A holistic perspective on the French building and construction GHG footprint

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Abstract. In order to deliver on the Paris agreement, the decarbonisation of the building sector is critical. An accurate assessment of its life cycle GHG emissions is essential to identify emissions hotspots and decarbonisation potentials in order to prepare future policies such as sectoral carbon budgets. However, today a lack of common GHG emissions accounting exists between climate policies and building environmental assessment. The first one relies on the production-based accounting system of national inventories, while the second one takes a life cycle approach, thus accounting for cross-sectoral emissions. As a result, at national level, there is no holistic assessment of the building and construction GHG footprint, which is detrimental to prepare decarbonisation pathways. This research aims to characterise the life cycle emissions of the sector, taking the French case as an example. A thorough analysis of operational direct and indirect emissions as well as embodied emissions allows the identification of emissions hotspots, both at sectoral and geographical levels. The methodology enables an integrated cross-sectoral perspective that is essential for national assessments and future policy interventions. Results show operational emissions represent 65% of the sector GHG footprint. Embodied emissions are mainly due to industry and energy upstream emissions, with roughly 60% imported from abroad. The results can help to identify main decarbonisation levers to reach net-zero emissions by 2050.

Keywords: emissions accounting; carbon footprint; input-output analysis; life-cycle approach; climate policies; building and construction

1. Introduction
The building and construction sector represents 38% of CO₂ emissions worldwide, 28% occurring during building operation, the remaining 10% arising from construction materials and building maintenance [1]. It is a critical sector to decarbonise as material production alone could represent 60% of the remaining global budget [2]. The carbon footprint of the building and construction sector has been subject to global studies ([3] and [4]) and national studies including in Hong Kong [5], Ireland [6], Australia [7], and Switzerland [8], although the scope of emissions is not homogeneous between studies. In France, there has been no precise quantification of the full scope of emissions of the sector. Although it is estimated to represent one third of national emissions [9], it is most probably underestimated due to imported emissions.
The United Nations Framework Convention on Climate Change (UNFCCC) harmonized accounting system enables to identify emitting sectors and track their decarbonisation through time. Four main sectors are displayed as indicated in the IPCC methodological guidelines: (a) energy, (b) industrial processes and product use, (c) agriculture, forestry and other land use (AFOLU), and (d) waste. In France, the CITEPA (Technical Reference Center for Air Pollution and Climate Change) is in charge of elaborating and reporting emissions both to the UNFCCC and to the EU. The “Secten” format is the most widely used by climate policies, e.g. by the French Low-carbon national strategy (SNBC) [10], and differentiates seven macro-economic emitting sectors: (a) industry, (b) residential and tertiary, (c) energy, (d) transport, (e) agriculture, (f) waste, (g) land-use, land-use change and forestry (LULUCF), the latest being also a source of carbon sequestration and storage in wood products. Inside each of them, the source of GHG and air pollutants are reported by SNAP (Selected Nomenclature for Air Pollutants) code that correspond to a detailed level [11].

In contrast, in building environmental assessment emissions are assessed along building’s life cycle according to the EN 15-978 stages [12]. From a macro-scale, they are thus considered cross-sectoral because they are reported in different economic sectors in the production-based accounting (PBA) system of national inventories. Indeed, the ‘residential and tertiary’ Secten sector, that was responsible for 19% of national GHG emissions in 2019 [11], only correspond to the use of fossil fuels and biomass as well as gas leaks during the use phase of buildings. Other significant posts of emissions, such as structural materials or electricity production are reported in the ‘industry’ and ‘energy’ sectors respectively.

Consequently, at macro-scale there is no holistic perspective on the life-cycle emissions caused by buildings. Because of these difference in emissions accounting, the building and construction stakeholders cannot soundly rely on climate policies and a common vision and targets are lacking. In order to create proper carbon budgets for buildings [13] and to guide the building and construction stakeholders in their decarbonisation roadmaps, it is vital to reconcile the two visions.

The study investigates the life cycle emissions of the French building and construction sector and aims to reconcile top-down and bottom-up emissions accounting. It raises several research questions:

What is the weight of the life cycle emissions of the sector in a life-cycle perspective? What are the emission hotspots and the cross-sectoral interactions of interest?

