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A market inventory of construction wood for residential building in Europe – in the light of the Green Deal and new circular economy ambitions

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A R T I C L E I N F O

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A B S T R A C T

Wood is an energy efficient, low carbon construction material that if carefully managed can contribute significantly to European climate policy goals in urban environments. The aim of this study is to assess the current construction wood use intensity — the ratio of apparent national consumption of wood for construction (in m^3) to the useful floor area of newly finished dwellings (in m^2) — and to identify when and where additional policy measures are required. Results show that Cyprus/Malta have the smallest use with a ratio of 0.01, Estonia/Romania the greatest use with a ratio of 0.32. The need for additional policy measures, was assessed using the Boston Consultancy Group (BCG) matrix with four product development phases, based on the aforementioned ratio versus future growth. Six, twelve, eight and two countries are in the "Introduction", "Growth", "Maturity" and "Decline" phases, respectively. At the EU level, the European Commission should consider introducing a Renewable Material Directive, in which a Non-biogenic Material Comparator shows the average GHG substitution effect of using wood for construction. At the international level, a new harvested wood product (HWP) category in the IPCC Guidelines is recommended for construction wood with a longer lifespan than the current HWP categories.

1. Introduction

Expanding global population, agricultural intensification and climate change are increasing pressures on natural and managed environments in Europe. To ensure sustainable land use in the context of economic expansion, it is essential that we develop tools and information services that can inform more effective about sustainable practices for climate mitigation. Those practices include the use of HWP in building new houses, for renovation or for non-residential buildings (Börjesson & Gustavsson, 2000; Allacker et al., 2014; Ramage et al., 2017; Lavagna et al., 2018; Hart & Pomponi, 2020; Göswein et al., 2021). In the mid-20th century, the FAO carried out an inventory of the utilization of structural wood in housing across some European countries (Westoby, 1958). At that time, the use of wood for construction had declined considerably following the Second World War because of a change in dominant dwelling types, new construction methods and technological advantages of reinforced concrete and bricks. Most European countries turned to new ways of building houses in response to shortages of various materials. Due to severely limited supplies, the cost of wood was up to double the price of cement or steel. The current climate emergency in the 21st century has led to renewed interest in wood products as an energy efficient and low carbon building material.

1.1. European climate policies and new circular economy ambitions

The forest-based sector can contribute significantly to climate change mitigation by increasing carbon stocks ('net sink' or 'CO_2 removals') in forest land, through altered management silvicultural practices and, or by using the harvested wood (Griscom et al., 2017; Jorgensen et al., 2021; Grassi et al., 2021). The use of wood for construction purposes, can combat climate change in two ways. First, through the additional carbon storage in buildings, extending the forestry carbon sink over a longer time frame. Second, by substituting steel, concrete, gypsum or other fossil fuel intensive materials, GHG

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emissions are reduced or avoided (Matsumoto et al., 2016; Rüter et al., 2016; Peñaloza et al., 2016; Geng et al., 2017; Hafner & Rüter, 2017; Mehr et al., 2018; Piccardo & Gustavsson, 2021).

To overcome climate change and environmental degradation, the European Green Deal aims to transform the EU into a modern, resource-efficient and competitive economy, ensuring amongst others: no net emissions of greenhouse gases by 2050, and economic growth decoupled from resource. In line with the new EU Circular Economy Action Plan (European Commission, 2020a), priority should also be placed on long term carbon storage in wood used for construction. The national energy and climate plans (NECP's) of the EU Member States (MS) are a first indication of how to move forward for a 'zero-carbon economy' or 'climate neutrality' by 2050 (Maris & Flouros, 2021; Zibell et al., 2021). Ten MS have included the use of HWP's for construction in their NECP's (Table 1). Another six MS have included HWP's, but not specifically for construction. The remaining MS did not mention them (European Commission, 2020b, 2020c). Moreover, Switzerland, the UK and Norway included the option of wood for construction (FOEN, 2018; DBEIS, 2020; NMCE, 2022).

The EU will develop a 2050 roadmap for reducing whole life-cycle carbon emissions in buildings, as well as a methodology to quantify the climate benefits of wood construction products and other building materials (European Commission, 2021a, 2021b). In addition, the new European Bauhaus initiative will provide support for innovative projects in wood construction. Engineered wood products (EWP's) such as glued laminated timber (GLT), laminated veneer lumber (LVL) and cross laminated timber (CLT) have allowed for an increased use of wood in large scale construction (Hurmekoski et al., 2015, Lu et al., 2017; Ilgın et al., 2021). Given that the market share of wood-based construction in Europe is below 10% (Hildebrandt et al., 2017), there is great

Table 1
Available datasets for wood for construction in new dwellings in 2017–2021 across the 30 European countries studied (see also Appendix B for the corresponding data).

		HWP as building element	Apparent consumption 2017-2020 (= production + import – export) in 1,000 m^3			Number of dwellings (see Appendix A for details of national statistical offices)	Floor area in 1,000 m^2
Selected countries in three inventory rounds	Code	HWP's included in NCEPs? (EC, 2020ab)	OSB, plywood & fibreboard data in m^3 (FAOSTAT, 2021-2022)	BJC production in kg * (Eurostat, 2021a)	BJC trade in kg* (Eurostat 2021b; SSB, 2021; UN Comtrade, 2022)	Newly finished dwellings, started dwellings or authorised dwellings in 2017-2021 (permits)	Useful floor area available national statistics?
Austria	AT	++	√	√	√	Newly finished dwellings (SA);	+/-
Finland	FI	-	√	√	√	Newly finished dwellings (SF)	√
France	FR	++	√	√	√	Started dwellings (INSEE)	√
Germany (2019-2020)	DE	++	√	X	√	Newly finished dwellings (DESTATIS);	√
Ireland	IE	++	√	√	√	Newly finished dwellings (CSO)	√
Italy	IT	-	√	√	√	Authorized dwellings (I-Stat)	√
Lithuania	LT	++	√	√	√	Newly finished dwellings (SL)	√
Netherlands	NL	-	√	√	√	Newly finished dwellings (CBS)	√
Romania	RO	-	√	+/-	√	Newly finished dwellings (INSSE)	√
Sweden	SE	++	√	X	√	Newly finished dwellings (SCB)	√
Belgium	BE	+	√	√	√	Authorized dwellings (STATBEL)	√
Czech Rep.	CZ	+	√	√	√	Newly finished dwelling s(SZSO)	√
Denmark	DK	+	√	√	√	Newly finished dwelling s(DST)	√
Hungary	HU	-	√	√	√	Newly finished dwellings (KSH)	√
Latvia	LV	++	√	√	√	Authorized dwellings (Stat Latvia)	√
Poland	PO	-	√	√	√	Newly finished dwellings (StatPol)	√
Portugal	PT	+	√	√	√	Newly finished dwellings (INE);	√
Slovakia	SK	+	√	√	√	Newly finished dwellings (StatSlo)	√
Spain	ES	-	√	√	√	Newly fin. dwellings (INE Formento)	√
United Kingdom	GB	++	√	√	√	Newly finished dwellings (ONS); 2021 data via the respective offices in England, Wales, Scotland & N. Ireland	+/- (England only)
Bulgaria	BG	-	√	√	√	Newly finished dwellings (NSI)	√
Croatia	HR	+	√	√	√	Newly finished dwellings (DZS)	√
Cyprus	CY	-	√	√	√	Authorized dwellings (Cystat).	√
Estonia	EE	++	√	√	+/-	Newly finished dwellings (StatEst)	√
Greece	GR	-	√	√	√	No dwelling data available (HAS)	√
Luxemburg	LU	++	+/-	√	√	Newly fin. dwellings 2017-19 only (Lu-Stat); 2020-21 data not yet published.	+/-
Malta	MT	-	√	√	√	Authorized dwellings data (NSO)	√
Norway	NO	++	√	+/-	√	Newly finished dwellings (SSB)	√
Slovenia	SI	++	√	√	√	Newly finished dwellings (SiStat);	√
Switzerland	CH	++	√	X	√	Newly finished dwellings 2017-2020 (BFS); 2021 data not yet published.	+/-

Legend NCEP's: - = HWP not mentioned; + = HWP generally included; ++ = HWP for construction specified;
Legend wood and dwelling statistics: √ = full datasets available; X = lacking/old dataset; +/- ambivalent/incomplete dataset.
[*] Average density 480 kg m^{-3} to 500 kg m^{-3} (Sutton et al., 2017: Hill & Zimmer, 2018).

development potential to reduce GHG emissions via the house construction sector (Zemaitis et al., 2021).

