
- ***Equipment selections are preliminary***, generally based on performance criteria and initial discussions with suppliers.
- ***Construction methodology is assumed***, not fixed, affecting access strategies, temporary works, preliminaries and programme allowances.

These uncertainties are inherent to early-stage decarbonisation planning and will reduce as the design evolves.

How cost confidence will improve

As options are progressed into concept and developed design stages, assumptions will be tested, site information will be confirmed, and technical solutions will be refined. This will naturally narrow the cost range—from ±30% at pre-feasibility stage, towards ±15–20% at developed design, and ±5–10% at tender stage. This progression is typical for projects of this nature.

Intended use of the estimates

The purpose of this cost exercise is to inform strategic choices, support early-stage budgeting and provide a basis for comparing decarbonisation pathways. These estimates are not investment-grade and should not be used for procurement or funding approval without further development.

Costs should be refined through detailed feasibility studies and subsequent design work undertaken by appropriately qualified cost consultants. Appendix B summarises the key cost assumptions and modelling inputs used in the analysis.

Key moves summary

This table shows the summary of the key moves in terms of carbon savings and capital cost. The central cost estimate is shown alongside the estimated cost range.

Table 5-1: Key moves carbon and cost summary

	Ref	Measure	Thermal carbon savings (tCO2e)	Total carbon savings (tCO2e)	Est. total CAPEX *(central estimate)*	Lower capex range (-30%)	Higher capex range (+30%)
2030	1	Grid decarbonisation	-	1,174	-	-	-
	2	Consolidation – planned disposals & additions	+7	+393	-	-	-
	4	Optimisation measures	808	953	€ 300 k	€ 200 k	€ 400 k
	5	System upgrades	2,178	2,385	€ 13.5 M	€ 9.5 M	€ 17.6 M
	6	Electrify hot water West End	288	447	€ 4.3 M	€ 3.0 M	€ 5.6 M
	7	Electrify heat at Dartry	669	694	€ 7.5 M	€ 5.3 M	9.8 M
	8	Electrify heat Sports/Crann (Cluster B)	1,119	2,252	€ 12.2 M	€ 8.5 M	15.9 M
	9	Heat pumps West End for space heating	538	887	€ 6.4 M	€ 4.5 M	8.3 M
	10	Electrify heat at Cluster D: Labs	265	531	€ 10.1 M	€ 7.1 M	13.1 M
		Total est. CAPEX for Target 2			**€ 54.3 M**	**€ 38.0 M**	**€ 70.6 M**
2040	11	Electrify heat at TBSI	1,262	2,349	€ 20.2 M	€ 14.1 M	€ 26.3 M
	12	Electrify heat St James	359	675	€ 8.9 M	€ 6.2 M	€ 11.6 M
	13	Electrify heat at Island Campus (Cluster E, Cluster C)	1,139	1,606	€ 32.1 M	€ 22.5 M	€ 41.7 M
		Total est. CAPEX for Overall Strategy			**€ 115.5 M**	**€ 80.9 M**	**€ 150.2 M**

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Capital cost analysis

Figure 5-1 shows the capital cost estimates for each key move in order of priority scoring to achieve Target 2 at 2030. The costs shown are the central point estimates and are subject to uncertainty at this stage.

As can be seen, the key moves are generally in order of cost with lower cost moves earlier apart from some notable exceptions:

- System Upgrades are recommended earlier as the measures are generally considered technically easier to implement and can reduce energy demand which would enable right sizing of subsequent plant upgrades. However, it is highlighted that these are numerous individual projects across multiple assets so managing delivery is likely to be difficult for the Estates team with the current level of resource available
- Cluster B: Sports & Crann is earlier as it is one of the most cost effective measures TCD can do to reduce carbon emissions and achieve the carbon targets.
- TBSI is the highest cost option but is complicated to deliver and would likely take a programme of works that would take TCD past the 2030 target year. However, we recommend that feasibility studies for decarbonisation are undertaken now to lay the foundations for decarbonisation.
- St James is lower capital cost but there are difficulties in terms of ownership structures with the hospital making delivery more complicated at this stage.

