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A review of existing policy for reducing embodied energy and greenhouse gas emissions of buildings

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ABSTRACT

The building sector is a significant contributor to global energy demand and greenhouse gas emissions and thus has a major role in combating climate change. To date, efforts to address this issue have focussed on reducing energy demand during building operation, resulting in significant reductions in this area. However, recent studies have shown that substantial improvements to operational energy efficiency have increased the relative significance of indirect or embodied energy demands and associated greenhouse gas emissions. Subsequently, policies addressing this next frontier of energy and emissions reductions are emerging. To understand different approaches and inform future development, this study reviews existing policy mechanisms targeting embodied energy and greenhouse gas emissions in the building sector for four countries – Australia, Canada, USA and United Kingdom. The study found that voluntary instruments dominate the policy landscape, with regulatory measures largely absent at national levels and confined to inconsistent application across lower levels of governance. Signals of change emerging from the analysis include growing private sector investment and increasing quantitative targets for reduction. The study concludes with the challenges facing this sector of energy governance, alongside recommendations for regulated caps, mandatory LCA reporting, prerequisite requirements in voluntary instruments, data accessibility and resolving methodological inconsistencies.

1. Introduction

In developed countries, building and construction is often one of the most energy and greenhouse gas (GHG) intensive sectors (International Energy Agency, 2014). Buildings are responsible for approximately 32% of global final energy use, 17% of direct CO_2 emissions and one third of indirect emissions (International Energy Agency, 2013; Lucon et al., 2014). As such, the sector is under pressure to significantly adapt current practice to align with global efforts to combat climate change. Recently, a range of measures have been developed to address these concerns, from mandatory regulations to voluntary assessment tools. However, the majority have concentrated on reducing operational energy demand and associated GHG emissions of buildings (i.e. those associated to heating, cooling, cooking, appliances and lighting), leaving energy/GHG emissions associated with the embodied life cycle stage (i.e. the initial construction of the building and the recurrent replacement/maintenance of its materials throughout its life) largely ignored (De Wolf et al., 2017). As the operational efficiency of buildings has increased – due to advances in standards, regulations and technologies targeting this area of performance – the share of embodied energy (EE) and embodied GHG (EGHG) emissions is becoming more significant. Forecast economic and population growth will see an additional 230 billion square metres of floor area constructed globally by 2060, further highlighting the significance of EE and EGHG emissions reduction as a key strategy for mitigating the climate impact of buildings (UN Environment and International Energy Agency, 2017). Therefore, to achieve significant future reductions in energy demand and GHG emissions within the building sector and subsequently contribute to global climate change action, it is essential that EE and EGHG emissions are addressed.

There is an increasing amount of literature concerning the reduction of EE and EGHG emissions in buildings, ranging from the standardisation of calculation methods to the use of smart retrofit proposals in decarbonising the sector (Tarabieh and Khorshed, 2019). However, limited research has examined policy or governance considerations for EE and EGHG emissions reductions. Studies that have adopted this focus fail to provide a detailed comparative review of policy mechanisms across multiple regions and levels of governance. An understanding of existing efforts will help the sector identify signals of change, create

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policy mechanisms that mutually reinforce one another, and build synergies across borders to achieve global objectives. In the interests of propelling further development in EE and EGHG emissions abatement within the building sector, this study addresses this gap by undertaking a comparative analysis of EE/EGHG emissions policy mechanisms across four countries.

The paper is structured as follows: a background on EE and EGHG emissions (including definition), followed by articulation of the framework for the policy analysis, which is applied to a detailed analysis of EE and EGHG emission policies across four countries: Australia, the United States of America (USA), Canada, and the United Kingdom (UK). This policy analysis identifies possible signals of change and is followed by a discussion of key priorities moving forward in regulating EE and EGHG emissions. The paper concludes with consideration of potential future actions that decision makers can take to address building-related EE and EGHG emissions.

2. Background on embodied energy and greenhouse gas emissions

2.1. Definition

This paper defines a building's embodied energy (EE) as the sum of all energy required by a building in the production, construction, refurbishment or maintenance, and end-of-life stages – including energy necessary for raw material extraction, manufacturing, transportation, construction, and demolition. It is typically reported in non-renewable primary energy terms to capture the depletion of non-renewable resources and acknowledge differences in electricity generation between countries (International Energy Agency, 2016). Embodied greenhouse gas (EGHG) emissions are the total greenhouse gases emitted from processes involved in the life cycle stages of a building listed above (International Energy Agency, 2016). This has also been referred to as embodied carbon by some researchers and organisations (United Kingdom Green Building Council, 2017). In this study, the term EGHG emissions is used synonymously with embodied carbon, although the former is a more scientifically accurate representation of what is being measured.

A common tool used to quantify EE and EGHG emissions of products and processes is Life Cycle Assessment (LCA). LCA evaluates the potential environmental effects of products holistically, including direct and supply chain effects (Lenzen et al., 2014). LCAs of buildings quantify relevant inputs (such as water, energy and raw materials) and the subsequent outputs (such as atmospheric emissions and waste) to determine environmental effects across the selected life cycle stages of a building.

While consideration of EE and EGHG emissions of buildings is growing, it is generally limited to the selection of low EE or EGHG emission materials. Full LCAs of buildings remain uncommon and thus the life cycle implications of material and assembly choices are not often addressed. Several reasons exist for the limited consideration of EE/EGHG emissions in buildings, including uncertainties and inconsistencies in EE/EGHG emission quantification techniques, and the sector's long-term focus on operational energy consumption and related GHG emissions (International Energy Agency, 2016). Furthermore, historically it was believed that EE/EGHG emissions of buildings were comparatively insignificant, representing as little as 10% of a building's life cycle energy demand and associated emissions (Ramesh et al., 2010). The development of more sophisticated assessment techniques (Crawford et al., 2018) and improved building operational efficiency has shown that EE and EGHG emissions can represent a significant proportion of the total life cycle energy demand and emissions of a building (Crawford, 2014).

2.2. Growing importance of embodied energy in the move to zero energy buildings

Depending on the building typology, location, material use, assessment method and assumptions, Chastas et al. (2016) demonstrated that the share of EE in the total life cycle energy of a building can range from 26% for some low-energy buildings to almost 100% for nearly zero energy buildings (nZEB). In some regions – particularly where the energy grid is decarbonised or rapidly transitioning to decarbonisation – EGHG emissions are more likely to be higher than operational GHG emissions (Bionova Ltd, 2018).

To date, policy actions associated with buildings have largely concentrated on operational energy and related GHG emissions, rather than broader life cycle concerns such as EE and EGHG emissions. Governance of building-related operational energy use and GHG emissions is common in many regions. For example, 41 countries have mandatory residential building codes for operational energy, and in at least 85 countries building energy certifications, ratings or labels are present (Global Alliance for Buildings and Construction et al., 2019). However, as industry and governments continue to focus on reducing the operational energy requirements of buildings through the creation of building codes and promotion of low-energy buildings strategies, the share of embodied energy in the total life cycle of buildings is increasing (Chastas et al., 2017).

