Leadership of EU member States in building carbon footprint regulations and their role in promoting circular building design

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Abstract. European countries are working towards carbon neutrality of the building sector. Regulations and initiatives, including the European Green Deal, aim at promoting circular buildings and low carbon design. Therefore, this paper seeks to investigate the role of legislation in paving the way towards achieving the circularity of buildings design and construction. A systematic literature review is conducted to compare the current regulations in different EU member states that address carbon emissions and life cycle thinking to achieve circularity. The study aims to demonstrate how the low-carbon emissions regulations in leading countries can lead to making the construction sector's circularity. The research is focused on five leading EU member states in low carbon buildings, including Denmark, Finland, France, the Netherlands, and Sweden. The study compares the performance indicators, metrics, and target thresholds found in the five selected states' regulations and examines them across a circularity assessment framework developed earlier by the authors. This paper provides insights on low emission building regulations state-of-the-art. Moreover, it offers a better understanding of the relationship between low-carbon emissions regulations and building circularity. The article explains the role of the legislative landscape and its impact on circular building design practices. Key findings from the study will assist the European Commission to identify policy options to support the uptake of "Circular economy principles for buildings design" in European, national and local policies

1. Introduction

On Oct 7 2020, the European Parliament voted to update the EU's climate target for 2030 [1]. The vote is backing the decision of a 60% reduction in greenhouse gas emissions by 2030 compared to the emissions of 1990. Collectively, buildings in the EU are responsible for 36% of greenhouse gas emissions, mainly stemming from construction, operational emissions (heating, cooling, ventilation, and power), renovation, and demolition [2]. Therefore, the building sector has a vital role in responding to the climate emergency, and addressing upfront carbon is a critical and urgent focus [3]. Bringing embodied carbon upfront and the fast energy transition towards carbon neutrality is crucial. Simultaneously, the energy and carbon transition need to be following the principles of the circular economy. The European Commission is looking forward to promoting circular economy principles for buildings' design. However, coupling the carbon neutrality target with the building circularity target is challenging, and there are no established national and local policies within Europe.

Therefore, this study aims to assist the European Commission in identifying policies that support the uptake of "Circular Buildings "and "Carbon Neutral Buildings "to increase buildings' service life and ease the use of secondary materials improve resource efficiency throughout the building lifecycle. The main research questions are: To what extent are carbon neutrality and circularity concepts integrated into mandatory building regulations, and who are the EU leading countries in this regard?

The paper provides an overview of leading EU member states that integrated both concepts in their regulations based on a systematic literature review and expert interviews with relevant circularity and carbon neutrality experts. The research is focused on five leading EU member states in low carbon buildings, including Denmark, Finland, France, the Netherlands, and Sweden. Key findings from the study will be used as an input to define the policies to be implemented in other EU member states. The paper is the audience is mainly scientists and actors involved buildings value chain, namely building engineers, architects, contractors, and builders, including renovators, manufacturers of construction products, and government/regulators, including national, regional, and local municipal authorities.

2. Literature Review

In this section, we focus on two major concepts that are the focus of this study, namely, carbon neutrality and circularity. Both concepts are chosen because they are the most effective concepts that can reduce greenhouse gas emissions and other environmental impacts, such as end-of-life waste.

Several terms are used to express the carbon emissions associated with building construction that depend on the carbon neutrality period's emissions calculation method. From a life cycle thinking approach [4] and based on EN 15978 [5], there are two definitions associated with building carbon neutrality: namely the embodied carbon emissions stage (A1-5) and the carbon emissions in use stage (B1-7) (see Figure 1). Since the European Energy Performance of Buildings Directive (EPBD) introduction, building regulations requirements evolved until we reached nearly zero and net-zero energy building [6,7]. Several studies tried to associate energy neutrality targets with building materials emissions; however, very few countries addressed carbon emissions in the EPBD before the use stage [8]. The Paris agreement emphasized the need for deep decarbonization of the building stock beyond the energy neutrality concept. Carbon emissions from building materials have a significant climate impact. The Incorporated Carbon Review reports indicate that even by de-carbonizing the energy grid, buildings can continue to be a substantial generator of emissions in the long term due to the carbon incorporated in the materials used in emerging countries [9]. Research shows that energy efficiency has decreased fossil energy use and increased renewables; however, the embodied carbon increased [9,10]. The introduction of the Environmental Product Declaration in 2018 for building materials in most EU member states was the first step that was taken to quantify the carbon emissions of buildings [11]. However, the use of EPDs is voluntary in most countries without any emission thresholds. Figure 2 illustrates the European countries driving the demand for EPDs based on the Once Click Life Cycle Analysis (LCA) database.

