

Article

Policy Mapping for Net-Zero-Carbon Buildings: Insights from Leading Countries

An Le ¹, Navodana Rodrigo ², Niluka Domingo ^{1,*} and Sepani Senaratne ³

¹ School of Built Environment, Massey University, Auckland 0632, New Zealand; a.lethihoai@massey.ac.nz

² School of Architecture and Civil Engineering, The University of Adelaide, Adelaide, SA 5000, Australia; navodana.rodrigo@adelaide.edu.au

³ Centre for Smart Modern Construction, School of Engineering, Design and Built Environment, Western Sydney University, Parramatta, NSW 2116, Australia; s.senaratne@westernsydney.edu.au

* Correspondence: n.d.domingo@massey.ac.nz

Abstract: The construction industry is a key contributor to greenhouse gas emissions, with buildings alone accounting for 39% of the global energy-related carbon emissions. Global carbon emissions from building operations increased by 5% in 2021 compared to 2020. However, the United Nations signed the Paris Climate Agreement in 2015 with global leaders, setting a limit to temperature increases below 2.0 °C or 1.5 °C. To achieve this goal, countries have established net-zero targets to reach carbon neutrality by mid-century. However, while some countries are making significant progress, others lag behind. Therefore, this study focuses on evaluating the actions taken by countries toward carbon neutrality, and on developing a policy roadmap for the construction industry to meet the net-zero-carbon commitments. This research adopted a systematic document review, including document analysis. The evaluation of countries' practices towards achieving net-zero targets reveals both similarities and differences. The policy maps developed can be customised for decarbonising a country's overall construction industry and building sector. This study provides insights for research, practice, and society, emphasising the importance of achieving net-zero targets through the implementation of policies, roadmaps, plans, and strategies.

Keywords: carbon neutrality; climate change; net-zero building; net-zero targets; net-zero policies



Citation: Le, A.; Rodrigo, N.; Domingo, N.; Senaratne, S. Policy Mapping for Net-Zero-Carbon Buildings: Insights from Leading Countries. *Buildings* **2023**, *13*, 2766. <https://doi.org/10.3390/buildings13112766>

Academic Editor: Baojie He

Received: 27 September 2023

Revised: 18 October 2023

Accepted: 27 October 2023

Published: 1 November 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The construction industry is one of the major contributors to global greenhouse gas emissions [1]. According to a World Green Building Council report in 2019, 39% of global energy-related carbon emissions result from buildings, of which 28% are operational emissions and the remaining 11% are embodied emissions [2]. In 2021, the global carbon emissions from building operations indicated an increase of 5% compared to 2020 [3]. The global average temperature is proportionate to the cumulative carbon emissions released into the atmosphere [4]. In 2015, the United Nations Paris Climate Agreement set a limit to maintain temperature increases below 2 °C or 1.5 °C, which was agreed to by global leaders [5]. Nearly 90% of the countries have updated their Nationally Determined Contributions (NDCs) under the Paris Agreement International Energy Agency (IEA) [6]. As a result, various countries have set net-zero targets to achieve net-zero emissions by mid-century. These countries submit national climate action plans, identified as NDCs [7]. Each successive NDC requires reflection on an increasingly higher degree of ambition compared to the previously submitted version.

According to the IPCC (2018), “net zero emissions are achieved when anthropogenic emissions of Greenhouse Gases (GHGs) to the atmosphere are balanced by anthropogenic removals over a specified period”. A country can achieve net zero by reducing GHG emissions and/or ensuring that any ongoing emissions are balanced by removals. Achieving real-zero emissions is more important than achieving net-zero emissions alone. Some

fossil fuel companies and industries tend to implement offsetting and carbon capturing and storing mechanisms. These do not result in actual emission reductions and provide a temporary solution. Hence, a more permanent solution is to reduce the overall GHG emissions and achieve real zero by 2050. According to the IEA (2023), in comparison to the 2022 level, declines of 80% emissions for advanced economies and 60% for emerging and developing economies are expected by 2035 [6].

There are different terminologies used by various countries when discussing net-zero-emission targets. It is noted that several terms, such as net-zero carbon, net-zero emissions, and net-zero GHGs, are used interchangeably [8]. For example, countries like the US, Canada, and Australia discuss reducing GHG emissions to achieve net-zero-emission targets. The US and Canada have specifically considered steps and actions to reduce CO₂ as well as non-CO₂ GHG emissions. Looking at the actions taken, it is evident that many countries are determined to reduce their operational carbon emissions to achieve net-zero targets; however, reductions in embodied carbon emissions also play a vital role [9]. Australia's Green Building Council introduced a roadmap that requires all new buildings from 2020 onwards to reduce their embodied carbon by 10%, and they will be incentivised for selecting carbon-neutral products and services, and for offsetting their embodied carbon and other emissions [10].

Various countries have developed various strategies and policies to achieve the globally accepted net-zero emissions by 2050. Reviewing some of the countries' policies and the steps followed to achieve net-zero targets revealed that there are similarities as well as differences among them. Some countries are well ahead in implementing the net-zero targets and plans, leading them to be closer to the target, while some are far behind. Hence, this paper is aimed at developing a policy map for the construction industry for delivering on net-zero-carbon commitments. The aim was accomplished by achieving the following objectives: (1) an exploration of the current status of selected countries in achieving net-zero targets; (2) a review of their policies, strategies, and actions introduced to achieve net-zero targets; (3) the performance of a cross comparison between the countries; and (4) introducing a policy map to guide authorities to shape their net-zero-carbon-related instruments.

This paper consists of five sections. Section 1 identifies the research problem, aim, and objectives of this research. The methodological approach adopted in this research is presented in Section 2. Section 3 presents the key findings of this study, while a detailed discussion, including the cross comparison and proposed policy map, is presented in Section 4. The conclusions and future research directions are discussed in Section 5.

2. Materials and Methods

This research employs a document analysis aimed at mapping relevant policies at the national/government level for the construction industry for delivering on net-zero-carbon commitments. Document analysis is a systematic procedure for reviewing or evaluating documents in which data can be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge [11]. Furthermore, document analysis provides a means of tracking change and development [12]; hence, it was chosen to track the development of the net-zero-carbon policies in the countries. The research design is outlined in Figure 1.

Step 1: Selection of the countries that have legislated commitments to meet carbon neutrality goals by 2050.

In this step, the authors checked the Climate Action Tracker website and the United Nation Environment Programme website until June 2023, to state the list of countries with legally binding agreements for net-zero carbon by 2050. To date, over 110 countries have pledged to reach net-zero emissions by 2050, but not all of them have put this into law or policies. The selected countries were then filtered by various criteria, such as the availability of details, advancement in implementing and taking actions, including strategies roadmaps, and the existence of a climate change act (or the equivalent) with the ambition of reaching carbon neutrality by 2050. The list then was cross-checked with a report of the net-zero-

emission legislation around the world, which was prepared by the staff of the Global Legal Research Directorate of the US Government [13]. The countries that have legislated commitments to meet carbon neutrality goals by 2050 include EU states (eight members), the UK, Canada, the US, South Korea, Japan, Singapore, Australia, and New Zealand, as illustrated in Figure 1. The UK, six European countries, the US, Canada, Australia, New Zealand, Singapore, and South Korea were shortlisted based on the access to their data. Some countries, such as Japan and Spain, satisfied the criteria, but their documents were not in English, so they were excluded. Unfortunately, non-African countries and some top carbon emitters, such as China and India, were not on the list;

Step 2: The gathering of documents from the countries' official climate change websites. Firstly, all documents relevant to national climate change plans were gathered. These included climate change acts, short-term and long-term carbon reduction targets, national emission reduction plans, and national monitoring frameworks. Then, policies and regulations for the building sector, such as whole-life-carbon assessment frameworks for buildings and national and local schemes for energy efficiency, were gathered to develop the data set for the analysis in the next steps;

Step 3: The document analysis in this study followed the steps suggested in [12], which involve skimming, reading, and interpretation. This iterative process combines elements of content analysis and thematic analysis. The content analysis involved organising information into categories to find any records setting out how each declaration was progressing, and the thematic analysis focused more on the reviewing of the data towards the identification of the themes. The aim was to address two themes: first, the level of coherence of the government delivery, and second, how this was being translated into actions for net-zero-carbon buildings;

Step 4: An evaluation of the findings and the proposal of a policy map for net-zero-carbon buildings. At this step, the findings were evaluated against the other sources of information, such as reports of non-government organisations about the net-zero-carbon progress. The findings were also cross-checked at different levels, such as the national level, local-government level, and non-government level, to draw a whole picture of the net-zero-carbon progress of each country. The findings then were used to establish a policy map framework for net-zero carbon, which can be used as a reference for other countries who have not yet legislated the net-zero-carbon goals.

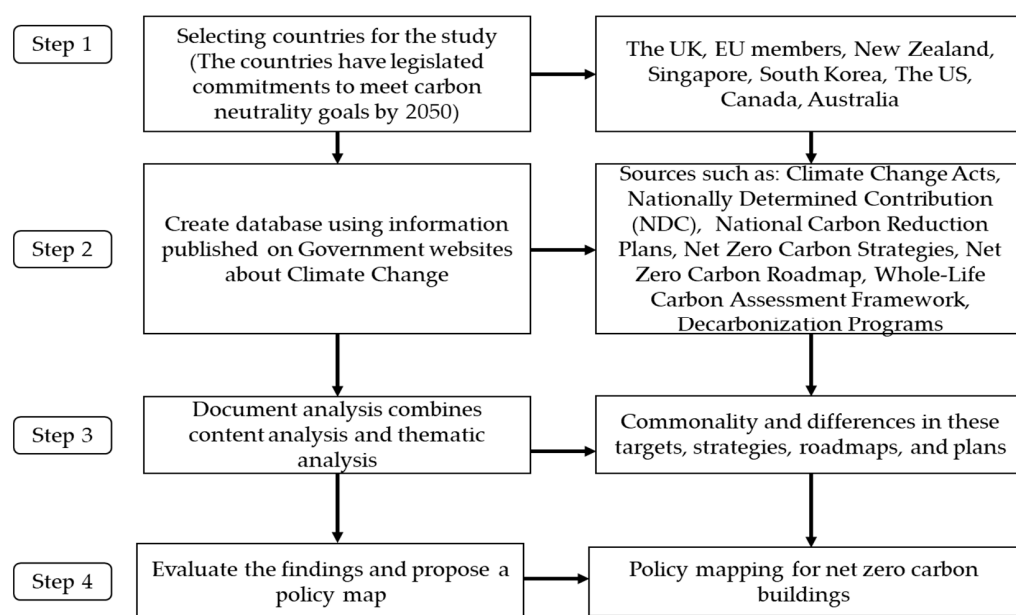


Figure 1. Research design.

3. Results

This section presents the findings related to various countries' net-zero targets and the policies, strategies, and actions taken to achieve them. The desktop analysis started by reviewing the countries' climate change acts as an overall national effort and mandatory approach to achieving the net-zero-carbon targets, and then it trickled down to policies of the building sector and local governments and the voluntary approaches of non-government organisations in the countries to review the overall application and implementation of their national policies, as well as the monitoring system in each country.

3.1. The United Kingdom

At the national level, the UK introduced the Climate Change Act in 2008 to set a comprehensive framework for climate change mitigation and adaptation across the country, which was the first of its kind in the world. The act includes a requirement for the government to develop a National Adaptation Programme (NAP) to manage the effects of unavoidable climate change. Each NAP sets out key actions that the government and others will take to adapt to climate change over five years. The act also sets out five emission reduction targets to reduce greenhouse gas emissions by 80% by 2050, compared to 1990 levels, that the UK must comply with legally. In 2019, the government adopted the sixth carbon target to cut emissions by 78% by 2035. This new target is the first carbon budget, setting the United Kingdom on the path to the net-zero goal by 2050.

At the sector level, in 2022, the UK government published the "Net Zero Strategy: Build Back Greener", which sets out policies and proposals for decarbonising all sectors of the UK economy to meet the targets by 2050 [14]. The strategy also introduced the Ten Point Plan for a green industrial revolution focusing on supporting green jobs and accelerating the path to net zero by 2050. The UK Net Zero Strategy sets out high-level, essential activity across the sectors to 2035. The key priorities and their milestones and interventions for the building sector are summarised in Figure 2.