Key Findings

- Target 2 (by 2030): Estimated investment of **€54.3M** required
- Total capex investment by 2040: **~€115.5 M**
- *Note cost estimates at this stage are ±30%*

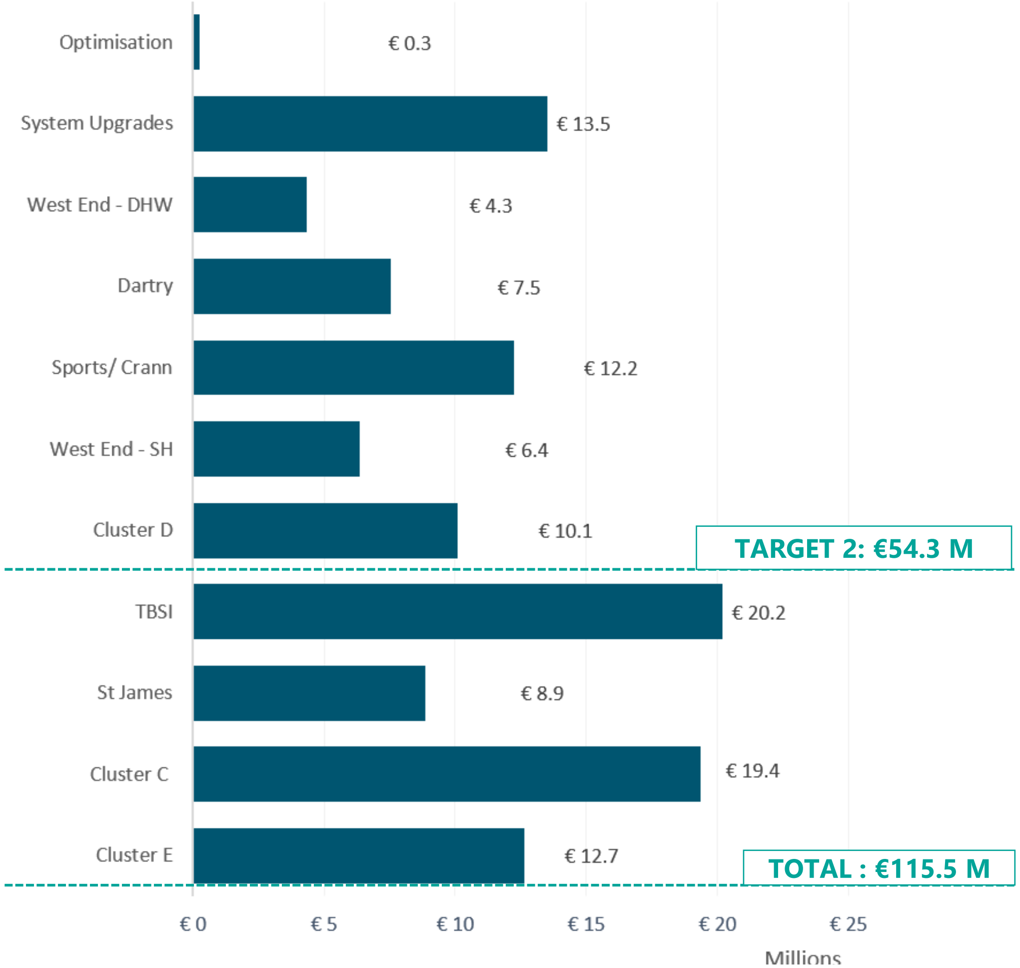

Figure 5-1: Capital cost estimates for the key moves

Decarbonisation uplift costs

If TCD did not progress the decarbonisation projects, significant investment would still be required to replace plant and associated systems like-for-like (e.g.. replace gas boilers with new gas boilers) for the assets related to the key moves.

Therefore, the like-for-like replacement costs for each move have been estimated at a high-level to provide an indication of the required 'uplift' cost for decarbonisation. This is more reflective of the true cost of decarbonisation and is important for making the business case for investment. The decarbonisation uplift cost is highlighted in Figure 5-2.

