An evidence review of data associated with non-domestic buildings

Dr Paraskevi Vatougiou, Dr Peter McCallum, Prof David Jenkins, Heriot-Watt University

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1 Executive summary

Scotland's Heat in Buildings Strategy sets out a pathway to zero emissions buildings by 2045 and details actions that will accelerate the transformation of the nation's building stock. The Strategy commits to the conversion of the equivalent of 50,000 non-domestic buildings to zero emissions heat by 2030. There are approximately 220,000 non-domestic buildings in Scotland and these buildings are hugely diverse. An understanding of the merits and limitations of existing building stock data is integral to developing policy that supports the Heat in Buildings Strategy commitment.

1.1 Aims and findings

This report, commissioned by the Scottish Government, aims to review available data that describes the non-domestic stock in Scotland. Whilst the key focus is limited to this specific geographic and sectoral scope, the background review is informed by studies from the UK and elsewhere, and work in other sectors. The report also provides a link between available data sources and non-domestic building policy areas, providing a framework to encourage evidence-based policy-making.

Data characterising the building stock, and related activities, can cover a diverse range of parameters, but this project focusses on:

i Building physical characteristics (dimensions, floor area, constructions, etc.);
ii Geographical information (locational data, Geographic Information System (GIS)-related information, etc.);
iii Activity overview (non-domestic sub-sector categorisation, multi- and mixed-use buildings, etc.); and
iv Inferred/modelled greenhouse gas emission data.

The report notes that:

- Comprehensive data inventories are often incomplete in the non-domestic sector, and this report references work that aims to resolve this.
- Data is used in at least three stages of policy formulation, categorised in this report as development, tracking, and enforcement. The link between these stages of policy formulation and data usage is not always clear, but the report proposes a structure to improve this.
- Data governance structures and access restrictions can make wider-scale dissemination of data (both inside and outside government) more challenging. Good policy formulation, and dissemination, must work within these restrictions.
- Whilst Scotland, and the rest of the UK, has a relatively strong data landscape in the area of built environment, the report alludes to the potential for good-practice sharing with other countries tasked with similar challenges.
- The data landscape within a country, and tools/methods to gather and collate that data, is not static. Government must continually review the data that is already being collected, but also identify how new forms of data collection (e.g., smart metering, online open-access databases) could be exploited to provide better evidence-based policy. Likewise, the opportunities created by ever-advancing data science to better analyse this data should be regularly reviewed.

In discussing these findings, with a wide-ranging review of the importance of data for policy, populating non-domestic stock models, and informing regulations, the report suggests (see Sections 1.2 and 7) a way forward for curating and using data in a more standardised and application-focussed way.

1.2 Conclusions

Based on the findings of the work the report concludes that:

1. Energy efficiency upgrade information is not currently well-reported in the non-domestic sector. Energy Action Plans could be used as a basis for an annual reporting mechanism to make this more transparent.
2. Display Energy Certificates are informative and standardised forms of energy and building data. Scottish Government could consider adopting these for all non-domestic buildings in order to monitor progress towards 2030 targets.
3. The Non-Domestic Analytics dataset could be updated more frequently to mitigate for the low number of non-domestic buildings with Energy Performance Certificates.
4. Bulk Energy Performance Certificate data could include information on the buildings' age band, constructions, and built form to add value to, for example, developing Scottish thermal stock models.
5. Improved quality controls on Energy Performance Certificate input data could improve the cross-referencing with other datasets.
6. Linking Energy Performance Certificate and other databases with interactive maps, such as those provided by local authorities, could aid policy observation and target monitoring.
7. The Scottish Government could consider undertaking a regular non-domestic building stock survey, analogous to the Scottish House Condition Survey and informed by other activities in the rest of UK and, in particular, the US.

8. This report also draws attention to the successful use of other surveying techniques and data collection (such as self-reporting and use of tax record information) that could form the basis of a wider surveying approach to non-domestic buildings.
9. The report has suggested a framework for tracking and mapping datasets and policy areas. This could be maintained to understand the value and impact of current and future data strategies.
10. Key parameters from Building Warrant applications could be registered and shared in a nationwide database to assist with the development of policy.

These conclusions are intended to support the Scottish Government's non-domestic building strategies.

Contents

2 List of abbreviations

ASHRAE:	American Society Heating Refrigerating and Air-Conditioning Engineering
BAR:	Building Assessment Report
BBP:	Better Buildings Partnership
BEES:	Building Energy Efficiency Survey (UK)
BEIS:	(Department of) Business Energy & Industrial Strategy
BPD:	Building Performance Database
BRANZ:	Building Research Association of New Zealand
BRE:	Building Research Establishment
BSO:	Building Stock Observatory
CaRB:	Carbon Reduction in Buildings
CBD:	Commercial Building Disclosure
CBECS:	Commercial Building Energy Consumption Survey
CEUS:	(California's) Commercial End-Use Survey
CNDEM:	Cambridge Non-Domestic Energy Model
CRR:	Carbon Reduction Reporting
CSE:	Centre for Sustainable Energy
DEC:	Display Energy Certificate
DfP:	Design for Performance
DLUHC:	Department for Levelling Up, Housing & Communities
DoE:	(US) Department of Energy
EAP:	Energy Action Plan
EED:	(European) Energy Efficiency Directive
EHS:	English Housing Survey
EIA:	Energy Information Administration
EPA:	Environmental Protection Agency
EPC:	Energy Performance Certificate
e-PIMS:	Electronic Property Information Mapping Service
EPBD:	Energy Performance of Buildings Directive
ESOS:	Energy Saving Opportunity Scheme
EST:	Energy Saving Trust
EU:	European Union
GDPR:	General Data Protection Regulation
GIS:	Geographic Information System
HA:	Home Analytics (Scotland)
HIB:	Heat in Buildings
HNPD:	Heat Networks Planning Database
IECC:	International Energy Conservation Code
LiDAR:	Light Detection and Ranging
MCS:	Microgeneration Certification Scheme
MEES:	Minimum Energy Efficiency Standard
NABERS:	National Australian Built Environment Rating System
NDA:	Non-Domestic Analytics (Scotland)

NDBS:	Non-Domestic Building Stock
ND-NEED:	Non-Domestic National Energy Efficiency Data-Framework
NEMS:	National Energy Monitoring System
NI:	Northern Ireland
NRCan:	National Resources Canada
NZ BEES:	New Zealand's Building Energy End-use Study
OIC:	Orkney Islands Council
ONS:	Office for National Statistics
OS:	Ordnance Survey
RRN:	Report Reference Number
rUK:	rest of the UK
SBEM:	Simplified Building Energy Model
SAA:	Scottish Assessors Association
SCIEU:	Survey of Commercial and Institutional Energy Use
SECR:	Streamlined Energy and Carbon Reporting
SEPA:	Scottish Environmental Protection Agency
SEPCR:	Scottish Energy Performance Certificate Register
SGN:	Scotia Gas Network
SHCS:	Scottish House Condition Survey
SIMD:	Scottish Index of Multiple Deprivation
TCTP:	Tokyo Cap-and-Trade Programme
TMG:	Tokyo Metropolitan Government
TOID:	Topographic Identifier
UK BEES:	UK Building Energy Efficiency Survey
UPRN:	Unique Property Reference Number
VOA:	Valuation Office Agency

3 Introduction

3.1 Background

There are approximately 220,000 non-domestic buildings in Scotland,[1] including 23,000 buildings in public ownership.[2] The recent Scottish Heat in Buildings (HIB) Strategy (Scottish Government, 2021c), noted that Scotland's non-domestic buildings accounted for 12% of Scotland's final energy consumption (17 TWh) and 7% of Scotland's total greenhouse gas emissions. Scotland's decarbonisation targets mean the need to characterise that building stock, and prepare solutions that are tailored to the specific needs of those buildings, is of great importance. In particular, the desire of the HIB Strategy to convert the equivalent of 50,000 non-domestic buildings to zero emissions heat by 2030 requires a thorough understanding of those buildings.

Data on non-domestic buildings tend to be inconsistent, intermittent, and of poor coverage. Historically, the non-domestic building stock has been seen as a difficult sector to characterise due to the lack of homogeneity in both activities and physical properties. The significant functional diversity of non-domestic buildings (commercial, industrial, educational, retail, health, etc.) leads to a wide range in sizes, built forms, occupancy patterns and energy requirements compared to residential buildings. This means that a large number of variables need to be collected in order to understand building variations and define representative building categories (Bischof and Duffy, 2022). Significant progress has been made on UK non-domestic stock models (Steadman *et al.*, 2020), informed in part by empirical datasets, but there is still the need for cross-referenceable, diverse datasets to efficiently describe the stock and the required action to meet zero-carbon targets.

This work will provide a review of energy performance data that has been collected on non-domestic buildings via physical and digital surveys as well as via regulatory frameworks and mandatory or voluntary schemes in Scotland, the rest of the UK (rUK), European Union (EU) and internationally (outside the UK and EU). It is worth noting that while the original aim of related regulatory frameworks and schemes is not data collection itself, they can act to incentivise the development of large databases, the analysis of which could be a valuable tool for policy formation, observation and enforcement. Through the review, we aim to identify exemplary data collection and policy schemes for non-domestic buildings and provide guidance as to how these can be applied within the Scottish context to increase data availability, improve data sharing, and enhance the way that data is currently used to inform policy and monitor the progress of energy and CO_2 targets. Although the discussion will focus on non-domestic buildings, data collection practices for UK residential buildings will be also reviewed, with the aim to explore whether these practices could also be applied for the case of the non-domestic building sector.