To answer these questions, this article first focuses on the methodology developed to account for the life-cycle emissions of buildings. Then, the results present the sectoral and geographical hotspots.

2. Methodology
The terms ‘operational’ and ‘embodied’ are widely used to describe the heterogeneous emissions associated with the EN15798 life-cycle stages and will be used as a guideline in this study.

2.1. Emissions accounting and calculations
Operational emissions refer to the B6-B7 stages of the EN-15798 and are further decomposed in direct operational emissions and indirect operational emissions. The first ones are related with the use of fossil fuels, biomass and the gas-leak of heat pumps (F-gases), while the second ones are associated with electricity production and district heating whose emissions do not occur at the building site. The construction materials and equipment’s life cycle emissions are called embodied emissions [14]. The ‘direct’ and ‘indirect’ approaches of the GHG protocol [15], e.g. scope 1-2-3 are also used, although they are not directly equivalent to the operational/embodied framework. The reason is the choice of emission factors for energy vectors that can depict either a life cycle approach or a direct combustion approach. With a life-cycle approach, a part of scope 3 is included in operational emissions which
corresponds to the upstream emissions caused by energy vectors (transport, losses). An equivalent between the operational/embodied and the GHG protocol frameworks is given below:

| EN-15978 phases | Direct operational emissions | Indirect operational emissions | Embodied emissions |
|-----------------|-------------------------------|-------------------------------|--------------------|
| With LCA-type emission factors | Scope 1 + Scope 3 | Scope 2 + Scope 3 | Scope 3 |
| With direct combustion emission factors | Scope 1 | Scope 2 | Scope 3 |

As the focus of the article is to incorporate all emissions associated with building’s life-cycle, the results will be presented using LCA-type emission factors taken from ADEME’s *Base Carbone* [16]. They include upstream processes (for example emissions from gas transport). Energy statistics are taken from the yearly energy balance provided by the SDES [17] which is the reference data to study energy flows across sectors.

Recently, embodied carbon is receiving growing attention [18] and numerous studies are trying to quantify the weight of supply-chain emissions, e.g. from construction materials life-cycle. Embodied emissions are generally a blind spot of construction policies [19], although the new Environmental Regulation (RE2020) for new buildings incorporates carbon thresholds since 2022 on both operational and embodied emissions [20]. At national level, calculating embodied emissions is challenging. As for operational emissions, one way could be to combine life-cycle inventory data with material flows statistics in order to assess the GHG impact of individual materials. However, the statistics on materials flows and stocks is lacking [21]. Moreover, a large part does not appear in national inventories because they are imported.

On this study, to overcome these issues, the calculation of embodied emissions follows a top-down approach using input-output analysis (IOA), which is particularly relevant for macro-scale assessment [22], such in this case a national sectoral GHG footprint. IOA has its origins in Leontief pioneering work in the 1940’s [23]. It has been used in environmental assessment since the 1970’s [24], giving rise to Environmentally Extended IO (EEIO) tables that combine economic IO tables with environmental flows data. For more information on IOA theory, the reader is referred to [25]. To analyze the rising environmental transfers between regions, multi-regional EEIO (MR-EEIO) have been flourishing in the last decades to study GHG, materials, lands, water and waste footprints and are now considered the state of the art to calculate footprint-type indicators [26]. On the other hand, IOA is not adequate to study the use phase of building because it has little information of specific contribution of energy use [27]. Among the different databases available, Exiobase [28] will be used in this study thanks to its large sectoral decomposition (163 sectors, 200 products) that can prevent from aggregation errors [29]. Plus, it has the largest set of environmental extensions so that the same methodology can be applied to other footprint-type calculations such as resources. The 2019 product by product (*pxp*) table is used, as it represents the latest year with accurate GHG emissions data.