Net-zero or low-energy principles in building design and construction are often reliant on more energy- or carbon-intensive building fabric or assemblies to ensure buildings remain fit-for-purpose (Seo et al., 2016). Increasingly, aims for net-zero or low-energy buildings are making their way into policy mechanisms of major jurisdictions or exist in popular voluntary instruments. For example, the Government of British Columbia have established the BC Energy Step Code as part of a roadmap to ensure buildings are net-zero energy ready by 2032 in the province (Government of British Columbia, 2018), and the City of Sydney is developing standards that aim for net-zero energy in their statutory planning system (City of Sydney, 2021). Although there remains a need to continually lower operational energy, without concurrent oversight of EE and EGHG emissions there is potential for these operational savings to be offset by more EE and EGHG emissions intensive materials and assemblies.

3. Methodology

The purpose of this study is to analyse the extent to which EE and EGHG emission reductions are included in policy mechanisms targeting the building sector in four key countries. A broad definition of 'policy' is adopted in this study and encompasses mechanisms instigated by private (non-government organisations, registration bodies, and private companies) and public sector entities (governments, regulatory authorities). The study examines policy mechanisms that explicitly address EE/EGHG emissions of buildings and does not include draft proposals for future EE/EGHG emission abatement, policies from allied industries (such as manufacturing) or broader environmental policies (such as economy-wide carbon taxes). Categories of policy mechanisms vary across different fields and literature, however those examined in this study are divided into three categories: regulatory measures, voluntary instruments, and economic incentives (Fig. 1). Each category has its own merits and weaknesses depending on the objectives under which it is evaluated and the context of its conceptualisation, application and enforcement.

The countries considered in this study are Australia, Canada, USA, and the UK. The selection of these four countries was motivated by their shared characteristics; all use English in policy documents, each has developed an internationally recognised green building rating tool (Kibert, 2016, p. 132), and each respective country's total GHG emissions are amongst the highest in the OECD (OECD, 2020). While progression in policy is not necessarily correlated with high environmental

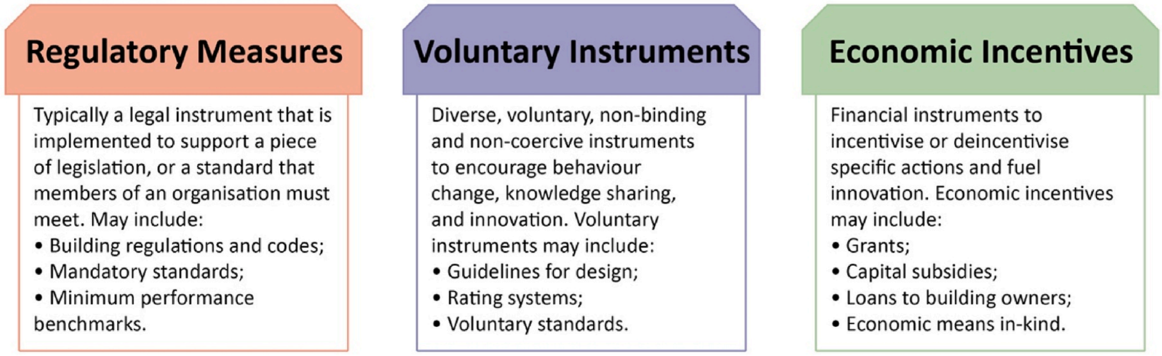

Fig. 1. A description of the three categories of policy mechanisms - adapted from Costantini et al. (2017); Kaufmann-Hayoz et al. (2001); Kibert (2002).

impact, and in fact, the opposite could be argued, the selection will help provide insight into current policy actions in countries where it is most needed.

Policy mechanisms were initially identified by searching the International Energy Agency's (IEA) Policy Database and limiting results to those mechanisms in-force and pertaining to buildings. The IEA is a long-established, intergovernmental organisation that has been noted as a leading agency in global energy policy and governance (Florini, 2011; Van de Graaf, 2012). Cues, institutions, and themes identified from the IEA Policy Database search results were subsequently used to locate further mechanisms and initiatives via web search. This method of obtaining and sampling policy mechanisms via a two-stage search was adopted due to the diversity and rapidly changing nature of the information being sought. As the policy landscape for EE/EGHG emission reduction in buildings is in its infancy, the available information is fragmented. As such, this study presents the mechanisms that were identified, but cannot be deemed an exhaustive review of all mechanisms present at the time of publication.

Policies from the following levels of administration were considered: city/local government, state/province/territory, and national. Policies developed by national bodies located in one of the four countries but applicable internationally were not excluded. Policies examined were limited to those focussed on the construction, design or performance of a building as the end-product and/or functional unit. In this review, 'building' refers to a habitable structure of any scale but excludes infrastructure such as roads. The building typologies considered in this analysis are adapted from the National Construction Code's Building Classifications Classes 1 through 9 (Australian Building Codes Board, 2020) and include residential, commercial, public, and industrial. In the description of policies, residential is disaggregated between single- (e.g., houses) and multiple-residential (e.g. apartments) buildings as they are often evaluated differently in policy mechanisms. Policies that are more narrow-in-focus – for example, standards for appliances or singular building products – were excluded. In Appendix A summary tables, very similar policies have been grouped into one-line items for brevity (for example, statutory planning policies that make mention of EE/EGHG emission reduction in a limited way).

The review adopted a similar method to Ürge-Vorsatz et al. (2007), whereby descriptive information for policies was extracted and tabulated to summarise and compare each of the policies examined (refer to Table 1). The object of this analysis was the policy output, which is defined as the objectives (ends) and mechanisms (means) of the policy (adapted from Howlett and Cashore, 2009).

To help identify signals of change in EE and EGHG emission governance, two dimensions were assessed: policy density (the number of policies in a particular country), and policy intensity, which is disaggregated between intensity of targets (the extent of reduction required/proposed by the policy) and intensity of scope (the degree of penetration with respect to building typology and scale of implementation). An analysis that solely considers the quantity of policies and disregards policy output may lead to an erroneous understanding of a country's progress in EE/EGHG emission governance. For example, one country may have a significant quantity of low-intensity policies, whereas another may have fewer yet more intense policies. Therefore, dimensions of density and intensity were considered concurrently to mitigate the risk of misrepresenting progress. The density and intensity of the policies reviewed have been determined by the authors using a grading scale described in Table 2.

It is important to note that this analysis does not consider the effect of the policies assessed, and in this sense is an *ex-ante* assessment. This is

Table 1
Attributes of policy mechanisms considered in the analysis.

Attribute	Description
Name	Name of the mechanism examined
Type	Type of mechanism following the three categories described in Fig. 1
Administrator	Organisation or institution responsible for the creation or administration of the mechanism
Scale	Scale of application (e.g. city-based/local government, state/province/territory, national, regional, international)
Typology	The building typology to which the mechanism is applied
Target	The goal, target or objectives of the mechanism
Date	Date of the mechanism being published and/or (if applicable) implementation date

Table 2
Grading scale used for qualitative assessment of policy intensity.

