

EDITORIAL

The role of carbon metrics in supporting built-environment professionals

Thomas Lützkendorf¹**Highlights**

Protecting the climate is an indispensable contribution to the conservation of the ecosystem. One approach is to reduce greenhouse gas (GHG) emissions to be within planetary boundaries. The quantification, allocation, assessment and control of GHG emissions affect a variety of actors, for example, manufacturers, planners, designers, clients, investors, contractors, facility managers, policy-makers, regulators, environmental economists, *etc.* To be effective, these actors need indicators to measure and influence GHG emissions associated with the creation and operation of the built environment. This editorial introduces the special issue and considers the creation and use of a coherent set of carbon metrics across different scales: construction products, buildings, neighbourhoods, cities as well as building stocks. Of particular importance is the agreement of clear terms, definitions, system boundaries and calculation procedures. Questions about scalability and aggregation are addressed as well as methodological issues associated with the use of biomass, a fair approach to budget-sharing and the design of emission balances including compensation options (*e.g.* offsetting and sequestration). Complementing the carbon metric approach is the development of a scalable carbon budget to determine the allocation of GHGs to a specific context: building, neighbourhood, city or building stock.

Keywords: buildings; built environment; carbon budget; carbon metrics; cities; greenhouse gases (GHGs); life-cycle analysis; mitigation

1. Introduction

The principle of staying within planetary environmental boundaries is now recognised internationally. This idea is also endorsed by a wide variety of professional groups and institutions and is today reflected in the internationally recognised Sustainable Development Goal (SDG) 13: ‘Take urgent action to combat climate change and its impacts’ (UN 2015). The built environment makes a significant contribution to greenhouse gas (GHG) emissions and thus to climate change. The science is clear (IPCC 2018) and there is broad acceptance of the need to drastically reduce GHG emissions from the built environment over a very short timeframe (fewer than 30 years). Past approaches to energy demand and GHGs have been based on incremental reductions from a baseline year (often 1990 is used). However, this approach fails to sufficiently account for the more meaningful small remaining amount of GHGs that can safely be emitted and how that is shared. It also fails to account for life-cycle emissions in the case of construction products and construction works.

The importance of the GHG emissions and the resulting environmental impacts associated with the built environment is often underestimated due to its cross-sectoral character. Around 30% of all energy-related GHG emissions worldwide come from the operation of residential and non-residential buildings, including direct and indirect emissions (GlobalABC 2018). Another 10% arises in connection with the manufacturing of construction products for building construction and renovation and is caused by energy- and process-related emissions (IEA 2019).

Given the many different actors (both up- and downstream in the supply chain) in creating, operating, maintaining, refurbishing and re-purposing the built environment, a set of key questions for climate protection (*e.g.* staying within a 1.5–2°C range of global warming) arises:

- a) How can the overarching goal of large GHG reductions be allocated for particular places, functions and circumstances?

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- b) Can the overall goal be translated into a quantifiable system of measurement (carbon metrics) that is a transparent, consistent, measurable and scalable system (global, national, city, neighbourhood, site, *etc.*)?
- c) How would a carbon metrics system operate? Who would use it and benefit from it?
- d) What assessment criteria and indicators are needed by built environment decision-makers?
- e) How can specific whole-life targets to be used to ensure actual performance and outcomes?
- f) Given that many existing and new buildings will exist beyond 2050, what emission targets need to be implemented now?
- g) Is differentiation needed for different building types, functions, construction types and location? How this can be done fairly and consistently whilst still meeting the overall target for climate protection?
- h) Can such an approach be used to define a coherent set of responsibilities and actions for each of the different actors?

This special issue examines these questions. It provides a process for creating a coherent set of targets and indicators based on the safe planetary boundary for GHG emissions. The intention is for these indicators to inform decisions and actions for the wide array of built-environment actors.

To limit global warming, the remaining total carbon budget is defined as an overall global target (IPCC 2018). Due to progress in climate science, it may be necessary to further adjust climate-protection goals in terms of the level of GHG reductions, and the timing of those reductions.

2. What are carbon metrics?

One approach is to set carbon budgets, which can be global, national, regional, local, specific project or sectorial. In apportioning a budget of GHG emissions (typically expressed as CO₂e), there are two essential aspects. First, the sum of the parts must not exceed the overall global budget. Second, the process must be accepted as fair, robust and transparent (Klinsky & Mavrogianni 2020). Such goals and approaches are indispensable elements of an overall strategy. They provide the wide range of built-environment actors with the necessary target values and assessment criteria. In order to support targeted climate protection activities with manageable principles, methods and tools, another important element is required: the establishment of assessment rules.