1.2. Diverging markets for construction wood across Europe

There are considerable differences as to the extent of wood-based construction in different parts of Europe, often attributed to differences in traditions, culture, and the associated technical know-how of building with wood (e.g. Jonsson 2009, Mahapatra & Gustavsson 2009, Hurmekoski et al. 2015, Gosselin et al. 2017). Likewise, national policy initiatives aiming to bolster wood construction, as well as the supply of wood, differ considerably across Europe. Here differences are highlighted using a comparison between Sweden and Ireland: Sweden having a large (69%) and Ireland a small forested land area (11%).

On the one hand, wood construction has a mixed history in Sweden. The construction and manufacture of single-family timber housing has a long tradition, as about 90% of single-family low-rise households have timber frames, often prefabricated off-site. However, wood represents only around 19% of the market for new construction of multi-family buildings in 2020 (SCB, 2021). After several city fires caused significant damage, a law was implemented in 1888 that prohibited the use of timber frames in buildings with more than two storeys. This ban was lifted in 1994. This century-long period of prohibition not only hindered the development of multi-storey wood construction technologies, but also served to establish the domination of other building materials, most prominently concrete (Bengtson, 2003; Mahapatra & Gustavsson, 2008). On the other hand, Ireland has increased its forest cover from ca. 1% in the early 20th century to 11% now, aiming to increase timber self-sufficiency and to provide rural employment (Forest Service, 2018). So far, Ireland does not have a significant history of timber-framed construction in the residential or commercial property sectors. Ireland has some lingering negative perceptions related to the quality of wood produced from fast-growing Sitka trees in its moist temperate oceanic climate (ITFHC, 2003). Construction elements can have a double wall of wood with insulation material in between for inside construction, but the outside needs always to be buildup of concrete blocks for weather protection (personal communication Cygnum). Finally, current building regulations generally limit timber framed buildings to a height of 10 m or three storeys for fire safety reasons (Harte et al., 2017).

There is a major difference in the characteristics of wood produced in Ireland and in Sweden, as expressed in the bending strength of sawn wood or lumber. Irish coniferous wood is generally graded as C16, whereas Swedish coniferous wood achieves higher bending strength C24 (Desmond, 2021). The difference is due to growth rates; trees in Sweden grow more slowly and have narrower annual rings and therefore a higher density. Grade C16 is equivalent to 370 kg m^{-3}, whereas C24 is about 420 kg m^{-3} for coniferous species (TRA, 2017). Greater bending strength is required in building uses, e.g. roof trusses are required to meet relatively demanding building standards, so wood from Nordic countries with higher densities is generally used. Although it is possible to use larger dimensions of lower grade Irish timber to achieve higher bending strengths, current market conditions and price settings are too tight to tolerate the extra dimensions or volume needed. Therefore, Irish wood manufacturers prefer to utilise materials of smaller dimension and higher density from Nordic countries (forests at a higher latitude) or from Austria, Czech Republic and Germany (higher altitude) for more demanding construction uses. Those materials are in particular C24 graded wood according to the Canadian (CLS) or Swedish Lumber Standards (SLS). A small number of Irish sawmills produce CLS or SLS from native timber. Another difference between both countries is a long traditional production of plywood in Sweden and a more recent production of oriented strand board or OSB in Ireland (FAOSTAT, 2021). The used timber species depend on the availability in national estates; mostly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) in Swedish plywood (Jonsson, 2021a) and Sitka spruce (*Picea sitchensis*) in Irish OSB (Desmond, 2021).

1.3. Scope and aim of research

To unlock the potential of wood as an energy efficient and low carbon construction material, a mix of policy instruments adapted to specific national contexts will be required (Hildebrandt et al., 2017). Thus the overriding objective of this study is to establish when and where additional national policy measures may be required to increase wood use in construction (green buildings in urban environments). There is a lack of European-wide data regarding the use of timber for construction. As such there is no baseline against which to measure progress and to identify where targeted policy measures are needed.

This study addresses this gap by estimating the wood-use intensity in newly finished or committed residential buildings as the ratio of apparent consumption of wood for construction and the useful floor area of new dwellings across thirty European countries (EU-27, UK, Norway and Switzerland). The Boston Consultancy Group (BCG) matrix — a useful approach to understand the stage of sector development in order to target appropriate policy support — is subsequently used to classify the 30 countries included in the study in terms of wood-based construction development stages. Further, the GHG displacement potentials of substituting construction wood for non-biogenic materials, like concrete and steel, are assessed to establish the validity of policy support. The use of construction wood is applied to newly built dwellings only, without taking non-residential buildings (offices, sport buildings) and renovation of residential buildings into account. There are insufficient data (e.g. office building numbers and useful floor area in m^2) at the EU level to merit their inclusion.

2. Materials and methods

For the market inventory of wood for construction, we have applied the Boston Consultancy Group (BCG) matrix and life cycle development stages. There are four life cycle stages in the BCG matrix that are relevant for the wood construction market and the role that national building sectors could play: I. Introduction; II. Growth; III. Maturity; IV. Decline (BCG, 1968; Henderson, 2012; BCG, 2021). Fig. 1 shows the progression of stages over time. The BCG approach and product development matrix are highlighted in Section 2.1. To draw the BCG matrix, we then estimated the wood use intensity in newly finished or committed residential buildings at national level. Data collection and availability is considered in Sections 2.2 and 2.3.

2.1. Marketing theory and development stages of Boston consultancy group

When a new product or service is launched in the market, its revenue-to-profit ratio is close to zero. Some product market introductions even allow for a negative revenue or profits to have the production first widely promoted and to have more market penetration. This is normal for a product with a small market share in a fast-growing industry. Such products ("question marks") consume more cash and resources than they generate. In this study the BCG matrix, and its four phases (Fig. 2) are used to illustrate wood use for construction and national wood construction sectors as follows:

(I) Introduction phase (question mark): the market share of wood for construction is low, while the market growth is positive. The introduction phase may remain uncertain for a few years, during which time it may evolve into a star (high market share, fast growing industry). Most products or businesses begin as a question mark, representing the big challenge of whether further potential will be realised. At the business or micro level, business management need to decide whether to commit extra resources to get a product to the next phase. At the country or macro level, representative bodies of the construction sector, or governmental agencies need to decide whether to commit extra support for the