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MNR	MNR	MNR	MND	MND	MND	MND	X	MND	X

Figure 1. Description of the stages during the buildings' life, according to EN 15978.

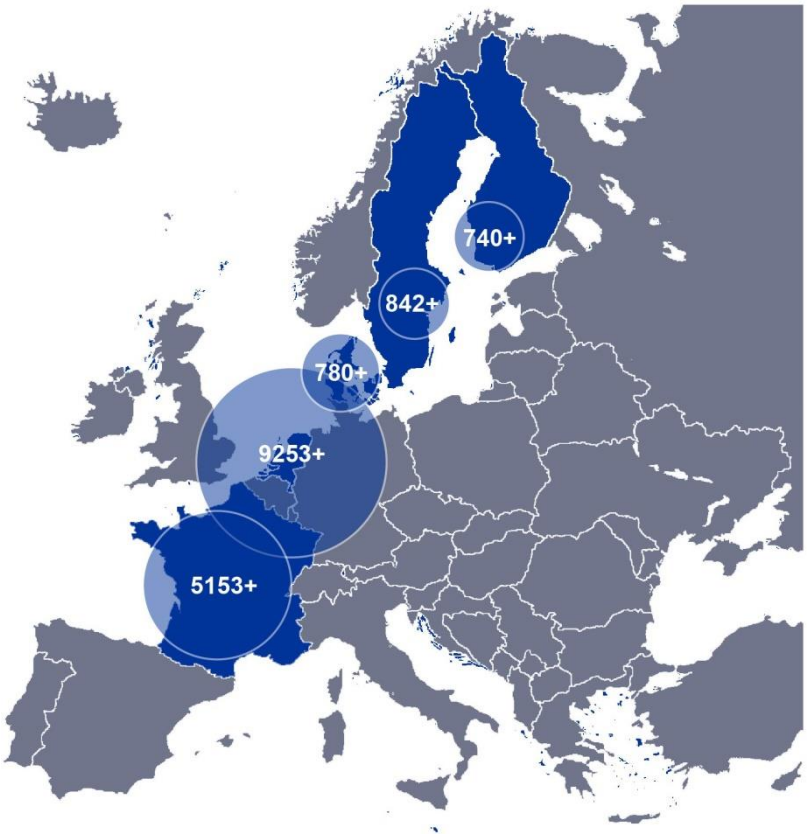

Figure 2. Numbers of European products EPDs available in One Click LCA's database.

The second concept investigated in this study is building circularity. A circular building seeks the highest efficiency in managing combined resources and the maximum generation of renewable resources. It seeks positive development to increase the carrying capacity to reverse ecological footprint [12]. Sustaining the material's value is the key to circular material use, and ways to harvest this value are at the center of the circular buildings. Few studies addressed the concept and definition of building circularity [13]. But several authors like Durmisevic and [14] Antonini et al. [15] tried to develop reliable indicators for reversibility and durability features of circular buildings. Cottafav et al. and Attia addressed the gap between embodied impacts and architectural and structural design aspects [12,16]. The difficulty of defining or building a circular building based on circularity indicators and technologies to enhance buildings' service life while closing material loops is still challenging [17].

Despite the evolution of the carbon neutrality and circular design of building, both concepts are not included in most European building standards and public procurements. The legislative requirements and compliance for circular construction remain excluded from most sustainable business models despite the climate urgency and resource scarcity. This literature review confirms the need to explore both concepts in national and local regulations to collect further insights on the leadership of EU member States in building carbon footprint regulations and their role in promoting circular building design.

3. Methodology

This study conducted a systematic literature review and expert interviews to build legislation concerning the two following concepts: circularity and carbon neutrality. Among the 27 EU member countries, a screening has been done to reduce the study countries to five: Denmark, Finland, France, the Netherlands, and Sweden. The inclusion criteria focused on countries that require a life cycle assessment and environmental product declarations (EPD) for building materials during building permit issuing.