The development of carbon metrics for buildings and cities is understood here as a basis for the quantitative determination of GHG emissions, combined with the aim of assessing them. Assessment can be undertaken by comparing carbon metrics with absolute or relative benchmarks.

A carbon metric can be understood as a standard of measurement of GHG emissions. It is based on transparent, verifiable, traceable, and reliable GHG accounting and assessment at all scales. Such standards are usually developed by a larger group of actors in which scientists as well as representatives of other interested parties are involved, including from politics and industry, as well as consumers and non-governmental organisations. Examples of relevant international standards in the context are shown in **Table 1**. In addition to the examples mentioned, the principles and rules for a carbon performance assessment based on the determination of a 100-year global warming potential (GWP 100) of emitted GHGs are also part of European standards for the environmental performance assessment of construction works, developed in the context of CEN TC 350.¹

The emergence of related standards within the framework of international or national standardisation bodies is not a prerequisite for recognised measurement regulations. Groups, committees or organisations can agree on standardised calculation and assessment processes (*e.g.* RICS 2017; WRI & WBCSD 2013; BSI 2011, UNEP 2009, WRI 2014, EU 2017; CMCE 2016). Key questions are whether and to what extent compromises arise as a result of a consensus-oriented approach and if this leads to deviations away from purely scientific positions.

In addition to the standards mentioned in **Table 1**, the International Organization for Standardization (ISO) provides a complete overview of the results of international standardisation activities in the area of climate change (ISO 2018).

A consensus-based and standardised measurement specification must also meet all the scientific requirements relating to the overall limits of GHG emissions. The following information should therefore always be publicly available:

- Description of the specific object of assessment and its physical, temporal and spatial system boundaries including the naming of components and parameters to be included in an assessment.
- Description of the indicator with a measured parameter, unit of measurement and measurement specification (*e.g.* m², occupant density) if necessary, with references to partial indicators and the basis for a summary.
- Characterisation factors.
- Allowable databases and type of quality assurance.
- Indication of possible reference values.
- Specification of possibilities for the presentation and analysis of the results.

Carbon metrics depend on energy information on the type, source and quality of emission factors and/or the data source. For large-scale observation it is possible to create measurement by remote sensing.

Table 1: Carbon metrics-related international standards: selected examples.

Number	Title	Comments
ISO 14064-1: 2018	Greenhouse gases—Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals	Describes how organisations (<i>e.g.</i> real estate development companies and property investment funds) can report and communicate greenhouse gas emissions
ISO 21929-1: 2011	Sustainability in building construction—Sustainability indicators—Part 1: Framework for the development of indicators and a core set of indicators for buildings	Lists global warming as a main indicator in assessing the contribution of buildings to sustainable development; points to the consequences of climate change in other dimensions of sustainability
ISO 14067: 2018	Greenhouse gases—Carbon footprint of products—Requirements and guidelines for quantification	Applicable to products of all kinds
ISO 21931: 2010 (in revision)	Sustainability in building construction—Framework for methods of assessment of the environmental performance of construction works—Part 1: Buildings	Formulates building-specific requirements for the life-cycle assessment of buildings, including in relation to GWP 100 indicator
ISO 16745-1: 2017	Sustainability in buildings and civil engineering works—Carbon metric of an existing building during use stage—Part 1: Calculation, reporting and communication	Specially developed for determining GHG emissions during the use phase of buildings
ISO 16745-2: 2017	Sustainability in buildings and civil engineering works—Carbon metric of an existing building during use stage—Part 2: Verification	Specifies the requirements for the verification of a carbon metric calculation for GHG emissions of an existing building during the use stage
ISO 21678: 2020	Sustainability in buildings and civil engineering works—Indicators and benchmarks—Principles, requirements and guidelines	Formulates the requirements for the development of performance levels/target values and the description of benchmarks—can be used for GWP 100 and carbon budgets
ISO 21930: 2017	Sustainability in buildings and civil engineering works—Core rules for environmental product declarations of construction products and services	Formulates the requirements for the provision of unassessed information on resource use and the effects on the environment in the life-cycle of construction products, including GWP 100
ISO 14040: 2006	Environmental management—Life cycle assessment—Principles and framework	Establishes the basic principles for life-cycle assessment (LCA)
ISO 14044: 2006	Environmental management—Life cycle assessment—Requirements and guidelines	Provides information on the implementation of LCAs
ISO 14026: 2017	Environmental labels and declarations—Principles, requirements and guidelines for communication of footprint information	'[P]rovides [the] principles, requirements and guidelines for footprint communications for products addressing areas of concern relating to the environment' ^a
ISO 14080: 2018	Greenhouse gas management and related activities—Framework and principles for methodologies on climate actions	Supports the management of GHG emissions as well as the preparation and implementation of mitigation measures

Source: ^a<https://www.iso.org/standard/67401.html/>.