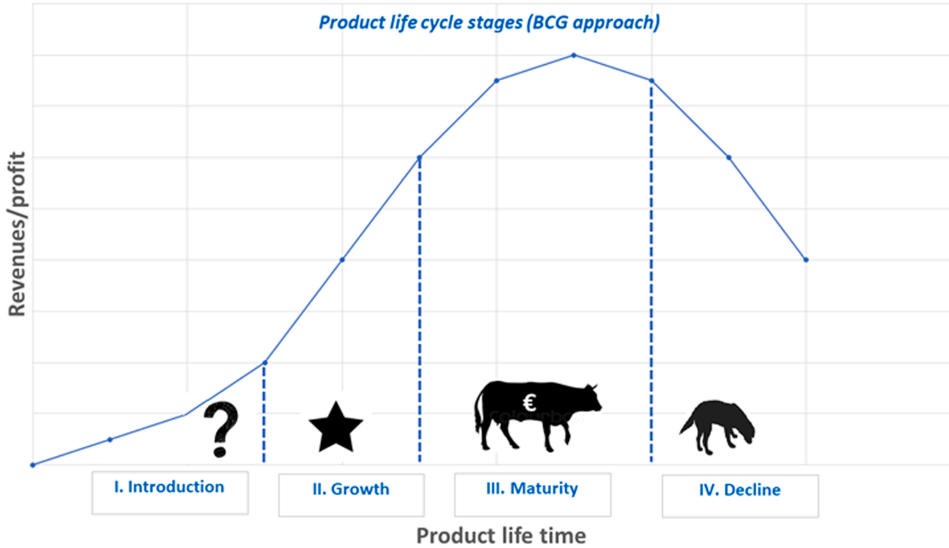

Fig. 1. Developmental stages of the product market over time according to the BCG approach.

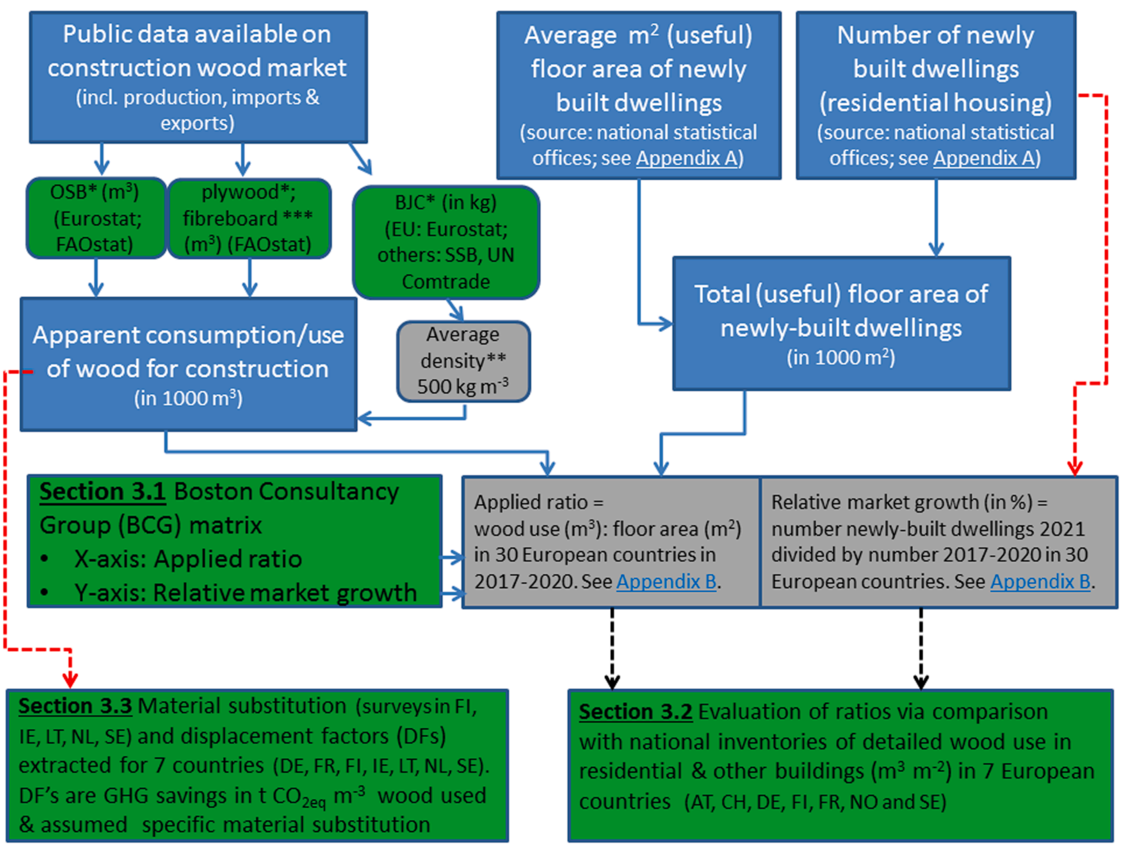

Fig. 2. The BCG matrix (BCG, 1968; Henderson, 2012; BCG, 2021), which is used in this study to illustrate the market development stages of wood for construction.

production, trade or use of the wood products for construction in this phase.

(II) Growth phase (star); the market share of wood for construction is high, while the market growth is positive. If successful, the star represents the growth phase, where the share of the market is high, and the company or economic growth performs higher. With a successful star strategy, the product can become a cash cow in the next phase of maturity. At the micro level, star strategies involve marketing and sales promotion, advertising, and others. At the macro level, the wood products for construction need a national support programme.

(III) Maturity phase (cash cow): the market of wood for construction high, while the market growth is negative. The maturity phase is accompanied by so-called cash cows in marketing terms and are valid market leaders. They exhibit a return which is greater than the market growth, thus generating more cash than needs to be expended. The cash from such products should be harvested, extracting the profits, while investing as little cash as possible.

(IV) Decline phase (dog): the market share of wood for construction is low, while the market growth is negative. At the end, there is a decline phase. During this phase, the market share is decreasing, and the relative market growth is low or negative. Typically, these kinds of products barely generate enough cash to maintain their market share in their industry. Even though this phase may involve making a loss, it is associated with the social advantage of maintaining employment, etc.

2.2. Data collection and analysis

Fig. 3 shows the work flow involved in using the data collected to calculate the ratio of wood for construction in residential buildings on the one hand, and the relative market growth on the other hand, both indicated in the grey boxes. The assessment of wood use intensity in newly finished or committed dwellings across Europe is assessed using a top-down approach, with the market share indicated as the ratio of m^3 of construction wood versus m^2 useful floor area of residential buildings in the period 2017–2020 in a first step (horizontal axis). In a second step, the relative market growth is indicated (vertical axis) via the number of new dwellings in 2021 versus the number of new dwellings in 2017–2020. For the first step, publicly available datasets on the production, import and export of different wood products (or commodities) for construction are used for most countries: (Eurostat, 2021a, 2021b; FAOSTAT, 2021, 2022). For Sweden and Switzerland, two additional datasets are consulted for the trade flows (SSB, 2021; UN Comtrade, 2022). The sum of production and import, minus export, is the apparent consumption of wood for construction. For the second step, the number of new dwellings, the average or total useful floor area of new dwellings, are derived from databases of the national statistical offices (see Appendix A).

The drawing of the BCG matrix needs two types of division lines (Fig. 2). The horizontal axis of the BCG matrix is arbitrarily split at a m^3: m^2 ratio of 0.10. To the left of this value on the axis, the ratio is lower than 0.10; while to the right of this value the ratio is greater than 0.10. The vertical axis in the BCG matrix is divided into a negative and positive market growth.