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[1] Source: Unpublished analysis by the Energy Saving Trust (EST)

[2] Source: Estimates from the electronic Property Information Mapping Service (e-PIMS)

3.2 Scope of regulations

In the UK, buildings generally become visible as subjects of energy regulation when one of the following takes place:

1. a new building is proposed, subject to Building Warrant and Energy Performance Certificate (EPC);
2. redevelopments of an existing building are proposed, subject to Building Warrant and EPC;
3. an existing building is being sold or the lease changed, subject to an EPC, an Energy Action Plan (EAP) (for buildings over 1,000m^2), which may subsequently require a Display Energy Certificate (DEC), condition survey and possible tax rate change.

These, correspondingly, form three groups of buildings with distinct regulation enforcement implications. For completeness, a fourth group of buildings can be defined:

4. existing buildings which are not being routinely assessed via formal regulations.

These four cases indicate the current scope that regulatory bodies have for advancing the condition of building stock. This broadly relates to (although is not defined by) the mechanisms that make buildings visible as data entries in various systems, which go on to form longitudinal records of building stock. Despite this, the overall data landscape is fractured, with no centrally managed database for unified stock records.

It is important to make a distinction between the mechanisms of data collection, and the undertaking of policy application which are reliant on data collection. Different data sources, and different data collection activities, can also serve different purposes. Gathering historic data, from EPC or DEC records for example, can help build a picture of existing stock, to help develop new policy. By mandating a new EPC or DEC for a specific purpose, for a specific building, this data gathering process can become a policy instrument. By tracking future EPCs or DECs for specific groups of buildings, policy can be enforced, monitored, and revised.

From the four cases above, cases 1 and 2 have well established policy frameworks and data gathering processes. EPCs are centrally managed by the Scottish Government, but only account for less than 15% of the non-domestic building stock (EST, 2021), and potentially represent a skewed section of the overall stock. Building Warrant information for non-domestic buildings, which has long historical relevance in building regulation enforcement, is not amenable to standardised data recording and indexing. This is also administered by Local Authorities, so is not presently supporting a unified nationwide database.

Case 3 has been used to administer energy efficiency policy since the introduction of the Energy Performance of Buildings Directive (EPBD). The scope of the Scottish Government to improve the building stock is severely limited if there is an over-reliance on building sales and changes of lease.

Case 4 – buildings which are not currently subject to intentional change by the owner – presents very different issues for policy administration. In domestic settings, policy has commonly used incentivised support for energy efficiency measures and low carbon technology. A notable exception to this, beyond environmental policy, was the recent fire safety standards change in February 2022. Despite the importance of this policy, enforcement of this law relies again on the sale of the property (case 3), or in response to building insurance renewals by the owners.

3.3 Structured application of data

While immediate energy policy making objectives rely on a combination of historic data and new data from ongoing collection frameworks, data on energy and buildings must evolve to meet changing priorities going forward to Scottish Government's 2045 net zero targets. One of the major deficiencies in the present context is the limited scope that Scottish Government have to enforce policy relating to the non-domestic building stock. This reduces to questions around how well certain datasets can be verified, potentially limiting the use of EPCs when, for example, enforcing policy. It becomes important to recognise both the primary aim of the policy-making objective – whether it is for policy development, policy tracking, or policy enforcement – and on what basis certain data was generated – i.e. derived from models, collected from surveys, originated from design material, or was measured using verifiable digital methods. This structure is discussed in more detail in Section 6.

4 Data collection and policy landscape

4.1 Scotland

4.1.1 Section 63 Regulations: The Assessment of Energy Performance of Non-Domestic Buildings

As of 1st September 2016, owners of non-domestic buildings in Scotland with a floor area of more than 1,000 m^2 that do not comply with the 2002 Building Standards (or later) or have not been improved under a Green Deal plan are obliged to produce an EAP in order to sell or let their property (Climate Change (Scotland) Act 2009, s. 63, 2016). The EAP is prepared and issued by a qualified member of an approved organisation ("section 63 advisor") using the building's non-domestic EPC as the basis for setting the improvement targets. Specifically, the EAP contains a programme for the implementation of measures to improve the building's energy performance and reduce its associated emissions. It must specify (amongst others) the list of the identified improvement measures as well as energy and emissions savings targets. The energy efficiency improvements considered in the Scottish EAP are limited to modest measures including the following: upgrading heating controls; upgrading lighting controls; installing draught stripping to doors and windows; installing insulation to hot water tank; upgrading low energy lighting; replacing boilers; and installing insulation in accessible roof spaces (Scottish Government, 2016). Building owners can then choose to either implement the measures within 3.5 years of the date of the first EAP or deferring these by reporting the building's operating energy ratings via a DEC on an annual basis. A DEC shows the energy performance of a non-domestic building over a 12-month period based on the building's actual energy consumption data. Specifically, it displays an operational rating illustrating the building's energy performance using an A-G scale and also shows how the building performs compared to the previous DECs issued. The 2018 Energy Efficient Scotland Route Map sets out the Scottish Government's ambition to expand the requirements for non-domestic buildings over 1,000 m^2 (set out in the 2016 building regulations) to all non-domestic buildings. The HIB Strategy confirmed the aim to develop and introduce strengthened regulations to ensure that non-domestic buildings install a zero emissions heating supply and reduce heat demand where feasible (Scottish Government, 2018a, 2021c).

EAPs and DECs are lodged in the Scottish Energy Performance Certificate Register (SEPCR) managed by the Energy Saving Trust (EST) and can be accessed at the individual building level by the EAP's unique Report Reference Number (RRN) or the building's postcode (EST, 2022). However, bulk data on EAPs is not publicly available. Hence, the number of buildings that are in scope of this regulation as well as the extent to which the improvement measures included in the EAPs are implemented or deferred are unknown. These limit the potential for the collected data to be used for increasing our understanding around non-domestic buildings in Scotland and assessing the success of the related policy.

4.1.2 Energy Performance Certificates (EPCs)

A valid EPC must be enclosed on the sale or lease of all non-domestic properties in Scotland (it is worth clarifying that buildings falling under the requirements of Section 63

Regulations are not excluded from their requirement to have a valid EPC). Unlike the related regulation in England and Wales, Scotland does not impose a minimum level of EPC rating for the case of non-domestic buildings.

Similarly to the EAPs and DECs, EPCs are held in the SEPCR with the exception that bulk data from EPCs (from 2012 to 2021) is publicly accessible (statistics.gov.scot, 2022). This provides a high potential for organisations, universities and public bodies to exploit the included information to inform related policy. However, as of November 2020, non-domestic EPC lodgements cover a percentage of less than 15% of the total estimated non-domestic buildings in Scotland. The latter significantly limits the effectiveness of the available data to provide a representative picture of the non-domestic buildings in Scotland and be used for the development of stock models. In addition, released data includes a reduced number of EPC input variables regarding the physical characteristics of the properties limited to property type, floor area, electricity source, main heating fuel, presence of mechanical ventilation and recommendation improvements.

4.1.3 Energy audits

Excluding some energy-intensive business, energy audits and reporting are not widely used by organisations within both the UK and international context, unless mandated by policy. Nevertheless, the analysis of data obtained from energy audit and reporting schemes could act as an information tool for policy to identify barriers (e.g. lack of awareness, financial resources and expertise) that prevent organisations from adopting energy efficiency measures (BEIS, 2020).

In response to Article 8 (4-6) of the European Energy Efficiency Directive (EED), the UK Government has mandated the Energy Saving Opportunity Scheme (ESOS) for large undertakings (i.e. more than 250 employees or annual turnover and balance sheet in excess of £44 million and £38 million, respectively) operating in the UK. The regulation is the same between Scotland and the rUK (rest of the UK). Buildings in scope of ESOS must undertake an energy audit every four years, with this involving at least 90% of an organisation's total energy used by its buildings, industrial processes and transport activities. The aim of the audit is to identify areas of significant energy use within the organisation and make a series of recommendations for the adoption of energy efficiency measures. It is not obligatory for organisations to implement those measures and recommendations are generally limited to easy-to-adopt and well-established improvements with a payback period of no more than 2 years (BEIS, 2021a). A similar scheme to ESOS is the Streamlined Energy and Carbon Reporting (SECR) framework involving energy and emissions reporting from large unquoted companies with annual energy use of more than 40,000 kWh (GOV.UK, 2021).

The mandatory nature of the ESOS and SECR schemes means that a large number of organisations provide measured data. However, neither energy data nor the recommendations can be accessed by the public. The UK Government is examining the potential of public disclosure of ESOS and SECR data as a means to make reporting more transparent and increase the uptake of ESOS recommendations by participating organisations (BEIS, 2021c). Although energy and emissions in ESOS and SECR are reported at the organisation-level and not the individual building-level, the data could potentially act as a rich source of information for better understanding the energy performance of particular building types and associated activities.