Any kind of institution or organisation producing and using a specific metric must have clear responsibility and authority for the oversight, validity and accuracy of the measurement regulations; the selection of groups (organisations or individuals) involved in the development, and whether there are reasons for the validity to be limited in time. In addition, it is possible to specify which actors can have an influence on GHG emission reductions, with which measures, whether there are interactions or conflicting goals with other indicators, or what are the relevant up- or downstream effects and processes.

3. Assessing the built environment

The elegance of a carbon metrics approach is that it is scalable and therefore can take an overall GHG emissions target and translate that to a specific circumstance. The objects examined in the built environment range from individual buildings to neighbourhoods, districts and cities or from the building stock of institutional and individual owners to the regional and national building stock of the federal states as well as from the areas of need of individual households (here for housing) to economic sectors and areas of action.

When determining GHG emissions in buildings, the carbon metrics approach considers the complete life-cycle. This increases the type and number of objects under assessment because buildings are comprised of a large variety of different types of products, and each individual product can be an object of assessment by itself. As a basis for

determining the carbon performance of buildings, data on GHG emissions during the manufacturing and disposal of construction products, as well as for construction processes, energy provision, transport and other services, are required. Requirements for the completeness of models describing the building structure and its life-cycle are important, possibly in conjunction with cut-off rules.

Construction works (*i.e.* buildings and infrastructures) have special features compared with other goods. They have a long lifespan and useful life, the need for repair and refurbishment, and sometimes the need to adapt to changing use requirements (or behaviour) and/or environmental conditions. The importance of dealing with the factor of time factor is clear. Many decisions are made that only have an impact in the medium to long term. The necessary assumptions and scenarios create uncertainties that must be dealt with appropriately.

The GHG emissions that arise in cities (or that are assigned to them from 'imported' GHGs) require the specification of clear system boundaries. A decision is needed about whether to use a production- or consumption-based accounting approach, or a combination of both. Compared with buildings, the complexity of the assessment task is increased.

4. System boundaries

This short overview alone makes one thing clear: the complexity, interdisciplinarity and multi-scale/multi-actor/multi-sector perspective of the built environment entails a comprehensive approach to the definition and assessment of carbon metrics. It is important that methodological consistency is maintained across all details and levels of action, that results are presented in both aggregated and disaggregated forms, and that gaps in the determination of GHG emissions are avoided by overlapping perspectives. The need to resolve this complexity in the interests of manageability is also apparent. Individual measurement regulations for specific applications are one approach. In addition to the features mentioned above, they must be described in such a way that the following information enables context-specific selection and application:

- Subject (object of assessment) and level of action.
- Needs for assessment results in a decision-making context.
- Actor groups that shall or should carry out a specific application.
- Actor groups to whom the results are directed.
- Indications of possible side effects.
- Indications of possible conflicting goals.

It is essential to clearly define measurement regulations and system boundaries. The narrower are the system boundaries for determining GHG emissions, the easier allegedly it is to avoid or compensate for them. Defining climate- or culturally specific environmental target values is a key task, *e.g.* for GHG emissions in the life-cycle in kg CO₂e/m².yr. A prominent example is SIA 2040 in Switzerland (SIA 2017). Specific measurement regulations have been and are required for this. If future climate neutrality is sought for the built environment, then zero or net zero can be seen as a uniform goal. However, this can be achieved with different means and in compliance with specific measurement regulations adopting specific system boundaries. To reduce the risk of manipulation, a transparent and comprehensible measurement rule is an indispensable basis for statements on climate neutrality. A future carbon budget of zero for the built environment is also a budget in terms of a target value. Specific measurement regulations are still required to show that all GHG emissions could actually be avoided or compensated for.

5. Actions and outcomes

The main purpose of carbon metrics is to aid decision-making and actions at many different levels. It provides an understandable currency of targets that different actors can understand and implement. As the research in this special issue shows, it provides a process for determining a coherent set of targets, and not all buildings will have the same target. In addition, it can provide clear data on whether targets are actually being met.

Politicians in their role as legislators are one potential user group of carbon metrics. In connection with the societal responsibilities to preserve the natural basis of life and safeguarding the future, it is inevitable that legal requirements will limit GHG emissions for the life-cycle of buildings. Several European countries are already working on this. One possible approach is to formulate binding requirements in the form of laws, but to refer to an international or national standard for the calculation and assessment rules—a carbon metric. Data on GHG emissions can also provide the basis for design and decision-making for regional policy-makers and their experts.