Intensity – Targets	*Refers to the targets of the policy. The 'intensity – targets' measures the extent of reduction in EE and EGHG emissions in the policy objectives.*
Low (Low)	No quantitative measure is offered for reductions, but it is encouraged in policy wording
Med (Medium)	A quantitative target of up to a 25% reduction in EE or EGHG emissions compared to a baseline is included
Hi (High)	Net zero objectives are included for either EE or EGHG emissions; or a quantitative target of more than 25% reduction in EE or EGHG emissions compared to a baseline is included
Intensity – Scope	*Refers to the scope of the policy's extent of application. The 'intensity – scope' measures the number of typologies affected by the policy and is adapted from* Knill et al. (2011). *In this study: scale and scope are used to determine 'intensity – scope'.*
Low (Low)	The mechanism is for a singular typology (e.g. commercial buildings) at a local-based scale (e.g. city, shire or local government area)
Med (Medium)	The mechanism is for multiple typologies at a local-or state-based scale, or for a single typology (e.g. public buildings) at a state, national or international scale
Hi (High)	The mechanism is for at least 3 building typologies (including one type of residential as a minimum) at a national or international scale

due to the infancy of the EE and EGHG emission policy landscape for the building sector and the fact that policy impact is typically affected by a plethora of exogenous factors, which are not accounted for in this work.

4. Embodied energy and GHG emissions governance in Australia

Although Australia is the smallest nation by population and gross domestic product (GDP) of the four countries examined, a comparable quantity of policy mechanisms exists across all levels of governance. However, most of the mechanisms identified were voluntary instruments, in the form of guidelines, rating tools and strategic planning advice (as opposed to enforceable planning regulations). Furthermore, intensity (by scope and target) is weak, pronounced by a lack of national, compulsory policy mechanisms that explicitly provide targets for EE/EGHG emissions. Table A.1 in Appendix A outlines the policy mechanisms that were identified in the Australian context and describes their key characteristics.

The most significant gap identified is the absence of enforceable EE/EGHG emission regulation at a national and state level. The current building code for Australia – known as the National Construction Code – has no mechanism for enforcing EE/EGHG emissions targets. The national plan for low-energy buildings – the 'Trajectory for Low Energy Buildings' – also focusses solely on operational emissions and energy demand. The absence of a national strategy directing the sector on how to manage EE/EGHG emissions is echoed at lower levels of governance, with state and city/local based policies typically offering guidance and advice, rather than enforceable regulatory measures.

At the city/local and state levels of governance, a common theme identified is the recommendation to select/specify materials low in EE during the planning and design phase of a building. In these measures, quantitative targets, a baseline to measure performance from, definition of what constitutes a low-EE material, and details regarding enforcement are typically not provided. For example, a guidance note published by the South Australian state government outlines the EE of various materials, yet the origin of the information is ambiguously cited as from 'several international sources' (Department of Planning, Transport and Infrastructure, 2017, p. 9), thus ignoring the importance of accounting for local energy contexts and the various methods of calculating EE.

Signals of change can however be seen in efforts from key industry organisations, namely the Green Building Council of Australia (GBCA) and their new Green Star Buildings (GSB) rating tool. Guided by their Carbon Positive Roadmap released in 2018, the new GSB tool has incorporated upfront (embodied) carbon emissions as part of the minimum expectations for buildings seeking a rating. Using a LCA or alternative documentation, GSB requires a 10% reduction of upfront carbon emissions in comparison with a reference building. This benchmark will progressively increase to 20% by 2030, and further credits are available for offsetting remaining emissions. Another voluntary instrument – EnviroDevelopment – holds similar ambitious quantitative targets that may be demonstrated via LCA, but EE/EGHG emission reduction is not mandatory and alternative compliance pathways exist. Although these targets remain part of voluntary mechanisms, the mandatory reduction of embodied carbon emissions in the GSB tool is novel in the Australian context and a signal that private actors in the Australian building sector are changing the way they perceive EE/EGHG emissions.

Although there is a notable lack of intensity in the policies that were identified in this review, demand for change has been advocated by several private sector stakeholders – including LendLease, the Australian Sustainable Built Environment Council, Planning Institute of Australia, and the Property Council of Australia. Several of these stakeholders have advocated for more stringent control and regulation of EE/EGHG emissions in the Australian context, either through their endorsement of the World Green Building Council's (WGBC) Bringing Embodied Carbon Upfront report (Adams et al., 2019) or via original publications (for example: Lendlease Building, 2020). However, despite stakeholders' efforts, legislation and mandatory compliance mechanisms addressing EE and EGHG emissions are not yet in train, and there are not any direct or indirect incentives being offered.

5. Embodied energy and GHG emissions governance in Canada

As summarised in Table A.2 of Appendix A, policies in Canada directly targeting EE and EGHG emissions vary in intensity. EE/EGHG emissions are also addressed in a range of ways in policy mechanisms – from consideration of EE and EGHG emissions during material specification to quantitative reductions in comparison to a baseline. Similar to Australia, Canada has no enforceable regulation of EE and EGHG emissions in mandatory building codes such as the National Building Code. Although the Pan-Canadian Framework on Clean Growth and Climate Change (PCFCGCC) acknowledges the potential for timber to store carbon and encourages its use in new construction (Environment and Climate Change Canada, 2016a, p. 22), nothing beyond encouragement is present. This is despite a working group informing PCFCGCC development remarking that carbon intensity targets for construction would give greater attention to embodied carbon (Environment and Climate Change Canada, 2016b, pp. 146–151) and think-tanks advocating for embodied carbon caps to be integrated into building codes (Frappé-Sénéclauze, 2020). Despite the lack of code-based action, national leadership was identified in the Greening Government Strategy, which calls for a 30% reduction in embodied carbon of structural materials in new government construction projects (Government of Canada, 2021).

At the province/state and city-based levels, there are further mechanisms that demonstrate awareness of EE and EGHG emissions abatement. For example, the City of Vancouver's Green Buildings Policy for Rezoning (City of Vancouver, 2018) aims to develop a contextually relevant evidence base to support future EGHG emissions reduction, and the Climate Emergency Big Move #5 (City of Vancouver, 2019) targets a 40% reduction in EGHG emissions by 2030. These actions signal commitment to long term planning with respect to EE/EGHG emissions reduction in the city and aligns closely with the visions of several independent bodies. Voluntary instruments – such as rating schemes and certifications – are also found in some regulatory measures for province/state and city-based jurisdictions, specifically for their government operations. For example, in seven provinces/territories, 34 separate municipal governments require that municipal owned or funded projects attain LEED certification as part of their procurement and/or renovation (Canada Green Building Council, 2017, p. 17). Yet the credit-based approach used by many green rating programs means stakeholders can opt-out of specific categories. For example, the use of LEED doesn't necessarily equate to action on EE/EGHG emissions as the credits associated with the relevant criteria are not mandatory.