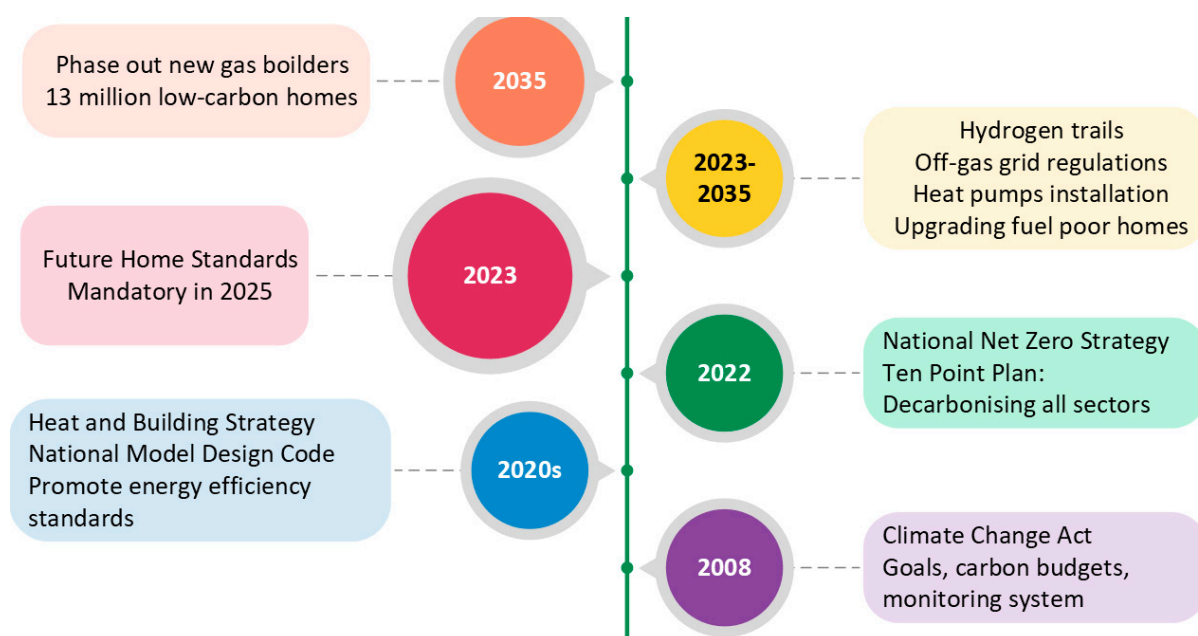


Figure 2. Action decarbonisation plan in building sector by 2035 in UK.

Regarding operational-carbon-emission reduction, in 2021, the UK government published the Heat and Buildings Strategy because heating and powering buildings accounts for 30% of the UK's total energy usage; thus, an energy efficiency strategy for the residential market will play a vital role in the UK's efforts to reach net-zero carbon emissions [15].

When it comes to new builds (later than 2023), the Future Homes Standard (FHS) [16] has been issued, and, from 2025 onwards, compliance with it will become mandatory for new homes and extensions. Its aim is to ensure that new homes built from 2025 will produce 75–80% less carbon emissions than homes built under the current building regulations. Regarding embodied-carbon reduction, the BS EN 15978 standard “Sustainability of construction works: Assessment of environmental performance of buildings calculation method” was identified as the accepted industry-leading standard for measuring and reporting the embodied-carbon impacts of buildings in the UK [17]. To decarbonise the construction of new buildings, low-carbon materials need to be selected. The government published the National Model Design Code in July 2021, providing guidance on the selection of materials and construction techniques for improving efficiency and reducing the environmental impacts of the materials used in construction.

Local authorities in the UK are recognised by the central government as key agents in implementing the net-zero-carbon policies in the UK [18]. In June 2023, the government issued “The role of local government in delivering Net Zero” to guide what policy areas are influenced by local authorities to deliver net zero, including implementing and enforcing national regulations and policies, carrying out statutory duties, such as planning, developing, and delivering heat network connections, and piloting low-carbon heating and energy efficiency measures. For example, local governments can bid for funding from the central government (total budget of GBP 2 billion) to deliver energy efficiency measures for existing buildings through the Green Home Grant Local Authority Delivery (LAD) Scheme and Home Upgrade Grant to fund energy efficiency and clean heat measures for social housing, low-income households, and low-energy-performance homes in their areas by 2035 [19].

In parallel with the government efforts, non-government organisations are supporting the net-zero-carbon goals in the UK by providing guidance and a framework for delivering net zero. In 2021, the UK Green Building Council introduced the Net Zero Whole Life Carbon Roadmap, providing general guidance on the pathway to net-zero carbon by 2050 [20]. The roadmap focuses on collaboration and stakeholder engagement at all stages to meet the net-zero targets. Additional guidance available includes the Royal Institution of Chartered Surveyors (RICS) Professional Statement on Whole Life Carbon, which provides a useful guide to the practical implementation of the BS EN 15978 principles. It sets out technical details and calculation requirements for whole-life-carbon assessment to be adopted across UK industry, but it is not mandatory [21]. In terms of monitoring the net-zero progress, the Climate Change Act established the Climate Change Committee (CCC), an independent statutory body, to monitor the progress in reducing carbon emissions and achieving carbon budgets and targets using the mitigation monitoring framework and the adaptation monitoring framework [22]. Annually, the committee publishes an independent assessment of the progress towards the carbon budgets, and based on the assessment results, it provides recommendations for the relevant stakeholders to ensure that the targets will be met.

3.2. European Countries

The European Commission is committed to making Europe the first climate-neutral continent by 2050. To make this objective legally binding, the commission forced the European Climate Law in 2021 with the key milestones in Figure 3. The law sets out long-term goals in the European Green Deal with key actions to make Europe climate-neutral by 2050, and the commission later set a new, more ambitious net greenhouse gas emission reduction target of at least –55% by 2030, compared to 1990 levels [23]. The commission established the EU Emissions Trading System (ETS) in 2005, the world’s first international emission-trading system, to achieve the Kyoto emission targets, and it is now in phase 4 (2021–2030) to achieve the Paris Agreement targets. The EU ETS aims to set a cap on how much carbon emissions can be emitted within one calendar year. EU companies need to have a European Emission Allowance (EUA) or buy these permits, which can be traded [24].

The law also sets out the monitoring mechanism to track the progress of the implementation of EU climate legislation. Member states report on the progress made in implementing their energy and climate policies.

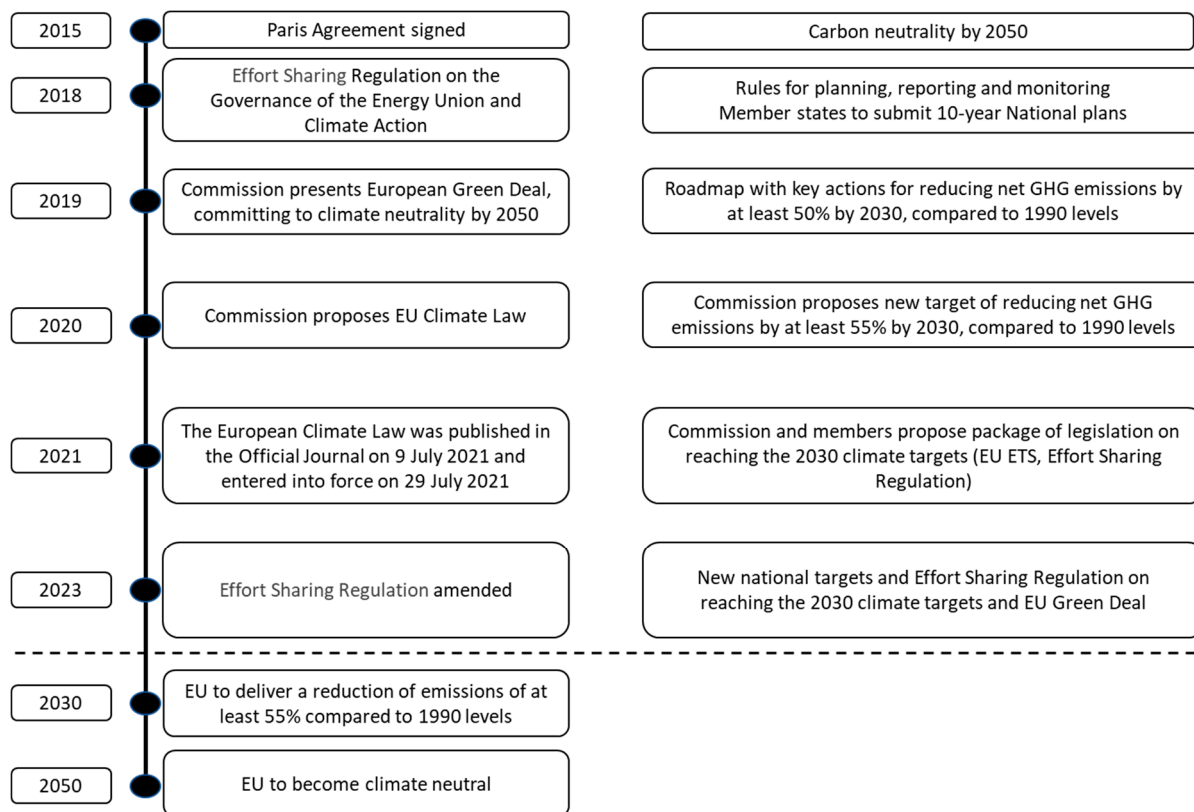


Figure 3. EU key steps to becoming carbon-neutral by 2050.

To ensure that the EU targets are met, each member state is required to draft a 10-year National Energy and Climate Plan (NECP), setting out their actions and plans to reach their national targets (the Effort Sharing Regulation), including the binding national targets. The EU legislation applies to all members, but some countries regulated their climate change policies before 2021, and they are ahead compared to other EU countries. For example, in Finland, the new Climate Change Act entered into force in 2022 from the Climate Change Act 2015, which set emission reduction targets for 2030, 2040, and 2050 and laid down the target of carbon neutrality in 2035. Sweden introduced a climate policy framework with a climate change act in 2017, which sets the goal of carbon neutrality by 2045, while the German government also set a 2045 net-zero target in law in June 2021. Both France and the Netherlands brought 2050 carbon neutrality into law in 2019 with France's Climate Change and Resilience Act and the Dutch Climate Act.

The built environment has a significant impact on the reduction in emissions in Europe because much of Europe's building stock is old and inefficient. Therefore, the EU Commission has launched various strategies and policies for the building sector to drive full decarbonisation. For example, the Circular Economy Principles for Building Designs was issued in 2020 to inform and support construction actors with principles for the circular design of buildings to improve sustainability, optimise the material used, and reduce the environment impact [25]. Additionally, the Construction Products Regulation (CPR) was initially proposed in 2016 and was revised in 2022 to address construction products' sustainability, including potential recycled content requirements for certain construction products [26]. Although the CPR is still in the second round of the public consultation process, Belgium, France, and Italy have mandated their Environmental Product Declarations (EPDs) [27]. Other countries, such as Denmark, Finland, Sweden,

France, and Norway, regulate requirements on the calculation of the building whole-life carbon for new building projects, and most of the countries have established product databases to support environmental-impact assessment nationally. For instance, The Danish Building Act 2018 sets whole-life carbon emissions for new buildings, encompassing both operational and embodied emissions from 2023 onwards [28]. In Finland, the new building act 2023 sets the whole-life-carbon assessment methodology with databases, intending to facilitate whole-life-carbon accounting and regulation in 2025 [29]. France's new building regulation (RE2020) aims to reduce the climate impact of new buildings by integrating enforced energy efficiency requirements and whole-life-carbon assessments. The regulation sets a maximum GHG energy consumption starting in 2022 [30].

In further guidance on how EU, national, and regional policy makers can decarbonise the built environment, the World Green Building Council has launched an EU Policy Whole Life Carbon Roadmap for climate-neutral buildings and constructions by 2050. The roadmap recommends the multi-level governance approach to ensure collaboration between the industry actors to fully tackle building emissions from the whole supply chain, including the construction and demolition sectors [27]. Each member state may also have non-government organisations to support its national implementation of net-zero-carbon policy through voluntary certification schemes, such as BREEAM and RICS.