The requirements and options for reducing GHG emissions must correspond to the area of work and responsibility of the many different actors, be integrated into decision-making processes and be adaptable to the specific circumstances of the object under assessment.

Other relevant stakeholder groups can use the metrics in the design process (designer, client), provide compliant data (manufacturer, service provider), take on special tasks (auditors, providers of sustainability assessment systems and tools, creators and providers of databases), use the results for their own decision-making processes (valuation professionals, banks) or check compliance with requirements (legislators, funding institutions).

Carbon metrics can also support other decision-making processes. In particular, it can inform management tasks by specific actors in their specific area of responsibility. Composed across all levels of action, it provides a clear system of measurement that is both shared, consistent and comprehensive by embracing all factors influencing GHG emissions in the built environment. This will help planners, mayors, clients, investors, designers, contractors, facility managers, tenants/occupants and material/component suppliers to understand whether a project, building, neighbourhood or portfolio is within the specified range of GHGs. It will also focus actions on how to achieve the target.

6. Contributions to knowledge of this special issue

The papers contained in the special issue cover a broad spectrum of questions. They will be of interest to the scientific community, policy-makers, educators and leading practitioners. Their range illustrates how wide and complex the scientific discussion is for the accounting, assessment and management of GHG emissions and their undesirable effects on the global climate. The respective objects of assessment in the papers range from individual building products and components to whole buildings, neighbourhoods and cities, and up to institutional, regional and national building stocks. The economic sectors relevant to the construction sector, the field of action 'construction and operation of buildings' and the area of need 'housing' are also covered. **Table 2** provides an overview of all the papers. With the exception of a contribution each from Australia and North America, all publications were written by authors from Europe. This shows how intensely the discussion is conducted on the European continent, which aims to become climate neutral by 2050 (EC 2020).

Table 2: Articles in this special issue 'Carbon Metrics for Buildings and Cities: Assessing and Controlling GHG Emissions across Scales', *Buildings & Cities* (2020), 1(1); guest editor Thomas Lützkendorf.

Authors	Title	DOI
T. Lützkendorf	The role of carbon metrics in supporting built environment professionals (Editorial)	10.5334/bc.73
G. Habert, M. Röck, K. Steininger, A. Lupísek, H. Birgisdóttir, H. Desing, C. Chandrakumar, F. Pittau, A. Passer, R. Rovers, K. Slavkovic, A. Hollberg, E. Hoxha, T. Jusselme, E. Nault, K. Allacker & T. Lützkendorf	Carbon budgets for buildings: harmonising temporal, spatial and sectoral dimensions	10.5334/bc.47
K. W. Steininger, L. Meyer, S. Nabernegg & G. Kirchengast	Sectoral carbon budgets as an evaluation framework for the built environment	10.5334/bc.32
R. Frischknecht, M. Alig, C. Nathani, P. Hellmüller & P. Stolz	Carbon footprints and reduction requirements: the Swiss real estate sector	10.5334/bc.38
M. Kuittinen & T. Häkkinen	Reduced carbon footprints of buildings: new Finnish standards and assessments	10.5334/bc.30
B. Bordass	Metrics for energy performance in operation: the fallacy of single indicators	10.5334/bc.35
T. Lützkendorf & R. Frischknecht	(Net-) zero emission buildings: a typology of terms and definitions	10.5334/bc.66
M. Balouktsi	Carbon metrics for cities: production and consumption implications for policies	10.5334/bc.33
T. Fawcett & M. Topouzi	Residential retrofit in the climate emergency: the role of metrics	10.5334/bc.37
A. Parkin, M. Herrera & D. A. Coley	Net-zero buildings: when carbon and energy metrics diverge	10.5334/bc.27
E. Hoxha, A. Passer, M. R. M. Saade, D. Trigaux, A. Shuttleworth, F. Pittau, K. Allacker & G. Habert	Biogenic carbon in buildings: a critical overview of LCA methods	10.5334/bc.46
C. E. Anderson, K. Kanafani, R. K. Zimmerman, F. N. Rasmussen & H. Birgisdóttir	Comparison of GHG emissions from circular and conventional building components	10.5334/bc.55
B. Waldman, M. Huang & K. Simonen	Embodied carbon in construction products: a framework for quantifying data quality in EPDs	10.5334/bc.31
M. Schmidt, R. H. Crawford & G. Warren-Myers	Integrating life-cycle GHG emissions into a building's economic evaluation	10.5334/bc.36

Table 3: Key themes of articles in this special issue ‘Carbon Metrics for Buildings and Cities: Assessing and Controlling GHG Emissions across Scales’.