These voluntary instruments and their stakeholders demonstrate that signals of change are emerging. As an additional example, the Canada Green Building Council's (CaGBC) Zero Carbon Building (ZCB) Standard v2 has a pathway for motivating EGHG emissions reduction in developments. The ZCB Design program includes the reporting of embodied carbon in a proposed development using a LCA and the option to obtain further credit if the proposal can demonstrate a 20% reduction of embodied carbon in reference to a baseline building (Canada Green Building Council, 2020a). Further, the ZCB Performance program builds on this reporting, by offering certification to buildings that can demonstrate zero net CO_2-eq emissions over a 12-month period with embodied emissions needing to be offset (Canada Green Building Council, 2020b). To support adoption of this mechanism and help offset concerns regarding upfront capital investment, the CaGBC has published data showing that ZCBs can result in a positive financial return over a 25-year period (Canada Green Building Council, 2019). However, despite the presence of these voluntary instruments, supporting data and information, there is an absence of other policy mechanisms providing direct or indirect incentives for EE/EGHG emissions abatement.

As noted by Zizzo et al. (2017) the groundwork for considering EE and EGHG emissions in the Canadian context is already present, indicating that the market may be ready for more stringent targets. Notes and actions from industry – such as think-pieces (O'Connor, 2020) and projects commissioned by industry bodies (Zizzo et al., 2017) – demonstrate that efforts to regulate EE and EGHG emissions would not be wholly unexpected. However, in the absence of mandatory, code-based regulation, substantial reduction in EE and EGHG emissions may remain gradual in the Canadian context for the foreseeable future.

6. Embodied energy and GHG emissions governance in the United States of America (USA)

Examination of the USA policy landscape demonstrated an absence of mandatory regulatory action on EE and EGHG emissions abatement at a national level, however state and city-level leadership on the issue is emerging. Although the USA is home to significant advocacy and research efforts addressing EE and EGHG emissions in the building sector – including Architecture 2030 and the Carbon Leadership Forum – voluntary instruments such as rating tools, declarations and certifications dominate the policy landscape. As seen in Table A.3 in Appendix A, policy density remains limited relative to the size and value of the nation's building sector. However, the actions of some states and cities indicate that change is occurring, as policy mechanisms to reduce EE/EGHG emissions are present at these lower levels of governance. Several voluntary instruments also cater for multiple typologies at national and international scales, however in most of these policies the EE/EGHG emissions component is optional.

Not unlike other countries examined in this study, nationally applicable EE and EGHG emissions abatement is absent from building codes applicable to most states in the USA (the International Building Code [IBC] and the International Residential Code [IRC]). An overlay code to the IBC and IRC – the International Green Construction Code (IgCC) – has been adopted by 14 states, however life cycle GHG emissions reduction is an optional pathway within the regulation. One federally issued, national regulatory measure was identified – Guiding Principles for Sustainable Federal Buildings – however, compliance appears to be optional, goals are internally set by the project team, and monitoring compliance is discharged to individual government agencies.

Further action is seen at the state and city level, particularly in the states of California, Washington and the city of Austin, Texas. The Buy Clean California Act (BCCA) is one such example. Although the BCCA examines building elements – rather than the whole building, which is the focus of this study – it has been included in this analysis as it oversees multiple materials concurrently. From 2021, the Act requires state-funded projects to comply with published maximum acceptable global warming potential (GWP) limits (reported as kg CO_2-eq) of key building elements, including structural steel, flat glass, steel for concrete reinforcement and mineral wool board insulation. The specific targeting of materials high in EE/EGHG emissions in the BCCA is aligned with Simonen's (2011) recommendations for stimulating low-carbon construction by limiting scope to high-embodied impact or large volume materials. Despite the BCCA being limited in its scope of application, learnings from the BCCA process – including adoption, costs and reception – may serve to inform other jurisdictions pursuing similar outcomes. Attempts to install an act similar to the BCCA have occurred – including Oregon in 2017, Washington in 2018, and Minnesota in 2019 – however, these efforts were not passed into law (Carbon Leadership Forum, n.d., 2018a).

In the absence of broader regulatory leadership on the issue of EE and EGHG emissions governance, the USA has several voluntary instruments such as building rating and certification schemes that may encourage public and private sector action. In some instances, these voluntary instruments have been rolled into the regulatory environment for particular states (Cowie, 2020) or are used to assess newly constructed, federally owned facilities (U.S. General Services Administration, 2021). These voluntary instruments include LEED, the Living Building Challenge (LBC), Zero Carbon Standard (ZCS), and Green Globes. Although these instruments are applicable to multiple building typologies, the extent to which EE and EGHG emissions abatement is required varies. LEED – which is the most popular green building certification (Wu et al., 2017) – includes credits for demonstrating reductions in GWP (measured in kg CO_2-eq) using a whole-building LCA, but the credits are not compulsory and the reductions are demonstrated against a reference building rather than an absolute limit or cap. The LBC takes a more hard-line approach requiring a 20% reduction in embodied carbon. However, market penetration of this mechanism is low; by 2020, just 26 projects had achieved full LBC certification worldwide (Living Future Institute Australia, 2020). The ZCS is a further signal of change as it provides pathways to demonstrate net-zero life cycle carbon; however, compliance is partially attained by purchasing offsets and installing renewables, with only a 10% reduction in reference to a baseline/cap of 500 kg CO_2-eq/m^2 required to be achieved via design and construction practice.

Although multiple policies were identified, the intensity of policies in the USA is limited. It is suggested that this is possibly due to the regulatory landscape being highly fragmented (Eisenberg et al., 2009). No economic incentive-based policies were identified to encourage the sector to engage in EE/EGHG abatement. Future progress for this high-emission, high-consumption nation will likely be driven by private sector investment and innovation, and environmentally progressive local or state governments.

7. Embodied energy and GHG emissions governance in the United Kingdom

The United Kingdom's efforts to address EE and EGHG emissions in the building sector consists of several voluntary instruments and regulatory measures as shown in Table A.4 in Appendix A. Initially, the density of policies appears limited, however, this may be attributed to several jurisdictions adopting BREEAM (a voluntary instrument) in their policies, as opposed to creating their own scheme(s). The policy mechanisms identified have similar characteristics to other countries examined – national regulatory measures are lacking, voluntary instruments will typically not make EE/EGHG emissions abatement compulsory, and regulatory measures largely encourage low EE/EGHG emissions materials. Furthermore, no explicit financial incentives for reducing EE/EGHG emissions of buildings were identified.