4.1.4 Surveys

The Scottish House Condition Survey (SHCS) is the only national building survey running in Scotland. It is a sample survey, which runs every year and involves around 3,000 physical inspections of permanently occupied domestic buildings and household interviews. Dwelling data collected as part of the SHCS is modelled using the UK Government's Standard Assessment Procedure (SAP) and updated Reduced data (RdSAP) methodology to derive energy use and associated emissions. The results of the SHCS are extensively used for policy monitoring in many areas such as changes in the conditions of the Scottish housing stock and progress on fuel poverty and carbon reduction targets (Scottish Government, 2021f).

To date, there is not a similar kind of survey conducted for the case of non-domestic buildings in Scotland.

4.2 Rest of the UK

4.2.1 Energy Performance Certificates

Since 1st April 2018, the Energy Efficiency (Private Rented Property) (England and Wales) Regulations 2015 set a Minimum Energy Efficiency Standard (MEES) of EPC E for all private rented properties on new leases and renewals (this is applicable to both domestic and non-domestic private rented buildings) (Energy Act 2011 s.49, 2015). By 1st April 2023, this will be extended to include existing leases. The UK Government has confirmed in the Energy White Paper (published in December 2020) that it intends to make it unlawful to let non-domestic properties with an EPC rating of below B by 2030, with an interim milestone of EPC C in 2027 (HM Government, 2020). It is still unknown whether Scotland will follow a similar approach to England and Wales and impose MEES for its non-domestic buildings (Scottish Government, 2021e). In Northern Ireland (NI), a valid EPC is needed at the point of construction, sale or new lease (as in the rUK). However, NI does not impose MEES for either its domestic or non-domestic properties (Department of Finance NI, no date).

Similarly to Scotland, non-domestic EPCs for the rUK can be accessed at the individual-building level through the EPC Register (GOV.UK, 2022b). For England and Wales, in particular, bulk EPC data is available through a regularly updated database managed by the Department for Levelling Up, Housing & Communities (DLUHC) (DLUHC, 2021a).

4.2.2 Display Energy Certificates

As discussed in Section 4.1.1, DECs in Scotland form part of the Section 63 Regulations (The Assessment of Energy Performance of Non-Domestic Buildings). These set out the requirement of non-domestic buildings over 1,000 m^2 to produce an EAP and implement the recommended energy efficiency improvements or defer these and produce a DEC on an annual basis. However, the regulation is different in the rUK (England, Wales, and NI), where any building of above 250 m^2 that is frequently accessed by the public (e.g. councils, leisure centre, schools, museums, etc.) is required to have a valid DEC in a place clearly visible to the public. Buildings with a floor area of more than 1,000 m^2 must issue a DEC every year, while for buildings with a floor area of between 250 m^2 and 1,000 m^2, DECs are valid for a period of 10 years (GOV.UK, 2016). Bordass (2020) notes that "*DECs seem to have become more of a compliance ritual than a spur to improvement*" and they have not accomplished their goal to help users understand their energy consumption mainly due to the fact that they provide limited information and indicators.

Despite the policy shortcomings on the implementation of DECs, they are one of the very few frameworks in the UK involving in-use energy performance data. This, combined with the mandatory requirement for eligible buildings to report their energy consumption at regular intervals, has led to the creation of one of the first databases of such scale in the UK including actual energy consumption data. DECs (from 1st October 2008 onwards) from England and Wales have been accumulated in a central database and can be browsed and downloaded at the individual-building level or in bulk (DLUHC, 2021a). They are publicly accessible in the sense that data relating to public authority buildings is not considered to be personal data. Public access to such a database creates a vast potential for universities or other organisations to monitor and track the energy performance of public-sector non-domestic buildings to help policy make informed decisions. The latter is particularly important in the UK as little action has traditionally been taken by public bodies to fully exploit DECs' potential to drive action on energy efficiency (Cohen and Bordass, 2015). An example in this direction is the recent study by Hong *et al.* (2019), who provided a statistical analysis on 59,740 DECs lodged between 2010 and 2016 to understand the latest patterns of energy use, how these have changed over this seven-year period, and when changes have occurred. Although the study recognises the value of a public database including operational data for such a large number of buildings, it mentions areas that can be improved in the future. The most noticeable is the fact that the released data does not include all variables from DECs, while access to these could potentially provide a deeper understanding of the performance of public sector buildings in the UK.

4.2.3 Surveys

The Non-Domestic Building Stock (NDBS) project (started in 1991 and ran for a ten-year period) constituted the first effort of the UK to develop a nationwide database of its non-domestic buildings (Steadman, Bruhns and Rickaby, 2000). The database was updated as part of the Carbon Reduction in Buildings (CaRB) and CaRB2 projects started in 2004 and 2011, respectively (Evans, Liddiard and Steadman, 2017). Following that, the Department of Energy and Climate Change, now part of the Department of Business, Energy & Industrial Strategy (BEIS), carried out the Building Energy Efficiency Survey (BEES) in 2014 to collect information on electricity and gas consumption of ~3,700 non-domestic premises in England and Wales using a phone survey method. The main purpose of BEES was to provide an update on the annual electricity and gas consumption data of the NDBS. A report was then published by BEIS to present the survey data and provide energy trends in non-domestic premises (BEIS, 2016). However, BEES was a one-off project with no plans for future updates.

Although non-domestic building surveys have not materialised in the UK, the domestic sector is far more advanced in this area. Apart from the SHCS (see section 4.1.4), the English Housing Survey (EHS) is a national survey commissioned by the DLUHC, which runs on an annual basis to collect information on the condition and energy efficiency of houses in England (DLUHC, 2021b). Although the survey has run since 1967, it was first composed in its current form in 2008. The survey consists of two component surveys: questionnaire-based interviews of around 13,000 dwellings to collect data on household characteristics (full survey sample); and follow-up physical inspections of a subset of the initial full survey sample (~ 6,000 dwellings) to collect information on house characteristics and energy efficiency (dwelling sample). The EHS data is publicly available via the UK Data Service.

4.3 European Union

EPCs play a key role in the EPBD, which was introduced to promote the improvement of energy performance of buildings within the EU in 2002, recast in 2010 and revised in 2018. Without requiring a uniform approach across the EU, the EPBD asks for each EU member state to establish a certification system and implement this in a way that meets its national and regional rules. Differences in the EPBD implementation and EPC methodology are even observed at the national level. This is the case in Belgium and the UK, where the EPBD is implemented differently in Brussels Capital Region, Flemish Region and Walloon Region as well as in England, Wales, Northern Ireland and Scotland, respectively (Concerted Action EPBD, 2018). However, according to a recent report published by the Horizon 2020 X-tendo project, the harmonisation of EPC calculation methodologies is key for enabling comparability between countries, increasing trust and accelerating building renovations in Europe (Volt *et al.*, 2020).

A key difference between EPC methodologies within the EU is that some member states have adopted a calculated (modelled) energy consumption (also known as asset rating) approach to evaluate the energy performance of all their buildings (Spain, Portugal, Italy, Greece, Bulgaria, Romania, Hungary, Lithuania, Slovakia, Austria, The Netherlands, Cyprus), while the rest use either the actual or the calculated energy consumption, depending on the building type (residential, commercial, public), status (newbuilt, renovated, existing) and available data (Volt *et al.*, 2020). For example, Sweden uses operational ratings in EPCs for both residential and non-residential buildings. An asset rating approach is only considered for new builds; but even for these, there is the need to issue an operational rating EPC within two years after they have been built. Other countries (such as Slovenia, France, Denmark) apply operational ratings to all the existing non-residential buildings, whereas Belgium as well as England and Wales use operational ratings for the case of public buildings only. Germany requires a modelled EPC rating for all new buildings and buildings undergone a major renovation, while it uses metered energy information for assessing the energy performance of existing non-residential buildings. Generally, an operational rating is considered to be more appropriate for existing commercial and public buildings, as a change of users is infrequent and behaviours are quite stable (Arcipowska *et al.*, 2014).

The EPBD recommends for each member state to maintain a publicly-accessible depository for gathering EPC information. Although today almost all countries have an EPC database, registers vary in terms of data upload procedures, data format, management, and sharing. In France for example, the EPC software is connected to the EPC registry and data is uploaded automatically. In other countries, assessors upload data manually, while in countries such as Sweden, Ireland, and Greece, data upload is based on the utilisation of data protocols. EPC databases can vary from simple Excel spreadsheets to more advanced SQL databases (e.g. Ireland and Norway). Another difference between EU member states lies in the amount of information held in their EPC registry. A number of countries (e.g. France, Ireland, Greece, Portugal) require assessors to upload additional information to the database than provided in the EPC so that the uploaded data is sufficient to reproduce EPC results.

The European Union (EU) has adopted a series of initiatives to support its member states in understanding their national and EU building stock, and monitoring its progress over time (Fabbri *et al.*, 2020). The Building Stock Observatory (BSO) was established in 2006 to collect data on all European buildings. It consists of a database, a data mapper and various factsheets providing statistics on energy-related aspects of buildings across Europe. The database contains a total of 250 indicators organised in different thematic areas (building stock characteristics, building shell performance, technical building systems, nearly zero-energy buildings, building renovation, energy consumption, certification, financing, energy poverty, energy market). Every set of data can be viewed in summary tables and graphs per topic, year, and country or the EU as a whole. In addition, the numerous indicators can be illustrated in maps allowing users to compare the energy performance of buildings between EU countries. However, coverage is still very limited and data reporting frequencies of many indicators is low, with this limiting the potential of the data to be used for policy development (European Commission, 2022). In addition to the BSO initiative, the recent amendment of the EPBD recommends for the member states to set up EPC databases and make all EPCs lodgements available (when aggregated and anonymised) for statistical and research purposes.