The inclusion criteria included mandatory requirements or measures to increase the service life of buildings. The exclusion criteria included regulations that define circularity on an urban or territorial scale. The search focuses mainly on carbon neutrality and circularity on building scales. Carbon criteria and circularity were assessed based on the building design criteria for circular buildings developed by Attia et al. [12, 17, and 18]. The selected countries were the only countries fulfilling all criteria.

The study is mostly qualitative, based on the literature review of collected documents and articles and short interviews with experts representing the five countries. The principle of "triangulation" for findings was used. Three sources have been used, primary sources, secondary sources, and experts' knowledge to confirm results. Primary sources are official documents such as scientific articles and regulations; secondary sources are constituted by a literature review in the form of articles and magazines, eventually, and experts' short interviews. The texts concerning regulations have been carefully analyzed and summarized in tables and described in the results section. Thus, through this approach, the five countries' relevant regulations and publications are selectively reviewed.

4. Results

The results of the literature review and expert interviews are presented in the section. Firstly, an overall comparative analysis is presented. Secondly, a detailed analysis and facts check is provided individually for each country. Table 1 lists the most important publications that we selected during our review. Each publication is shortly described concerning building carbon footprint and circularity. Moreover, Table 2 compares the five investigated countries against a carbon neutrality and circularity checklist developed by Attia [17].

Table 1. Key publications in the five countries related to carbon neutrality and circularity criteria.

Country	Reference	Description
Denmark	(19,20)	- Denmark outperforms EU28 on most selected resource and innovation metrics, such as share of renewable energy or Eco-innovation index. The improved utilization of assets and better use of waste or by-products as a resource has a potential value as a resource; however, recycled materials should be used in higher-value cycles, such as reuse or remanufacturing [19]. - Denmark has ambitious climate neutrality targets. Energy taxes stand in getting the electrification that can ensure a socio-economically beneficial integration of renewable energy in the total energy system. Even the reduced tax on electricity for space heating is almost twice as high as the energy tax on heating oil and natural gas. That inhibits the electrification of buildings heating and district heating, where heat pumps are both energy efficient and socio-economical efficient technology. [20]
Finland	(21,22)	- The goal is for Finland to build its competitiveness using sustainable material use. The demand for virgin materials will be minimized, the length of material and product life cycles maximized, and products designed so that they can be maintained and reused at the end of their first useful life [21]. - Finland developed a whole life carbon assessment of buildings method. The method is based on the European Commission's Level(s) method and European Standards [23]. A low-carbon building has a low carbon footprint and a giant carbon handprint. The method is intended

		to assess the carbon footprint and carbon handprint of new buildings and buildings undergoing extensive repairs [22].
France	(24)	- The new French Building Regulation RE2020 introduces a new threshold of 4 $kgCO_2$ operational emissions equivalent/m^2 for new residential buildings and set at a level sufficiently ambitious to favor the low carbon-intensive energies [24]. This will eliminate the use of gas for heating. A conversion coefficient between primary energy and final energy of electricity of 2.3 will be used. It corresponds to the expected average value of this coefficient over the next 50 years, thus making it possible to consider the forecast evolution of the French electricity mix -over the life of new buildings. -The new RE2020 is introducing a dynamic LCA calculation method that is ambitious, proposing a threshold for embodied carbon emission of 100 kg of CO2 per m^2, which favors biobased materials and timber [24].
Netherlands	(25,26)	-In the Netherlands, the government and the business community work are currently using a method to measure the building's environmental performance via a life cycle analysis. LCA is used as a criterion for construction procurement. The Dutch recognize the limitation of their method regarding the treatment of demolished materials and their reuse [25,26].
Sweden	(27,28)	-The Nordic construction section is witnessing acceleration towards circular construction. Experts suggest anchoring the requirements in the building regulation in Denmark, Finland, Norway, and Sweden in Environmental Product Declarations (EPD), Construction Products Regulation (CPR), Building Information Modelling System (BIM), and Material and building passports [27,28]. - Sweden has set the goals for achieving a climate-neutral value chain in the construction and civil engineering sector reaching by 2045: Net-zero emissions of greenhouse gases by 2040: 75% reduced greenhouse gas emissions by 2030: 50% reduction in greenhouse gas emissions [28].