2.3. Available datasets

After acquiring opinions from experts in the field (see Acknowledgements for their contribution and approval), it was decided to account for the following wood products for construction: builders' joinery and carpentry (BJC), oriented strand board or oriented structural board (OSB), plywood, hardboard and softboard for insulation. BJC is 100% allocated to house construction and includes laminated timber products (like CLT, GLT), cellular wood panels, posts & beams and bamboo. Floors, doors, window frames, shuttering, shingles and shakes are not included in this BJC aggregate (Eurostat, 2021a, 2021b). The BJC aggregate will be further enlarged with new wood for construction categories in the Discussion section. The share of OSB used in construction in Europe in the period 2017–2021 was 77% to 87%. Of plywood the corresponding range was 39% to 40%, of hardboard 8% to 13% and of softboard 64% to 80% (personal communication European Panel Federation or EPF). The European average shares for construction are applied to each country (see Appendix C), as there are no individual country data available. The remaining shares of those wood based panels are used for packaging, flooring, furniture Do It Yourself (DIY), automotive and others (EPF, 2022).

To combine various types of residential buildings, numbers of dwellings are used: dwellings are the quantity of living units, namely one for one-family houses, two or more for multifamily houses, and a multiple number for residential apartments. The associated useful floor space is defined as the living area available within a dwelling, as measured by floor space inside the outer walls of a building. The useful floor area includes kitchens, sanitary facilities, halls, built-in wardrobes, cabinets, heated attics, and other warm auxiliary areas. Useful floor area does not include balconies, terraces, cellars, unheated attics in family houses, or common spaces such as foyers, corridors, lifts and stairwells in multi-dwelling buildings (Eurostat, 2015, 2021c).

For this inventory, wood use is allocated as much as possible to the number of newly finished dwellings, as extracted from the databases of national statistical offices (Appendix A). This basic approach was applicable to twenty-two countries (Table 1). In cases where no data on finished dwellings were available in the national statistics, the apparent consumption of wood for construction was compared with started dwellings or authorised dwellings (the latter are also defined as confirmed permits or commissioned dwellings) for building of houses and apartments. France is the only country, for which the national statistics' category "started dwellings" is applied in our inventory. The confirmed permits alternative is applied for five countries, Belgium, Cyprus, Italy, Latvia and Malta. In the statistical databases of Greece and Luxemburg, there are no dwelling data or at least insufficient data to compile the 2017–2021 ratio for construction wood and useful floor area of new dwellings. Thus GR and LU are left out of the inventory.

After the before-described assessment twenty-eight European countries remain, of which five require major corrections, while one remains unchanged: (i) The Austrian average floor area in 2020 is applied to the whole 2017-2020 period; (ii) German production of BJC is not available via Eurostat (Eurostat, 2021a). After extra literature research, the German market inventory among 41 manufacturers of Glulam, CLT and cellular wood panels, expressed as m^3 of produced wood products for construction, is applied for 2019 and 2020 (EUWID, 2021); (ii) Swedish production of BJC is not indicated in Eurostat either. Data were provided by the Swedish statistical office (SCB) with the disclaimer that the Swedish figures may still need some correction; (iii) the Estonian export of BJC was corrected downwards by expert judgement with a factor 10, to bring it in line with the Estonian production and import figures; (iv) Norwegian BJC production in 2018 was corrected downwards with a factor 10 to align it with the Norwegian harvest statistics. See Discussion section 5.1 for a further review of BJC production versus harvested volumes; v) For Switzerland: BJC production is provided by Holzindustrie Schweiz (HIS, 2022), The BJC production is corrected by about 20% for raw material (sawn wood) that is cut off in the processing stages to manufacture the building elements (personal communication HIS-IBS). The incomplete dataset for newly built dwellings is replaced by the new dwelling data set of Euroconstruct (Dorffmeister, 2019, 2020, 2021, 2022), to compile the relative market growth; (vi) Romanian BJC production data are currently under review and may be

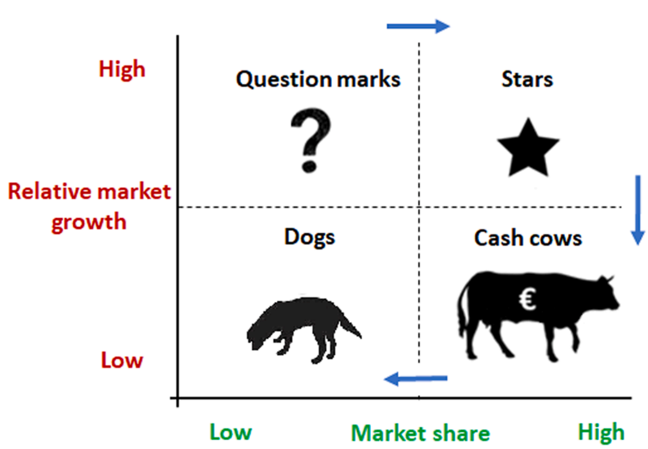

Fig. 3. Flow-diagram of data collection and data analysis
*Section 4.3 discusses the January 2022 changes and registration of the trade of new wood products (commodities) for construction ** Section 4.3 includes a sensitivity analysis on the applied conversion of 500 kg m−3 for BJC. *** Only softboard and hardboard are regarded in our wood for construction survey. Both MDF and mediumboard are not included.

updated in a next release (personal communication, INSSE). Our inventory remained with the actual data (Eurostat, 2021a).

3. Results

The compiled wood for construction data are reported and illustrated in Section 3.1. These data are compared with available data from detailed bottom up inventories of wood use in residential housing across Europe in Section 3.2. In addition a survey is conducted among preselected national experts on harvested wood for construction, to seek feedback on material substitution options for building houses (Section 3.3).

3.1. BCG matrix for construction wood

The BCG product development phases are considered in successional order i.e., introduction, growth, maturity, and declining market stages (Fig. 4). The details for compiling the illustrated annual inventory data can be found in the country profiles in Appendix B.

Six countries have construction wood markets in the introduction phase I: CY, ES, HR, IE, NL and PO. Overall, Cyprus and Spain have the lowest ratios (0.01 and 0.03 m^3 m^{-2}). In Spain, as in many other European countries, timber construction has been traditionally used. However, in the last century the use of concrete and steel changed this situation, pushing timber construction into the background (Queipo de Llano, 2011). Also Ireland has a relatively low ratio of 0.07 m^3 m^{-2}. Sector representative businesses will need to decide whether to use extra resources to incentivise product usage and drive the market position to the next phase. In the case of wood for construction, this decision may also be made by a national government to allow for extra public support of wood construction in the introduction phase (I) to facilitate national bioeconomy goals. Ireland, for example, has launched its Climate Action Plan 2030 (Government of Ireland, 2021). Among the planned measures to cut GHG emissions is the increased use of wood as a building material. The Irish government will continue to support the mobilisation of wood, through initiatives such as investing in harvesting infrastructure, and research in timber and processing industries. The Irish roundwood harvest is expected to increase from 4.74 million m^3 in 2021 to 7.6 million m^3 by 2040, (Phillips et al., 2021) both sawlogs (production of BJC by sawmills and further processing stages) and pulpwood (OSB and other panelboards). In another setting, the Netherlands (ratio 0.09), bio-based mortgages were recently introduced by the private banking sector to promote wood use for buildings (*personal communication Triodosbank*).