4.4 International (outside the UK and EU)

4.4.1 United States

The United States (US) runs two major nationwide surveys for collecting non-domestic building stock data, the Commercial Building Energy Consumption Survey (CBECS) and the Building Performance Database (BPD). These use different methods for data collection and compilation and vary in data specifications, structure, and stock coverage, with each serving different purposes and supporting different types of analysis. Another example of a fairly successful survey conducted in the US is the California End-Use Survey (CEUS). The latter is specific to California’s commercial building stock and follows a similar approach to the CBECS.

Commercial Building Energy Consumption Survey (CBECS)

Since 1979, the US Energy Information Administration (EIA) has been periodically collecting data through the CBECS to provide summary statistics for the US non-domestic building stock, explore long-term energy trends and inform related policy. The survey is usually conducted every four years, with the most recent having taken place in 2018. The type of information included in the CBECS concerns energy-related building characteristics (such as geographic region, age of construction, size, wall materials, renovations, etc.), building activity, building use (such as hours of operation, occupancy-related factors, etc.), equipment and building systems (space heating, cooling, ventilation, etc.), fuel source as well as energy usage (whole-building energy consumption by major energy sources and end-use consumption for space heating, cooling, ventilation, lighting, etc.).

Data from the CBECS is statistically analysed and presented in a user-friendly format using detailed cross-tabulations that show the number of buildings and amount of floorspace by multiple building characteristics (EIA, 2022b). In addition to the aggregated data, microdata is also publicly available and can be accessed through the EIA's website. Since the very early years of the survey, easy access to the CBECS data has offered the opportunity to multiple users, including academics, to implement different types of analysis varying from improving benchmarking for various building types (Sharp, 1998; Yalcintas and Ozturk, 2007) to applying advanced data-driven methods to understand complicated non-linear relationships between energy variables (Choi and Kim, 2021).

The CBECS is based on a national sample of buildings selected to represent the entire US non-domestic building stock. As of the latest CBECS (2018), a total of 6,436 commercial buildings were surveyed with each representing a particular number of similar buildings in the larger US non-domestic stock, estimated at 5.9 million buildings at that time (weights are used to project survey outputs to the entire stock) (EIA, 2022b). In an attempt to reduce survey costs and improve coverage, the CBECS sampling method has gone through several revisions over the years. The current approach is based on the construction of a statistically valid sample for the survey, where all the building types and sizes are represented, and each building has an equal probability of being selected. The sampling frame consists of an area-frame component (including all commercial buildings in statistically selected areas as recorded in-person by field staff or virtually through a GIS web-based tool) and a list-frame component (list of buildings compiled by a number of different sources). More detailed information on the sampling process can be found in the EIA's website (EIA, 2014).

The data collection process takes place in two stages and includes a Building Characteristics Survey and an Energy Suppliers Survey. During the first stage, data is collected through in-person or telephone interviews with the building owner, manager, tenant, or any other knowledgeable person of the selected sampled building. The second stage is initiated only in those cases that respondents are not able to provide adequate or accurate information on energy-related aspects during the first data collection stage. In this case, energy suppliers are contacted to provide actual energy consumption and expenditure data based on their records (EIA, 2015).

A significant application of the CBECS involves the utilisation of the aggregated data to inform and update energy performance benchmarking used for the purposes of the ENERGY STAR programme. ENERGY STAR is a well-recognised voluntary government scheme administrated by the US Environmental Protection Agency (EPA) for rating the energy performance of commercial and industrial buildings in the US. On a scale from 1 to 100 energy stars, ENERGY STAR compares a building's energy performance (normalised for weather conditions and operating characteristics) against building benchmarks (energystar.gov, 2022). Additionally, CBECS is used for energy demand forecasting purposes, tracking energy efficiency progress, and as a key input to the National Energy Monitoring System (NEMS). NEMS is an integrated computer-based model of the US energy system linked to a macroeconomic model. It is used to generate projections of energy production, conversion, imports and prices through 2050 (Annual

Energy Outlook) (EIA, 2022a). Finally, CBECS data constitutes a rich source of information for the development and improvement of building standards and codes such as the American Society Heating Refrigerating and Air-Conditioning Engineering (ASHRAE) Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings and the International Energy Conservation Code (IECC).

The CBECS data sets are considered to maintain high data quality standards for the purpose of conducting national-scale analyses (Gabe and Christensen, 2019). The large number of in-person surveys means that reporting frequencies for all the surveyed data fields are high compared to similar surveys (Sohn and Dunn, 2019). However, it should be noted that, as the main objective of the CBECS is to provide the large picture of the energy performance of the commercial building stock in the US (representing all the 50 states), it presents limited geographic granularity (Iyer *et al.*, 2016). Moreover, CBECS is a resource-intensive survey in terms of data collection with this resulting in relatively small sample sizes and infrequent data updates (National Research Council, 2012). The small sample size, in particular, further limits the effectiveness of the data to represent the diversity of energy consumption and building stock characteristics at the regional-scale or between certain types of buildings (Gabe and Christensen, 2019; Sohn and Dunn, 2019). The National Research Council has also raised concerns regarding the increased amount of time it takes for the CBECS data to be collected, processed, and released. They have recommended the division of the full survey sample into smaller sub-samples followed by the collection of data for each sub-sample every year (instead of once per four years for the full survey sample). Additionally, a portion of the face-to-face data collection could be replaced by web-based data collection processes (National Research Council, 2012).

Commercial End-Use Survey (CEUS)

Following a similar approach to the CBECS, California's CEUS is a sample survey of California's commercial building stock able to more effectively capture geographic-specific characteristics of energy consumption compared to the CBECS. The survey is authorised by the California Energy Commission with further support from investor-owned and publicly-owned utilities (California Energy Commission, 2022). The CEUS was first piloted in 1996, repeated in 2006, while the latest data collection took place between 2018 and March 2022.

The aim of the CEUS is to support the Energy Commission's commercial sector forecasting model as well as energy efficiency market activities, with its particular objectives focusing on: (1) providing estimates of end-use saturations, energy use by end-use and hourly load profiles for commercial market segments; (2) collecting data on end-use energy efficiency to support the design and planning of energy efficiency programmes and policies; (3) constructing a flexible building energy demand analysis model to support the estimation of the hourly end-use load profiles; and (4) developing a means of estimating the hourly impacts of energy efficiency measures, load management strategies, building standards, alternative rate designs, and other programmes and policies (California Energy Commission, 2006).

The CEUS implements a random sampling approach, with the sampling data being obtained from electric investor-owned utilities and stratified by service area, climate zone, building types, and size. It is based on detailed on-site surveys to gather information on business types, building physical properties (including geometry, building shell characteristics), activities and equipment inventories. While the data collected as part of the CEUS captures many variables also captured by the CBECS, CEUS obtains more robust data for building equipment and activities. This includes detailed information on efficiencies and operating patterns of energy-consuming devices as well as detailed occupancy schedules. Another key difference between CBECS and CEUS is that the latter incorporates a software modelling component. Specifically, a software explicitly developed for the purposes of the CEUS (DrCEUS) uses the survey data to automatically generate energy simulation models providing hourly energy use estimates throughout an entire year. The constructed models are calibrated using actual electricity and natural gas data obtained by utility companies and are used to evaluate the impact of energy efficiency measures, weather scenarios, and energy rates on the buildings' energy use patterns (California Energy Commission, 2006). Unlike the CBECS, microdata from the CEUS is not publicly available due to privacy concerns.

The results of the 2018-2022 CEUS have not been released yet. Nevertheless, the CEUS website mentions that the survey aims to collect information on a few key variables from as many sites as possible as a means to provide better statistical precision of population estimates. While the sample of the 2006 CEUS consisted of some 2,800 commercial buildings, the sample of the latest CEUS will include a total of 27,000 commercial buildings (California Energy Commission, 2022).

Data from the CEUS is also used for benchmarking purposes (Cal-Arch tool developed by the Lawrence Berkeley National Laboratory) (Ye, Zuo and Wang, 2019), with regional (rather than national) data being generally more relevant for informing building energy performance benchmarks (Kinney and Piette, 2002). An increasing number of US cities (e.g. Washington DC, Austin, New York City, Seattle, San Francisco, Philadelphia, Minneapolis, Boston, Chicago, Cambridge, Berkeley, Atlanta, Portland, Kansas City, Boulder) have recently passed ordinances and laws to make energy benchmarking, which has been a traditionally voluntary activity, mandatory (Palmer and Walls, 2017).

Building Performance Database (BPD)

The US Department of Energy (DoE) has adopted a different approach to CBECS to collect and share energy data for both the domestic and non-domestic US stock. BPD has established a framework to facilitate data collection from different existing databases (including the CBECS) as well as from multiple data contributors including entities monitoring building performance, building portfolio owners and managers, researchers, electric utilities and federal agencies, who submit data to the BPD on a voluntary basis. Provided that the submitted data does not miss key fields such as location, size, building type and energy consumption, BPD generally accepts buildings missing asset and equipment data. Unlike the CBECS, which uses statistical methods to derive missing energy consumption data, BPD is restricted to measured (rather than modelled) records. An incentive for people to provide data to the BPD is that the DoE returns mapped and cleansed data as well as a statistical overview of the database to all data contributors (Gabe and Christensen, 2019).