Two different calculation methods and different data sources are used to determine operational and embodied emissions but they can be aggregated in order to depict the life-cycle emissions of the building and construction. Below, the table summarizes the vocabulary and the calculation process used for this study.
Table 2. Sum up of the emission calculation methodology

|                  | Direct operational emissions | Indirect operational emissions | Embodied emissions |
|------------------|------------------------------|-------------------------------|-------------------|
| EN-15978 stages  | B6-B7                        | A1-A5, B1-B5, C1-C4           |                   |
| GHG Protocol scopes | Scope 1 + % Scope 3        | Scope 2 + % Scope 3           | Scope 3           |
| Calculation      | Energy statistics * life-cycle emission factors | Consumption-based accounting |
| Results          | By energy type, for residential and tertiary | By 200 Exiobase products and 8 aggregated sectors |
| Sources          | SDES and Base Carbone       | Exiobase and INSEE            |

2.2. Additional steps for embodied carbon

Embodied emissions gather very heterogeneous sources of emissions, ranging from transportation to end-of-life processes. Contribution analysis is an important tool as it enables the identification of emissions hotspots. In this study, the decomposition by industry described in [30] is used. It gives the GHG weight (e.g. contribution) of the different industries implicated in the construction sector supply chain. It is calculated by:

\[ CA_{\text{sector}} = \mathbf{S} \mathbf{L} \mathbf{y} \]  

(1)

Where \( S \) represents the matrix of environmental extensions (here, the relevant indicator is the GWP100), \( L \) depicts the requirement matrix (also called Leontief matrix) and \( y \) the final demand vector for construction in France. Calculations are handled using pymrio module [31].

The Exiobase ‘Construction work’ sector corresponds to the NACE [32] ‘Construction’ sector that includes civil engineering works, that are out of the scope of this study. In order to remove the associated emissions, the Exiobase 200 symmetric IO table is linked with a 139 symmetric IO table provided by the French statistical office INSEE, which includes a subdivision of the NACE ‘Construction’ sector in four subgroups namely ‘Development of building projects’ (41.10), ‘Construction of residential and non-residential buildings’ (41.20), ‘Civil engineering’ (42) and ‘Specialised construction activities’ (43) for both France and the Rest of the World (RoW). A concordance matrix is created to link the Exiobase 200 products with the INSEE 139 industries classifications, in order to remove the emissions associated with the ‘Civil engineering’.

At last, a concordance matrix is created between the 200 Exiobase products classification and the Secten format. It allows to gather the 200 Exiobase products classification in 8 sectors (representing the Secten sectors minus the ‘residential-tertiary’ sector, plus an additional ‘service’ sector and the inter-sectoral exchanges between the construction sector, labeled ‘construction’). This step adds clarity to the results and enables to couple the present emission accounting with the SNBC sectoral carbon budgets.
3. **Results**

Applying the methodology, emissions statistics and life-cycle emission factors are used to calculate operational emissions. Input-output analysis (IOA) is used to quantify embodied emissions and identify sectoral contributions. The year of reference is 2019 due to data availability. The results are given in Fig. 1 by energy vector for operational emissions, whereas they are reported by economic sectors for embodied emissions.

**Figure 1**: Results for operational and embodied emissions, in MtCO$_2$eq

The operational emissions dominate the sector footprint as they represent 65% of the life-cycle emissions. The combustion of fossil fuels (gas, oil and coal products) causes 75 % of operational emissions while indirect operational emissions represent a relatively small portion compared to other countries because of the low carbon content of electricity in France.

The results differ from [33] as the emission factors and GHG coverage is different. Indeed, using LCA emission factors add nearly 20% of the footprint compared to direct emission factors, although this figure varies between energy vectors.

For embodied emissions, the detailed results of the contribution analysis is given in Fig.2, when all countries are aggregated.
Figure 2: Results for the decomposition analysis of embodied emissions by Exiobase products

The top contributor of the embodied emissions is the ‘Cement, lime and plaster’ sector (included in “Industry”) which represent more than 20% alone. Globally, only 8 sectors out of the 200 Exiobase sectors contribute to more than half of the impact. As shown in Fig. 1, when aggregating the 200 products Exiobase classification with the Secten format, the importance of industry and energy-related upstream emissions is underlined, as they cover 70% of embodied emissions. The results are aligned with [34].