Another twelve countries are in the BCG growth phase II (stars), with a relative market share of 10% or higher: AT, BE, BU, CZ, DE, DK, GB, IT, PT, RO, SI and SK are among these. Star strategies at business level or a representative overall construction sector level could be marketing and sales promotion, advertising, and various other strategies. State support programs may still be needed such as low tax incentives to promote wood use in buildings. Some possible solutions to allow wood building materials to become economically competitive include a carbon tax on products, subsidies, or procurement policies, such as supporting first use (Howard et al., 2021). As an example for the star segment, the Austrian Environmental Agency (UBA, 2016) stated that a comprehensive concept for the use of wood is missing in Austria. The findings of a recent study by five large Austrian research organisations, including the Austrian Environmental Agency (Ludvig et al., 2021) reflect diverging perspectives on the use of wood. For an increase in carbon efficiency, all the participants unanimously emphasise long lasting material use rather than wood for energy. Extra promotion of wood for construction was recently enhanced within Austria's Klima-aktiv Standard (BMK, 2022). Additional supporting measures are needed in the next years to increase the use of wood material through the Austrian Climate Fund (Ludvig et al., 2021). For reasons that are unclear, Romania has the largest ratio of 0.32 m^3 m^{-2}. In Romania, despite historical use of wood in buildings, in recent decades reinforced concrete structures have been the preferred option. Green building materials have only recently started to be included as a building material in the offer of manufacturing companies. Through the Green House Program, the Romanian state wants to encourage the use of organic and natural insulating materials in order to reduce the energy consumption (Simion et al., 2019).

Eight countries' construction wood markets are in the BCG maturity phase III (cash cow products): CH, EE, FI, HU, LV, LT, NO, and SE. The cash from such products is often "harvested", with profits directed elsewhere. Estonia is the largest user of wood in this phase, with a ratio of 0.32 m^3 m^{-2}. Modern construction activities are moving from open construction sites to factories. In Estonia, this is currently manifested in a private cluster of wooden house construction (Civitta, 2017). Norway has an ambition to be a global leader in the innovative use of wood. An important goal for both the Norwegian government and the wood processing industry is to increase the use of wood where it can replace

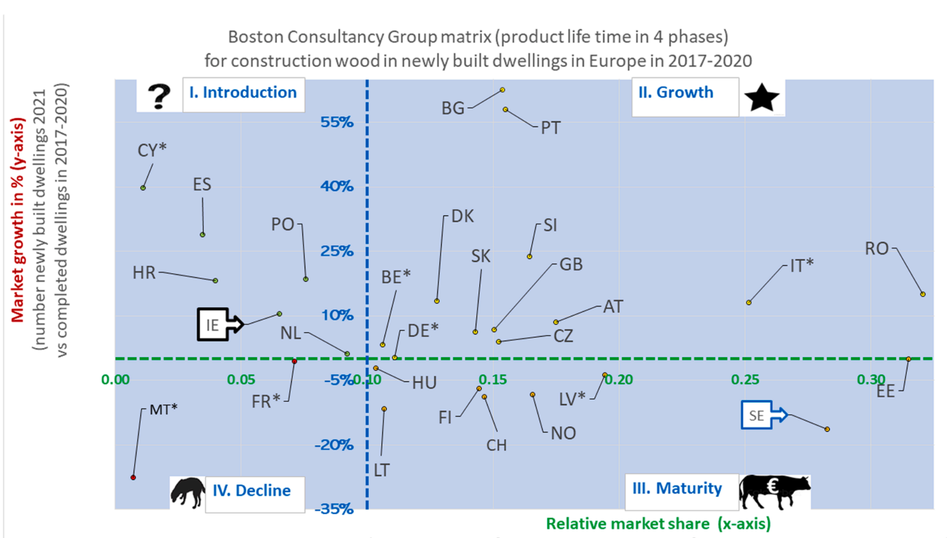

Fig. 4. BCG matrix for construction wood in newly built dwellings in Europe in 2017-2020.*
*Due to data availability, German situation is based on 2019-2020. Also, French data are fully based on started dwellings, whereas Belgium, Cypriot, Italian, Latvian and Maltese data are fully based on authorized dwellings (permits).

materials with higher negative environmental impact. The Norwegian Wood-based Innovation Scheme addresses different parts of the market: companies, decision-makers, architects, entrepreneurs, traders, research & innovation. Industrial building and construction with wood is one of the key goals (UNECE, 2016). The Swedish government appointed a National Wood Construction Strategy Committee in 2006 to promote the use of wood in apartment houses and public buildings (Kitek Kuzman & Sandberg, 2017). Nowadays Swedish business enterprises can sustain themselves and diverse their marketing industry, either within the country or via the export to other countries. Lithuania exports large quantities of final products that might be used in the local construction sector as well. About 80% of Lithuania's glue laminated timber for wooden construction is exported, while 20% is used in the national construction sector. As a result, Lithuania misses out on the possibility to develop its low-carbon economy based on high value-added products (Zemaitis et al., 2021). The outcome in Fig. 4 confirms this point of view. While Lithuania has a relatively small ratio of wood use in dwellings (0.11), the other Baltic States Latvia and Estonia have much higher ratios.

Finally, France and Malta are allocated to the declining market stage IV. France is the only country that has based its statistics on started dwellings. Corona or COVID-19 may have played a role, as the start-up of new dwellings is lower in 2020 and 2021, in comparison with the previous years (see Appendix B). In the end, the French product development phase has become IV decline instead of I Introduction.

3.2. Comparison with bottom-up inventories for HWP in residential buildings

The ratio cannot be straightforward converted into m^3 wood per m^2 of new dwellings, because part of the construction wood may be used for purposes other than construction of new dwellings such as renovation of buildings, or for construction of offices or temporary structures on building sites. As such this study is designed to provide robust indicators of relative change across the region. We continue thus with a comparison of our global ratio with detailed country inventories. Table 2 shows the global ratios of timber use in new dwellings on the left side and detailed inventories on the right side. Generally, the order of magnitude of the m^3 per m^2 floor area (or the m^3 per new dwelling) data for the selected bottom-up studies comes close to calculated global ratios at country level.

Obviously, wood use per dwelling is considerably lower for multi storey buildings in comparison with one- and two-family dwellings. In Sweden the range is 4 to 36 m^3, with the lower range for multiple storey buildings and the upper range for one- and two-family houses (Baudin, 1989; Dackling, 2002). However, the Swiss inventory shows a relatively large use of wood for multi storey housing (Neubauer Letsch et al., 2015; FOEN, 2021). At least, there is a significant difference in wood use between a massive cross-laminated timber frame building and a light timber frame building. The latter dominates the Swedish market, with an 85% share (Gustavsson et al., 2017). Finally, the Swedish, Swiss and German bottom up inventories all include doors and assembled floor panels, as considered in the upper range of our inventory. These inventories, hereafter called oversized, also include other supplementary wood products like windows and window frames. Overall, there is little available data for the m^3 per m^2 or m^3 per dwelling rubrics across all European countries, so it is difficult to compare the trend of global ratios in this rubric with detailed outcomes of national inventories.

3.3. Material substitution options

Feedback from national experts shows that various wood products used in construction replace a range of non-biogenic alternatives, depending on the country involved (Table 3). Whereas CLT, LVL or other wooden beams replace reinforced concrete in most countries, in Finland these products replace solid wood and in Lithuania they also supplant concrete clay blocks made from limestone, clay, gypsum and water. OSB or plywood for internal walls mostly replace gypsum walls. This is the case for non-structural walls. In the case of structural walls, masonry blocks or bricks are replaced, as specifically mentioned by Irish and Lithuanian experts. However, the degree of relative substitution by EWP's such as GluLam beams, is tempered somewhat by the amount of energy and chemicals expended in their manufacturing. This in itself is not straightforward since such products also enable the utilisation of a wider range of small dimensioned material, which would otherwise not be suitable or available for use in relatively high-specification end-uses. Wood floors replace a wide range of materials with very different GHG-intensities, from linoleum through carpet to stone tiles. Wood-framed windows can replace high GHG-intensity aluminium- (FI, LT, NL and SE) and PVC- (IE, LT, NL) framed windows and as such are an important element for house building.