Although representativeness (i.e. the ability of the data to provide a representative picture of the stock) is a fundamental principle within the CBECS, this is not the case for the BPD, where particular building subsets are considerably underrepresented. Due to the voluntary and self-reporting nature of data contribution within the BPD context, certain building types are more likely to be included in the database than others (e.g. buildings with benchmarked energy use) (Sohn and Dunn, 2019). This, however, creates the opportunity for a more in-depth analysis to understand the variation of energy performance between buildings sharing similar characteristics (Hong *et al.*, 2019). In this sense, BPD would be more suitable for addressing questions such as “how does energy consumption vary between school buildings of similar size that vary in age of construction?” compared to the CBECS. Similarly, as energy regulation and energy schemes usually run at the state-level (rather than the federal-level), certain regions are better represented in the BPD than others (Sohn and Dunn, 2019).

Furthermore, the large diversity of interests, expertise and motives of the multiple data contributors has several implications for the type, level of detail, and quality of the data submitted to the BPD. Generally, data provided by building portfolio managers is most likely to include energy consumption information of the in-scope buildings, but not as detailed as in the CBECS. In addition to that, data submitted to the BPD by owners and managers of certain building portfolios can be very specific to the scope of particular energy efficiency programs and schemes. These result in very low reporting frequencies for certain data fields (e.g. end-use and appliance-level data), with this limiting the effectiveness of the data to be used for in-depth energy consumption analyses (Gabe and Christensen, 2019; Sohn and Dunn, 2019). However, despite particular concerns around accuracy, sparse detail, and low resolution of energy data included in the BPD, it has been built (and is still growing) in response to the policy and industry need for large databases including up-to-date data and employing low-cost data collection methods. The in-depth analysis of well-represented building categories or well-covered regions can inform relative policy in a more effective way than the CBECS, which fails to capture the variations of energy consumption between similar buildings.

4.4.2 Canada

Following a similar approach to the US CBECS, the Survey of Commercial and Institutional Energy Use (SCIEU) (commissioned by Natural Resources Canada (NRCan) and carried out by Statistics Canada) takes place every five years to support policy development and energy efficiency programmes in Canada. Started in 2009, the SCIEU collects building characteristic and energy-related data on a sample of buildings selected following a random sampling approach to accurately represent the stock, both at the national and regional level. The recent 2019 SCIEU targeted commercial and institutional buildings that belong to specific building categories classified by activity to 23 individual types (offices, schools, warehouses, museums, restaurants, retail stores, etc.). In order for the buildings to be included in the SCIEU, they must have a minimum floor area of 50 m^2, where at least 50% of this must be used for commercial/institutional activities (NRCan, 2020a). Responding to the survey is mandatory and the survey asks for the respondent to be the person who has the best knowledge of the building’s energy-related aspects. The in-scope buildings/institutions participate in a two-stage on-line survey. The first stage involves the completion of a pre-contact questionnaire that is used to identify contact persons and ensure that the selected sampled buildings are on-scope for the survey. The second stage includes the actual questionnaire, where respondents are asked to provide detailed information on energy-related characteristics of the surveyed building/institution (including floor areas, year of construction, activities, occupancy, retrofits/renovations, on-site generation, and energy consumption) (NRCan, 2020b).

The Canadian ENERGY STAR (registered in Canada by the US EPA and administrated by NRCan) relies heavily on aggregated data from the SCIEU to inform energy benchmarking through the ENERGY STAR Portfolio Manager and thus enable building owners to track and compare their building's energy use against similar buildings (Government of Canada, 2017; US EPA, 2021). Both aggregated data and anonymised microdata from the SCIEU is publicly available online (Statistics Canada, 2022).

4.4.3 New Zealand

New Zealand's Building Energy End-use Study (NZ BEES), carried out by the Building Research Association of New Zealand (BRANZ), was a six-year project (started in 2007) involving the first (and only) national survey of the country's non-domestic building stock. The aim of the survey was to gather information and provide insightful knowledge around variations of the energy and water consumption of non-domestic buildings in New Zealand and use this information to update assumptions used in non-domestic building stock models and relevant forecasting works (BRANZ, no date).

Similarly to the non-domestic business rates imposed on commercial properties in the UK through the Valuation Office Agency (VOA) in England and Wales and Scottish Assessors Association (SAA) in Scotland, New Zealand has a building-based property taxation system. One of the main interests of the NZ BEES was to develop a complete and accurate list of New Zealand's non-domestic buildings using the property valuation records. This list was used as the basis to select the buildings to be surveyed by creating a sampling frame divided into five building-size strata (based on floor areas), five building-use strata (based on activity) and two geographic group strata.

The data collection included a web-based search of an initially identified large sample of buildings (~3,000) to match information on building size, orientation, constructions, etc (used to justify representativeness of sample) and develop a rich dataset, which was then used to estimate energy use. From this initial sample, a smaller sample (~2,000) was selected to participate in a telephone survey and/or provide energy and water billing information. In total, 848 premises were interviewed through telephone and another 312 gave their consent to access billing records from their energy and water suppliers over a two-year period. Telephone survey questions were around number of employees, occupancy, tenure, building characteristics, building management arrangements, types of energy, equipment and appliances. Following that, a total of 101 premises participated in a monitoring activity used to obtain detailed energy and environmental data. This monitoring activity also included audits (of appliances, lighting equipment, physical building characteristics, water equipment, hot water systems), occupant questionnaires and photographs. Finally, the information collected through the NZ BEES was used to create calibrated thermal simulation models (Amitrano *et al.*, 2014).

The NZ BEES was a one-off survey with no particular plans for the future. However, the design of the survey and the particular methods used to determine the sampling frame are quite relevant and applicable to the UK as both countries use valuation records to understand certain aspects of their non-domestic stock. For example, Section 5 will present efforts that have been made in both Scotland and the rUK so far to develop non-domestic building stock models, most of which are highly dependent on valuation records from SAA and VOA, respectively.

4.4.4 Australia

The National Australian Built Environment Rating System (NABERS) is an energy rating scheme run in Australia for assessing a building's energy performance against that of similar buildings (benchmarks) using 12 months of post-occupancy metered energy data adjusted for building area, hours of use, climatic conditions, equipment density, and greenhouse gas intensity of the energy source. It is mainly applicable to office buildings of more than 1,000 m^2, but it has progressively started to be applied to other types of buildings such as shopping centres, hotels, public hospitals, blocks of apartments and data centres (NABERS, 2022). In its current version, NABERS is based on a 13-level scale ranging from 0 to 6 stars (including 0.5 stars), with 0 and 6 indicating non-certified and market leading performance, respectively (Gui and Gou, 2020).

The Australian Government's policy is considered to represent international best practice in conception, design, and implementation and is of interest to many governments (Mallaburn *et al.*, 2021). While NABERS was introduced as a voluntary scheme in 1998, it has been progressively associated with legal requirements for office building owners. In 2004, the New South Wales government set its own minimum NABERS energy rating standard by not allowing government leases in properties of below three stars. By 2009, all states (except Tasmania) and federal government had adopted a minimum standard of 4.5 stars for new and existing government leases (Bannister, 2012). In 2010, the disclosure of a valid NABERS Energy rating became mandatory by the federal government at the point of sale or lease of commercial office buildings of more than 2,000 m^2 under the Commercial Building Disclosure (CBD). From 2018, the mandatory disclosure threshold has been lowered to 1,000 m^2. Apart from the operational energy and greenhouse gas emissions ratings, NABERS also looks at wider sustainability factors, including additional operational ratings for water consumption, waste, and indoor air quality (BEIS, 2021b).

The implementation of NABERS had been well-publicised and disseminated even before disclosure became compulsory. Between 1999 and 2010, the average energy rating of Australian office buildings in the NABERS scheme increased from 2.5 to 3.6 stars (until 2011, the rating scale was between 1-5 stars). Ratings have continued to improve ever since with a short setback when they became mandatory as more poor performance buildings started to be recorded. The almost continuous rise of the average NABERS rating across offices included in this scheme proves that both transparency and mandatory disclosure have acted as significant drivers to improve energy efficiency (Cohen *et al.*, 2017). An analysis of offices with NABERS ratings for 13 consecutive years showed that these offices have reduced their energy use by 34% since 2010 (BEIS, 2021b).

Taking the implementation of NABERS in Australia as a successful policy example, Mallaburn *et al.* (2021) identified four basic elements for governments to consider when developing related policy shemes and incentives. These involve:

- a strong political leadership supported by adequate financial resources and people with the right engineering, market skills, and experience;

- an in-use performance benchmarking approach designed to allow industry to innovate and aligned with the way both buildings and energy managers operate;
- the careful and progressive application of government interventions to tackle poor performance without compromising the voluntary nature of the policy;
- and, a governance model to give industry effective, but measured and proportionate, influence over the design and implementation of the policy.