Observations on chart:

- TBSI has a significant like for like cost of ~1/3 of the total estimated capex. This is because the current HVAC plant is relatively complicated and sizeable. Plant is at EOL and there is an opportunity window to invest this money into decarbonisation rather than like for like replacements.
- West End DHW and space heating also have notable like for like costs and taken together are ~46% of the total capex. The West End plant in boiler house A would require significant investment to bring it up to the required level. The like for like estimate also allows for replacement of the existing DHN pipe between buildings which would be a high cost, and its current condition is unknown (but expected to be poor).
- Dartry has a low like for like cost as plant is relatively simple and straight forward to replace compared to other clusters.

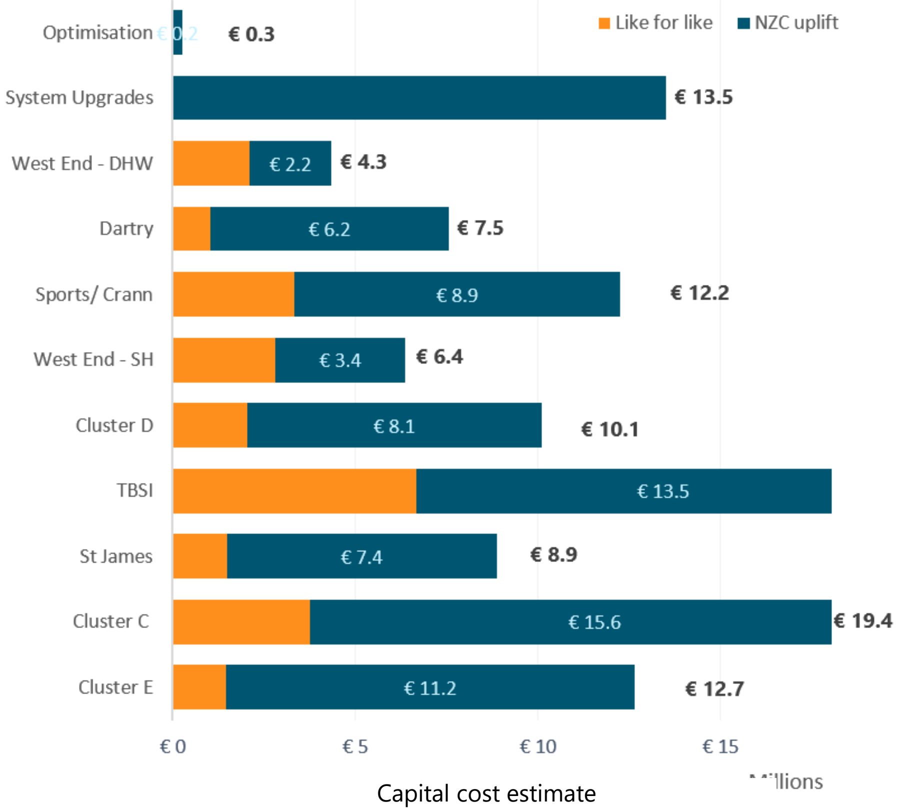

Figure 5-2: Estimation of decarbonisation cost uplift for the key moves

Summary

- Total est capital cost: **~€115.5 M**
- Total est like-for-like cost: **~€25.3 M**
- Total uplift cost: **~€90.2 M**

Note cost estimates at this stage are ±30%

Key moves

Cost effectiveness

Figure 5-3 shows an estimate for the cost effectiveness of each of the key moves in terms of operational carbon emissions reduction. This is represented by € per tonne of carbon saved at 2030 (so the grid decarbonisation achieved through replacing fossil fuel plant with electric is considered).

Observations on chart:

- Optimisation measures are the lowest cost per tonne saved as they do not involve implementing new technology or systems.
- Cluster B: Sports/ CRANN is the most cost-effective heat decarbonation measure and is even slightly more cost effective than the System Upgrade measures (if they were all deployed together). It is ranked below other heat decarbonisation measure though as it is more complex to deliver.
- West End Electrify DHW is relatively cost effective and is one of the easier heat decarbonisation measures to progress.
- TBSI is one of the more cost-effective heat decarbonisation moves but requires high capital outlay, is complex to delivery and is likely to require a longer delivery period.
- St James, Cluster C, D, and E are all relatively expensive options for decarbonisation so feature towards the end of the recommended delivery order.