3.3. The United States

In 2021, the US introduced a long-term strategy to achieve net-zero greenhouse gas (GHG) emissions by 2050. Though the US had introduced an act on energy policy in 2005, it did not involve discussions on or requirements for achieving net-zero emissions (United States Congress, 2005, [31]). This act covered energy-related matters for products and buildings, while discussing ways to reduce GHG emissions. However, there was no indication of targets to achieve net zero. Although there were established NDCs in line with Article 4 of the Paris Agreement focusing on reducing the net GHG emissions of the United States by 50–52 percent below 2005 levels by 2030 [32], it was the long-term strategy that introduced achieving net-zero targets by 2050. According to the United States Department of State and the United States Executive Office of the President (2021), the current emission reduction pathways to achieving 2050 net-zero emissions in the US are as follows [33]:

- Decarbonising electricity by shifting to renewables and other types of emission-free power;
- Using energy more efficiently to provide the same services, for example, through better insulation, advanced heat pumps for space and water heating, and efficient computers and electronics that can reduce annual energy bills;
- Not only introducing clean energy, including clean electricity, but also including low-carbon fuels and clean hydrogen. For example, electric motors in vehicles are approximately three times more efficient than internal-combustion engines, and electric heat pumps are up to three times more efficient than heating with natural gas or electric resistance;
- Reducing non-CO₂ GHG emissions. For example, the US is implementing comprehensive actions to reduce methane by including new standards for landfills and oil and gas operations, as well as major investments to remediate abandoned coal, oil, and gas mines and wells;
- Removing CO₂ from the atmosphere via, for example, (1) nature-based approaches that rely on natural carbon sinks related to land and ocean, by expanding or enhancing conservation, restoration, sustainable management, and other similar activities, and (2) various technologies and processes that directly capture CO₂ from the atmosphere and store it.

The US building sector currently accounts for about three-quarters of the US electricity sales. Since 2005, the commercial building square footage has increased by more than 25%, while the population has grown by more than 10%. Hence, the above-discussed reduction pathways are vital to increase the energy efficiency and decarbonise the electricity sector by implementing trends towards the use of renewable energy sources. Most mechanisms are

for new buildings, while the current building stock will still exist in 2050 due its lengthy lifespan. Hence, the long-term strategy identified three sources of emission reductions that play important roles in building decarbonisation: (1) envelope improvements, (2) improved efficiency in electric end uses, and (3) the efficient electrification of space and water heating (e.g., introducing renewable energy).

The Inflation Reduction Act (IRA) was introduced in 2022, and it has been law since 16 August 2022 [34]. It allocates approximately USD 250 billion in funding towards clean energy, focusing on reducing the nation’s carbon emissions by the end of this decade. In addition, areas such as manufacturing, the environment, transportation, agriculture, and water received about USD 150 billion through a mix of tax incentives, grants, and loan guarantees. The timeline related to actions taken by the US towards decarbonisation is demonstrated in Figure 4.

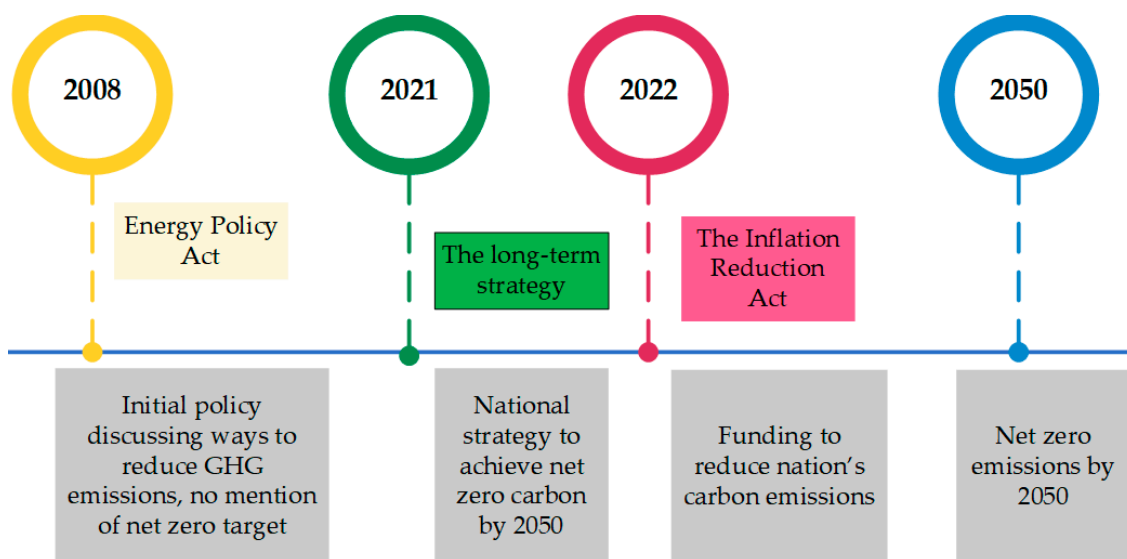


Figure 4. US timeline for decarbonisation by 2050.

At the national level, US actions towards achieving net-zero targets include acts and strategies that have been active since 2021. However, different states within the US took necessary actions soon after the energy policy was introduced in 2005. For example, California legislated Senate Bill 32—the California Global Warming Solutions Act of 2006—to ensure that state-wide GHG emissions are reduced to at least 40 percent below the state-wide GHG emission limit no later than 31 December, 2030. Similarly, Connecticut introduced the Global Warming Solutions Act in 2008, which requires the state to reduce its GHG emissions to at least 10 percent below 1990 levels by 2020, and to at least 80 percent below 2001 levels by 2050. A Memorandum of Understanding has been signed by 11 states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia) to implement the Regional Greenhouse Gas Initiative to cap climate-damaging emissions from power plants. It commenced with 7 states in 2005 and, by 2022, 11 states were in line with this initiative.

3.4. Canada

The Canadian Net-Zero Emissions Accountability Act was introduced on 29 June 2021 [35]. The purpose of this act is to set the national targets for the reduction in GHG emissions and to promote transparency, accountability, and immediate and ambitious action in relation to achieving those targets, in order to achieve net-zero emissions in Canada by 2050 and fulfil Canada’s international commitments with respect to mitigating climate change. The act further establishes targets to be achieved in various years. For example, the minister must set the national GHG emission target for (a) the

2035 milestone year no later than 1 December, 2024; (b) the 2040 milestone year no later than 1 December, 2029; and (c) the 2045 milestone year no later than 1 December, 2034. The act required the minister to establish an emission reduction plan for 2030 within six months of the day on which this act came into force. As a result, the 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy was introduced in 2022.

Building on the actions in Canada's strengthened climate plan (2020), and the Pan-Canadian Framework (2016), the 2030 Emissions Reduction Plan (2022) provides a roadmap to how Canada will meet its enhanced Paris Agreement target to reduce emissions by 40–45% from 2005 levels by 2030 [36]. Progress under the plan will be reviewed in progress reports produced in 2023, 2025, and 2027. Additional targets and plans will be developed for 2035 through to 2050. Canada's Emissions Reduction Plan for 2030 and pathway to 2050 focus on several sectors, such as buildings, electricity, heavy industry, oil and gas, transportation, agriculture, waste, and nature-based solutions. Under each sector, (a) the current sector emissions, (b) what action has been taken so far, and (c) what is next are summarised and presented clearly.

The building sector accounted for 12% of Canada's direct GHG emissions in 2019. Canada has introduced several mechanisms to achieve the GHG emission reduction targets: the Canada Greener Homes Grant, the Green and Inclusive Community Buildings program, Canada Infrastructure Bank's Growth Plan, and Energy Efficiency in Indigenous Housing. As a way forward, the Government of Canada will invest CAD 150 million to develop the Canada Green Building Strategy, which focuses on achieving net zero by 2050. This strategy will focus on (i) developing a Low Carbon Building Materials Innovation Hub to promote the use of lower-carbon construction materials, (ii) developing regulatory standards, (iii) developing a complimentary Climate Adaptation Home Rating Program, (iv) launching a new Net Zero Building Code Acceleration Fund to accelerate the adoption of the national model energy codes, (v) improving the federal capacity and technical support for the development and adoption of net-zero-emission codes, and alterations to the existing buildings codes, and (vi) developing an approach to increase the climate resilience of the built environment. A summary of the above-discussed act, plan, and roadmap is presented, along with their timelines, in Figure 5.

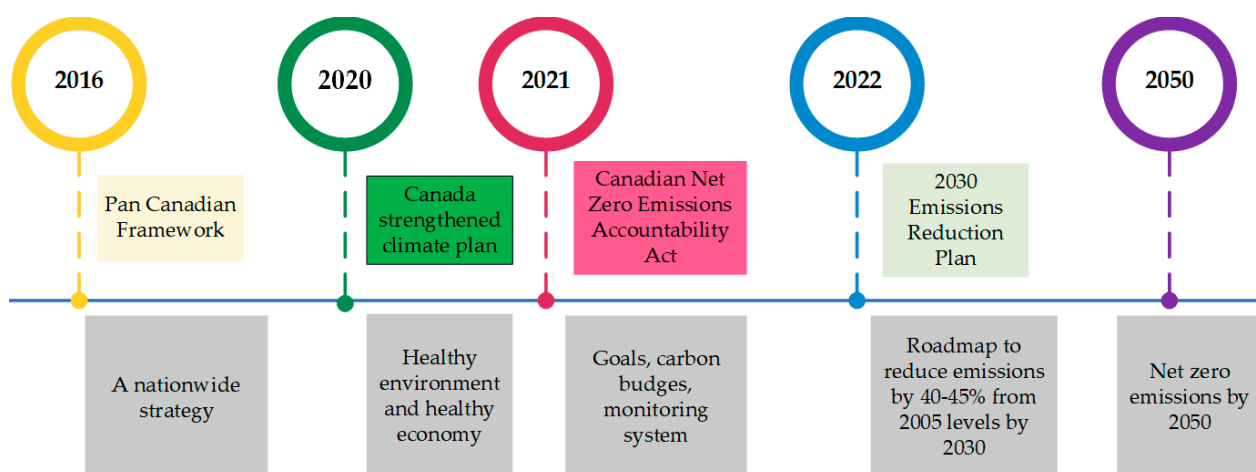


Figure 5. Canada's timeline for decarbonisation by 2050.

3.5. Australia

Australia's Climate Change Act was introduced in September 2022 [37]. Australia's GHG emission reduction targets are (a) to reduce net GHG emissions to 43% below 2005 levels by 2023, and (b) to reduce net GHG emissions to zero by 2050. As per the act, the minister is required to prepare an annual climate change statement indicating the progress made during the year, international developments during the year, climate change policies, the effectiveness and impact of the policies, and any risks to Australia.

The Climate Change Authority can provide advice to the minister on preparing the annual climate change statement, as well as any changes to new /adjusted NDCs of Australia. The minister has to carry out periodic reviews to assess the operation of this act.

The Australian government published its Long-Term Emissions Reduction Plan to achieve net-zero-emission targets by 2050 [38]. It is based on a technology-based approach, while protecting industries, regions, and jobs. In order to achieve net zero by 2050, in comparison with the levels in 2005, Australia had already reduced 20% by 2020 and is ambitious enough to reduce 40% through the Technology Investment Roadmap, the next 15% through global technology trends, 15% through further technology breakthroughs, and the last 10–20% through international and domestic offsets.

Along with this reduction plan, Australia’s Technology Investment Roadmap has been established, which prioritises the technologies of clean hydrogen, ultra-low-cost solar power, energy storage, low-emission steel and aluminium, carbon capture and storage, and soil carbon. These technologies have been adapted at the deployment stage by various sectors, such as the electricity, transport, building, agriculture and land sector, industry, mining, and manufacturing sectors.