As the home nation of the first green building assessment tool to achieve mainstream success (BREEAM), the UK has a culture of voluntary instruments, assessment schemes and rating programs initiated by the private sector. Like other countries examined, voluntary instruments such as BREEAM have also been integrated into government procurement practices and local planning policy. For example, the UK Government's Common Minimum Standards for construction of public sector buildings (Government of the United Kingdom, 2017) requires BREEAM assessments on most projects. Furthermore, several local plans released by councils mandate the use of BREEAM for projects of a certain size/type (Goodey and Gent, 2019). However, in the UK context, few voluntary instruments mandate the reduction of EE/EGHG emissions, with associated credits generally being voluntary and comprising a small amount of the total credits available. In the case of BREEAM, EE/EGHG emissions are not mandatory for certification at present, therefore its potential to contribute to significant EE/EGHG emissions reductions may remain unrealised.

At the city level of governance, further progress can be seen in actions by local governments and unitary authorities such as Blackpool Council, Brighton and Hove Council, Bracknell Forest Borough, the Greater London Authority, Leeds City Council, and Manchester City Council. In these cases, specification of materials that are low in EE or EGHG emissions and/or retention of existing structures to mitigate additional EE or EGHG emissions expenditure are encouraged in Supplementary Planning Documents. However, there is little detail in these policies outlining how these measures are to be achieved, what constitutes 'low' (as no caps, targets or minimum standards are mandated), or whether policy compliance is mandatory.

Policies in their current form will serve to increase awareness of and interest in EE/EGHG emissions, however given that numerous private sector stakeholders already advocate for more ambitious action (see Craigforth (2020); Embodied Carbon Industry Task Force (2014); Grosvenor Britain & Ireland (2020); United Kingdom Green Building Council (2015a)), regulation in the UK could be more progressive. However, one notable private sector governing body – the Royal Institution of Chartered Surveyors (RICS) – has taken leadership through their professional standards and guidelines. The European standard for assessing the environmental sustainability of construction, namely EN15978 (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method), is a commonly specified standard or reference in voluntary instruments like BREEAM and Green Star (Australia). As a result, RICS has developed a standardised interpretation and implementation methodology. RICS members are required to adhere to the approach as outlined in their professional standards and guidance document 'Whole Life Carbon Assessment for the Built Environment' when undertaking calculations required to comply with EN15978.

With the exit of the United Kingdom from the European Union (EU), the potential for EU directives for sustainable buildings and actions of many European countries (such as The Netherlands, Belgium, France, etc. – refer Zizzo et al. (2017) and Bionova Ltd (2018) for more detail) translating into similar UK action is diminishing. This is emphasised by the UK Government's reversal of several sustainable building strategies in the last 10 years, an example being the Zero Carbon Homes programme announced in 2007 and retracted in 2015 (United Kingdom Green Building Council, 2015b). Further to this, the UK Government's most recent initiative – the Future Homes Standard – neglects to consider EE/EGHG emissions; again, despite industry calling for more ambitious targets (Royal Institute of British Architects, 2020).

8. Discussion of key findings from the policy analysis

Overall, the policy analysis of the four countries identified that EE and EGHG emissions reductions are starting to emerge in current policy mechanisms related to the building sector. This indicates that the sector and policy makers have begun to recognise its significant contribution to global GHG emissions and are open to making efforts to adapt current practices. Table 3 outlines a summary of the intensity of targets and scope of the 40 policy mechanisms identified in this study. Broadly, the USA has the greatest density of policies of the four countries (n = 16), with Australia (n = 9), United Kingdom (n = 8) and Canada (n = 7), demonstrating similar numbers of policy mechanisms identified. For further detail on each of these policy mechanisms, refer to the tables in Appendix A. Across the four countries, the policy mechanisms identified demonstrated a range of scope and intensity. Of the policy mechanisms reviewed, voluntary instruments (n = 20) were dominant, compared to regulatory measures (n = 14) or hybrid mechanisms that spanned across regulatory, economic and/or voluntary classifications (n = 6). No policy mechanism solely classified as an economic incentive was identified in any of the countries.

All countries except Australia had one mechanism that achieved a high (green) rating for both policy intensity scope and targets. However, two of these mechanisms – the Zero Carbon Standard in the USA and the UKGBC Net Zero Carbon Framework – include the use of purchased offsets to reach net-zero status. One regulatory measure achieved a high rating for scope and targets without the need for offsets: the Canadian Government's Greening Government Strategy. However, this is a mechanism solely for government-owned projects.

Common characteristics for signals of change in the policies and their implementation were identified across all countries; these included:

- Use of quantitative targets to enforce monitoring and measurement, typically demonstrated using LCA;
- Investment in long-term strategic development by developing an evidence base for future EE/EGHG emission reductions (except Australia);
- Leadership through exemplar practices in public or government funded buildings; and
- Private sector investment and research via green building tools.

A signal that organisations are moving towards more strict monitoring and measurement of EE/EGHG emissions in buildings was exemplified through the inclusion of quantitative targets for EE/EGHG emissions reductions in several mechanisms identified (n = 22). Importantly, mechanisms that included a quantitative target for EE/EGHG emission reduction were generally dated post-2017, whereas those that did not pursue quantitative reductions were largely dated pre-2017. This emphasises the recent shift towards more ambitious goal setting in this area. Quantitative targets also varied, including absolute reductions against a reference building ranging from 5 to 50% or net-zero as the mechanism's goal. Inconsistency in policy mechanisms' characteristics and implementation exists across countries, including the composition of the reference building, the methodology used to quantify EE/EGHG emissions, and the timeframe for meeting the target. These inconsistencies make comparison across borders difficult to achieve. However, it is noted that the RICS professional standards and guidelines has tried to address this by prescribing a standardised approach for adherence by all RICS members when undertaking calculation for EN15978. Non-specific, qualitative goals are present in all countries, particularly in the UK, Canada and Australia. A common requirement was for projects to use low-EE/EGHG emitting materials, however such requirements were typically accompanied by minimal detail regarding enforcement. While these non-specific goals are useful in fostering awareness of EE/EGHG emissions in the building sector, it is unclear what effect these policies have.

In Canada, the United Kingdom and USA, several mechanisms appear to be investing in a long-term strategy for EE/EGHG emissions governance, by developing an evidence base for EE/EGHG emission reductions through the inclusion of reporting as part of their implementation (for example, the BCCA [USA], the City of Vancouver Green Buildings Policy for Rezoning [Canada], and RICS's Whole Life Carbon Assessment for the Built Environment professional standard [UK]). Although these mechanisms don't necessarily result in an immediate reduction in EE/EGHG emissions from the building sector, establishing an evidence base will aid decision makers in developing the next stage of their policy frameworks: benchmarks, targets and caps.

Leadership from governments was another signal of change identified, through several policy mechanisms specifically addressing public-funded buildings or government operations. In Australia, Canada and the USA, selected mechanisms encouraged the use of low EE/EGHG emitting materials in public-funded buildings. State based policies in Minnesota (Minnesota B3, 2017) and California (State of California, 2018) in the USA go further than encouragement and include targets/caps for the GWP of a building or building elements in state-funded projects. Governments further utilised voluntary instruments – LEED in Canada, BREEAM in the UK and Green Star in Australia – as a means to assess, benchmark, or drive adoption of green building practices in their operations at multiple levels of governance (for example: Canada Green Building Council, 2017; Green Building Council of Australia, n.d.). This leadership demonstrates that from a regulatory perspective, governments of various levels understand the importance of EE/EGHG emissions abatement and are thus keen to demonstrate model behaviour in their own procurement practices. As Koski and Lee (2014) identified, this 'policy by doing' may help stimulate behaviour in the private sector, but even more so at a level of government that is closer to the consumer (e.g. local/city government).