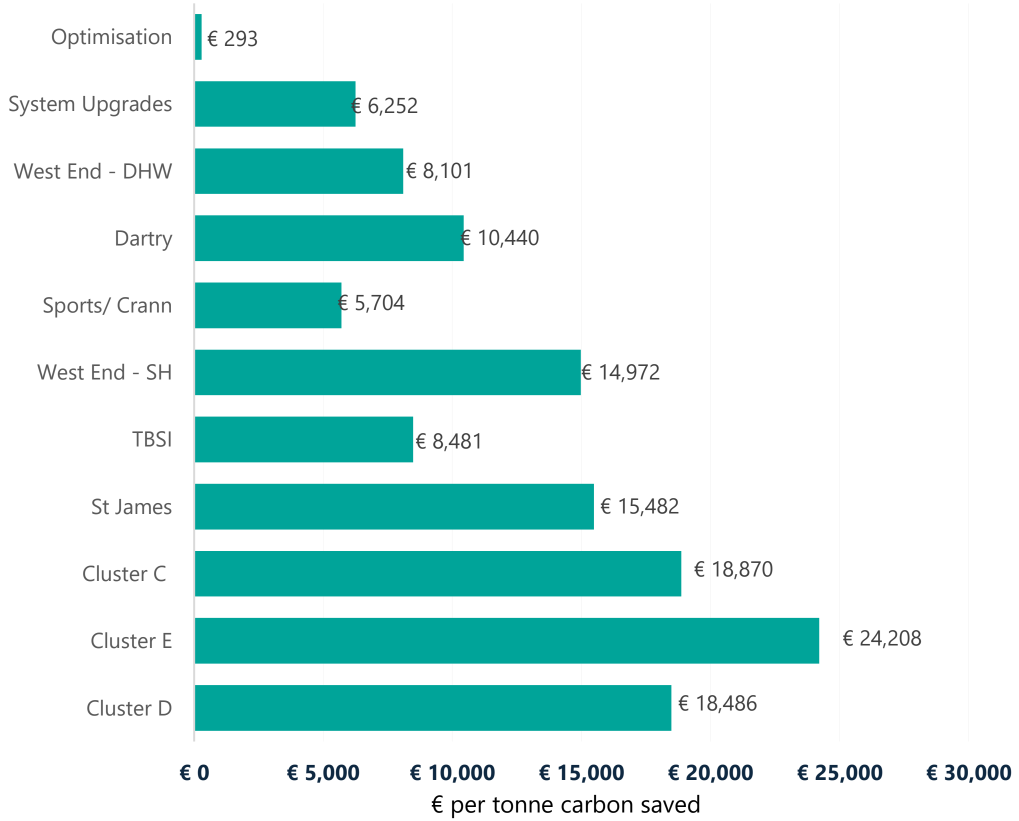

Figure 5-3: Cost effectiveness of key moves (e.g.. € per tonne carbon saved)

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Demand reduction measures

Cost effectiveness

Figure 5-4 shows the heat decarbonisation key moves (pink) combined with the systems upgrade measures (green) and an estimation of their cost effectiveness in terms of capex and Year 1 carbon emission savings. The Optimisation measures are grouped as one category at the bottom of the chart. The measures are ranked by €/tCO_2e saved..

Observations on chart

- Optimisation measures such as HVAC setpoints review, Lab- Vent Rates reduction adjustment are anticipated to provide the most carbon savings for the lowest cost.
- Local steam generators and Exhaust Air Heat pump AHUs are generally expensive in terms of capital cost compared to other measures but are cost effective as they can potentially offer high fossil fuel savings.
- Demand control ventilation and fume cupboard upgrades can potentially save high amounts of energy but have high capital costs associated with them meaning they come out lower on cost effectiveness.
- Behaviour change programme and analytics are both estimated to be cost effective measures. Generally, this is because they are able to be implemented across all buildings. There is a high degree of uncertainty with energy savings achieved through behaviour change campaigns and this measure would typically require ongoing costs to ensure savings do not reduce over time.