For buildings, the critical pathways identified are low-emission electricity, electrification, and energy efficiency, and to achieve them, technologies such as ultra-low-cost solar power, energy storage, and clean hydrogen are considered important. In order to deploy these technologies, the following are important: (1) improving energy efficiency through standards, information, and tools, (2) lowering costs through incentives/finances, and (3) developing workforce skills and supply chains. The Nationwide House Energy Rating Scheme (NatHERS) for residential buildings, National Australian Built Environment Rating System (NABERS) for commercial buildings, and Greenhouse and Energy Minimum Standards Act 2012 for appliances are some of the mechanisms that have been introduced to improve the energy efficiency in buildings [38]. Australia focuses on producing low-emission cement, as concrete is the most widely used material in the construction industry. Hence, the government has invested AUD 75 million for Cooperative Research Centres (CRCs), including the SmartCrete CRC, Building 4.0 CRC, and Low Carbon Living CRC. A summary of the actions taken by Australia for decarbonisation, along with their timelines, are presented in Figure 6.

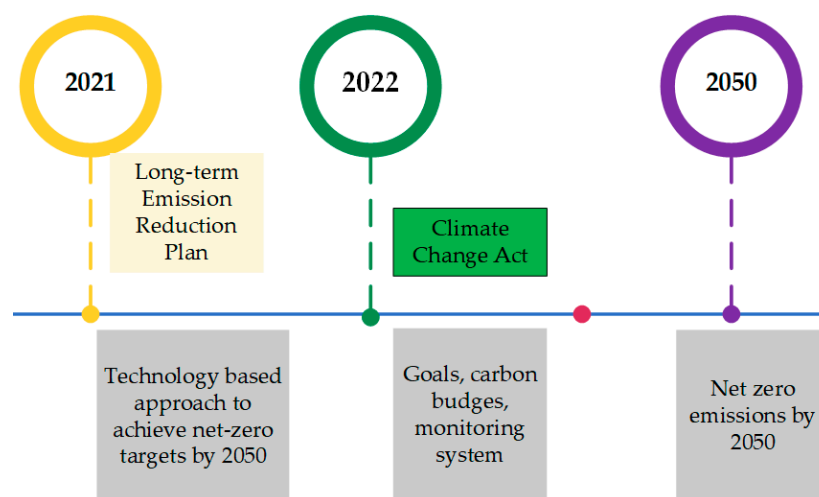


Figure 6. Australia’s timeline for decarbonisation by 2050.

3.6. New Zealand

New Zealand (NZ) has committed to net-zero carbon emissions by 2050. The target was signed into law in November 2019 with the Climate Change Response (Zero Carbon) Amendment Act. The act provides a framework by which NZ can develop and implement climate change policies to achieve net-zero carbon by 2050. The act establishes a system

of emission budgets as the interim targets of the long-term target. Three emission budget periods (2022–2025, 2026–2030, and 2031–2035) were set up in 2020, which set the total carbon emissions allowed in each period [39]. The government published the first national emission reduction plan, which sets out required actions across the economy to help achieve the emission budget in 2022–2025, as shown in Figure 7. The plan contains strategies, policies, and actions across sectors, including transport, energy, and industry, building and construction, agriculture, forestry, waste, and fluorinated gases. The plan also focuses on how parties such as government, local government, industry, business, and communities work together to achieve the goal [40]. The New Zealand Emissions Trading Scheme (NZ ETS) is one of the key policy tools, which puts a monetary price on each tonne of carbon emitted to encourage behavioural change. Under the NZ ETS, businesses that carry out certain activities that lead to emissions must surrender an emission unit for each tonne of pollution that they produce [41]. They can buy these units through government auctions or trade them on the secondary market.

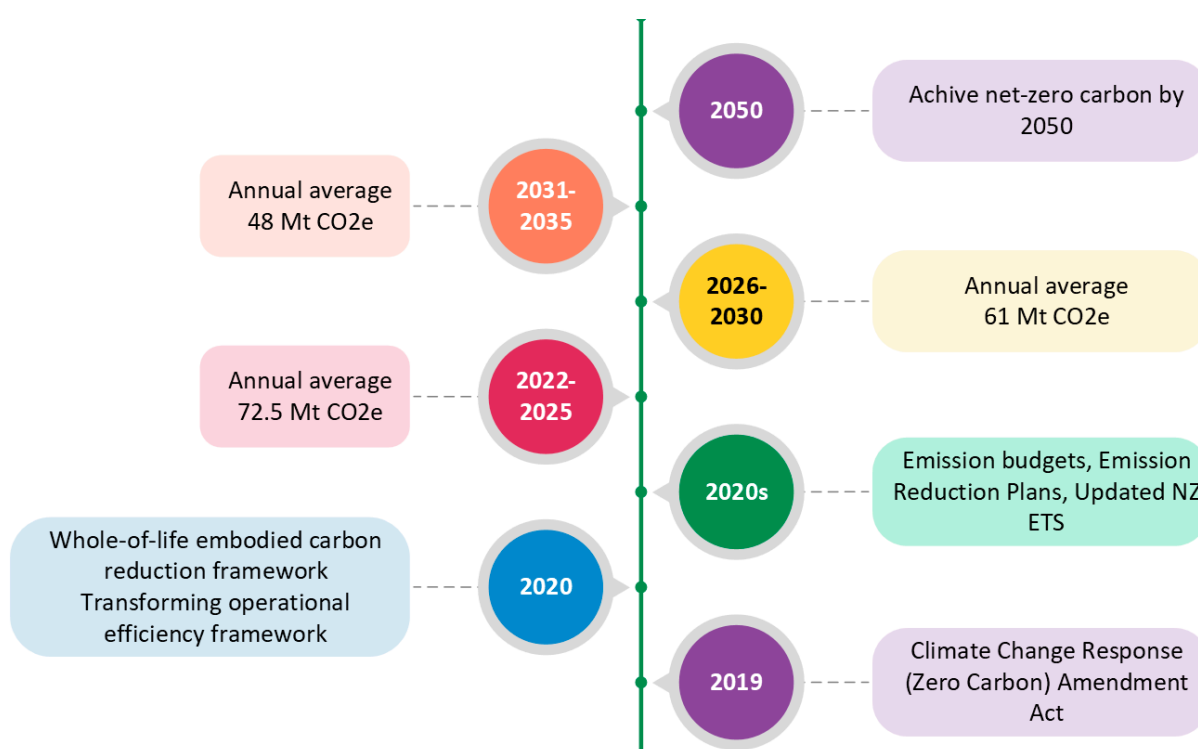


Figure 7. Timeline of net-zero carbon in NZ.

In the Emission Reduction Plan, the government sets out targets for the building sector to play its part in meeting the goal of NZBs by 2050. Chapter 12 in the plan, Building and Construction, sets out the key actions to build healthier homes and more sustainable living [42]. Aligning with the action plan, the Building for Climate Change programme was formed by the government to provide frameworks for reducing embodied and operational carbon emissions and has published a technical methodology for assessing the whole-of-life embodied carbon for new buildings in New Zealand [43]. Under the programme, the whole-of-life embodied-carbon reduction framework and transforming operational efficiency framework to achieve reductions in carbon emissions from the building and construction sector. Regarding the embodied-carbon reductions, buildings will be required to meet a mandatory cap on their whole-of-life embodied carbon to obtain a building consent [44]. In 2022, the government published a technical methodology to facilitate future regulatory changes, incorporating requirements to report and then meet caps on the embodied carbon of buildings in New Zealand [45]. The methodology sets out mandatory and voluntary building elements to be included in the embodied-carbon assessment, the

scope of the lifecycle, data sources, and the form of results. The methodology also sets out the level of data quality used in the embodied-carbon assessment. The highest level of data quality uses the EN 15804 standard [46] for capturing the product embodied carbon in buildings. Regarding the operational-carbon-emission reduction, the government also proposed a mandatory Operational Emissions Cap setting out the total allowable annual emissions per square meter per annum for all new buildings.

These progresses are monitored by the Climate Change Commission. The commission's role is to produce independent advice to the government on the development of policies that will enable New Zealand to achieve a low-emission target [47]. At the local level, the Auckland council, Auckland being the biggest city, has released the Low Carbon Auckland plan towards taking climate actions that enhance the transition to a low-carbon city [48].

3.7. Singapore

Singapore introduced a carbon tax in 2019 through the Carbon Pricing Act and was the first country in Southeast Asia to introduce a carbon price [49]. The Amended Carbon Pricing Act was passed in Parliament in 2022, and it came into force in March 2023, in order to support Singapore in achieving the aim net-zero carbon by 2050. The carbon tax is applied to all industrial facilities with annual direct GHG emissions of 25,000 tonnes of carbon dioxide equivalent (tCO₂e). The initial carbon tax rate was set at SGD 5 per tonne for 2019–2023, and the rate will be raised to SGD 25 per tonne in 2024–2025 and SGD 45 per tonne in 2026–2027, with a view of reaching SGD 50–80 per tonne by 2030 [50]. The government also introduced a measurement, reporting, and verification framework to assist facilities and businesses to fulfil the compliance obligations. Under the act, all industrial facilities need to submit an emissions report, which contains information on their activity data and the quantity of GHG emissions. All report templates are provided by the government agency. The government's strategy to facilitate the low-carbon transition has three thrusts [51]:

- Transformations in industry, economy, and society, focusing on renewable energy, greater energy efficiency, and reducing energy consumption;
- The adoption of advanced low-carbon technologies, accelerating the use of low-carbon hydrogen;
- Effective international collaboration, cooperating through the carbon market, and international and regional climate action.

The government also has a vision to establish Singapore as a carbon service and trading hub. In 2022, the International Emissions Trading Association, the World Bank, and the Singapore government officially launched the Climate Action Data Trust (CAD Trust), which is an open-source system, to link and harmonise information on carbon credits and projects across registries globally [52].

In terms of decarbonising the built environment, the whole-of-government approach has been adopted to implement measures of reducing carbon emissions across various key sectors, including the building sector. The building sector launched the super-low-energy programme, aiming to meet 80% green buildings by 2030 [53]. To achieve the goal, compliance with the respective environmental sustainability standards for both existing and new buildings with the scope and detail of the building characteristics was mandated in 2021 under the Code for Environmental Sustainability of Buildings, 4th Edition. For example, the code is applied to all new buildings and major retrofits to existing buildings with GFAs of 5000 m² or more for planning permission from 1st December 2021 onwards [54]. The building plan needs to include the declaration showing that the building works meet the minimum environmental sustainability standard (MESS) for approval. The industrial facilities have the pathway to meet the MESS from 2025 for new facilities to 2029 for all types of facilities. A summary of the policies related to decarbonising the building sector in Singapore is presented in Figure 8. Similar to other countries, the Singapore Green Building Council (SGBC) plays an important role in enabling sustainability across

the building and construction sector through their members, certification, and outreach programmes. The SGBC provides solutions towards building a greener, healthier built environment [55].