4.1. Denmark

Denmark has adopted the German certification system, DGNB (*Deutsche Gesellschaft für Nachhaltiges Bauen*). A large part of the certification system refers to the Life Cycle Assessment (LCA). However, the use of LCA is voluntary. The promotion of sustainable solutions and green products is carried out through the Partnership for Public Green Procurement, a community of municipalities, regions, and public associations. The use of the Environmental Product Declaration (EPD) is voluntary in Denmark, except in Copenhagen, it is mandatory. However, there are strong incentives to use EPDs [19].

The Danes aimed that by 2030, 50% of all energy used in buildings should come from renewable sources, and it wants to reduce buildings total carbon emissions by 9.4 million tons by 2030 [20]. However, there is uncertainty to attain this target. In terms of energy consumption, the legislation provides that new buildings must be built as low-energy houses that consume up to 90% less energy. These requirements are implemented for the 2020 building regulations.

The current state of transition to a circular economy in the Danish construction sector is elaborated on to improve material recycling quality in the construction sector. Preferably, greater direct reuse and

removal of hazardous substances in construction materials. The Danes developed their material passport tool, called "*Materialepas*," to improve circular product policies [29]. Denmark is increasing existing building assets by encouraging multifunctional buildings such as schools and building reuse through building components' modular design. The construction industry had shown concerns in the disassembly process to enable the separations of materials after construction [28]. The main innovation area is industrial production processes to reduce waste during construction and renovation, including modular construction and 3D printing construction modules [19].

In terms of construction waste management strategies, the government plans to separate ten waste fractions: 1. natural stone, for example, granite and flint, 2. non-enameled tiles (bricks and tiles), 3. concrete, 4. mixtures of stone materials and unglazed tiles and concrete, 5. iron and metal, 6. plaster, 7. rock wool, 8. soil, 9. asphalt, 10. and mixtures of concrete and asphalt. Currently, 87% of building materials are recycled with low-quality applications, and less than 1% are made into components and materials for new construction [30]. However, large construction companies are going beyond their initiative's requirements - small builders can deliver different construction waste fractions to local recycling centers [31].

Table 2. Mapping of carbon neutrality and circularity criteria regulation landscapes in the five countries.

		Denmark	Finland	France	Netherlands	Sweden
Carbon Footprint Reduction Criteria	Carbon emission threshold	✓	✓	×	×	✓
	Green Public Procurement (GPP)	✓	✓	✓	✓	✓
	Embodied carbon in products	✓	✓	✓	✓	✓
	LCA	✓	✓	✓	✓	✓
	EPD & %	×	✓	✓	✓	✓
	Energy efficiency improvements	✓	✓	✓	✓	✓
Circularity Criteria	Building Materials Passport	✓	×	×	✓	✓
	Dismantling Protocol	✓	×	×	×	×
	Carbon + water footprint	×	×	×	×	×
	Competitiveness and innovation industrial	✓	✓	×	×	✓
	Waste management	✓	✓	✓	✓	✓
	Adapt Spaces	×	×	×	×	×
	Reconfigure \ upgrade structure	✓	✓	×	×	×
	Separate elements material	✓	×	×	×	×

4.2. Finland

In Finland, the goal for a building's lifespan neighbors 80 years [7]. The plan will be to prolong this lifespan. This is where the idea of circularity comes into account. Construction parts must have net benefits and affect lowering carbon footprint. The first edition of the system for the lifetime carbon assessment of buildings was based on the Level(s) framework developed by the European Commission [23]. A project named "Circular Economy in the Built Environment" was launched by the Finnish Innovation Fund Sitra in early 2018 [21].