A significant shortcoming of the Australian NABERS programme lies in the lack of clarity around the development and update of the benchmarks used. Specifically, NABERS references a benchmark survey carried out in 1999 and, to the best of our knowledge, there are no plans in place for the implementation of a new survey. This is of great importance considering that the performance of office buildings has been significantly improved over the years, reaching an average of 4.2 stars (out of 6 stars) in 2019, with this being much higher than the average 2.5 stars (out of 5 stars), which had been used for calibration in 1999 (Gabe and Christensen, 2019). Unlike the ENERGY STAR programme in the US, which uses the CBECS data to update building benchmarks, there is not a similar building energy performance survey in Australia. Instead, NABERS is mostly based on bespoke or ad-hoc industry surveys for its external data collection (Bannister, Burt and Hinge, 2016).

The UK Better Buildings Partnership (BBP) in collaboration with the Building Research Establishment (BRE) and the Australian NABERS scheme has assessed the suitability of NABERS to be used within the UK context for offices and a UK version of NABERS (NABERS UK) was launched in November 2020 (BRE, 2022). NABERS UK has two products available: NABERS UK Energy and Design for Performance (DfP). The purpose of the former is to measure and verify the actual energy use of existing offices, providing a rating from 1 to 6 stars, while DfP provides a framework by which new offices (or offices under major refurbishment) can commit (pre-construction) to design, commission and operate the nominated building to achieve a NABERS Energy star rating of at least 4 stars. The latter includes a DfP agreement between BRE (scheme administrator) and the applicant.

In March 2021, the UK Government launched a formal consultation on the introduction of a performance-based scheme to be mandated for UK commercial offices with a particular interest in the Australian government's approach and NABERS UK scheme (BEIS, 2021b). The same document identifies those features that have made NABERS a successful scheme, which (amongst others) include the fact that it is based on actual (rather than modelled) energy consumption, allows for like-for-like comparisons between buildings, and aligns with responsibilities within the building.

4.4.5 Japan

The Tokyo Metropolitan Government (TMG) runs two distinct schemes to improve the energy performance of non-domestic buildings in Tokyo, the Tokyo Cap-and-Trade Programme (TCTP) and the Carbon Reduction Reporting (CRR) programme, with each targeting different building types. Specifically, energy-intensive buildings are required to comply with the TCTP, while the CRR targets all those non-domestic buildings that are outside the scope of the TCTP. Under the TCTP, the in-scope buildings must reduce their emissions by a certain percentage from their baseline during two back-to-back compliance periods of the scheme (five years) by implementing energy efficiency measures, generating renewable energy, purchasing credits from other participants, or any combination of these. Depending on the building type, the required emissions reduction was in the range of 6%-8% from baseline during the first compliance period, increased to 15%-17% during the second period and 25%-27% during the third period (started in April 2020) (International Carbon Action Partnership, 2021). TCTP is considered to be a successful Cap-and-Trade scheme with the participating facilities having already achieved a 27% reduction by the end of the second compliance period (TMG, 2021).

CRR targets small and medium-sized commercial buildings, with the scheme being mandatory for buildings with annual energy consumption of between 30 kL to 1,500 kL in tonnes of oil equivalent, and voluntary for buildings with lower energy consumption. However, CRR has attracted a significant number of voluntary submissions from facilities keen to track their annual emissions and compare these to industry benchmarks (approximately 1,871 enterprises submitted reports voluntarily in 2015 representing 11,476 individual facilities) (C40, 2017). While CRR originally started solely as a reporting program, it has evolved over the years. In 2014, TMG introduced a Carbon Report Card that could serve as the beginning of a building labelling initiative. It contains both quantitative information on emissions performance as well as qualitative information on ongoing or planned energy efficiency measures (Hinge and Ribeiro, 2019).

Amongst others, one goal of the CRR scheme is to provide policy makers with reliable and regularly updated data of the Tokyo building stock. Both mandatory and voluntary reports are publicly available on the official TMG website. Publicly disclosed data includes total annual CO_2 emissions from energy use and water consumption, gross floor areas, carbon intensity and qualitative information on energy consumption reduction measures. However, raw data on energy consumption is not publicly available. The focus of CRR on carbon emissions rather than energy consumption data is considered to be one of the main reasons explaining why the scheme has attracted much interest and far more submissions than expected. Energy consumption data can potentially indicate intensity of internal business operations, which many industrial facilities prefer to keep confidential. Therefore, transparency and public disclosure of energy consumption could act as a restrictive factor for facilities to participate in the CRR scheme. In addition, TMG pays particular attention to accuracy and reliability of reported data as a measure to maintain industry support. The submitted quantitative data (e.g. energy consumption and CO_2 emissions) as well as qualitative information (such as energy efficiency improvements) is checked and verified. When problems are identified (e.g. inconsistences and sudden changes from one year to another), the participating organisations are contacted by trained staff to confirm data entries and address any potential errors (C40, 2017).

5 Non-domestic building stock models

5.1 Scotland

5.1.1 Non-Domestic Energy Efficiency Baseline

Scotland's Non-Domestic Energy Efficiency Baseline was developed in 2018 to provide an estimate of the baseline energy efficiency performance of the Scottish non-domestic building stock (Scottish Government, 2018b). It is based on 30,000 EPCs issued between 2013 and 2017, which were linked to SAA records (non-domestic rates data) by matching the properties' UPRNs (Unique Property Reference Numbers). The SAA data was used to estimate the number of buildings within each sector (e.g. education, healthcare, offices, retail, restaurants, etc.). Mean EPC ratings were estimated across the stock using the mean rating for each building type and the total number of buildings of each type (Scottish Government, 2018b).

5.1.2 Non-Domestic Analytics Scotland

Non-Domestic Analytics (NDA) Scotland, developed by the EST, is an attempt at creating a stock list of all non-domestic buildings in Scotland with associated data, mainly around energy use. The approach followed to construct the NDA is based on the modelling of known EPC records across Scotland to impute data for buildings with missing EPCs using other available databases accessible by the Scottish Government. However, as of November 2020, less than 15% of the estimated population of the Scottish non-domestic building stock is available and lodged in the SEPCR. The data sources used for the purposes of NDA v1 are included in Table 1 (EST, 2021).

As of the NDA Release Notes report, a number of additional datasets can be potentially used to improve the NDA modelling. EPC recommendations for improvements can be used to infer specific improvement pathways as well as building characteristics that are not directly provided as EPC inputs. However, as EPC recommendations are not provided in the form of standardised text, a suitable method should be developed to mine key words that can fill the gaps on existing information. For example, the available EPC input data does not include information on construction (e.g. type of wall, presence of insulation, etc.). In this case, an improvement recommendation such as "Introduce cavity wall insulation" would mean that the in-scope building has uninsulated cavity walls. In addition, information from Microgeneration Certification Scheme (MCS) installations could be a source of information to better understand properties that have already installed renewable energy technologies. Finally, information accessed through the Scottish Land Registry could be used to derive data on property class, type and tenure. For England and Wales, specific land registry data is publicly available via Open Government License. However, this is not the case within the Scottish context.

5.1.3 Further Categories

Public buildings

The Scottish Government has committed to start setting decarbonisation targets for the public sector estate in 2024, with a desire to achieve zero emissions heat across all the

23,000 public buildings in Scotland by 2038 (Scottish Government, 2021c). The voluntary Net Zero Public Sector Buildings (NZPSB) Standard, applied to newbuilds and major refurbishment projects, is in place to support public buildings meet their net zero emissions commitment (Scottish Government, 2021d).

Heat networks

Based on the Heat Networks (Scotland) Act 2021, local authorities across Scotland must identify particularly suitable areas for the construction and operation of heat networks known as Heat Network Zones (Heat Networks (Scotland) Act 2021, s.47, 2021). Publicly-owned non-domestic buildings are subject to the legislation and their suitability to be connected to a heat network must be assessed through Building Assessment Reports (BARs). However, whilst there is a legal requirement for BARs, the form that these will take has not yet been confirmed. The Scottish Government desires to extend the requirement for BARs to other non-public sector non-domestic buildings. It is estimated that this will affect the owners of up to an additional 197,000 non-domestic buildings (Scottish Government, 2021a).

BARs will be used to identify buildings with anchor loads (i.e. buildings with high, constant and reliable heat demand) (e.g. hospitals, schools, etc.). Buildings with anchor loads are generally considered to be more suitable for being connected to a heat network in the sense that each anchor building requires a significant and predictable amount of heat to be supplied by the network and consequently, ensures a stable income stream for that network. In addition, mandatory connection may be required for buildings identified through BARs. The HIB Strategy mentions the Scottish Government's desire to create a sustainable market for heat networks and attract the interest of future investors. In this direction, the Scottish Government will require for anchor buildings to make any necessary adaptations to become "heat network ready" to connect; the way that this will be implemented has yet to be confirmed (Scottish Government, 2021c).

Data sources

- The Electronic Property Information Mapping Service (e-PIMS) is the UK Government's Property and Land asset database including details of location, building characteristics (e.g. floor areas, age, number of floors, refurbishment date), tenure, DEC operational rating, and other key attributes for the Government's Central Civil Estate properties and land (vacant properties are also included) (see Table 1). The database is updated on a daily basis and can be accessed via the Open Government License (data.gov.uk, 2019). e-PIMS database could act as a rich source of information for the central and local government to target buildings that are in scope of the aforementioned public building and heat network policies.
- The Scotland Heat Map Interactive is a tool allowing for the identification of existing and planned heat networks as well as buildings' demand for heat across Scotland. The data included in the interactive map tool can, amongst other functions, be downloaded in bulk (data.gov.uk, 2021) and used to inform building stock models (e.g. development of future scenarios). Similar information can be found in the UK Government's Heat Network Planning Database (HNPD) (GOV.UK, 2022c) (publicly accessible). In both datasets there is a single entry for each different network and, therefore, they do not show all connected properties individually. However, the HNPD

provides information on the number and type of properties connected to each heat network. Table 2 provides a description of these datasets.