Author	Object of assessment/scale					Methodological aspect				Application								
	Product/component	Building	Urban district/ neighbourhood	City	Building stock	Construction/real estate sector	Indicator development	Assessment method	Creation of a carbon budget	Reduction requirements	Policy-making	Regulation/standardisation	Tool development	Provision of data	Design: new construction	Design: retrofit	Economic evaluation	Macroeconomics
Lützkendorf (editorial)																		
Habert <i>et al.</i>		■	■	■	■	■		■		■								■
Steininger <i>et al.</i>						■		■										■
Frischknecht <i>et al.</i>						■			■	■								■
Kuittinen & Häkkinen		■						■		■	■							
Bordass		■					■			■	■				■			
Lützkendorf & Frischknecht		■						■		■	■							
Balouktsi				■				■		■								
Fawcett & Topouzi		■						■						■				
Parkin <i>et al.</i>		■					■							■				
Hoxha <i>et al.</i>		■						■										
Anderson <i>et al.</i>	■							■						■	■			
Waldman <i>et al.</i>	■							■					■					
Schmidt <i>et al.</i>		■						■									■	

The spectrum of contributions ranges from a review of the development of indicators in the context of energy performance assessments of buildings (*Bordass*) to the clarification of current methodological questions on the use of wood in the assessment of GHG emissions in the life-cycle of buildings (*Hoxha et al.*) and the development of national assessment methods and standards (*Kuittinen & Häkkinen*) up to various applications, exemplified by a comparison of building components (*Anderson et al.*) and residential retrofit (*Fawcett & Topouzi*) or up to carbon metrics for cities (*Balouktsi*). But the topic goes far beyond the spectrum of the contributions presented here. Many other activities are occurring in the development and use of carbon metrics. **Table 3** shows the key themes that individual papers address.

As an introduction to the collection of publications, *Bordass* is recommended. This paper presents the basic principles and elements surrounding a metric, and also discusses experiences from the past decades in the UK and the problems associated with benchmarking. The paper focuses initially on the operation of buildings and thus on the operational part of an energy and carbon performance assessment. Other publications in this special issue complement this approach by examining the embodied aspects over the complete life-cycle.

An important and newly emerging areas of research is macro-economic considerations relating carbon to the built environment. This involves both cross-sector considerations and the specification of carbon budgets (*Steininger et al.*, *Habert et al.* and *Frischknecht et al.*). To support this topic, an illustration is offered here that shows the existing relationships between sectoral considerations, the dynamics of the building stock as a field of action, the life-cycle of individual buildings and the areas of need of households (**Figure 1**).

Several key points can be drawn from the papers individually and collectively:

- Science makes important contributions by developing science-based targets, which provide the basis for deriving