Whilst governments appear to be signalling change, efforts in

Table 3
Summary of policy mechanisms identified and analysed as part of this study.

Country	Name	Type	Scale	Typology	I - Scope	I - Targets	Source
AUS	Green Star Buildings	V	N	All	**Hi**	**Med**[a]	Green Building Council of Australia (2020)
AUS	GBCA Carbon Positive Roadmap	V	N	Commercial[b], Institutional, Public (government)	**Med**	**Med**	Green Building Council of Australia (2018)
AUS	Australian Institute of Architects – Sustainability Policy	V	N	All	**Hi**	**Low**	Australian Institute of Architects (2008)
AUS	EnviroDevelopment	V	N	All	**Hi**	**Med**	Urban Development Institute of Australia (2019)
AUS	Environmentally Sustainable Materials - Selection	V	S	Public (government)	**Med**	**Low**	Government of South Australia (2017)
AUS	General Design Standards for Justice, Health and Public Buildings	R	S	Public	**Med**	**Low**	Government of Western Australia (2012a)
AUS	Education facilities design standards	R	S	Public (education)	**Med**	**Low**	e.g. Queensland Government (2014); Government Architect New South Wales (2018); Government of South Australia (2020); Government of Western Australia (2012b)
AUS	Various Office or Government Accommodation Standards/Guidelines	R	S	Public (government)	**Med**	**Low**	Victorian Government (2007); Office of the Queensland Government Architect (2010)
AUS	Various Planning Schemes/Policies	R V[c]	C	Projects subject to relevant scheme	**Unclear**	**Low**	e.g. NSW Government (2020); Department of Environment, Land, Water and Planning (2021)
CAN	Canadian Green Building Council – Zero Carbon Building (ZCB) Program (Design; Performance)	V	N	All except residential	**Med**	**Med** (ZCBDes) **Hi** (ZCBPerf)	Canada Green Building Council (2020a, 2020b)
CAN	Greening Government Strategy	R	N	Varies (buildings in government portfolio)	**Hi**	**Hi**	Government of Canada (2021)
CAN	Built Green	V E	N	Residential	**Med**	**Low**	Built Green (n.d.)
CAN	Charte du bois[d]	R	S	All except single residential	**Med**	**Low**	Gouvernement du Québec (2019)
CAN	City of Vancouver Climate Emergency Report	R	C	N/A	**Unclear**	**Hi**	City of Vancouver (2020)
CAN	City of Vancouver Green Buildings Policy for Rezoning	R	C	N/A	**Unclear**	**Low**	City of Vancouver (2018)
CAN	Waterfront Toronto Green Building Requirements	R	C	All	**Med**	**Low**	Waterfront Toronto (2021)
USA	LEED (v4.1) Building Design & Construction	V	I	All	**Hi**	**Med**	U. S. Green Building Council (2021)
USA	Living Building Challenge (LBC) Version 4.0	V	I	All	**Hi**	**Med**	International Living Future Institute (2019b)
USA	Zero Carbon Standard	V	I	All[e]	**Hi**	**Hi**[f]	International Living Future Institute (2020)
USA	Core Green Building Certification	V	I	All	**Hi**	**Med**	International Living Future Institute (2019a)
USA	Envision Sustainable Infrastructure Framework v.3	V	I	Infrastructure projects	**Med**	**Hi**	Institute for Sustainable Infrastructure (2018)
USA	Carbon Smart Building Declaration	V	I	N/A	**N/A**	**N/A**	Carbon Leadership Forum (2018b)
USA	Green Globes New Construction	V	I	All	**Hi**	**Med**	Green Building Institute (2019)
USA	National Green Building Standard	V	N	Residential	**Med**	**Med**	National Association of Home Builders of the United States (2020)
USA	Guiding Principles for Sustainable Federal Buildings	R	N	Varies (federally owned buildings)	**Med**	**Low**	Council on Environmental Quality (2020)
USA	International Green Construction Code (IgCC)	V R	I S	All except low-rise residential	**Med**	**Med**	International Code Council and ASHRAE (2018)
USA	C40 Clean Construction Declaration	V	I C	N/A	**Med**	**Hi**	C40 Cities (2020)
USA	Buildings, Benchmarks and Beyond (B3) Guidelines	V R	S	Varies (state-funded buildings)	**Med**	**Med**	Minnesota B3 (2017)
USA	Buy Clean California Act (BCCA) - Assembly Bill No. 262	R	S	Varies (state-funded buildings)	**Med**	**Med**	State of California (2018)
USA	California Green Building Standards Code 2019 (aka CalGreen)	V R[g]	S	Non-residential	**Med**	**Low**	California Building Standards Commission (2019)
USA	State of Washington Executive Order 18-01	R	S	Varies (state-owned buildings)	**Med**	**Low**	Inslee (2018)
USA	City of Austin Energy Green Building Rating System	R	C	Residential Commercial	**Med**	**Med**	Austin Energy (2020)
UK	Home Quality Mark (HQM ONE)	V	N	Residential	**Med**	**Med**[h]	Building Research Establishment Limited (2018)
UK	BREEAM UK – New Construction Standards	V[i]	N	All except single residential	**Hi**	**Med**[j]	Building Research Establishment Limited (2019)
UK	BREEAM UK – Refurbishment and Fit-Out (Domestic and Non-Domestic)	V[k]	N	Varies (refurbishment and fit-out)	**Hi**	**Low**	Building Research Establishment Limited (2016, 2020)
UK	UKGBC Net Zero Carbon Framework - Construction	V	N	All	**Hi**	**Hi**[l]	United Kingdom Green Building Council (2019)
UK	Whole Life Carbon Assessment for the Built Environment	R[m]	N	All	**Hi**	**Low**	Royal Institute of Chartered Surveyors (2017)
UK	Code for Sustainable Homes	V[n]	N	Residential	**Med**	**Low**	United Kingdom Government (2010)
UK	London Plan – Sustainable Design and Construction Supplementary Planning Guidance	R	C	Not specified	**Unclear**	**Low**	Greater London Authority (2014)
UK	Various UK Planning Regulations for Councils, Unitary Authorities, Cities	V R[o]	C	Varies	**Varies**	**Low**	e.g. Bracknell Forest Council (2008); Leeds City Council (2011)

Key: **Low** (Low), **Med** (Medium), **Hi** (High).

Note: V: Voluntary, R: Regulatory, E: Economic Incentive; I: International/Intergovernmental, N: National, S: State, C: City/County/Borough; I-Scope: Intensity – Scope; I-Targets: Intensity – Targets; N/A: Not Applicable or Not Specified in Policy.