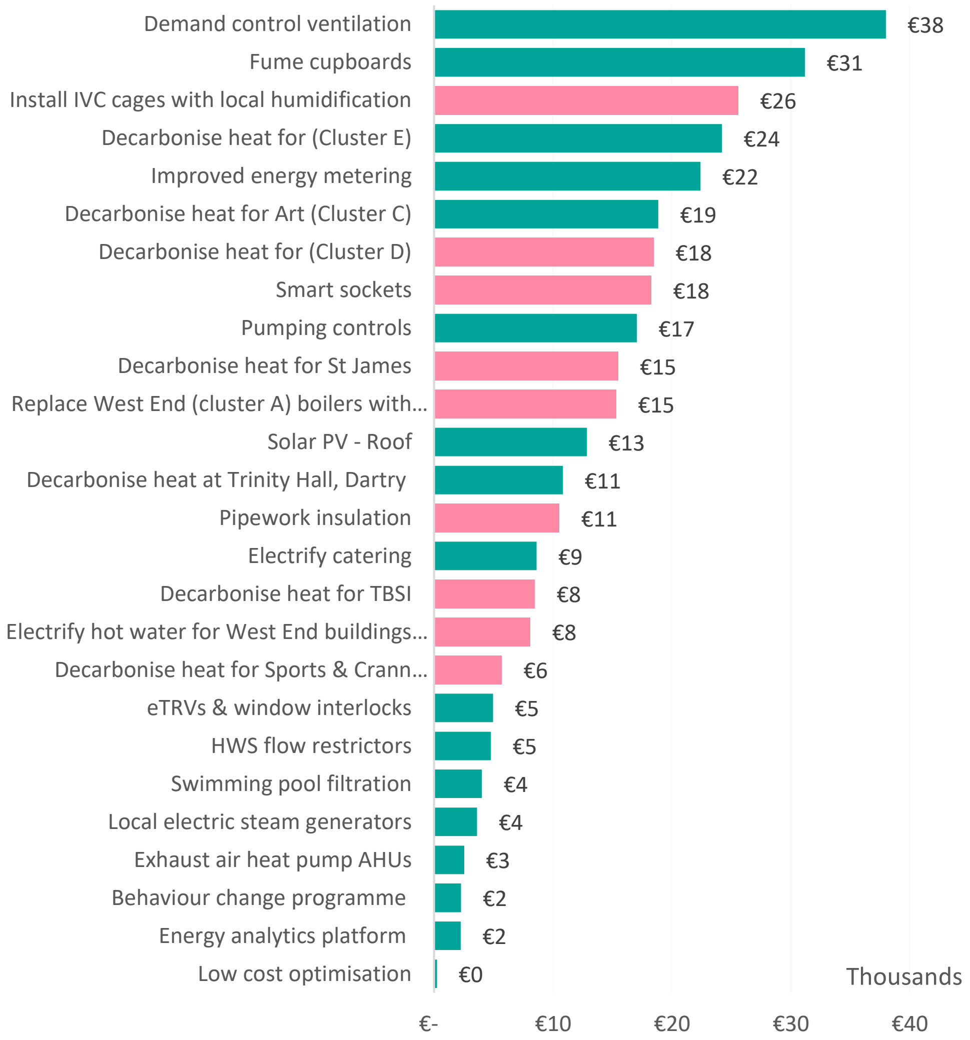

Figure 5-4: Shows the recommended measures ranked by €/tCO_2e

Operational cost analysis

Figure 5-5 the estimated impact of the heat decarbonisation options on annual utility energy costs, comparing the current baseline position with the post-decarbonisation scenario. The stacked bars illustrate how costs are distributed across the different clusters, with the right-hand column showing the relative change in annual OPEX at a cluster level.

Overall, the analysis indicates an increase in total annual energy costs from approximately **€8.8m (baseline)** to **~€10.1m** (circa **+15% increase**). This reflects the shift from fossil fuel–based systems to electrified heating, where higher electricity consumption and current price differentials drive increased operational costs.