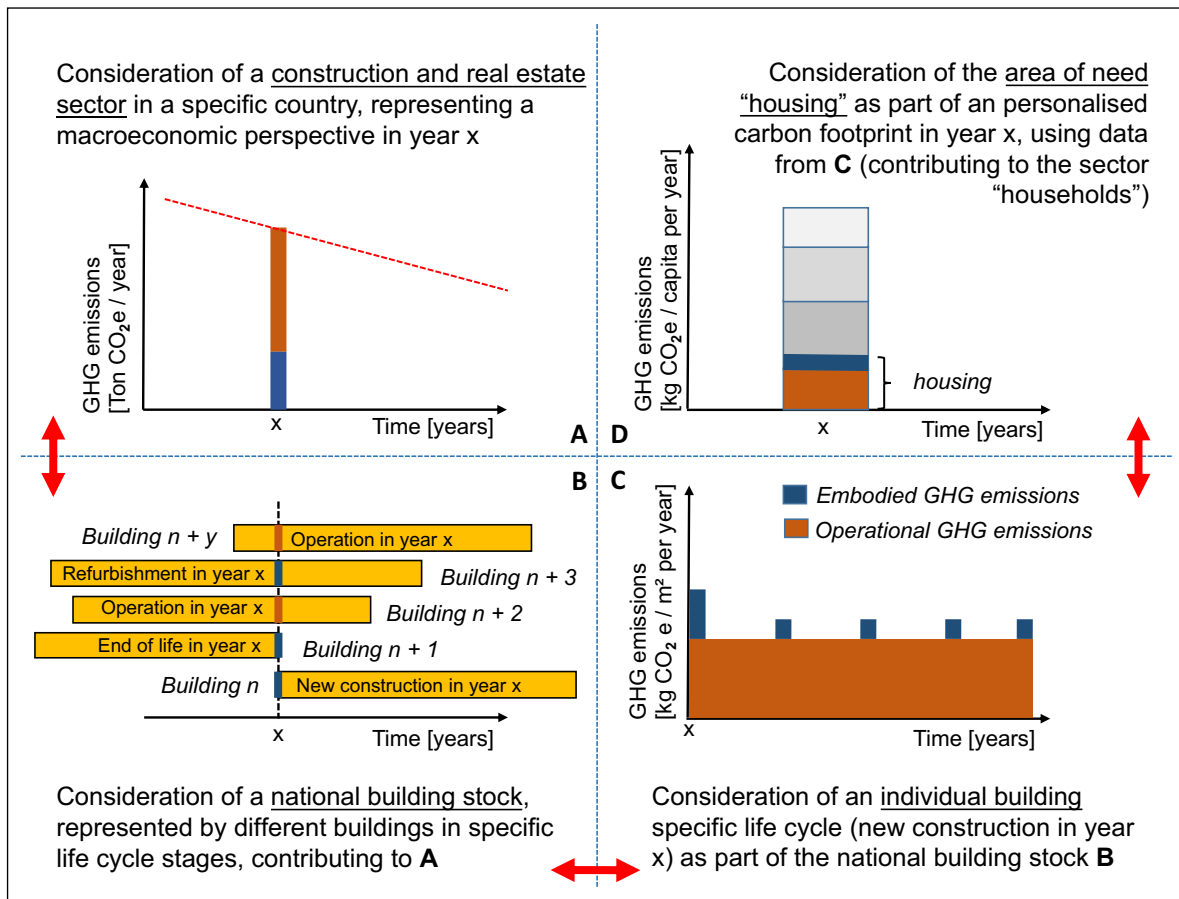


Figure 1: Linkages between different levels of scale and specific objects of assessment.

a global carbon budget. The Intergovernmental Panel on Climate Change (IPCC) provides such global budgets for different temperature thresholds and probabilities. However, the methodological approaches to distribute the global budget fairly among countries as well as the allocation of national budgets to sectors, fields of action and areas of need require further development in order to have targets that are scalable (Steininger et al.).

- Life-cycle assessment (LCA) provides an important tool to quantify and assess GHG emissions in the life-cycle of individual buildings. International and European standards within the framework of ISO TC 59 SC 17 and CEN TC 350 are based on the methodological foundations of ISO 14040 and ISO 14044 and represent a construction-related application. There is an ongoing discussion on selected sub-questions. An important one is how to treat biogenic carbon emissions coming from wood and biomass in LCA (see also Hoxha et al.). These questions must require intensive examination and resolution from a scientific point of view. However, under no circumstances should an ongoing discussion of methods further delay the provision of usable carbon metrics, robust assessment methods and practical tools. These will be needed within the next three years to be able to provide the basis for legal requirements by 2025 for the limitation of GHG emissions over buildings' life-cycle.
- Several different scientific approaches have emerged to address key questions. One example is the consumption-versus production-based approach when accounting for city-level GHG emissions. In the interest of covering all causes/sources and possibilities of influence or action, it can make sense to combine such approaches (Balouktsi). It also becomes clear that districts and cities are becoming increasingly more important objects of assessment and levels of action, and their administrations are becoming important players.
- Cities are currently developing their own initiatives and guidelines as they are closer to some levels of implementation. However, this entails a process involving the scalability of targets from international to national to municipal and even to neighbourhood and building levels—for certain purposes. In addition to the topics covered in the special issue (e.g. Habert et al.), see Sala et al. (2015).
- A shift has occurred in the assessment of GHG emissions in the life-cycle of buildings. Previously, work has advanced the methodological foundations and provided insights into respective magnitudes associated with operational and embodied emissions. This situation has now changed. The uses of a whole-life carbon metric are being incorporated into building permits, purchase and rental decisions, corporate sustainability reporting, valuation and risk analysis, and the determination of financing terms. This has considerable legal consequences and financial implications—particularly on the need for reliable data. This new reliance emphasises the significance in assuring the quality of information on embodied emissions in construction products and the capability to communicate this information

- clearly to third parties (*e.g. Waldman et al.*)
- A carbon metric is not the only element of an environmental performance assessment. For the inclusion of other protected goods—beyond the climate—as well as the identification of side effects, consequences and conflicting goals, it is necessary to embed the assessment of GHG emissions in the concept of multicriteria decision support. A partial aspect is the question of similarities and differences in an assessment of energy performance or carbon performance (*Parkin et al. and Bordass*).
 - A carbon metric can be used as a tool to support real decisions in design and product development. For example, the possible benefits of recyclable components can be assessed systematically. In addition to the resource-saving aspect of such practice, it is now also possible to expand such considerations and include the climate-relevant impacts. *Anderson et al.* explore the recycling of different components under different scenarios. Their findings suggest that not all aspects of the circular economy will lead to carbon reductions and therefore calculations are needed.
 - A significant role of science is to advise policy-makers. This applies not only to the provision of data, methods and tools but also to the use of suitable terms and definitions. *Lützkendorf & Frischknecht* show how important correct terms, definitions and system boundaries are for policy and practice.