Table 1 : Data sources for non-domestic properties in Scotland

Dataset name	Description	Date	Geographic location	Example data	Links to other data	Publicly accessible (Y/N)
Non-Domestic EPCs (Scottish Gov.)	List of all non-domestic EPC lodgements held by the SEPCR	2012-2021	Scotland	• Property type • Floor area • Modelled energy performance rating • Electricity source • Main heating fuel • Presence of mechanical ventilation • Recommendation improvements	• UPRN • Postcode • Data zone	Y
Non-Domestic Rates * (SAA)	List of rateable properties in Scotland	2016	Scotland	• Property type • Floor area	• UPRN • Postcode	N
BEIS	Metered annual electricity/ gas consumption	2010-2018	GB	• Annual metered electricity consumption • Annual metered gas consumption	• • UPRN • Postcode	N
SGN (Scotia Gas Networks)	List of properties with gas connection	2018	Scotland	• Primary fuel type	• Postcode	N
Xoserve (CSE)	List of postcodes without gas connection	2017	GB	• Fuel type	• Postcode	Y

Dataset name	Description	Date	Geographic location	Example data	Links to other data	Publicly accessible (Y/N)
Postal Directory (ONS)	List of all live and terminated postcodes	2021	GB	• Urban/rural classification	• Geographic identifiers • Postcode • Data zone	Y
AddressBase Plus (OS)	Database with address information and xy coordinates	2020	GB	• Property classification • Topographic Identifier (TOID)	• UPRN • Address • TOID	N
MasterMap (OS)	property polygons and attributes	2020	GB	• Building footprint (floor areas) • Building height • Property Type	• TOID	N
Geomni UKBuildings (Verisk)	Estimation of building description from aerial photography	2021	UK	• Property type • Floor area • Property age • Building height	• UPRN • TOID	N
Home Analytics (EST)	List of residential building data including mixed-use buildings	2021	Scotland	• Domestic EPC input data • SIMD ranking	• UPRN • Postcode • Data zone	N
SIMD (Scottish Gov)	SIMD postcode lookup table	2020	Scotland	• SIMD ranking	• Postcode • Data zone	Y

Dataset name	Description	Date	Geographic location	Example data	Links to other data	Publicly accessible (Y/N)
e-PIMS ** (Cabinet Office)	Key attributes for Central Civil Estate properties and land including vacant spaces	2022	UK	• Property type • Floor area • Building age • Number of floors • Listed status • DEC operational rating	• Postcode • Geographic identifiers •	N

* Similar bulk data can be accessed through local authorities. All non-domestic buildings not rateable/ approved for tax relief to be listed by local authorities and become publicly available. Orkney Islands Council (OIC), for example, publishes in its website the complete list of non-domestic properties (both rateable and non-rateable) in Orkney (OIC, no date).

** e-PIMS data is not included in the NDA v1.

Table 2: Heat network datasets

Dataset name	Description	Date	Geographic location	Coverage	Example data	Links to other data	Publicly accessible (Y/N)
Scotland Heat Map (Scottish Gov)	List of communal and district heat networks (both operational and planned projects)	2021	Scotland	1,193 entries	• Primary fuel and technology • Installed capacity range • Development status	• UPRN • X and Y coordinates	Y
HNPD (UK Gov)	List of communal and district heat network from	2021-2022	UK	580 entries	• Number and type of buildings connected • Primary fuel and technology type	• Postcode • X and Y coordinates	Y

	inception to decommissioning phase				• Installed capacity and generation capacity		

5.2 Rest of the UK

5.2.1 Cambridge Non-Domestic Energy Model

The Cambridge Non-Domestic Energy Model (CNDEM) is a bottom-up non-domestic building stock model that follows an archetyping approach to model the energy performance of the non-domestic building stock in England and Wales. A similar archetype-based model has been developed for the domestic stock (Cambridge Housing Model), which uses data derived from the EHS to estimate the energy consumption and associated carbon emissions of dwellings based on SAP methodology (Hughes, Palmer and Pope, 2013). As there is no equivalent to the EHS for non-domestic buildings, CNDEM uses aggregated data from VOA records, DECs, BRE Non-domestic Factfile, and estimates number of buildings by use, area, built form, age, fuel type, and HVAC type. SBEM (Simplified Building Energy Model) algorithms are then used to perform energy consumption calculations (Armitage, Godoy-Shimizu and Palmer, 2015).

5.2.2 The Non-Domestic National Energy Efficiency Data-Framework

The Non-Domestic National Energy Efficiency Data-Framework (ND-NEED) has been developed to give an estimation of the energy performance of the non-domestic building stock in England and Wales using measured energy data. Metered electricity and gas consumption data provided by BEIS at the meter point level are matched with business characteristics from Experian to provide information on the size and use of a business occupying a building. The 2021 ND-NEED version is based on samples from 847,000 metered electricity non-domestic buildings and 373,000 gas non-domestic buildings, covering a seven-year period between 2012 and 2019. The sample is weighted to the entire non-domestic building stock, which is estimated using non-domestic rate records from VOA (BEIS, 2021d). ND-NEED is updated on a regular basis to reflect changes in energy trends and stock characteristics.

5.2.3 UCL's 3Dstock model

The UCL Energy Institute has developed the 3Dstock model, a method for modelling complete building stocks including domestic, non-domestic and mixed-use buildings. Using a variety of different data sources, 3D stock models are automatically assembled and studied through a dynamic building performance simulation tool (EnergyPlus). In summary, building footprint polygons combined with address data are obtained from OS digital maps (OS AddressBase). For the case of non-domestic buildings in particular, OS data is linked to information on activities and floor areas (both provided at the floor level) drawn from databases possessed by the VOA (the equivalent of the SAA for England and Wales) (GOV.UK, 2022a). For those buildings where VOA data is not available or incomplete, Light Detection and Ranging (LiDAR) data collected by overflying aircraft and provided by the UK Environmental Agency is used. A combination of OS (MasterMap) and Land Registry data is also used to define boundaries of land parcels and sites. Similarly to NDA Scotland (section 5.1.2), data for inferring information on buildings' constructions and materials as well as ages of construction is derived from the Geomni UKBuildings database. Additionally, the 3Dstock model integrates gas and electricity metered data (not publicly available, provided by BEIS). The data is matched by address (via UPRN) to the modelled properties and is used to provide statistics on energy use as well as to compare energy use predictions obtained through the dynamic simulations (Steadman *et al.*, 2020). The UCL Energy Institute was commissioned by BEIS to develop a model suitable for providing detailed information (energy consumption and efficiency, geometry, materials, activities, occupancy, potential for renewable generation) for all non-domestic buildings in England and Wales following a building-by-building methodological approach similar to the 3Dstock method (Non-Domestic Building Survey (NDBS) project) (UCL Energy Institute, 2021). As part of the NDBS project, BEIS will conduct a series of remote and on-site surveys to collect information on energy use, building fabric characteristics and building use (BEIS, 2022). Further details of these surveys have not yet been published.

6 Policy development, tracking, and enforcement

The role that data plays in policy making depends on what specific objective is being sought. Policy objectives generally fall within the three main policy activities:

1. policy development,
2. policy tracking,
3. policy enforcement.