Observations on chart

- The cost increase is not uniform across the estate, with some clusters (e.g. West End and Arts) showing higher proportional increases (circa 20–28%).
- Other areas (e.g. TBSI, NE Cluster, and Labs) show more moderate increases (~11–15%).
- Despite higher operating costs, the options deliver substantial reductions in fossil fuel use and associated emissions.
- The analysis highlights the importance of demand reduction and optimisation measures to mitigate cost increases, as these reduce overall energy consumption and therefore exposure to higher electricity prices.

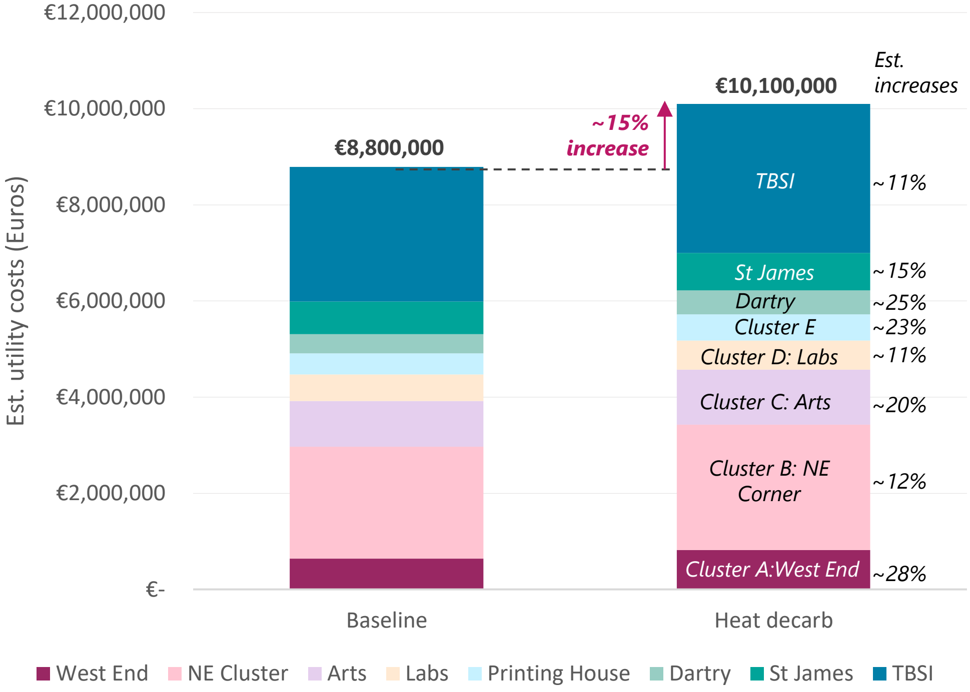

Figure 5-5: High-level estimated impact of heat decarbonisation options on operational energy costs

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SECTION 6

IMPLEMENTATION ROADMAP

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Implementation Roadmap

Delivering Trinity College Dublin's decarbonisation strategy will require a coordinated, multi-year programme of actions. The roadmap below sets out the key phases, responsibilities, and milestones to ensure successful delivery.

1. Programme Governance & Resourcing

Establish a Net Zero Delivery Team:
Form a dedicated cross-functional team within Estates, including project management, engineering, finance, and communications, with clear leadership and reporting lines to senior management.

Define Roles & Responsibilities:
Assign building-level "champions" and clarify accountability for each workstream (demand reduction, heat decarbonisation, capital projects, stakeholder engagement).

Secure Funding:
Develop a capital investment plan, identify internal and external funding sources, and align with annual budgeting cycles.

2. Detailed Planning & Feasibility

Prioritise Actions:
Sequence interventions based on carbon impact, asset condition, operational risk, and ease of implementation. Focus first on high-emitting, end-of-life plant and "quick win" demand reduction measures.

Conduct Technical Feasibility Studies:
Commission detailed studies for heat pump installations, energy centres, and electrical infrastructure upgrades. Assess structural, acoustic, and planning constraints for each cluster.