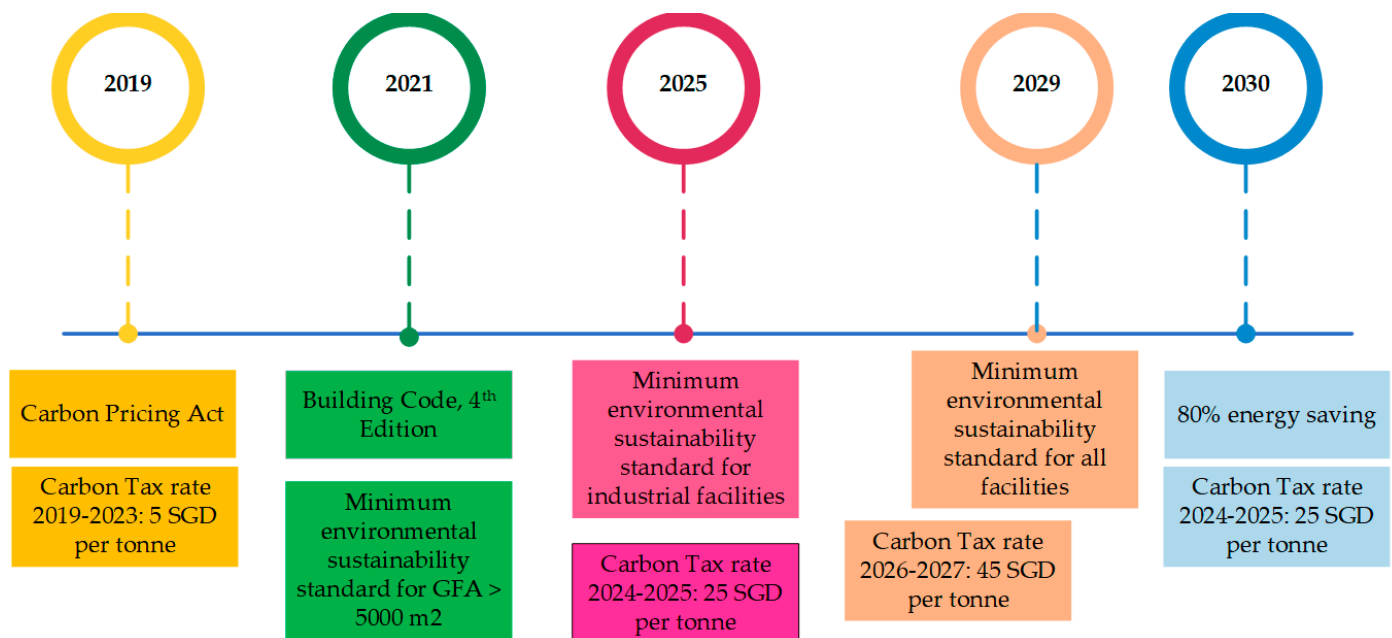


Figure 8. Timeline of net-zero carbon in Singapore.

3.8. South Korea

South Korea legislated the Carbon Neutrality and Green Growth Act for the Climate Change in 2021 to commit to achieving carbon neutrality by 2050. It requires the government to cut its greenhouse gas emissions by 2030 by 40% or more from the 2018 levels and consists of several policy measures to achieve carbon neutrality by 2050 [56]. The government also introduced the National GHG Reduction Roadmap 2030 in 2016, which has been continuously updated since then to ensure it is well aligned with the latest trends in policies and sectoral policy tools to reach the goal [57]. Earlier, the Korea Emissions Trading Scheme (K-ETS) launched in 2015 as East Asia's first nationwide, mandatory ETS to increase incentives to reduce emissions and facilitate low-carbon investment. The scheme has three phases (between 2015 and 2017, between 2018 and 2020, and between 2021 and 2025) covering different sectors and sub-sectors, with an increasing number of sub-sectors, under the scheme [57]. The scheme also allows for the share of auctioning as a carbon pricing system. The government also introduced reduction plans for key six sectors (heat and power, industry, buildings, transportation, waste, and the public sector), in total covering 74% of South Korea's national GHG emissions. The implementation mechanism is at both the national master plan level (20-year plan) and regional master plan level (10-year plan). The government set up the Korean Climate Action Fund to effectively implement policies towards carbon neutrality. The two main policies are the Digital New Deal and Green New Deal, with the investments of the Green New Deal of around USD 4.5 billion for green remodelling to ensure that new and renovated buildings are energy-efficient and constructed from sustainable materials [58].

For the building sector, the 2030 GHG roadmap outlines several policies and measures for reducing emissions from the sector [56]:

- Enhancing the energy efficiency standard: strengthening permit standards for new buildings, and certifying zero-energy buildings;
- Upgrading the existing energy efficiency of buildings and homes: promoting green renovation and green remodelling, and retrofitting public buildings and old buildings;

- Introducing an energy information system and consumption change pattern: identifying new circular business models, and expanding the renewable energy supply by customising an energy-saving service or monitoring system.

A summary of the policies related to decarbonising the building sector in metropolitan Seoul, which accounts for approximately 70% of the carbon emissions from buildings in South Korea, is presented in Figure 9 [59].

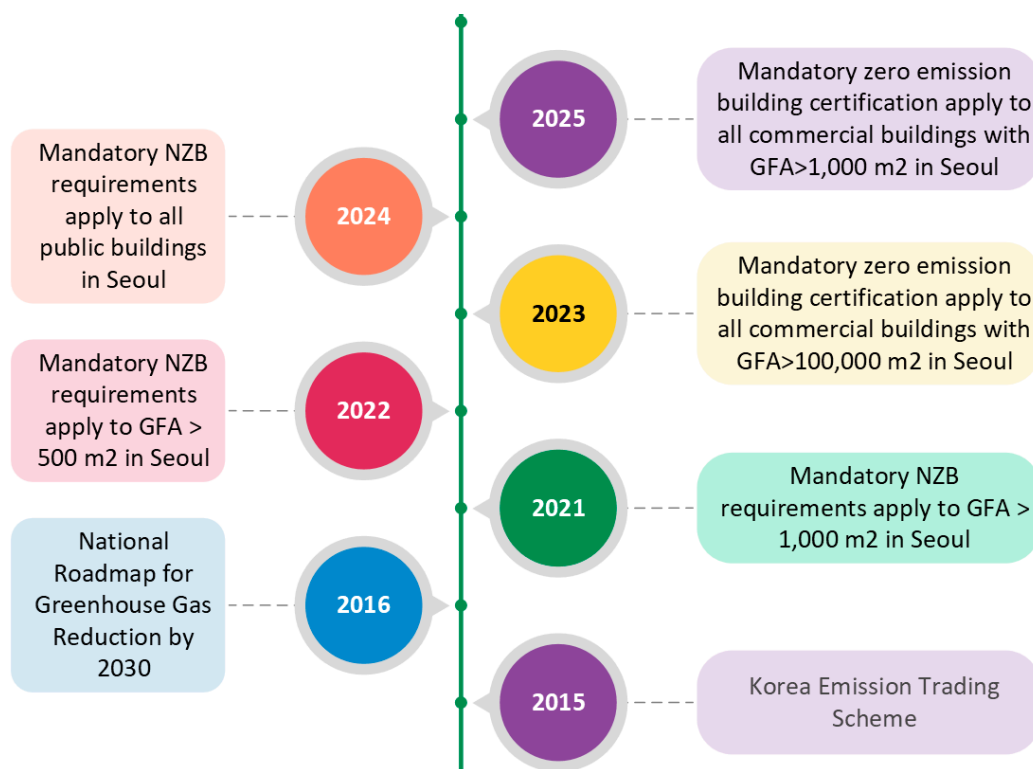


Figure 9. Timeline for decarbonising the building sector in Seoul, South Korea.

4. Discussion and Cross-Country Analysis

4.1. National Policy Mapping

Section 3 presents the results, which help to accomplish the following objectives: (1) to explore the current status of the selected countries in achieving net-zero targets, and (2) to review the policies, strategies, and actions introduced to achieve the net-zero targets. In this section, a cross comparison between the countries is presented to show the commonalities and differences in the net-zero-carbon-related policies among the countries (refer to Figure 10), which help to achieve objective 3 of this study. Finally, policy maps are introduced (refer to Figures 11 and 12) to guide authorities to shape their net-zero-carbon-related instruments both at the national level and the construction industry level, which fulfils objective 4.

Amongst the selected countries, Finland is the leading country, setting out their target of carbon neutrality by 2035, followed by Sweden (2045), and many countries, like Canada, the US, Australia, the UK, and New Zealand, are ambitious to achieve these net-zero targets by 2050. They have identified milestones to be achieved every 5 years to ensure that the final goal is achieved. Thus, acts, policies, actions, strategies, and roadmaps have been introduced to monitor their progress and are reported as per the Paris Agreement. Various countries have taken different approaches and strategies to establish their Nationally Determined Contributions (NDCs) and achieve their net-zero targets by 2050. It is evident that the countries that have introduced acts have taken the necessary steps to ensure that they will be practically achieving their net-zero targets by 2050 or earlier through continuous monitoring and reporting mechanisms. Figure 10 provides a summary of the acts introduced by various countries, along with their timelines.

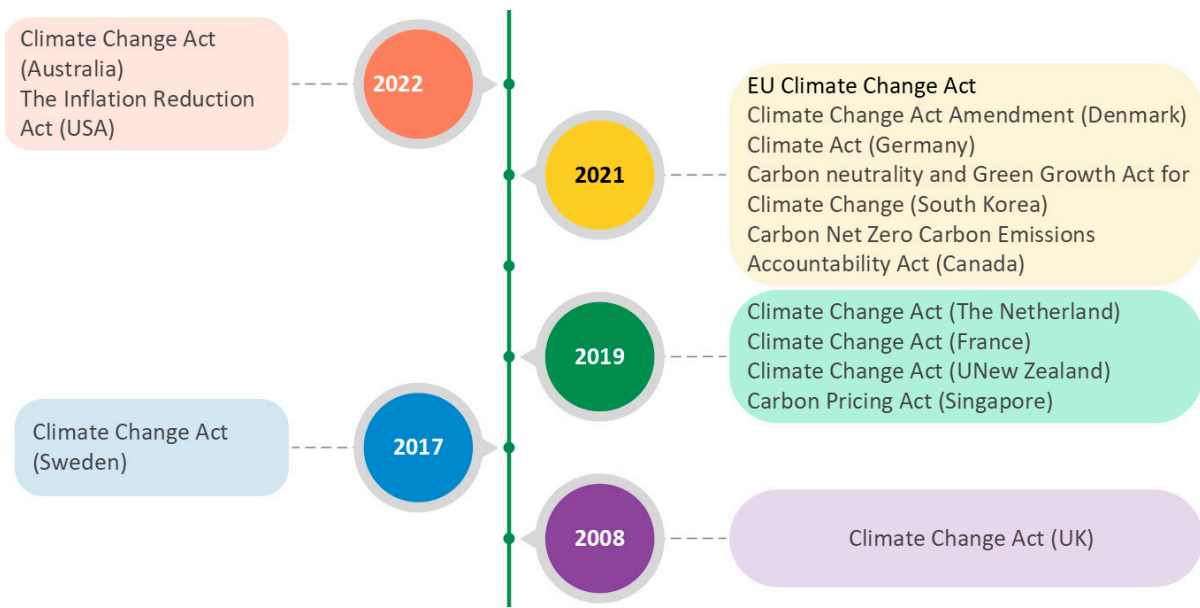


Figure 10. Timeline of the climate change acts in selected countries.