Based on the present papers as well as on the additional literature, an attempt can now be made to answer questions a)–h) provided above:

- a) The drastic reduction in GHG emissions is a complex task. It must be integrated into the respective work and responsibility area of all actors who not only have a direct influence on their own decisions and processes but also exert an indirect influence on up- and downstream processes. This is done by taking carbon performance into account in the procurement processes and purchase decisions, and by means of the product properties and results only having an effect in the long term and are made available to third parties along the value chain.
- b) The goal formulated with SDG13 to reduce the negative effects caused by climate change requires operationalisation. In principle, it is a management task. Goals, indicators derived from them, measurement specifications and assessment standards are required. Carbon metric systems provide a basis for determining and assessing GHG emissions. Therefore, they are an indispensable element. However, they should be situated within a comprehensive system for sustainability assessment to: (1) identify side impacts and consequential effects, (2) avoid burden shifting and (3) subject mitigation measures to an environmental performance assessment or, even better, to a complete sustainability assessment. The integration of carbon metrics into an overall environmental performance assessment forms the current work of the International Energy Agency's (IEA) Energy in Buildings and Communities Programme (EBC) Annex 72.²
- c) GHG emissions can be determined in connection to every product or service. In this respect, they are both scalable and cumulative. Application levels range from the product to the building component and the entire building structure, to the building groups and city districts, to the building stocks of individual and institutional actors, cities, regions and countries. Other objects of assessment to be considered are the operation of buildings, energy and transport services, construction processes as well as end-of-life processes, such as repurposing, recycling and disposal. The connection to specific products and services can be established at any time by specifying the object of assessment and its system boundaries as well as by choosing a suitable reference value. It is advisable to choose system boundaries so that they fit the work and responsibility area of the actor whose decisions are to be supported. Care must be taken to avoid double-counting. An example is the combination of a consumption with a production-based approach in order to identify and activate both the influence of producers and demand—see also SDG 12 (Responsible consumption and production).
- d) A carbon metrics system relies upon clear, robust definitions, system boundaries and calculation procedures for industry-specific objects of assessment. In some cases, the results must allow aggregation. The information on the GWP100 in the life-cycle of construction products provides the basis for a carbon performance assessment as part of an environmental performance assessment of buildings. The carbon metric has several roles: (1) a signal of quality to buyers/procurers; (2) as a criterion in sustainability assessment systems (*e.g.* as GWP 100 in sustainability assessment systems such as BNB³ or DGNB⁴ in Germany); (3) as a requirement and proof of achievement in the design process (*e.g.* SIA 2040 in Switzerland); (4) as a prerequisite for the granting of preferential financing conditions (TEG 2020); (5) as a prerequisite for financial support; (6) as target and design values for strategies at the level of cities, companies, administrations and countries; and (7) constituting as part of a (future) product environmental footprint (PEF) (EC 2018). It is expected that a carbon metrics will soon be used in the context of binding legal requirements (see the example of Finland⁵). A carbon metrics system thus also becomes the basis and prerequisite for the development and review of target values, benchmarks and carbon budgets.
- e) For a carbon metric, the GWP 100 is an established and generally recognised indicator. However, the shares to be included (or excluded) have been recently specified. There are special regulations regarding the consideration of biogenic carbon, the inclusion of impacts from land use and land-use change (LULUC) as well as regarding the handling of additional information on the carbon content of products (EN 15804:2020 and ISO 14067:2018) (*Hoxha et al.*).

- f) It is advisable not to use a carbon metric only in the context of predicting GHG emissions. Partial values can be established in such a way that continuous checks in the operation are possible. An example is provided by ISO 16745-1:2017. Even then, it should be noted that GHG emissions can only be calculated using data on energy consumption. Changing emission factors and influences from use, operation or climate must be considered when interpreting characteristic values in comparison with benchmarks. Possibly, benchmarks are to be adapted to a changing type and pattern of use.
- g) Buildings that are newly constructed or renovated today will form a large part of the building stock in 2040, 2050 and thereafter. In most cases, they should be able to be used for at least 20 years without further adaptation. The design of such measures should therefore already be based on requirements that will be imposed on new buildings and existing buildings from 2040 to 2050.
- h) With the general goal of climate neutrality, the way design targets for new construction and renovation projects are dealt with has dramatically changed. In the past, the specific requirements were dependent on the building type, function, construction type, location, *etc.* Today and in the future, however, there must be specific solutions to achieve the uniform requirement of climate neutrality. A carbon metric system is indispensable here since it must guarantee the specific calculation and verification rules, considering all specific boundary conditions and part sizes. The response to question h) is provided below as recommendations for action for public policy, research and practice.