Engage Utility Providers:
Initiate early discussions with utility companies and other relevant bodies to secure future electrical capacity and grid connections.

Implementation Roadmap

3. Stakeholder Engagement & Communication

Develop a Communications Plan:
Inform and involve staff, students, and external partners. Use workshops, briefings, and digital platforms to explain the rationale, benefits, and timelines.

Coordinate with Building Users:
Schedule works to minimise disruption to teaching, research, and residential operations. Provide advance notice and clear points of contact for queries.

4. Early Actions: Demand Reduction Measures

Roll Out Low-Cost Measures:
Implement HVAC and lighting controls, ventilation optimisation, and behaviour change campaigns across the estate.

Upgrade Metering & Analytics:
Install sub-metering and deploy an energy analytics platform to enable real-time monitoring and continuous improvement.

Monitor and Report:
Track savings and performance, using dashboards to provide feedback to building users and leadership.

5. Major Capital Projects: Heat Decarbonisation & System Upgrades

Phase 1 (Years 2026-28):

- Commence low cost 'Optimisation' programme focused on controls improvement and behaviour change.
- Begin systems upgrades in high-impact buildings (e.g. TBSI).
- Replace end-of-life gas boilers in priority buildings with heat pumps or connect to new energy centres.
- Commence electrification of hot water at Cluster A West End.
- Commence electrification of heat for Cluster B NE Corner

Phase 2 (Years 2029–30):

- Expand heat decarbonisation to remaining Cluster A space heat
- Commence electrification of Trinity Hall, Dartry and Cluster D.
- Complete heat decarbonisation projects to achieve Target 2.
- Continue system and controls upgrades in priority buildings.

Phase 3 (Years 2031–35):

- Commence heat decarbonisation of TBSI
- Expand heat decarbonisation to remaining high impact clusters including Arts and St James.

Phase 4 (Years 2036-2040):

- Commence heat decarbonisation of Cluster E.
- Complete heat decarbonisation rollout to all remaining assets in the Estate to achieve near-full removal of fossil fuel plant.
- Review and refine based on performance data and evolving technology.

Implementation Roadmap

6. Risk Management & Continuous Improvement

Identify and Mitigate Risks:
Maintain a live risk register covering technical, financial, operational, and stakeholder risks. Update mitigation plans regularly.

Annual Review and Adjustment:
Review progress against targets annually. Update the roadmap to reflect policy changes, new technologies, and lessons learned.

Benchmarking and Best Practice:
Participate in sector networks to share learning and adopt emerging best practice.

7. Monitoring, Reporting & Compliance

Establish KPIs and Reporting Framework:
Define clear metrics for carbon, energy, cost, and delivery milestones. Report progress to senior leadership and external stakeholders.

Compliance and Certification:
Ensure alignment with SEAI, and other relevant standards e.g.. SBTi, . Prepare for external audits and certification as required.

8. Next Steps

- Finalise and approve the detailed implementation plan.
- Launch the Net Zero Delivery Team and secure initial funding.
- Begin feasibility studies and early demand reduction measures.
- Schedule regular progress reviews and stakeholder updates.