The further assessment of the substitution impact of wood use normally comprises all fossil emissions in the techno-sphere for wood and non-wood products, from the 'cradle to grave' of raw material

Table 2
Comparison of inventory with available literature data for housing in Europe.

Countries	Inventory based on BCG- matrix		For comparison: bottom-up inventories of wood used for housing			
	Ratio's 2017-2020 in declining order* (m^3: m^2)	Wood per newly built dwelling*, in m^3 (assuming no renovation or new offices)	Scope: which type of the building (unit) is investigated?	m^3 wood per m^2 floor area	m^3 wood per dwelling	References
SE	0.28-0.35	20.5-25.4	Residential buildings (single- and multifamily houses)	0.04–0.27**	4-36**	Gontia et al., 2018; Baudin 1989, Dackling 2002
AT	0.17-0.22	17.1-21.1	Residential buildings	0.08-0.11	-	Kalcher et al., 2017
NO	0.17-0.18	20.9-23.1	Multi storey buildings (up to eight floors)	0.09-0.25	-	Nygaard et al., 2019 ; Tupenaite et al., 2021
CH	0.15-0.16	15.0-16.5	Multi storey housing (timber structure projects recalculated to all new dwellings)	-	29-34**	Neubauer-Letsch et al., 2015; FOEN, 2021
FI	0.14-0.16	12.5-14.0	Residential buildings (multi storey houses; attached & detached houses)	0.22-0.58	27	Hurmekoski 2016; Nasiri et al., 2021;
DE	0.11-0.18	11.4-18.7	Prefabricated houses (wood construction)	0.17-0.18**	-	Achenbach & Rüter, 2016
FR	0.07-0.09	5.8 -7.5	Residential buildings	0.05	-	Donadieu de Lavit & Leridon, 2019

[*] Lower values are ratio's as derived from Fig. 4, i.e. our inventory for BJC, OSB, plywood, hardboard & softboard. Upper values include additional OSB, particleboard and MDF panels used for doors & floor applications (EPF, 2022).

[**] This bottom up country inventory include doors, assembled floor panels and, or other supplementary wood products for house building like windows (see also Appendix B: "oversized wood inventories").

Table 3
Qualitative feedback acquired from the national experts (FI, IE, LT, NL, SE) about material substitution options for houses (see Acknowledgements for the names of the national experts).

Survey: which material substitution options are applicable for housing? Wood products	Purpose	Finland (FI)	Ireland (IE)	Lithuania (LT)	Netherlands (NL)	Sweden (SE)
A. OSB or Plywood	Internal walls	Gypsum	Masonry blocks	Gypsum, blocks & bricks (plaster)	Gypsum	Gypsum, MDF blocks
B. CLT, LVL, wooden beams, Brettstapel etc.	Structural elements for housing	Solid wood	Concrete, reinforced steel	Steel, reinforced concrete, lightweight blocks (AAC), clay blocks	Reinforced concrete	Concrete
C. solid wood parts, hardboard or MDF with laminate cover	Flooring	Linoleum, stone, full laminate, carpet	Stone, carpet	Stone, linoleum, full laminate, carpet	Tiles	Plaster, full Laminate, Textile, Linoleum
D. Wooden windows	Window frames	aluminium	PVC	PVC, aluminium	Aluminium, PVC	Aluminium

extraction, product manufacture, product use, product end-life (recycled use) to energy recovery or landfill. Biogenic emissions are not included, as they are accounted for in the ecosystem, as implied emissions to the atmosphere upon harvest of forests. Substitution impacts at the product or functional unit level are measured by a so called displacement factor or DF (Table 4), expressed as fossil emissions avoided when using one unit of a wood-based product in place of an alternative product or energy carrier (Leskinen et al., 2018).

In a global review, Leskinen et al. (2018) derived an average product-level DF of 1.2 tonne C (tC) emissions avoided per tC of wood products used, equal to about 1.1 tonne CO_2 m^{-3} of wood product with a density 500 kg m^{-3}. The outcome is corresponding with the overall market DF of 0.55 tC avoided per tC of harvested wood, identified by Hurmekoski et al. (2021). This latter is equal with 1.0 tonne CO_2eq. m^{-3} of a wood product, assuming a sawmill efficiency of 50% from stem (harvested roundwood) to construction wood. A third review of DFs was recently undertaken for construction and other wood uses in amongst others FR, FI and DE (Myllyviita et al., 2021). The DF's of the third overview are extracted from the available literature resources and are included in Table 4. A brief survey among country experts completed the list for IE, LT, NL and SE. At the end, Myllyviita et al. (2021) stated that determination of functional equivalence is not straightforward. A DF calculated for a wood material used in a building without taking the volumes of different products into account may look different from a DF calculated for the whole building. Only very few wood products such as window frames can replace non-wood products with the same functionality.

4. Discussion

For thirty countries, we compiled available data on the use of wood for construction in Europe, like BJC, plywood, OSB and fibreboards and related them to the newly built or committed dwellings in 2017–2021 to identify opportunities for promoting wood as an emission efficient construction material. There are few other studies with such a pan European approach, thus the findings have significant relevance for EU-level policy development, as well as guidance for European national timber market trajectories.

4.1. GHG emission reduction opportunities for using wood for construction

First, there is a trade-off in the near to medium term between enhancing wood-based substitution through increased wood harvests and the use of forests for carbon sequestration, as illustrated by numerous studies (e.g. Valade et al. 2018, Jonsson et al. 2021b, Skytt

Table 4
Example displacement factors across some European countries, derived from our brief survey and literature reviews (Leskinen et al., 2018; Hurmekoski et al., 2021; Myllyviita et al., 2021).

Displacement factors (DF's) wood for construction	Global overview	France (FR)	Finland (FI)	Germany (DE)	Ireland (IE)	Lithuania (LT)	Netherlands (NL)	Sweden SE)
		In: Myllyviita et al. (2021)			Brief survey national country experts (see Acknowledgements)			
What is the average displacement factor (DF)? Limited to wood elements for construction of dwellings	1.2 t C per t C in wood products (Leskinen et al., 2018) 0.55 tC per tC of harvested wood* (Hurmekoski et al., 2021)	0.169 t C m^{-3} for trusses & flooring (Fortin et al., 2012)	1.1 tC per tC (Hurmekoski et al., 2020, Kunttu et al., 2021) for sawnwood and plywood	0.16-0.24 tC per tC harvested wood* (Böttcher et al., 2012); 1.1-1.62 tC per tC for OSB and plywood (Knauf et al., 2015); 1.66 tC per tC for timber (Härtl et al., 2016).	0.9 - 2 kg CO_2 per kg wood (Styles, 2021)	0.514 t C per tC (Zemaitis et al., 2021).	0.9 tonne CO_2eq. per m^3 of wood (pers. comm. Centrum Hout)	1.10 -1.82 tC per tC (Piccardo & Gustavsson 2021)
Equivalent with tonnes CO_2 m^{-3} of wood for construction	1.1 tonnes CO_2 m^{-3} 1.0 -1.3*	0.62	1.0	0.37-0.55* 1.0-1.49 1.66	0.45-1.0	0.48	0.9	1-1.6

[*] Assumption: sawmill efficiency of stem to sawn wood for construction is about 50% (FAO, ITTO & UN, 2020); another 20% losses occur for the final manufacturing of some EWP's, HIS, 2022 i.e. sawmill efficiency of stem to EWP's is about 40%. See Appendix C for all conversions to tonne CO_2 m^{-3}.