[a] An exceptional performance pathway - which requires a 20% reduction and all remaining emissions to be offset - is an optional net-zero objective, but not compulsory or core to the mechanism.

[b] Excluding specialist commercial buildings such as data centres.

[c] Although this is in a regulatory document – a planning policy – it is encouraged and not enforced.

[d] Known as the Quebec Wood Charter in English – under review as of mid 2020.

[e] The amount of offsets/reduction required varies depending on the building typology.

[f] Net zero can be attained through offsets. Offsets may be onsite energy generation and/or the purchase of offsets from third-parties.

[g] The Code itself is a regulatory measure, but the pathway for LCA integration is voluntary.

[h] The quantitative target is in an Ecopoint unit, making it difficult to understand what the actual reduction is on a percentage level without understanding the methodology to calculate Ecopoints.

[i] Although technically voluntary, the BREEAM suite of standards is used or referenced in multiple planning schemes policies.

[j] The quantitative target is comparison to a BREEAM benchmark, which is unique to the BREEAM tool.

[k] Although technically voluntary, the BREEAM suite of standards is used or referenced in multiple planning schemes policies.

[l] Net zero can be attained through offsets. Offsets may be onsite energy generation and/or the purchase of offsets.

[m] Regulatory in the sense that if you are a member of RICS, you must conduct the assessment on projects under their purview.

[n] Prior to 2015, the Code for Sustainable Homes was a mandatory measure in the UK, however following a change in government policy that sought to lower the rules and restrictions on home builders, the code transitioned to a voluntary model.

[o] The planning policy itself is a regulatory measure, but the integration of LCA assessments, EE or EGHG emission reporting/reduction is often voluntary.

addressing EE/EGHG emissions in the building sector are also being championed by the private sector, particularly in the UK, Australia and USA. These efforts are seen in voluntary instruments – such as LEED, Green Star, BREEAM – where the inclusion of EE/EGHG emissions reductions in their respective tools is a signal that they recognise its importance and perceive a willingness in stakeholders to consider EE/EGHG emission reductions as part of certification. However, EE/EGHG emissions reductions are one of several pathways to achieve certification or credits, with the exception of Australia's Green Star where a minimum expectation is required. In the absence of clearly defined targets or mandatory considerations of EE/EGHG emissions, the private sector leads action with ambitious visions set out by the WGBC and GBCA (Adams et al., 2019; Green Building Council of Australia, 2018), research by LendLease and the World Wildlife Fund (Lendlease Building, 2020; Waters et al., 2020), and advocacy work by Architecture 2030 and the Carbon Leadership Forum. However, as many of these actions are not yet policy mechanisms, most do not feature in this analysis.

9. Key challenges moving forward

Reflecting on the policy mechanisms identified, this section discusses the common challenges that have emerged and would require attention in order to progress efforts in EE and EGHG emissions governance. These challenges include defining terminology; methodologies, data and uncertainty; benchmarking, caps and targets; and financial incentives/costs.

9.1. Defining terminology

From the policies analysed, a lack of clarity in the definition of various terminology was observed, providing opportunity for inconsistencies to emerge. These inconsistencies pertain to the boundary as to what constitutes 'embodied' and the metrics that define 'low'. The most fundamental term – embodied – can have varying interpretations if the policy instrument is not explicit in defining which life cycle stages it covers. Moncaster and Symons (2013) noted in their study that embodied may mean cradle-to-gate, cradle-to-grave, or cradle-to-cradle if end-of-life stages are included. It was generally observed that when a specific assessment method was stipulated in a policy, 'embodied' was defined by referencing stages in EN15978. Whereas policy mechanisms that were less specific in their method did not reference a common standard. The inconsistency in defining 'embodied' may limit comparability between assessments and across policy outcomes. Further obscurity was identified in numerous guidelines encouraging reductions via material specification, with multiple mechanisms noting that materials used should be 'low' in EE or EGHG emissions. Consistently, little to no guidance on what constitutes 'low' in that specific context nor any method for validating compliance was provided in these policies. The lack of contextualisation makes it difficult for those implementing this directive and concurrently, difficult to enforce. Moving forward, policymakers need to ensure that terminology in policy mechanisms is clearly defined using common, accepted standards and measurable thresholds.

9.2. Methodologies, data and uncertainty

For those policy mechanisms (voluntary or otherwise) that do require a cradle-to-grave LCA to report or demonstrate EE and/or EGHG emissions reductions, inconsistencies exist due to the variation in calculation methods and/or Life Cycle Inventory (LCI) databases that may be used. Although international standards to guide the LCA process – including the ISO14040 series and the CEN TC350 standards including EN15978 – have been developed and accepted by the sector, inconsistencies and lack of consensus remains in the methodologies used by many stakeholders and in the calculation of EE/EGHG emissions values within LCI databases. These inconsistencies result in a large variability in the assessment of EE and EGHG emissions for buildings, with Säynäjoki et al. (2017) and Crawford (2008) demonstrating that the choice of method – process, input-output, hybrid – may influence an assessment outcome significantly. Although widely discussed in academic literature, the variability of different methods, the subjectivity of the assessor's assumptions, the differences between calculation tools, and the uncertainty that these factors may collectively place on assessment outcomes is often not highlighted in practice. In some cases, a policy's guidance on conducting the LCA itself is sparse, with many only offering information on which third-party calculation tools they deem to be compliant with their model, or information directing assessors to follow international standards for conducting an LCA with locally relevant data. If methodological inconsistencies continue to persist, comparability between assessments and tracking of policy outcomes will remain difficult.

9.3. Benchmarking, caps and targets

Variability in methodologies and data give rise to another issue: the ability to establish benchmarks for EE and EGHG emissions. Benchmarking can inform caps and targets that limit permissible EE or EGHG emissions on a material, assembly, or whole building level. However, the variability of LCA methodologies, LCI databases, and inconsistent use of uncertainty analysis in LCAs, makes it difficult to benchmark performance across different policy mechanisms and geographic regions (De Wolf et al., 2017). In the review, it was identified that several policy mechanisms attempt to overcome these difficulties by demonstrating EE/EGHG emissions reduction using reference buildings as a benchmark or baseline. Verification using a reference building (VURB) is not uncommon in regulatory frameworks for building performance and building codes, as it is useful in accommodating the unique circumstances that each project or site presents. However, the VURB method limits comparability beyond individual projects or LCAs, as the LCA methodology, LCI database, software used, assessor's assumptions, and the objectives of the policy mechanism itself would likely differ. Efforts to establish databases of EE/EGHG emissions benchmarks are underway in some European countries – e.g. Switzerland, Germany, France as discussed by Zizzo et al. (2017) – however, as outlined by Simonen et al. (2017), significant areas of uncertainty exist in database establishment, particularly relating to data, scope, and methodology. Without harmonisation of LCA characteristics, benchmarking efforts will continue to be challenged by these issues.