Material economics predicts that only cement, steel, aluminum, and plastic used for construction in Finland would result in emissions of 230 Mt CO_2 by 2050 if produced using today's manufacturing processes. The Ministry of the Environment released a plan for low-carbon construction in 2017: by the mid-2020s, a life-carbon assessment of buildings must be included in the building regulations. As Finland intends to achieve carbon neutrality by 2035, estimating buildings' carbon footprint and building-type specific emission limits are introduced in the building regulations of 2020. Furthermore, Finland also plans to reach an 80 percent reduction in greenhouse gas emissions by 2050 under the Climate Change Act, compared to the 1990 baseline figure. The Land Use and Construction Act, a recent reform, embraces low-carbon aspects and a life cycle thinking approach for a low-carbon construction sector [22,32].

4.3. France

The recently updated Energy-Climate Law promises to fight against climate change to reach a carbon-neutral France by 2050 [33]. The future French Environmental Legislation goals within this framework are to reduce the effect of new buildings on the environment by considering all of the building's pollution, right from construction, over its life cycle. A focus and special attention to bioclimatic design is (known as 'Bbio' indicator) is highlighted [34]. In the new building regulation law (RE 2020), new constructions carbon emissions are reduced substantially. Through the promotion of Energy Positive and Low Carbon Buildings, the regulation introduces a new threshold for CO2 emissions [24]. The CO2 emission factor is expressed in kg eq.CO2 /m² [24]. Unfortunately, according to the best available data, French regulations do not address circularity.

Moreover, according to the French Ministry of Energy Transition LCA methodology used to calculate the impact on global warming, buildings mandated by RE2020 will be based on a dynamic LCA methodology. The static LCA method proposed by the E + C- standard is going to be replaced. The calculation of global warming impacts via the dynamic LCA method will widen the gap already present between timber constructions and reinforced concrete construction. The new dynamic calculation will take into account benefits beyond the life cycle of building materials. It will be more adjusted to the reality of the materials integrated in projects, favoring bio-sourced construction solutions.

4.4. Netherlands

The Dutch Building Environmental Performance Declaration (DBED) is mandatory for every environmental permit [35]. The declaration indicates the environmental impact of the materials used in a building. This concerns new office buildings (larger than 100 m²) and new-built homes. As of Jan 1, 2018, a maximum limit value of 1.0 applies to the Building Environmental Performance Declaration. The DBED is an essential measure of the sustainability of a building. The lower the declaration value the more sustainable the use of materials. The DBED is a tool that should be used during the design process, and it can be used in a Design Brief to record the result of a design process [26]. For example, recycled floor covering gives a sustainable value and is an essential means of communication. However,

the DBED calculation shows that the floor slab's sustainability has a much more significant effect on the environmental impact than the floor finishing.

To determine the material's environmental impact, an LCA is performed. A qualified expert must perform the LCA. The LCA results are reported for 11 environmental indicators of a product. These 11 indicators are combined into one value: the environmental cost per unit of the product (kg, m3, m2, etc.). It is not necessary to perform an LCA of the same product/material over and over again. For the Netherlands, the characteristics of materials from the LCAs are collected in the National Environmental Database (NMD). The Building Quality Foundation manages this database (SBK). A producer or supplier must ensure that a product is included in the NMD.

Regarding circularity, no enforced building regulations exist. However, many guidelines and initiatives taken by municipalities and companies encourage green and circular building materials procurement. The Design for Modularity (DfM) or Design for Disassembly (DfD) concepts are implemented in several pilot projects. The renovation and adaptation of existing buildings, such as churches, and their transformation into dwellings, are examples of layouts circular design strategies in the construction, including adaptively, modularity, and design for reuse [25]. In 2019, 12.5 thousand homes were created by transforming existing buildings, such as offices, schools, and shops [36]. Netherlands is seeking to have a circular economy by 2050 and reduce the materials used by 50% [37].

4.5. Sweden

Under the Paris Agreement requirement, Sweden aims to eliminate its greenhouse gas emissions until 2045 [28]. The climate program legislation is made according to Ordinance (2015: 517) and is supported by local climate investors (Klimatklivsförordningen) [38]. Starting in 2022, all new buildings must reduce carbon emissions to meet a specific threshold. The approach is based on the LCA of buildings.

To ensure that the national energy target is 50% more efficient by 2030, Sweden has created several instruments that provide incentives to promote carbon efficiency and circularity. For waste management of the construction industry, Sweden aims to recycle 70% of materials [39]. The Swedish, Environmental Protection Agency requires recycling large amounts of construction residues guided through a manual to facilitate recycling in an environmentally safe and health-friendly manner. The Swedish Public Procurement Act states that contracting authorities should follow green procurement for public-funded projects [40].