In terms of geographic repartition, the top three foreign contributors to the French construction GHG footprint are China and the aggregated regions of Asia and Africa. When aggregating the results in 3 regions, 40% of the footprint is located in France, while 20% lies in the European Union and 40% in the Rest of the World (RoW). The RoW regions can be further disaggregated to analyze the influence of each regions on the emissions. The repartition is aligned with the recent Haut conseil pour le climat analysis [35].

4. Discussion and conclusion
The present work seeks to capture life cycle emissions caused by buildings. By depicting a thorough analysis of direct and indirect emissions, it is easier to bring emissions inventories and building environmental assessment closer. It is highly relevant when looking at decarbonisation pathways and sectoral carbon budgets, such as the ones stated by the SNBC.

One limitation of the study is that it does not include the emissions associated with land-use changes. Indeed, residential buildings are by far the first source of land artificialisation in France [36]. However, along with carbon credits associated with temporary carbon storage, these emissions are rarely present in most assessments [37], and this study is no exception. What’s more, biogenic carbon is not treated particularly and should deserve more focus in future studies.

Concerning the calculation of embodied emissions, one limitation of the present top-down method is the dependence upon the MRIO database, e.g. Exiobase. Other approaches following a bottom-up perspective could be developed, with the use of emissions factors or carbon standards (in kgCO\textsubscript{2eq}/m\textsuperscript{2}}.
for instance) along with material flow statistics and building archetypes. In future studies, a comparison between top-down and bottom-up methods to estimate embodied emissions could bring valuable insights.

References

[1] UNEP 2021 2021 Executive summary Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector

[2] Müller D B, Liu G, Łovik A N, Modaresi R, Pauliuk S, Steinhoff F S and Brattebo H 2013 Carbon emissions of infrastructure development Environ. Sci. Technol. 47 11739–46

[3] Huang L, Krigsvoll G, Johansen F, Liu Y and Zhang X 2018 Carbon emission of global construction sector Renew. Sustain. Energy Rev. 81 1906–16

[4] Onat N C and Kucukvar M 2020 Carbon footprint of construction industry: A global review and supply chain analysis Renew. Sustain. Energy Rev. 124 109783

[5] Hung C C W, Hsu S C and Cheng K L 2019 Quantifying city-scale carbon emissions of the construction sector based on multi-regional input-output analysis Resour. Conserv. Recycl. 149 75–85

[6] Acquaye A A and Duffy A P 2010 Input-output analysis of Irish construction sector greenhouse gas emissions Build. Environ. 45 784–91

[7] Yu M, Wiedmann T, Crawford R and Tait C 2017 The Carbon Footprint of Australia’s Construction Sector Procedia Eng. 180 211–20

[8] Frischknecht R, Alig M, Nathani C, Hellmüller P and Stolz P 2020 Carbon footprints and reduction requirements: the Swiss real estate sector Build. Cities 1 325–36

[9] Daunay J, Dugast C, Bachelet L and Schmitt-Foudil H 2019 Neutralité & bâtiment 33

[10] Ministère de la Transition Écologique et Solidaire 2020 National Low Carbon Strategy 1–29

[11] CITEPA 2021 Rapport Secten 2021

[12] AFNOR 2012 Norme NF EN 15978

[13] Habert G, Röck M, Steininger K, Lupishek A, Birgisodottir H, Desing H, Chandrakumar C, Pittau F, Passer A, Rovers R, Slavković K, Hollberg A, Hoxha E, Jusselme T, Nault E, Allacker K and Lützkendorf T 2020 Carbon budgets for buildings: harmonising temporal, spatial and sectoral dimensions Build. Cities 1 429–52

[14] Lützkendorf T and Frischknecht R 2020 (Net-) zero-emission buildings: a typology of terms and definitions Build. Cities 1 662–75

[15] WBCSD and WRI 2012 The GHG Protocol: A Corporate Accounting and Reporting Standard Greenh. Gas Protoc. 116