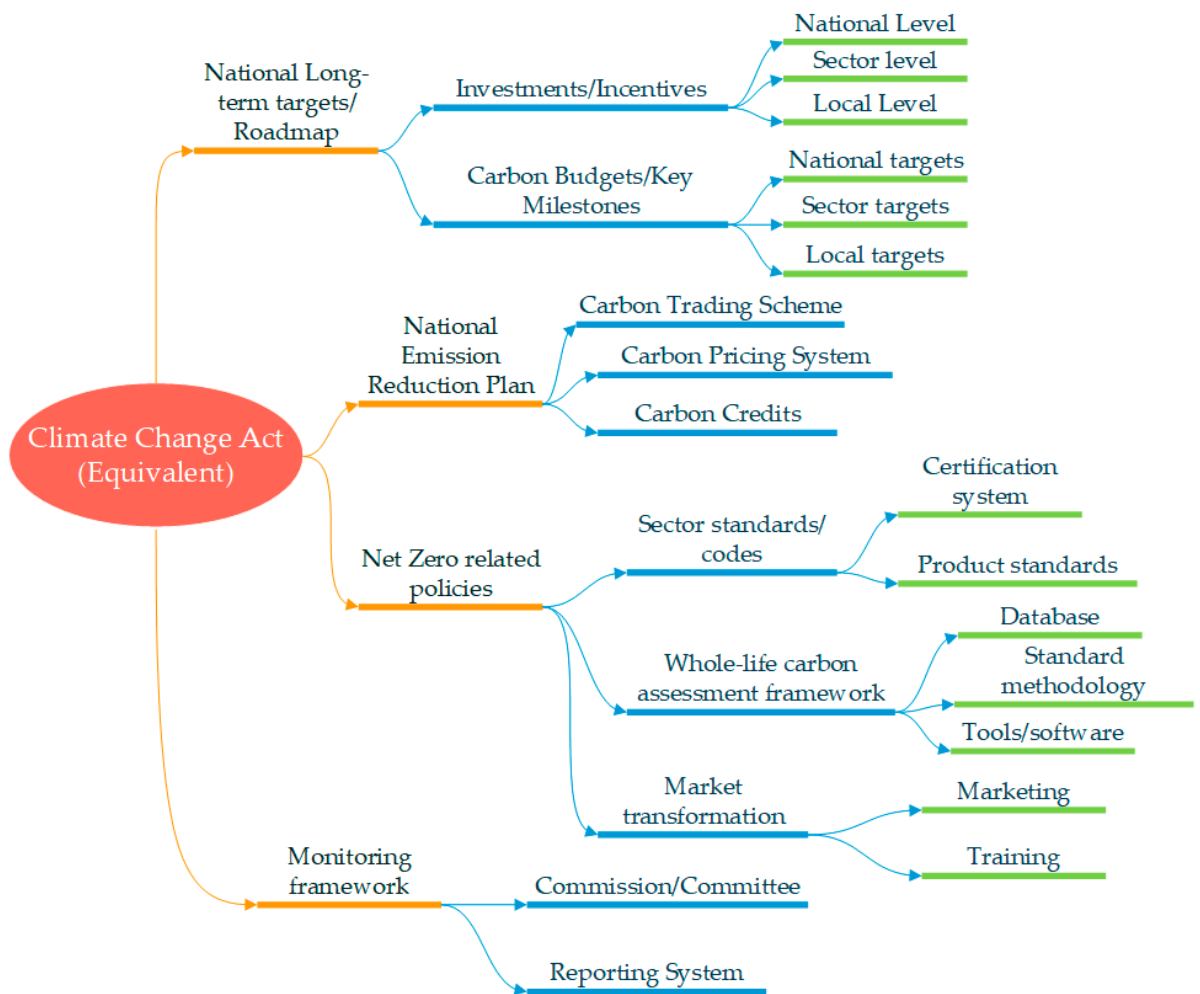


Figure 11. Policy mapping for net-zero carbon.

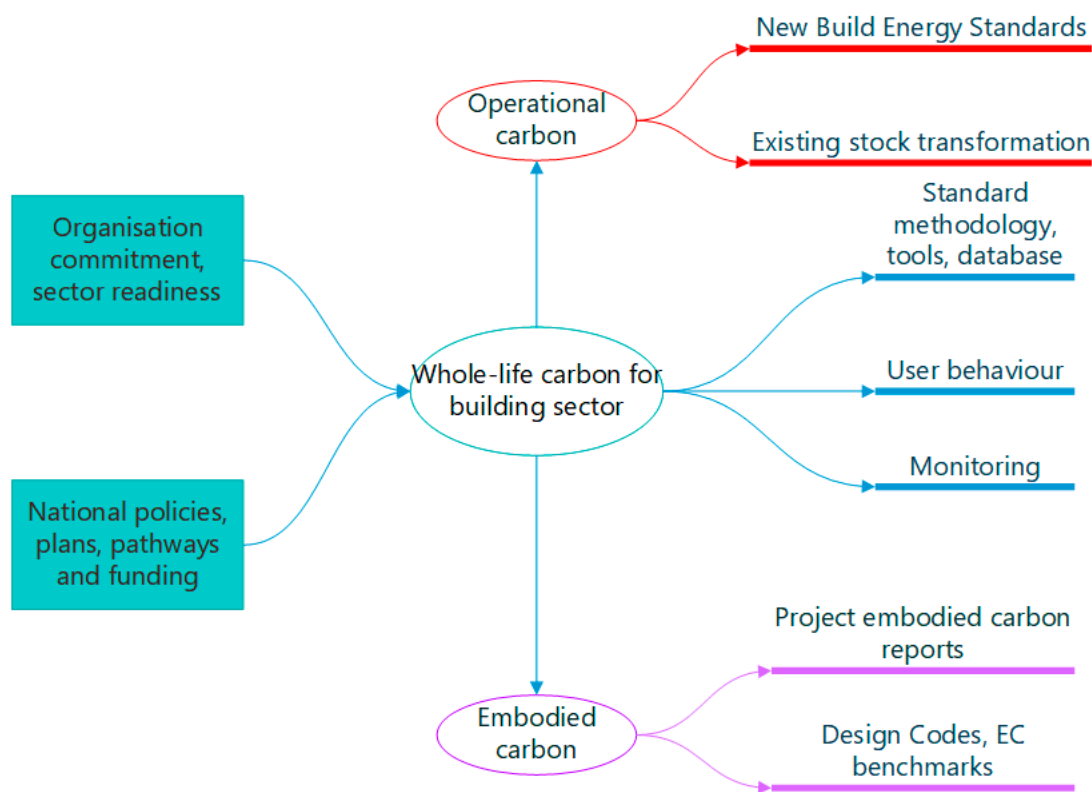


Figure 12. Policy mapping for net-zero buildings.

All the reviewed countries have adopted the top-down approach to promote net-zero carbon. These countries use climate change acts or their equivalents as the basis for the development of climate legislation, setting out the goals, policies, pathways (targets), and monitoring of their implementation. The UK is the first country to put the legal duty to the Climate Change Act in 2008. Most EU countries, the US, Canada, Singapore, South Korea, Australia, and New Zealand set legally binding targets to reduce carbon emissions in the early 2020s. The US introduced “The long-term strategy” and the “Inflation Reduction Act of 2022” to reduce their GHG emissions and achieve the net-zero target by 2050. The “Canadian Net-Zero Emissions Accountability Act (2021)”, “2030 Emissions Reduction Plan (2022)”, “Canada’s strengthened climate plan (2020)”, and the “Pan-Canadian Framework (2016)” all focus on achieving the net-zero target by mid-century. The EU has a similar focus. Denmark introduced the “Climate Change Act amendment in 2021”, while the Netherlands released the “Dutch Climate Act in 2019”. Being one of the countries with the most foresight and highly active in this aspect, the UK introduced the “Climate Change Act in 2008”, and several other actions, such as the “Local Authority Decarbonisation (LAD) Scheme”, “Future Homes Standard (FHS)”, “The Industrial Decarbonisation Strategy”, and the “National Model Design Code”, amongst others. Australia’s “Climate Change Act of 2022” and “Long-Term Emissions Reduction Plan” and “Australia’s Technology Investment Roadmap” will assist them in achieving their net-zero targets by 2050. New Zealand introduced the “Climate Change Response (Zero Carbon) Amendment Act”, “National emissions reduction plan”, and “New Zealand Emissions Trading Scheme (NZ ETS)” to achieve its net-zero targets. Singapore introduced the “Carbon Pricing Act” as well as the “Code for Environmental Sustainability of Buildings” to achieve net-zero carbon by 2050. South Korea legislated the “Carbon Neutrality and Green Growth Act for the Climate Change”, “National GHG Reduction Roadmap 2030 in 2016”, and “Korea Emissions Trading Scheme” in order to achieve carbon neutrality by 2050.

Each country has its own approach and pathway to achieving its carbon neutrality goals, but the key principles are the establishment of national long-term targets/roadmaps,

emission reduction plans, policies/tools, and monitoring frameworks, as summarised in Figure 11.

The countries have set up national long-term targets and roadmaps for different levels. The first level is the government, top level, which usually sets the net-zero-carbon targets, key milestones, and sub-targets, together with the investments and incentives to achieve the targets. These then trickle down to sectors, who legislate the context-specific regulations for the application in the sectors or across sectors. For example, based on the national targets, the building sector sets its targets for decarbonising existing stock and new builds to contribute to the achievement of the country goal. Meanwhile, the local governments play an important role in translating and implementing the national and sector regulations and policies to the communities. Some cities in the selected countries also set out their own net-zero/low-carbon city targets (London, Auckland, Copenhagen). More importantly, the connection between the policies at the national, sector, and local-government levels should be clear and cohesive to ensure the successful delivery of the national net-zero-carbon targets.

Regarding emission reduction plans, most countries use an emissions trading scheme (ETS) (New Zealand, the US, Germany), or a carbon tax (France, Sweden, Finland, Singapore, South Korea, Canada) and a mix of an ETS and carbon tax support (UK), or a carbon-crediting mechanism (South Korea, Australia, Canada) to ensure that they can meet the pre-allocated carbon budget [60]. An ETS establishes a market price for GHG emissions, which allows low-emission companies to sell their extra allowances to larger emitters. Meanwhile, a carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions. There are also other indirect ways to reduce carbon emissions, such as through fuel taxes or product taxes. The selection of the reduction instruments will depend on the national and economic circumstances. Under the acts, the countries develop toolkits, including policies, standards, codes, methodologies, classifications, and tools, to guide manufacturers, suppliers, and users for the implementation of the regulations. For example, in the UK, some standards and codes have been developed to support manufacturers, suppliers, and users to achieve the NZCB goals, such as the BS EN 15978 standard, PAS 2080—Carbon management of infrastructure works, and National Model Code Design 2021. In the EU, the commission proposed a new Ecodesign for Sustainable Products Regulation in 2022 for more environmentally friendly and circular products. In the US, ASHRAE Standard 228 [61] in 2023 set the standard method of evaluating the net-zero net energy and net-zero net carbon building performance. All of the selected countries have introduced the whole-carbon assessment framework as guidance on the pathway to net-zero-carbon targets, but not all of them are mandated. Some governments have introduced standardised national methodologies for embodied-carbon assessment and carbon data sources (Finland, Sweden, New Zealand) to highlight the importance of standardised embodied-carbon data sources and methodologies because various software tools and data sources to carry out embodied-carbon assessments and lifecycle assessments will lead to variations in the assessment results, creating inconsistencies and reducing the comparability of the outputs. Along with the standards and assessment framework, market transformation policies, including behaviour changing, training, and promoting, are critical to the achievement of net-zero-carbon targets. Although the information is limited, research programmes, awareness, and behaviour-changing schemes for net-zero carbon have been found in some countries, such as the environment and zero-carbon research in New Zealand [62], and the energy research partnership in the UK [63].

Last but not least, a monitoring framework and reporting system are critical to assess the effectiveness and monitor the government's progress. Each country in this study has established a committee or commission to monitor the progress made in reducing carbon emissions, and to advise the government to prepare for and adapt to the change. The committees/commissions mainly deal with the following:

- Conducting analyses of climate change policies;
- Reporting progress in achieving the carbon budgets and targets;
- Providing advice on setting and meeting carbon budgets and targets;
- Coordinating stakeholder engagement.

The assessment results show where the country is on the road to net-zero carbon and what actions need to be taken to be on the right track. The submission of the reports are required annually or regularly. The European Commission has established a comprehensive emission monitoring and reporting system that other countries can refer to [64].

The policy mapping illustrated in Figure 11 was checked by cross-referencing the findings in other reports and studies. The findings are aligned with various studies that have performed analyses on the current net-zero-carbon-related policies, long-term targets, and regulations in the countries [13,59,65,66], studies focusing on policies regarding specific aspects, such as embodied carbon, energy, databases, or monitoring frameworks [67–69], and studies identifying barriers to and drivers of carbon neutrality [70–72]. The increasing consideration of reducing carbon emissions across countries and sectors has led to a surge in international, national, and local actions, including initiatives, policies, tools, and schemes. All the actions can be overwhelming for people who seek to understand where to begin, where to look for guidance, or what changes need to be made to achieve the targets. Figure 11 provides a visual presentation of all the actions, which will allow the reader to quickly refer to the information. The limitation of the mapping is that it only considers the “horizontal relationships” of the actions. It does not present the “vertical relationships” amongst the initiatives, policies, or schemes.

4.2. Decarbonising the Building Sector

The building sector is a key sector in the transition to net-zero-carbon economics in all countries, as it is responsible for emissions throughout every single stage of the construction and use cycle, from the manufacture of material through to construction, maintenance, and demolition. Therefore, it is critical to driving change to achieve the net-zero targets and goals. In this study, the governments have established sets of policies in the building sector to progressively reduce carbon emissions and energy consumption in buildings and the construction sector. Figure 12 summaries the policies and actions required for the building sector to reduce carbon emissions and respond to climate change.