5. Discussion

This research presented a literature review and expert interview results of five countries regarding building regulations associated with carbon neutrality and circularity. The five leading European countries are slowly increasing wood and biobased materials in construction to sequester carbon emissions. The use of EPDs and LCA with performance thresholds for carbon emissions is transforming the construction industry. However, the circularity concept is still not gaining momentum in regulations. As shown in Figure 3, our study indicates that Denmark is the most leading EU state to incorporate the circular economy's principles in the construction sector. The regulations landscape in Denmark is almost mature, with policies and tools that aim to waste reuse and materials separation. In second place comes Finland, with a multi-stakeholder approach to adopt "Circular Economy in the Built Environment" in the construction sector and achieve carbon neutrality by 2035. Sweden comes in third place by implementing a climate legislation that introduces and favors the execution of measures and supports the transition toward carbon neutrality in 2045, entering into effective January 2022. France is in fourth place in the qualification, leading to carbon footprint reduction measures and lagging regarding building circularity. The Netherlands comes forth with the mandatory LCA requirements for all new constructions.

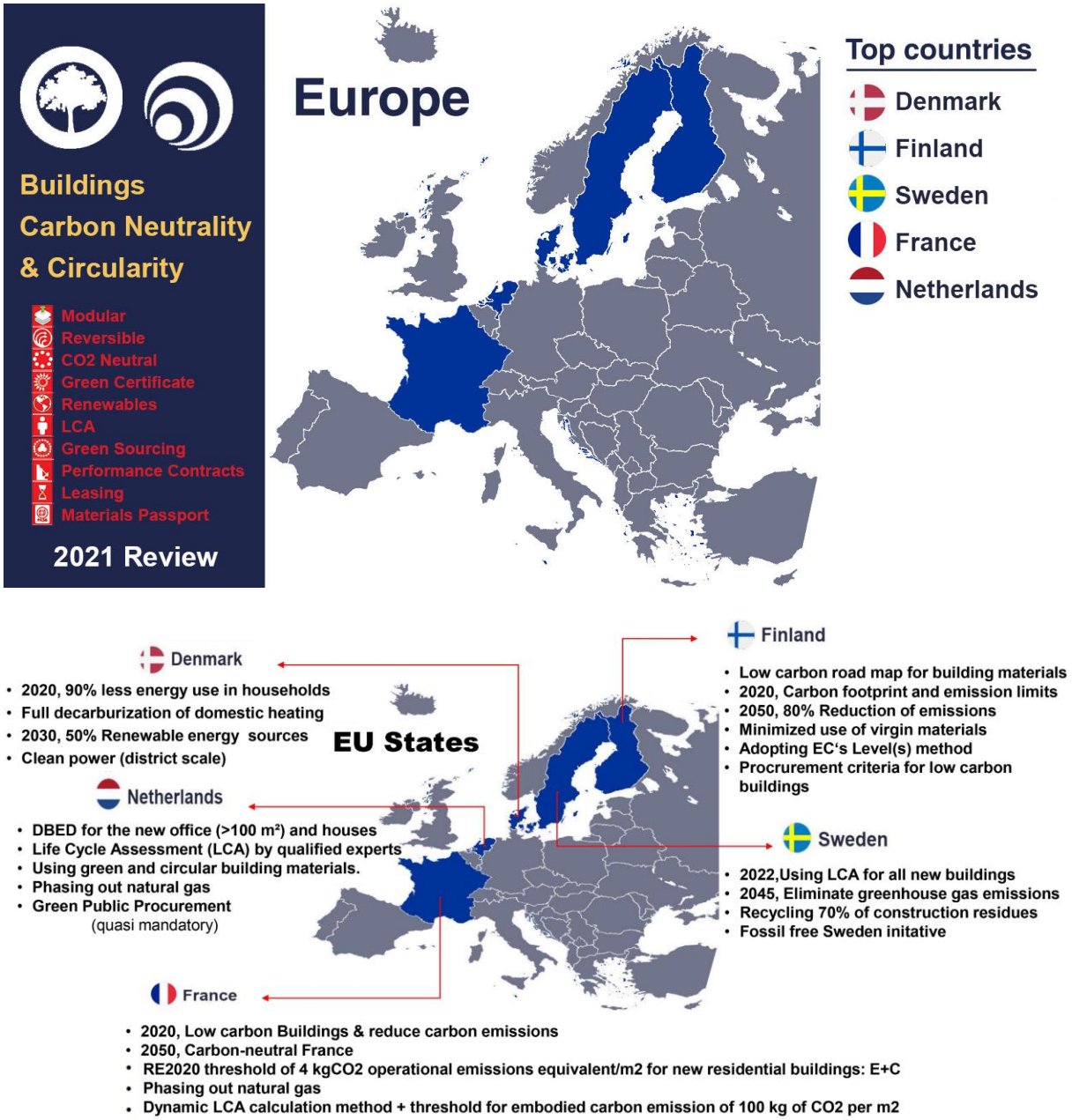

Figure 3. Ranking of EU leading member states that couple carbon neutrality and circularity requirements for new constructions.

Based on our review and analysis, we provide three main recommendations. Firstly, EU member states must adopt measures to limit carbon emissions and the carbon incorporated in products based on European standard EN 15978 and Level(s) framework [5, 25, 41]. The use of wooden buildings as carbon sinks or carbon sequestration is gaining momentum in the five investigated countries based on the evolving regulatory landscape [42]. Carbon emissions from heating are already very low in Sweden, Denmark, the Netherlands, and Finland due to district heating and heat pumps. France has recently adopted a new regulation that prohibits using gas as a source of heating in new households and is encouraging reversible heat pumps across the country.

Secondly, circularity criteria for buildings should not be treated in isolation from carbon neutrality. The circularity criteria must be coupled to carbon footprint reduction measures. As a consequence,

timber construction materials and biosourced insulation materials will be in great demand. The current supply chain of timber is already under pressure, and the availability of wood sourced from sustainably managed forests will not be enough to meet the European demand. Moreover, the number of trained workers who can deliver timber construction projects is not enough. The training of professionals, including architects, masons, electricians, and plumbers, will require significant investments to prepare them to design and build timber constructions.