9.4. Financial incentives and costs

Another challenge to EE/EGHG emissions reduction was the absence of direct or indirect financial incentives. The voluntary nature of several policy mechanisms combined with the perception of increased project costs presents a possible disincentive for stakeholders seeking to engage with EE/EGHG emissions reduction in building projects. Although the specification of low-EE/EGHG emitting products may not result in an increase of total project cost (Giesekam et al., 2016), there remains a perception in industry that such materials introduce an 'uncertainty premium' and are thus more expensive than comparative incumbents (Lendlease Building, 2020). Provision of incentives to compel or induce stakeholders to implement EE/EGHG emission reduction measures might assist in overcoming the perceived higher risk, possible higher financial costs, or low upfront benefit to investors. In the policy mechanisms examined, no evidence of standalone financial incentives for EE/EGHG emission abatement were identified, whether direct (such as monetary support via tax relief, rebates, grants or loans); or indirect (such as administrative and market-based bonuses that may hold a financial reward, including expedited planning approval, or density bonuses/floor-area-ratio (FAR) uplift). In green building practice generally, financial incentives have been cited as a means to overcome barriers to implementation (Darko and Chan, 2017). As such, considering the limited implementation of financial incentives in the contexts studied, offering of incentives may stimulate stakeholders to address EE/EGHG emission reductions.

10. Conclusion and policy implications

The EE and EGHG of buildings are significant and growing contributors to the environmental effects of the building sector. While the focus on mitigating EE and EGHG emissions in this sector has been limited to date, there is increasing interest and action in this area. Governance of EE and EGHG emissions will have an important role to play in global efforts to mitigate the environmental burden of human activity. This study reviewed the EE and EGHG emissions policy mechanisms in-force across four countries – Australia, Canada, USA and the UK – with the aim of identifying signals of change occurring across public and private sectors.

Existing mechanisms were found to range from voluntary instruments (incl. ratings and certifications) to mandatory regulatory measures, each varying in scale, scope and prescribed targets. The review assessed the intensity of existing mechanisms in relation to scope and targets and found that there was a lack of enforceable regulations in mandatory building codes. Mandatory mechanisms tended to focus on smaller subjective targets, such as encouraging the use of low EE/GHG emissions materials, with more stringent and quantitative requirements tending to occur at a municipal, city or state level. Voluntary mechanisms tended to be more rigorous with more clearly defined targets and detail. Much of this was found to be driven by private sector investment and innovation. Common signals of change occurring in the public sector were centred on mandatory reporting to build an evidence base and leadership by example. This has the potential to stimulate further behavioural change in the private sector.

The review identified a range of challenges that currently exist in the development and implementation of EE and EGHG emissions governance. These included a lack of clarity in the definition of terminology used in policy mechanisms targeting EE/EGHG emissions reduction, inconsistent methodologies and data for EE/EGHG emissions quantification, incomparable benchmarks and targets, and an absence of financial incentives.

We propose a range of recommendations for future progress in the governance of EE/EGHG emissions. Although these recommendations originate from the analysis of the four countries examined in this study, their applicability can be extended to other developed economies that demonstrate similar methods of building procurement, governance structures, level of private sector participation, and maturity of policies targeting EE/EGHG emissions reduction. The following recommendations are less relevant to contexts where EE/EGHG emissions-related policy is further advanced (e.g., Europe – see Zizzo et al., 2017) or where multi-level governance and/or private sector participation in green building strategies is less developed.

From the analysis, short-term recommendations include:

- *Elemental caps as part of building regulations* – national building codes may specify limits to EE/EGHG emissions for specific building elements (such as super-structure, finishes etc.);
- *Mandatory reductions of EE/EGHG emissions in voluntary instruments via LCA* – including ambitious targets set for achieving certification;
- *Mandatory LCA reporting in building regulations* – to demonstrate compliance with regulatory targets, compare project performance and establish nationally relevant databases of building LCAs that may be used for benchmark creation. This action must be accompanied by the remedying of methodological inconsistencies in EE/EGHG emissions calculation and reporting (see below); and
- *Requirements for EE/EGHG emissions mitigation via material selection embedded in statutory planning documentation* – a requirement for the selection of low EE/EGHG emitting materials or materials with a high recycled content or recyclability potential to be reported, documented and rigorously assessed.

Potential longer-term solutions include:

- *Remedying of methodological inconsistencies, including standardisation of calculating and reporting of EE/EGHG emissions* – use of robust, comprehensive, consistent EE/EGHG emissions quantification techniques, based on agreed, standardised parameters and definitions of terminology, improving comparability between analyses, benchmarks and targets;
- *Whole building targets/caps as part of building regulations* – establishing benchmarks and targets for EE/EGHG emissions performance for different building typologies;
- *Diversity and network of policies across governance type and level of jurisdiction* – establishing a range of policy mechanisms to address the diverse range of contexts and compliance routes; and
- *National EPD and co-efficient databases* – accessible, transparent, and consistent data for quantifying EE and EGHG emissions.

In addition to these higher-level policy-related mechanisms, significant reductions in EE and EGHG emissions within the building sector will not be possible without practical, project-based solutions. Development and specification of materials and products aimed at reducing the EE and EGHG emissions of buildings across their lifetime will be needed, along with education, increased awareness, behavioural change, and improvements to design, construction practices and waste management.

Support for the above recommendations would also be enhanced if stakeholders adopted a systems perspective to EE/EGHG emissions governance that considers the contribution of broader environmental policies and efforts in allied sectors. While this review has not considered policies targeted at reducing EE/EGHG emissions that may exist in related sectors, such as manufacturing or mining, these will affect the EE/EGHG emissions intensity of and ability to reduce EE/EGHG emissions within the building sector due to their closely connected supply chains. For example, a shift to a more renewable, low emissions fuel mix in the mining or manufacturing sector may significantly reduce the EGHG emissions associated with construction materials. As such, policies focusing on reducing EE/EGHG emissions associated with the building sector must be part of a coordinated, multi-sector response to EE/EGHG emissions governance and consider mechanisms that may be applicable across the broader economy.

In conclusion, this study has revealed that although some signals of change in the consideration of building-related EE and EGHG emissions exist in the four major economies examined, further effort from the building sector, allied industries, and policy stakeholders is needed. Greater policy attention that encompasses ambitious targets/caps, data transparency, a consistent methodological approach, multi-sector participation, and a diversity of policy mechanisms is urgently required. This is particularly critical in the context of delivering zero energy/emissions buildings and global efforts to address climate change. Realisation of these aims can only be achieved with concurrent attention to operational energy and EE/EGHG emissions, and via a coordinated policy approach that encompasses all levels of governance.

CRediT authorship contribution statement

Katie Skillington: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Robert H. Crawford:** Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Georgia Warren-Myers:** Conceptualization, Data curation, Methodology, Writing – review & editing. **Kathryn Davidson:** Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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Appendix A. Supplementary data

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