There is no doubt that the national policies, plans, and pathways are shaping the decarbonisation of the built environment. Other vital control factors that the decision-makers need to consider is the community awareness and sector readiness. Zhang, Wang [73] argued that the most challenging factors for net-zero energy in the built environment are insufficient education and training and low awareness and consumer acceptance. Other authors have also stated that there is a lack of qualified building design and professional education and training programs for NZCBs [74]. Many other studies have provided evidence that building occupant behaviours are critical to energy efficiency [75,76]. There is an urgent need for a combined effort in social marketing programs and community and professional training to enhance the transition to net-zero-carbon buildings. This aspect is still very limited in the current policies of the countries.

It is inevitable that whole-life-carbon (WLC) assessment, including both embodied-carbon and operational-carbon assessment, is critical to reduce carbon emissions in the building sector, leading to the achievement of net-zero carbon by 2050. Previous studies have developed different frameworks and methods for the assessment of WLC [77–79]. However, the researchers also admitted that WLC assessment is challenging, especially embodied-carbon assessment due to the uncertainty of the variables, such as the databases, methodologies, and tools discussed above. The countries in this study have set out pathways for carbon limits for new buildings, encouraging low-carbon products, and encouraging embodied-carbon reports through building consent, but they are not mandatory yet. The proposals of new-product carbon certification/labelling should be implemented so that users can select materials appropriately. Some countries in this study have already started the application of WLC assessment with public buildings with various targets, such as initial caps, medium caps, and intermediate caps, such as New Zealand, Denmark, Finland, and Switzerland [42,65].

For operational-carbon reduction, all the countries are focused on both new-build energy standards and retrofitting existing poor-energy-performance buildings. Low-income households are primarily considered for retrofitting financial assistance programmes through different schemes, such as short-term (subsidies, vouchers for energy bills), medium-term (subsidies, incentives for the installation of energy-efficiency measures, such as heating and insulation), and long-term (subsidies, incentives, and policies for new technologies, such as hydrogen or grid heating systems) solutions. New home standards have been developed in most of the studied countries but have not been mandated on a large scale. Singapore currently applies the new home standards for projects more than 5000 m² GFA, while the UK and Finland intend to implement the Future Home Standard in 2025, and Sweden plans to make the new home standard mandatory in 2027. More importantly, the technical guidelines and mechanisms to implement the standards should be established firmly to ensure that the right track is followed. Similar to the national level, standard methodologies, tools, databases, and behaviour changing and monitoring systems should be included in the decarbonising the built environment strategy [80,81].

Apart from the policies mapped in Figure 12, other approaches also have been used to contribute to decarbonising the built environment, such as circular-economy principles, smart procurement, and innovation technology. The circular economy is linked to the WLC with the aims of maximising the use of existing material, minimising wastes, and reusing assets, thereby reducing the need for new materials, leading to reduced embodied carbon emissions [82]. The links between the policies of the circular economy and WLC have been promoted in some countries, such as the EU, UK, and NZ [25,83,84]. Meanwhile, modern construction methods, such as the electrification of on-site construction vehicles, increased use of off-site manufacturing, and automation of construction, can reduce the energy consumption on site. Furthermore, technology innovation in construction plays an important role in decarbonising the sector [81]. The application of BIM, digital twins, and drones can help with the collection of carbon data and the creation of a more accurate database system [85]. Meanwhile, public procurement has the potential to be used as a mechanism to reduce greenhouse gas emissions and stimulate action on low-carbon development [86–89]. For example, in the UK, New Zealand, South Korea, and Singapore, the governments have committed themselves to using public procurement to drive demand for low-carbon industrial products. The procurement policies, which mandate the completion of whole-life-carbon assessments, could kick-start the market for low-carbon construction.

5. Conclusions

This study aimed at developing a policy map for the construction industry to deliver on net-zero commitments. A systematic document analysis was carried out to review existing published material and develop the policy map. The selection of the countries was carried out based on the availability of details in English and advancement in the actions taken to achieve the net-zero targets, especially the availability of a climate change act or the equivalent. The UK, European countries, the US, Canada, Australia, New Zealand, Singapore, and South Korea were selected for the study. The actions taken by each of the selected countries introduced by their respective governments to achieve the net-zero targets, including acts, roadmaps, and reduction plans, are presented in this paper.

The paper presents a detailed discussion by evaluating the similarities and differences identified among the countries discussed. Most of the countries are focused on reducing their operational carbon to achieve carbon neutrality by 2050, while some countries have identified the importance of reducing embodied carbon as well. A policy map has been developed considering the actions taken by the countries to achieve the net-zero targets. This policy map includes the key mechanisms, including acts (climate change acts or the equivalent), long-term targets/roadmaps, national emission reduction plans, net-zero policies, and monitoring frameworks. Specific to the building sector, decarbonisation has to focus on whole-life-carbon reduction, including both operational and embodied carbon.

This paper provides a summary of the actions undertaken by countries to achieve net-zero targets, providing an insight for countries that are far behind in achieving carbon neutrality by mid-century. Also, it provides clear implications for research, practice, and society by highlighting the importance of achieving net-zero emissions while establishing and implementing the necessary policies, roadmaps, and plans, among others. Similarly, future research could be undertaken to explore other countries that are lagging behind and identify the decarbonisation strategies and mechanisms that these countries need to establish to achieve carbon neutrality by 2050. It is evident that all countries have a vital role to play in reducing GHG emissions to create a more sustainable environment with improved living conditions for all.

Author Contributions: Conceptualization, N.D. and S.S.; methodology, A.L., N.R., N.D. and S.S.; formal analysis, A.L. and N.R.; data curation, A.L., N.R., N.D. and S.S.; writing—original draft preparation, A.L. and N.R.; writing—review and editing, A.L., N.R., N.D. and S.S.; visualization, N.D. and S.S.; supervision, N.D. and S.S.; project administration, N.D. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data can be shared upon request.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

BREEAM:	Building Research Establishment Environmental Assessment Methodology
GHG:	Greenhouse Gas
NZ:	New Zealand
NZBs:	Net-Zero Buildings
RICS:	Royal Institution of Chartered Surveyors
UK:	United Kingdom
US:	United States
WGBC:	World Green Building Council
WLC:	Whole-Life Carbon

References

1. Akan, M.Ö.A.; Dhavale, D.G.; Sarkis, J. Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. *J. Clean. Prod.* **2017**, *167*, 1195–1207. [[CrossRef](#)]
2. World Green Building Council. *2019 Global Status Report for Buildings and Construction*. 2019. Available online: <https://worldgbc.org/article/2019-global-status-report-for-buildings-and-construction/> (accessed on 24 August 2023).
3. *Annual Report 2022*; UN Environment Programme: Paris, France, 2022.
4. Rogelj, J.; Schaeffer, M.; Meinshausen, M.; Knutti, R.; Alcamo, J.; Riahi, K.; Hare, W. Zero emission targets as long-term global goals for climate protection. *Environ. Res. Lett.* **2015**, *10*, 105007.
5. United Nations. *Paris Agreement*; 2015. Available online: <https://www.un.org/en/climatechange/paris-agreement> (accessed on 24 August 2023).
6. International Energy Agency (IEA). *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach*; IEA: Paris, France, 2023.
7. Rogelj, J.; Geden, O.; Cowie, A.; Reisinger, A. Net-zero emissions targets are vague: Three ways to fix. *Nature* **2021**, *591*, 365–368. [[PubMed](#)]
8. Loveday, J.; Morrison, G.M.; Martin, D.A. Identifying Knowledge and Process Gaps from a Systematic Literature Review of Net-Zero Definitions. *Sustainability* **2022**, *14*, 3057. [[CrossRef](#)]
9. Rodrigo, M.N.N.; Perera, S.; Senaratne, S.; Jin, X. Potential Application of Blockchain Technology for Embodied Carbon Estimating in Construction Supply Chains. *Buildings* **2020**, *10*, 140. [[CrossRef](#)]
10. Green Building Council Australia. *A Carbon Positive Roadmap for Buildings*. Available online: https://gbca-web.s3.amazonaws.com/media/documents/carbon-positive-roadmap-summary-paper-fa-web_onU8cXm.pdf (accessed on 30 July 2023).
11. Corbin, J.; Strauss, A. Qualitative research. In *Techniques and Procedures for Developing Grounded Theory*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2008.
12. Bowen, G.A. Document analysis as a qualitative research method. *Qual. Res. J.* **2009**, *9*, 27–40.
13. US Global Legal Research Directorate. *Net Zero Emissions Legislation around the World*. Available online: <https://tile.loc.gov/storage-services/service/ll/llgldr/2021687417/2021687417.pdf> (accessed on 30 July 2023).

14. The UK Government. *Net Zero Strategy: Build Back Greener*; 2021. Available online: <https://www.gov.uk/government/publications/net-zero-strategy> (accessed on 30 July 2023).
15. The UK Government. *Heat and Building Strategy*; 2021. Available online: <https://www.gov.uk/government/publications/heat-and-buildings-strategy#:~:text=This%20strategy%20sets%20out%20how,to%20net%20zero%20by%202050> (accessed on 30 July 2023).
16. The UK Government. *The Future Home Standards*. 2023. Available online: <https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings> (accessed on 24 August 2023).
17. The UK Government. *Building to Net Zero: Costing Carbon in Construction*. 2022. Available online: <https://committees.parliament.uk/publications/30124/documents/174271/default/> (accessed on 30 July 2023).
18. The UK Government. *The Role of Local Government in Delivering Net Zero*. 2023. Available online: <https://researchbriefings.files.parliament.uk/documents/CDP-2023-0122/CDP-2023-0122.pdf> (accessed on 30 July 2023).
19. The UK Government. *Green Homes Grant Local Authority Delivery (LAD) and Home Upgrade Grant (HUG)*; 2022. Available online: <https://www.gov.uk/government/statistics/green-homes-grant-local-authority-delivery-lad-and-home-upgrade-grant-hug-release-october-2022> (accessed on 30 July 2023).
20. UKGBC. *The Net Zero Whole Life Carbon Roadmap*. Available online: <https://ukgbc.org/our-work/topics/whole-life-carbon-roadmap/> (accessed on 30 July 2023).
21. *Whole Life Carbon Assessment for the Built Environment*; RICS: London, UK, 2017.
22. The UK Climate Change Committee. *CCC Monitoring Framework*. Available online: <https://www.theccc.org.uk/#:~:text=CCC%20Monitoring%20Framework,to%20climate%20risks%20and%20opportunities> (accessed on 30 July 2023).
23. *European Climate Law*; European Commission: Brussels, Belgium, 2021.
24. *EU Emissions Trading System (EU ETS)*; EU Commission: Brussels, Belgium, 2018.
25. *Circular Economy Principles for Buildings Design*; European Commission: Brussels, Belgium, 2020.
26. *Construction Products' Regulation Revision*; European Commission: Brussels, Belgium, 2022.
27. WGBC. *EU Policy Whole Life Carbon Roadmap*. *Clima2022*. 2022. Available online: <https://worldgbc.org/article/eu-policy-whole-life-carbon-roadmap-for-buildings/> (accessed on 30 July 2023).
28. *A Quick Guide for the Construction Industry on the Danish Building Regulations 2018*; Danish Knowledge Center for Energy Savings in Buildings: 2018. Available online: https://byggeriogenergi.dk/media/2202/danishbuildingregulations_2018_energy-requirements.pdf (accessed on 24 August 2023).
29. Finnish Government. *Parliament Adopted Acts that Will Reduce Emissions from Building and Promote Digitalisation*. 2023. Available online: <https://valtioneuvosto.fi/en/-/1410903/parliament-adopted-acts-that-will-reduce-emissions-from-building-and-promote-digitalisation#:~:text=Parliament%20adopted%20the%20new%20Building,improve%20the%20quality%20of%20building> (accessed on 24 August 2023).
30. French Government. *RE2020 Environmental Regulations*. 2020. Available online: <https://www.interregeurope.eu/good-practices/environmental-regulation-2020-re2020> (accessed on 24 August 2023).
31. United States Congress. *Energy Policy Act of 2005*. 2005. Available online: [https://www.congress.gov/bill/109th-congress/housebill/6#:~:text=Energy%20Policy%20Act%20of%202005%20%2D%20Sets%20forth%20an%20energy%20research,electricity%3B%20\(10\)%20energy%20tax](https://www.congress.gov/bill/109th-congress/housebill/6#:~:text=Energy%20Policy%20Act%20of%202005%20%2D%20Sets%20forth%20an%20energy%20research,electricity%3B%20(10)%20energy%20tax) (accessed on 10 October 2023).
32. *The United States of America Nationally Determined in Reducing Greenhouse Gases in the United States: A 2030 Emissions Target Department of Energy*; Department of Energy: Washington, DC, USA, 2021.
33. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*; The US Government: Washington, DC, USA, 2021.
34. The White House. *Building A Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action*; The White House: Washington, DC, USA, 2023.
35. *Canadian Net-Zero Emissions Accountability Act*; Government of Canada: Ottawa, ON, Canada, 2021.
36. *Net-Zero Emissions by 2050*; Government of Canada: Ottawa, ON, Canada, 2023.
37. *Climate Change Bill 2022 and Climate Change (Consequential Amendments) Bill 2022*; Government of Australia: Canberra, Australia, 2022.
38. *Australia's Long-Term Emissions Reduction Plan*; Government of Australia: Canberra, Australia, 2021.
39. New Zealand Government. *Climate Change Response (Zero Carbon) Amendment Act 2019*; 2019. Available online: <https://environment.govt.nz/acts-and-regulations/acts/climate-change-response-amendment-act-2019/> (accessed on 24 August 2023).
40. New Zealand Government. *Towards a Productive, Sustainable and Inclusive Economy: Aotearoa New Zealand's First Emission Reduction Plan*; 2022. Available online: <https://environment.govt.nz/assets/publications/Aotearoa-New-Zealands-first-emissions-reduction-plan.pdf> (accessed on 24 August 2023).
41. New Zealand Government. *New Zealand Emissions Trading Scheme*; 2023. Available online: <https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/ets/> (accessed on 24 August 2023).
42. New Zealand Government. *New Zealand Reduction Plan Chapter 12: Building and Construction*; 2022. Available online: <https://environment.govt.nz/assets/Emissions-reduction-plan-chapter-12-building-and-construction.pdf> (accessed on 24 August 2023).
43. New Zealand Government. *Building for Climate Change*; 2021. Available online: <https://www.mbie.govt.nz/building-and-energy/building/building-for-climate-change/> (accessed on 24 August 2023).