Thirdly, the EU member states must increase the share of recycled and reused construction waste and the possibility of separating the materials for future reuse. Timber and biosources materials will not cover the demand/supply during the coming 20 years. Also, none of the investigated countries addressed this matter thoroughly. Therefore, increasing the share of recycled and reused construction materials can help during the transition towards timber constructions. EPDs can facilitate the decision-making of architects and design teams while keeping the embodied carbon low.

Finally, this research's strengths are centered on reviewing carbon neutrality and the circularity of buildings together. The exhaustive analysis of the state of the art, regulation, and legislation resulted in selecting and ranking five leading member states incorporating the circular economy in buildings. At the same time, the research provides a snapshot and status quo analysis of a very dynamic field. The European housing market is under pressure to produce more and more housing units. There is already a housing supply gap in Europe. Most leading EU states are stopping the urbanization of land and setting limits for urban sprawl. The circularity and carbon neutrality paradigms will intensify this challenge of building sustainably.

We imagine it will be outdated very soon once this paper is published. Besides, the analysis is mainly quantitative and is not based on case studies or quantitative research approaches. However, this article aims to help researchers, the EU commission, and member states take the lead in legislation and regulation to embed circularity and carbon neutrality in buildings. The paper brings perspectives regarding the regulatory landscape of the construction sector in Europe. Future research should update our review and focus on case studies and a detailed dynamic LCA approach to assess carbon neutrality and circularity.

6. Conclusions

The three Nordic countries (Denmark, Finland, and Sweden) are leading the way in implementing policies and regulations that reduce the carbon footprint and incorporate the circular economy principles in the building construction sector. The five investigated countries implementing ambitious measures to reduce the environmental impact of buildings operation and materials use. However, our study found a separation between carbon neutrality targets and circularity targets. Integrating both targets in future building regulations is fundamental to reducing buildings' overall carbon and environmental footprint. The quantification of carbon neutrality and circularity targets through measurable indicators and critical performance thresholds is the key to accelerate the market uptake and inform policies and decision making.

7. Acknowledgments

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