et al. 2021, Soimakallio et al. 2021, 2022, Deng et al. 2022). The EU's Green Deal and its Forest Strategy's objective is to make sure that the forests in the EU are growing, healthy and resilient for decades to come. The strategy aims to ensure that wood is used optimally, in line with the cascading principle, that harvesting remains within sustainable limits and that the requirements of the European Climate Law and the 2050 climate neutrality target are respected, as agreed by all EU MS. In light of the EU's climate targets for 2030 and 2050, wood is not a limitless resource and MS need to take this into account (European Commission, 2021a). Under current EU legislation, MS have to ensure that accounted GHG emissions from land use, land use change and forestry (LULUCF) sector are balanced by at least an equivalent accounted removal of CO_2 from the atmosphere in the period 2021 to 2030 (DG Clima, 2022). For the EU MS, but also for Norway, Switzerland and the UK, it is desirable to have an increase in high quality sawlog harvests. As such, GHG emissions from LULUCF can be partly compensated by an extra long-term build-up of BJC carbon in the HWP pool.

To facilitate this first discussion item, an alternative ratio of BJC production versus total roundwood production in 2017-2020 is compiled as a first indication (Table 5). Currently, this alternative ratio is mostly around 1% in our inventory: twelve countries remain within a range from 0.5% to 1.5%. They probably depend on their own forest resources for BJC products, although high quality timber may be imported as in Ireland, for example (Section 1.2). Further, nine countries have an alternative ratio lower than 0.5%. Most likely, those countries have exported part of their harvested wood (high quality sawlog assortments) for further processing to other European countries. Although a relatively low harvest of sawlogs (applicable for young forests) may be another cause for a low ratio. At the end, our inventory remained with nine countries that have an alternative ratio above 1.5%. Apparently, those latter countries use a larger share of their harvest for BJC products or import a large share of high quality sawlogs or lumber (including tropical timber species) for further processing in their BJC production facilities. Overall, it is valuable and recommendable - in the light of the European circular economy ambitions - to find out to what extent domestically harvested wood plays a role in BJC production.

Second, lower quality pulpwood also has a role to play, in substituting fossil-based counterparts. In current forest practice, we should think of small dimensioned thinning, both from softwood and hardwood stands. Particularly softwood and to a lesser extent hardwood can be used as raw material for wood based panels, like OSB, plywood and fibreboard in our inventory. In line with the new EU Circular Economy Action Plan (European Commission, 2020a), priority should be placed on reusing and recycling all wood-based feedstock resources, from sawmill residues to post-consumer wood wastes. OSB is generally produced from sawmill residues and pulpwood, like in Ireland (Knaggs & O'Driscoll, 2019). So far, the use of post-consumer wood waste in Europe is only practiced in by particleboard industries, with little or no recycling by OSB or plywood manufactures (Höglmeier et al, 2015; Sikkema et al., 2013, 2017). Enhanced circularity of products offers a possibility of maintaining all wood-based products longer in the economy, thereby extending the sequestration effect. Thus use of post-consumer wood waste is desirable as raw material for OSB production. Such an approach, combined with afforestation programmes can maximise the contribution of forests to long-term climate mitigation, helping to maintain strong removals for a net zero balance of GHG emissions beyond 2050 (European Commission, 2021b).

Table 5
Overview of alternative ratio BJC production: total roundwood harvest. Based on average annual volumes in 2017-2020 (Eurostat, 2021a; SSB, 2021; EUWID, 2021; FAOSTAT, 2021; BIS, 2022).

Relative low ratio Below 0.5%		Average ratio Range 0.5%-1.5%		Relative large ratio Above 1.5%	
CY	No BJC production	PT	0.6%	FR	2%
LU		SK	0.8%	CH	3%
MT		EE	1.0%	NO	3%
HR	0.07%	CZ	1.0%	DK	4%
BU	0.22%	PO	1.1%	RO	6%
GR	0.26%	FI	1.1%	BE	8%
HU	0.28%	LV	1.1%	NL	10%
LT	0.30%	IT	1.1%	AT	12%
ES	0.33%	DE	1.1%	GB	14%
		SE	1.2%		
		IE	1.2%		
		SI	1.3%		

4.2. Policy improvements

A particular role exists for policies to support such production and to direct a greater proportion of national forest production towards longer-lived HWP. First, the UNFCCC climate agreement allows for the temporary uptake of carbon by domestically produced wood products. The carbon of exported HWP may be considered (for the country of origin), if the fate of HWP is precisely inventoried in those countries of export. At least imported wood is not applicable for carbon accounting in the importing country according to the underlying IPCC guidelines (IPCC, 2019). In a separate document, the European Commission allows for new categories of 'carbon storage products, including HWP's' to be added in the EU's new carbon accounting period until 2030 (European Commission, 2021c). OSB, plywood and fibreboard are currently represented by wood-based panels with a half-life of 25 years and construction timber by sawn wood of 35 years. Following the outcome of our study, the intake of a new category "Builders' joinery and carpentry (BJC)" is recommended, as its half-life is considerably longer than the 35 years default for sawn wood (Kayo & Tonosaki, 2022; Matsumoto et al., 2022; Sianchuk, Ackom, & McFarlane, 2012). This recommendation is also valid for further integration in the IPCC Guidelines on worldwide reporting of national GHG inventories, assuming that international statistics (UN Comtrade, 2022; FAOSTAT, 2021–2022) shall have sufficient worldwide coverage of the new BJC data.

Second, the European Commission may wish to introduce a Renewable Material Directive (RMD), in which case a Non-biogenic Material Comparator (NMC) would show the average GHG substitution effect. The RMD should be followed by national programs to support the use of biogenic building materials in the house construction sector. The NMC follows the Renewable Energy Directive in the EU (European Commission, 2018), in which a fossil fuel comparator indicates the business as usual emissions for transportation, power production and heating & cooling sectors. The European Commission could imply one European average for material substitution (roughly 1 t CO_2 m^{-3} of wood replaced). The ultimate GHG effect of wood material substitution could be country- and technique-specific, varying from gypsum substitution for non-structural walls, through masonry substitution for structural walls and reinforced concrete substitution for structural floors, to steel substitution for roof trusses. In our inventory, the ultimate GHG effect of material substitution varies from 0.45 to 1.66 ton CO_2 eq. m^{-3} for diverse wood for construction products. Likewise, national policy instruments promoting the diversion and recycling of construction wood products will be needed in unison to more fully capitalise on the carbon storage and possible substitution effects.

4.3. Data availability, omissions, and estimations

First, the inter-secretariat working group on forest sector statistics (IWG, 2020) proposed in 2017 some new trade categories (commodities) for construction in the international harmonised system nomenclature. Per 1 January 2022 those new commodities have been added to Chapter 44 of the European Combined Nomenclature (Eurostat, 2022a): LVL as plywood and Glulam, CLT, I-beams as engineered structural timber products or EWP's for construction. Thus any future inventory on wood for residential and other construction will be affected by the new statistical commodities in Table 6. To calculate the long sequestration

Table 6
New categories of wood products (commodities) for construction in the European Combined Nomenclature (CN) - per 1 January 2022 (Eurostat, 2022a).