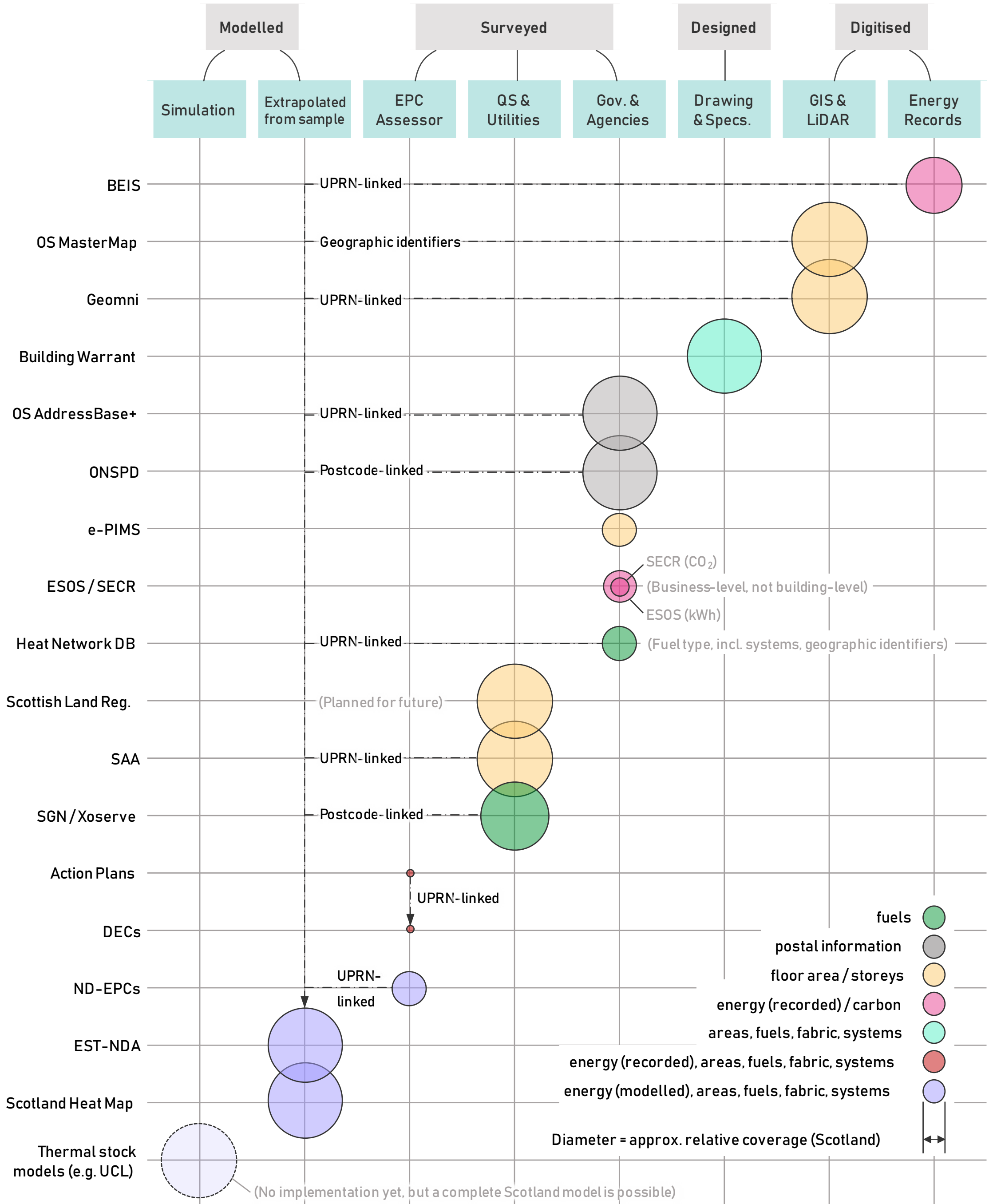
These three activities form a sequential hierarchy, where (1) allows the most permissive conditions on the 'quality' of the data used, and the most onerous conditions are associated with (3).

Different datasets can be grouped according to the above policy activities, to form an approximate indication of the degree of data verification. Figure 1 provides an illustration of the relevant datasets discussed in Section 5, indicating how these map to the main policy activities. The datasets can be classified under the main headings: 'modelled', 'surveyed', 'designed', and 'digitised', with the latter offering the greatest degree of verification. These main headings break down further, as follows:

- **Modelled:** thermal stock models; extrapolated-from-sample models
- **Surveyed:** EPC Assessor; Quantity Surveyor; Government and Agencies
- **Designed:** as submitted for Building Warrant or Planning
- **Digitised:** GIS, LiDAR or satellite; energy meters

In the context of the datasets discussed in Section 5, all of the available datasets relating to the Scottish non-domestic building stock can be used to aid policy development activities. In the case of model-derived data, the abstract nature of representative model results means that this data is only suitable for policy design objectives. This type of data lacks the necessary verification to monitor the real impact of policy over time. Compiled stock lists such as NDA provide an important role in harmonising many different datasets with distinct taxonomies and, as such, can be used as a tool to track policy where real building data (i.e. not extrapolated or artificially normalised) is not comprehensively available.

For policy enforcement, a much greater degree of verification is necessary, and this may be limited to measured energy consumption. The BEIS metered energy dataset represents a large-scale example of this. Figure 1 describes the data sources available for policy development, tracking and enforcement across the non-domestic building stock in Scotland.



Policy	Simulation	Extrapolated from sample	EPC Assessor	QS & Utilities	Gov. & Agencies	Drawing & Specs.	GIS & LiDAR	Energy Records
... d evelopment	✓	✓	✓	✓	✓	✓	✓	✓
... tracking	✗	✗/✓†	✓	✓	✓	✓	✓	✓
... e nforcement	✗	✗	✗	✗	✗	✗	✗	✓

Figure 1: Datasets available in Scotland for 'policy development', 'policy tracking', and 'policy enforcement'. Distinct datasets are coloured according to data content (see key), marker size indicates approximate coverage of the data across the Scottish N-D building stock. The datasets are aligned in columns relating to the underlying basis and collection method used, from abstracted models on the left, to verified metered data on the right.

† *Harmonised data from external sources can be used to monitor existing policy, in contrast to extrapolated data.*

7 Conclusions

7.1 Action Plans and Display Energy Certificates

- The impact of the Section 63 Regulation (Assessment of Energy Performance of Non-Domestic Buildings) on the uptake of energy efficiency measures is unknown.
    - Further analysis is needed to identify the number of Energy Action Plans (EAPs) issued per year as well as the extent to which the in-scope buildings implement the measures included in the EAPs or defer these and issue a Display Energy Certificate (DEC) instead.
    - publication of assessment reports on an annual basis may be a useful tool.
- Several EU member states as well as England and Wales have already adopted an operational ratings approach for assessing the energy performance of commercial and/or public buildings. The analysis of DEC data has potential as a monitoring tool.

7.2 Energy Performance Certificates

- As of November 2020, less than 15% of the estimated non-domestic buildings in Scotland had an EPC.
    - The Non-Domestic Analytics (NDA) Scotland dataset (developed by Energy Savings Trust) uses the available EPC records, while the remaining data is modelled. An increased number of EPC records would reduce model imputations and, consequently, increase the accuracy and reliability of the developed dataset.
- The released bulk EPC data includes limited information regarding the physical characteristics of non-domestic properties, which restricts modelling potential.
    - Including information on the buildings' age bands, constructions and built forms could be valuable for developing Scottish thermal stock models (such as the UCL 3DStock model) and would also improve the NDA dataset.
- A significant number of EPC records come with missing Unique Property Reference Numbers (i.e. unique identifier), which limits the ability of the data to be cross-referenced with other datasets (e.g. Scottish Assessors Association (SAA) records). This was also pointed out (after discussions with Energy Saving Trust) as a limiting factor in the development of the NDA.
    - Performing frequent quality controls on the uploaded EPC input data and providing better data could improve the usability of EPCs.
- There may be value in the development of a database to include interactive maps and aggregated data on EPC scores and coverage and building characteristics. by local authority/data zone.

7.3 Surveys

- The Scottish House Condition Survey (SHCS) and English Housing Survey (EHS) are two mature nationwide surveys applied within the Scottish and English context, respectively. There may be value in considering a similar approach for its non-domestic building stock.
- In the area of non-domestic building stock surveys, the US national sample Commercial Building Energy Consumption Survey (CBECS) is considered to constitute international best practice. There are valuable insights to be gained from

its application regarding survey design and implementation as well as data standards, analysis and sharing. These are summarised as follows:
  - Implementation:
    - survey results are valuable for benchmarking purposes, demand forecasting, and improvement of building standards and codes.
    - There are different options for carrying a survey, including the combination of in-person and web-based approaches, depending on resource availability.
  - Sampling method:
    - National sample surveys are generally considered to offer limited geographic granularity due to the small samples used.
    - In addition to factors such as building location, size, age, and property type, survey samples should also consider energy consumption variations between buildings with similar characteristics. This would considerably increase the usability of survey outputs and should be taken into consideration when defining a survey sample.
  - Data analysis and accessibility:
    - Following the example of the CBECS, public accessibility to both the aggregated and raw data would benefit a potential non-domestic building survey by enabling further and different types of analysis.
    - The CBECS website is a good example of data statistical analysis and presentation and for sharing aggregated data from EPCs, EAPs, (and DECs).
- Despite concerns around accuracy and sparse detail of self-reporting surveys, the US Building Performance Database (BPD) has proven a rich source of information, setting the foundations for the development of large and up-to-date databases that involve less resource-intensive data collection processes.
- New Zealand's Building Energy End-use Study (NZ BEES) uses records from the country's building-based property taxation system to compose a full list of non-domestic buildings and define a representative building sample to be used for the survey.
  - The sampling approach of the NZ BEES is of particular relevance for Scotland, which also has a building-based taxation system.

7.4 Further Examples

- The Scottish Government issued a call for evidence in late 2021 for the development of a new regulatory framework for its non-domestic buildings[3]. The analysis of this consultation summarises the evidence provided with regard to the effectiveness of regulations beyond Scotland.
- The National Australian Built Environment Rating System (NABERS) has proved effective in improving the energy efficiency of buildings which it applies to.
- The Japanese Carbon Reduction Reporting (CRR) voluntary carbon rating scheme is a useful example of how to increase sharing of measured data collected as part of energy audits.

[3] https://www.gov.scot/publications/regulation-energy-efficiency-existing-non-domestic-buildings-call-evidence/

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climateXchange

Scotland's centre of expertise connecting climate change research and policy

info@climatexchange.org.uk
+44(0)131 651 4783
@climatexchange_
www.climatexchange.org.uk

ClimateXChange, Edinburgh Climate Change Institute, High School Yard, Edinburgh EH1 1LZ