[16] ADEME Documentation Base Carbone

[17] SDES 2021 Bilan énergétique de la France pour 2019

[18] Röck M, Saade M R M, Balouktis M, Rasmussen F N, Birgisodottir H, Frischknecht R, Habert G, Lützkendorf T and Passer A 2020 Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation Appl. Energy 258 114107

[19] Buildings Performance Institute Europe 2022 READY FOR CARBON NEUTRAL BY 2050? ASSESSING AMBITION LEVELS IN NEW BUILDING STANDARDS

[20] Ministère de la Transition Écologique 2021 Décret n° 2021-1004 du 29 juillet 2021 relatif aux exigences de performance énergétique et environnementale des constructions de bâtiments en France métropolitaine

[21] Heeren N and Fishman T 2019 A database seed for a community-driven material intensity research platform Sci. Data 6 1–10

[22] Hertwich E G and Wood R 2018 The growing importance of scope 3 greenhouse gas emissions from industry Environ. Res. Lett. 13
[23] Leontief W 1936 Quantitative Input and Output Relations in the Economic Systems of the United States Rev. Econ. Stat.

[24] Leontief W 1970 Environmental Repercussions and the Economic Structure: An Input-Output Approach Author(s): Wassily Leontief Source: The Review of Economics and Statistics, Vol. 52, No. 3 (Aug., 1970), pp. 262-271 Published by: The MIT Press Stable URL: http://www.jstor.org/stable/1921028

[25] Miller R E and Blair P D 2009 Input–Output Analysis: Fundations and Extensions 768

[26] Minx J C, Wiedmann T, Wood R, Peters G P, Lenzen M, Owen A, Scott K, Barrett J, Hubacek K, Baiocchi G, Paul A, Dawkins E, Briggs J, Guan D, Suh S and Ackerman F 2009 Input–output analysis and carbon footprinting: An overview of applications vol 21

[27] de Koning A, Eisenmenger N and van der Voet E 2013 Topical Paper 1: Resource-efficiency in the built environment - a broad-brushed, top-down assessment of priorities Scenarios and Options towards a Resource 1–40

[28] Stadler K, Wood R, Bulavskaya T, Södersten C J, Simas M, Schmidt S, Usubiaga A, Acosta-Fernández J, Kuenen J, Bruckner M, Giljum S, Lutter S, Merciai S, Schmidt J H, Theurl M C, Plutzar C, Kastner T, Eisenmenger N, Erb K H, de Koning A and Tukker A 2018 EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input–Output Tables J. Ind. Ecol. 22 502–15

[29] Steen-Olsen K, Owen A, Hertwich E G, Lenzen M, Owen A and Hertwich E G 2014 EFFECTS OF SECTOR AGGREGATION ON CO2 MULTIPLIERS IN MULTIREGIONAL INPUT–OUTPUT ANALYSES EFFECTS OF SECTOR AGGREGATION ON CO2 MULTIPLIERS IN MULTIREGIONAL INPUT–OUTPUT ANALYSES Econ. Syst. Res. 5314

[30] Wiedmann T 2017 On the decomposition of total impact multipliers in a supply and use framework J. Econ. Struct. 6 1–11

[31] Stadler K 2021 Pymrio – A Python Based Multi-Regional Input-Output Analysis Toolbox J. Open Res. Softw. 9

[32] Eurostat 2008 Nomenclature statistique des activités économiques dans la Communauté européenne

[33] SDES 2021 Les facteurs d’évolution des émissions de CO2 liées à l’énergie en France de 1990 à 2019

[34] Zhang X, Li Z, Ma L, Chong C and Ni W 2019 Analyzing carbon emissions embodied in construction services: A dynamic hybrid input–output model with structural decomposition analysis Energies 12

[35] Haut Conseil pour le Climat 2020 Maîtriser l’empreinte carbone de la france

[36] The Shift Project 2021 Habiter dans une société bas carbone 80

[37] Hoxha E, Passer A, Saade M R M, Trigaux D, Shuttleworth A, Pittau F, Allacker K and Habert G 2020 Biogenic carbon in buildings: a critical overview of LCA methods Build. Cities 1 504–24