Wood products	Code of new commodities	Description in Harmonised system (HS)	Code of old commodities
Oriented Strand Board (OSB)	CN – 6 digit level	Extracted from HS 4410, excluding all particleboard categories	CN – 6 digit level
-OSB*	4410.12 (no changes)	Oriented Strand board	4410.12
Fibreboards		Extracted from HS 4411, excl. all MDF and mediumboard (latter density 500 to 800 kg m^{-3})	
- Hardboard	4411.92 (no changes)	Fibreboard of wood or other ligneous materials**, exceeding a density exceeding 800 kg m^{-3}.	4411.92
- Softboard	4411.94 (no changes)	Fibreboard of wood or other ligneous materials**, with a density not exceeding 500 kg m^{-3}.	4411.94
Plywood*		Extracted from HS 4412	
- plywood*	4412.31 – 39 (no changes)	Plywood, with at least one outer ply of tropical wood, non-coniferous wood, coniferous wood	4412.31 until 4412.39
- laminated veneer lumber* (LVL)	4412.41	LVL, at least one ply of tropical wood	-
	4412.42	LVL, at least one ply of non-coniferous wood	-
	4412.49	LVL, at least one ply of coniferous wood	-
Builders' Joinery and Carpentry (BJC)		Extracted from HS 4418. BJC excl. doors, floors, window frames, shuttering, shingles and shakes	
- Posts and beams	4418.30	Posts and beams other than EWP's	4418.60
- Engineered structural timber products* (EWP's)	4418.81	Glue laminated timber or Glulam	-
	4418.82	Cross laminated timber (CLT or X-lam)	-
	4418.83	I-beams	-
	4418.89	Other EWP's	-
- Other BJC	4418.91	Other BJC, of bamboo	4418.91
	-	Other BJC, laminated timber elements	4418.99 (10)
	4418.92	Other BJC, including cellular wood panels and other	4418.99 (90)
	4418.99	Other BJC, other	-

* The manufacturing of these wood based materials includes non-biogenic glues (Mantanis et al., 2017; Ilgin et al., 2021).
** bagasse, flax, hemp, straw or other non-wood lignocellulosic materials

effect of the new commodities, the published market volumes may need some minor correction for the non-biogenic binder and filler content of wood based panels that are used for construction (FAO, ITTO & UN, 2020).

Second, the European countries have diverging statistics for the number of residential buildings (Table 1): (i) authorisation stage (BE, CY, LV, MT, IT), (ii) start of construction stage (FR) and (iii) newly completed dwelling stage (twenty-three countries). The dwelling numbers of those stages in any one year may differ from each other. Thus the actual wood consumption flows in a certain year are relatively early assigned in case of commissioned or started dwellings and relatively late in case of completed dwellings. Moreover, building rates are likely to be affected from year to year by general economic development. As far as the authors are aware, there are only detailed data available for the average construction times of residential buildings in Austria (Statistics Austria, 2021): 1.7 years for one and two family houses, 2.3 years for multifamily buildings. For comparison, the time interval between the authorisation and the completed stage is 7 to 8 months for one and 16 to 17 months for multi-unit residential buildings in the United States (US Census Bureau, 2021). Overall, the figures of realised wood use for newly completed dwellings may have a delay up to about one and a half years in comparison with expected wood consumption on started dwellings (FR) and even more for authorised dwellings (BE, CY, IT, LV, MT). The Euro-construct dataset (Dorffmeister, 2019, 2020, 2021, 2022) publishes the number of newly finished houses for BE and IT. When we apply that number for the relative growth and also multiply it with the average floor areas (see Appendix B), Belgium moves from the growth to the maturity phase, and Italy would remain in the same phase.

Third, our ratio (construction wood in m^3 per useful floor area in m^2) is based on average figures for Europe, without considering country-level specifics. One example is the applied average density for BJC: i.e. 480 to 500 kg m^{-3}. This is applicable for a mix of coniferous and broadleaved species. In practice, coniferous tree species are most frequently used for BJC (Mantau et al., 2013; Sandhaas et al., 2018). Also, the wood density is highly dependent on the forest growth conditions in a country (see Section 1.2). We did a brief sensitivity analysis for the conversion from kg's to m^3 in two ways. First we applied an average density of 420 kg m^{-3}, for a situation in which all BJC is composed of high quality C24 timber. This conversion results in the largest increase for our ratio in Sweden: from 0.28 to 0.32, while Netherlands would move to the Growth phase. Second, we assumed that Ireland would use only domestic timber (C16) with a wood density of 370 kg m^{-3} for its BJC products: its ratio would increase by 0.01, thus no phase switch. Another example is the provided construction shares in wood based panels consumption for whole Europe. Those are not necessarily applicable for each individual country. We did an extra sensitivity analysis for panels, by including the 5% remaining share for basic flooring (EPF, 2022) on top of the OSB construction share. OSB is the second largest market in our inventory, after BJC (see Appendix B). Overall, all ratios change marginally by 0.01 and all countries remain in the same product development stage as before.

5. Conclusions

Overall, this paper compares the extent of wood use in buildings across twenty-eight European countries using a quantitative metric, and evaluates the level of market development for wood use in new buildings (excluding renovated houses and non-residential buildings like offices and sport buildings) using the BCG matrix. Two countries could not be classified due to the lack of necessary statistical data: GR and LU. Both produced lacking or incomplete data on housing.

The BCG matrix identifies four phases of product development that can be used to target appropriate policy and market interventions.

- Introduction phase. Six countries (CY, ES, HR, IE, NL, PO) have construction wood markets in the introduction phase. Ireland is one of them, with a relatively low ratio of 0.07 (m^3 construction wood versus m^2 newly built dwellings in 2017-2020). Business management need to decide whether to use extra company resources for the next phase. This decision can be facilitated by national governments to allow for extra wood construction support to facilitate climate policy goals. Tax exemption or green mortgage rates of using wood for construction are two examples.
- Growth phase. Another twelve countries are in the growth phase of the BCG matrix, with a ratio larger than 0.10 (m^3 m^{-2}): AT, BE, BG, CZ, DE, DK, IT, SI, SK, PT, RO, GB. State support programs are

needed, to further increase or accelerate the use of construction wood. The Romanian Green House programme is an example of a new initiative at the governmental level.
- Maturity phase. Eight countries (CH, EE, FI, HU, LV, LT, NO, SE) are classified as having a mature construction wood market, with a current negative relative market growth (number of new dwellings in 2021 in comparison with the number in 2017–2020). Any extra investment required can be made by private companies, without government support. Remarkably, most of the maturity phase is filled up by the Baltic States and the Nordic countries. Sweden is an exemplar country, with a long history of using wood for houses. Estonia is the largest user, with a ratio of 0.32 $m^3\ m^{-2}$, and the ambition to become a global leader in the innovative use of wood.
- Decline phase. There are two countries (FR, MT) classified as having wood for construction in the decline phase. In this phase, enterprises must make their own decision whether or not to proceed with wood for construction. Also, the French allocation may be a temporary decline (due to Covid-19 circumstances) and soon be followed by new economic growth of the French construction sector.

Results should support policy developments pertinent to the 2050 climate neutrality objective. This manuscript builds on an earlier article about the contribution of wood-based construction materials for leveraging a low carbon building sector in Europe (Hildebrandt et al., 2017), by highlighting where additional policy measures may be required. As such, the inventory of wood for construction can further be used as a point of departure for increasing the extent of wood use across Europe. By repeating the inventory in future, it will be possible to evaluate whether new polices introduced are successful in terms of reaching consecutive construction wood development stages in the BCG matrix. Per January 2022, new statistical categories on wood for construction are included in the harmonised trade system. LVL and other EWP's are among those commodities and may affect the future ratio of wood for construction.

Declaration of Competing Interest

The authors have no conflict of interest to declare

Data availability

Data will be made available on request.

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Supplementary materials

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