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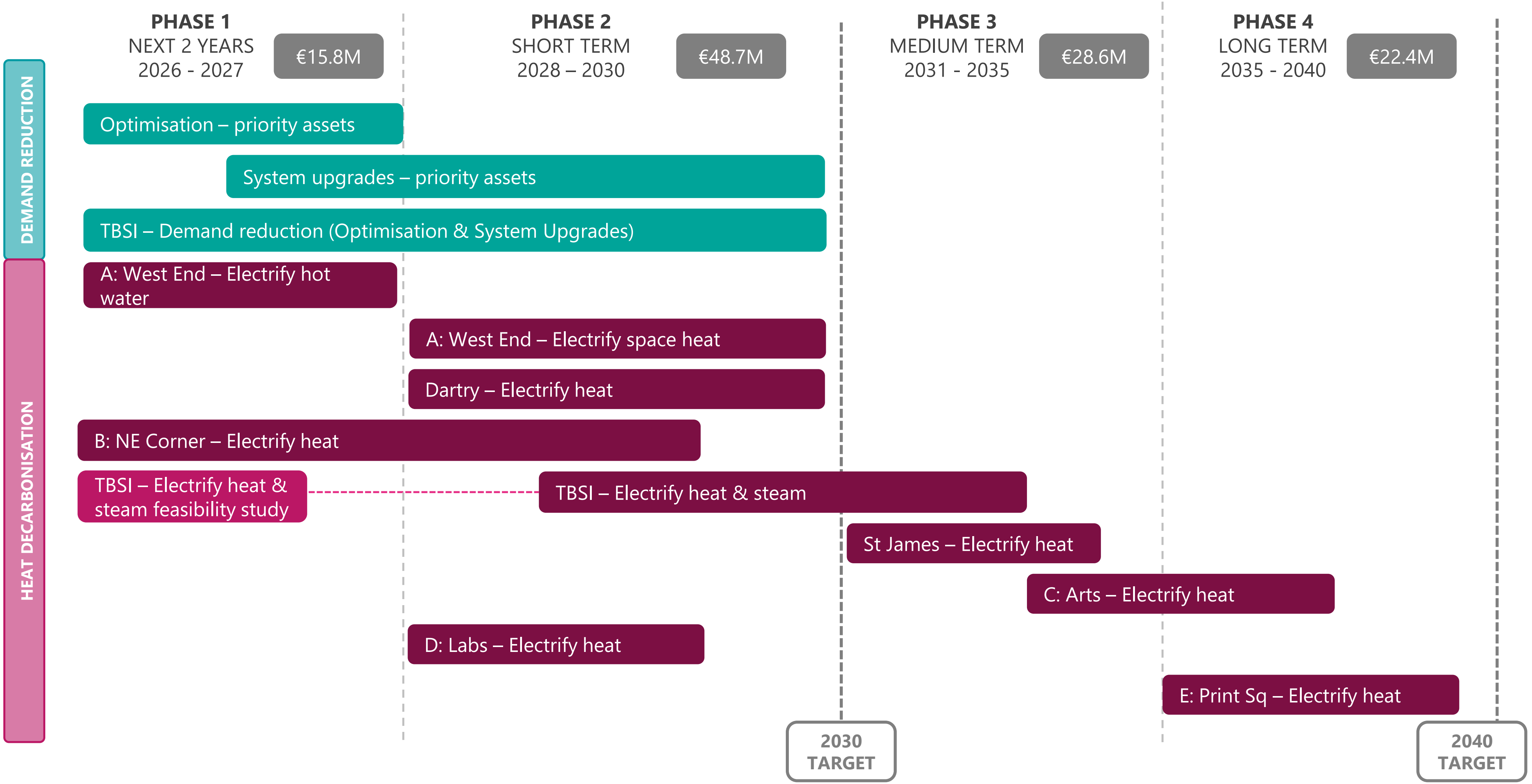
Implementation timeline

TOTAL EST. COST = €115.5M
±30%



Summary of key messages

Meeting Targets & Investment Overview

- Target 1: Achievable through low-cost optimisation and grid decarbonisation
- Target 2: Requires major heat decarbonisation at key sites (West End Boiler House A, Trinity Hall Dartry, Northeast Corner, and Cluster D).
  - Estimated investment: **€54.3M by 2030**
  - Includes **€33.3M uplift over like-for-like** plant replacement
  - Additional funding may be needed depending on risk appetite

Key Challenges

- Many gas boilers at end of life; replacing with gas risks SEAI & TCD net-zero goals
- TBSI offers large carbon savings but faces complex operational and spatial constraints
- Significant programme requires extra estate resources and ongoing energy/programme management
- Potential for significant disruption across campus

Key Recommendations

- Improve energy metering for all priority buildings to optimise designs and cost-efficiency for decarbonisation key moves (right-sizing)
- Begin electrification feasibility studies now to assess practicalities, costs, and timelines
- Commence planning for delivery of major programme of works and establishing TCD resource impacts
- Maintain the roadmap as a living document o be updated as new data, technologies, and lessons emerge.
- Commence strategic planning for how to manage and reduce risk around disruption.