44. New Zealand Government. *Whole-of-Life Embodied Carbon Reduction Framework*; 2020. Available online: <https://www.mbie.govt.nz/dmsdocument/11794-whole-of-life-embodied-carbon-emissions-reduction-framework> (accessed on 24 August 2023).
45. New Zealand Government. *Whole-of-Life Embodied Carbon Assessment: Technical Methodology*; 2022. Available online: <https://www.building.govt.nz/assets/Uploads/getting-started/building-for-climate-change/whole-of-life-embodied-carbon-assessment-technical-methodology.pdf> (accessed on 24 August 2023).
46. British Standards. *BS EN 15804:2012+A2:2019*; 2021. Available online: <https://www.standards.govt.nz/shop/bs-en-158042012-a22019-2/> (accessed on 24 August 2023).
47. New Zealand Government. *Climate Change Commission*; 2023. Available online: <https://www.climatecommission.govt.nz/> (accessed on 24 August 2023).
48. Auckland Council. *Auckland's Climate Plan*; 2020. Available online: <https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/Pages/te-taruke-a-tawhiri-ACP.aspx> (accessed on 24 August 2023).
49. Singapore Government. *Carbon Pricing Act*; 2023. Available online: <https://www.nccs.gov.sg/singapores-climate-action/mitigation-efforts/carbontax/> (accessed on 24 August 2023).
50. Singapore Government. Carbon Tax. Available online: <https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/climate-change/carbon-tax#:~:text=In%20order%20to%20support%20Singapore%20T1%20textquoterights,be%20made%20available%20when%20ready> (accessed on 20 July 2023).
51. Singapore Government. *Singapore's Enhanced Nationally Determined Contribution and Long-Term Low-Emissions Development Strategy*; 2020. Available online: <https://www.nccs.gov.sg/media/press-release/submission-of-singapores-enhanced-nationally-determined-contribution-and-long-term-low-emissions-development-strategy/> (accessed on 24 August 2023).
52. Singapore Government. Climate Action Data Trust (CAD Trust). Available online: <https://climateactiondata.org/> (accessed on 20 July 2023).
53. Singapore Government. *Green Building Master Plan*; 2020. Available online: <https://www1.bca.gov.sg/buildsg/sustainability/green-building-masterplans> (accessed on 24 August 2023).
54. Singapore Government. *Amendments to the Environmental Sustainability Regulations*; 2021. Available online: https://www.corenet.gov.sg/media/2330717/industry-circular_sep-2021_es_r1.pdf (accessed on 24 August 2023).
55. SGBC. *Inspiring a Greener Singapore as a Green Beacon of Asia*; 2023. Available online: <https://www.sgbc.sg/about-us> (accessed on 24 August 2023).
56. South Korea Government. *Climate Change*; 2023. Available online: <https://eng.me.go.kr/eng/web/index.do?menuId=463> (accessed on 24 August 2023).
57. South Korea Government. *Korea's Efforts to Address Climate Change*; 2023. Available online: https://www.mofa.go.kr/eng/wpge/m_5655/contents.do (accessed on 24 August 2023).
58. South Korea Government. *The Korea New Deal*; 2020. Available online: https://climate-laws.org/document/korean-new-deal_a665 (accessed on 24 August 2023).
59. *Regulations from 2023 on Carbon Emissions for New Buildings to Drive ESG Adoption*; Savills: London, UK, 2022.
60. The World Bank. State and Trends of Carbon Pricing 2023. Available online: <https://openknowledge.worldbank.org/entities/publication/58f2a409-9bb7-4ee6-899d-be47835c838f> (accessed on 20 July 2023).
61. ANSI/ASHRAE Standard 228-2023. 2023. Available online: <https://www.ashrae.org/technical-resources/bookstore/ansi-ashrae-standard-228-standard-method-of-evaluating-zero-net-energy-and-zero-net-carbon-building-performance> (accessed on 24 August 2023).
62. BRANZ. Environment and Zero-Carbon Research. Available online: <https://www.branz.co.nz/environment-zero-carbon-research/> (accessed on 20 July 2023).
63. *Behaviour Change and Reaching Net Zero*; The UK Government: London, UK, 2021.
64. *Emissions Monitoring & Reporting*; EU Commission: Brussels, Belgium, 2023.
65. *Construction Carbon Regulations in Europe: Review & Best Practices*; OneClick LCA: Helsinki, Finland, 2022.
66. Yu, F.; Feng, W.; Leng, J.; Wang, Y.; Bai, Y. Review of the US Policies, Codes, and Standards of Zero-Carbon Buildings. *Buildings* **2022**, *12*, 2060.
67. Forde, J.; Osmani, M.; Morton, C. An investigation into zero-carbon planning policy for new-build housing. *Energy Policy* **2021**, *159*, 112656. [[CrossRef](#)]
68. D'Agostino, D.; Tzeiranaki, S.T.; Zangheri, P.; Bertoldi, P. Data on nearly zero energy buildings (NZEBS) projects and best practices in Europe. *Data Brief* **2021**, *39*, 107641. [[CrossRef](#)]
69. Hart, J.; D'Amico, B.; Pomponi, F. Whole-life embodied carbon in multistorey buildings: Steel, concrete and timber structures. *J. Ind. Ecol.* **2021**, *25*, 403–418. [[CrossRef](#)]
70. Ohene, E.; Chan, A.P.C.; Darko, A. Prioritizing barriers and developing mitigation strategies toward net-zero carbon building sector. *Build. Environ.* **2022**, *223*, 109437. [[CrossRef](#)]
71. Ohene, E.; Chan, A.P.; Darko, A. Review of global research advances towards net-zero emissions buildings. *Energy Build.* **2022**, *266*, 112142. [[CrossRef](#)]
72. Tirelli, D.; Besana, D. Moving toward net zero carbon buildings to face Global Warming: A narrative review. *Buildings* **2023**, *13*, 684. [[CrossRef](#)]

73. Zhang, S.; Wang, K.; Xu, W.; Iyer-Raniga, U.; Athienitis, A.; Ge, H.; Cho, D.w.; Feng, W.; Okumiya, M.; Yoon, G. Policy recommendations for the zero energy building promotion towards carbon neutral in Asia-Pacific Region. *Energy Policy* **2021**, *159*, 112661. [CrossRef]
74. Liu, G.; Li, X.; Tan, Y.; Zhang, G. Building green retrofit in China: Policies, barriers and recommendations. *Energy Policy* **2020**, *139*, 111356. [CrossRef]
75. Paone, A.; Bacher, J.-P. The impact of building occupant behavior on energy efficiency and methods to influence it: A review of the state of the art. *Energies* **2018**, *11*, 953. [CrossRef]
76. Weerasinghe, A.S.; Rotimi, J.O.B.; Rasheed, E.O. Modelling of underlying social psychological effects on occupant energy-related behaviours. *Build. Environ.* **2023**, *231*, 110055. [CrossRef]
77. Kuittinen, M. Method for the Whole Life Carbon Assessment of Buildings. 2019. Available online: <https://julkaisut.valtioneuvosto.fi/handle/10024/161796> (accessed on 24 August 2023).
78. Futas, N.; Rajput, K.; Schiano-Phan, R. Cradle to Cradle and Whole-Life Carbon assessment—Barriers and opportunities towards a circular economic building sector. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019.
79. Zimmermann, R.K.; Andersen, C.M.E.; Kanafani, K.; Birgisdottir, H. *Whole Life Carbon Assessment of 60 Buildings: Possibilities to Develop Benchmark Values for LCA of Buildings*. 2021. Available online: <https://vbn.aau.dk/en/publications/whole-life-carbon-assessment-of-60-buildings-possibilities-to-dev> (accessed on 24 August 2023).
80. Clarke, J.; Littlewood, J.R.; Karani, G. Developing Tools to Enable the UK Construction Industry to Adopt the Active Building Concept for Net Zero Carbon Buildings. *Buildings* **2023**, *13*, 304. [CrossRef]
81. Wilkinson, S.; Ghosh, S.; Quintana Vigiola, G. Decarbonising Australian housing: Policy, problems, profiles of current stock and progress. *Hous. Financ. Int.* **2021**, *XXXVI*, 40–49.
82. Vuuren, T.J.v. *Mapping the Landscape of Decarbonising Construction*; University of Cambridge: Cambridge, UK, 2022.
83. New Zealand Government. *Circular Economy and Bioeconomy Strategy*; 2023. Available online: <https://www.mbie.govt.nz/business-and-employment/economic-development/circular-economy-and-bioeconomy-strategy/> (accessed on 24 August 2023).
84. Charnley, F. *The Circular Economy: Towards Net Zero*; UK Research and Innovation: London, UK, 2022.
85. Shen, K.; Ding, L.; Wang, C.C. Development of a Framework to Support Whole-Life-Cycle Net-Zero-Carbon Buildings through Integration of Building Information Modelling and Digital Twins. *Buildings* **2022**, *12*, 1747. [CrossRef]
86. Kuittinen, M.; le Roux, S. Procurement Criteria for Low-Carbon Building. Available online: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/160737/EG_2017_Producement%20criteria.pdf?sequence=1&isAllowis=y (accessed on 24 August 2023).
87. Jalaei, F.; Masoudi, R.; Guest, G. A framework for specifying low-carbon construction materials in government procurement: A case study for concrete in a new building investment. *J. Clean. Prod.* **2022**, *345*, 131056. [CrossRef]
88. Sparks, D.G. Exploring Public Procurement as a Mechanism for Transitioning to Low-Carbon Buildings. Doctoral Dissertation, Queensland University of Technology, Brisbane, Australia, 2018.
89. He, P.; Bui, T.T.P.; Shahzad, W.; Wilkinson, S.; Domingo, N. Towards Effective Implementation of Carbon Reduction Strategies in Construction Procurement: A Case Study of New Zealand. *Buildings* **2022**, *12*, 1570. [CrossRef]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.