7. Recommendations for action

Several recommendations arise from this special issue for public policy:

- The sectoral analysis of the construction and real estate industries requires a reassessment to include up- and downstream GHG emissions. An underestimation of the importance of buildings' contribution to climate change currently exists (*Habert et al.*).
- Appropriate indicators must be used to formulate clear goals to reduce the adverse impacts on the global climate. The consideration and limitation of non-renewable primary energy use was a typical indicator in the past. This should be supplemented today with other indicators. The reduction of GHG emissions is more suitable for environmental and climatic impacts in relation to ecosystem protection. Both energy performance and carbon performance are equal parts of a life-cycle environmental performance of buildings, so an energy metric remains important (*Fawcett & Topouzi and Bordass*).
- National statistics should be developed to record the GHG emissions caused by the construction and operation of the national building stock. It is essential to compare them with an available carbon budget. An example is provided by *Frischknecht et al.*
- Governments have responsibilities to protect the natural foundations of life and coordinate social and economic development within the limits of an ecosystem's carrying capacity (planetary boundaries). These overarching requirements need translating into specific targets and actual measurements. For the built environment, this means the specification of an overall carbon budget that is scalable down to the life-cycle of individual buildings. *Kuittinen & Häkkinen* provide an important example of developments in this direction. Such requirements must include targets and actions for existing buildings.
- To achieve the current climate protection goals across the full breadth of the market, it is important to provide suitable methodological foundations, data and design tools. The state can promote the development of the fundamentals or make them available free of charge (*e.g.* see the database ÖKOBAUDAT⁶ and the calculation tool eLCA⁷ in Germany).
- Policy and law-makers influence the general conditions under which market participants operate. Wherever possible, greater attention should be paid to the fact that the carbon footprint of buildings is nowadays increasingly considered in the valuation of buildings (*Schmidt et al.*) or in the determination of financing conditions. The latter is currently being discussed by the European Commission in the context of developing a taxonomy (TEG 2020).

Carbon performance assessment (involving valuation assessors, funding agencies, investors, *etc.*) has wider implications for design and construction practice. These include the following:

- Design and construction practitioners (and their organisational bodies) need to engage with the concepts and practices for determining and assessing GHG emissions. They should acknowledge the need to catch up in this area.
- Representatives of the construction product industry should provide additional data on resource use and the effects on the global and local environment associated with the industry average product (suitable for early design stages) through their associations. In addition, greater transparency is needed for product-specific information whose quality can be checked (*Waldman et al.*). Possibilities for checking and communicating the quality of LCA data are the subject of intensive discussions in Europe. There is a need for environment-related product data at the early design stages. Possible sources are generic data or sector environmental product declarations (EPDs) from industry associations for specific product groups. In the case of such sector EPDs, information about the weighting methods and the range should be provided. In later design stages, product- and manufacturer-specific EPDs can be used as source of information. For a deeper analysis of published EPDs, see Anderson & Moncaster (2020). A key task will be to further reduce the GHG emissions associated with the manufacture, use and disposal of their products.

- Valuation professionals and their organisations need to expand how the carbon performance of buildings is taken into account in the appraisal. Although various suggestions exist (RICS 2013), precise guidelines for specific procedures are missing. The question also arises here of how a carbon tax will affect the economic valuation of buildings (see also *Schmidt et al.*).

Notes

- ¹ CEN Technical Committee 350—Sustainability of construction works. European Committee for Standardization (CEN). Retrieved from https://standards.cen.eu/dyn/www/f?p=204:7:0:::FSP_ORG_ID:481830&cs=181BD0E0E925FA84EC4B8BCCC284577F8/.
- ² See <https://annex72.iea-ebc.org/>.
- ³ See <https://www.nachhaltigesbauen.de/en/publications/federal-publications/>.
- ⁴ See <https://www.dgnb.de/en/>.
- ⁵ See [https://www.ym.fi/en-US/Latest_News/Method_for_assessing_the_carbon_footprint\(51474\)/](https://www.ym.fi/en-US/Latest_News/Method_for_assessing_the_carbon_footprint(51474)/).
- ⁶ See <https://www.oekobaudat.de/en.html/>.
- ⁷ See <https://www.bauteileditor.de/elements/>.

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Competing interests

The author has no competing interests to declare.

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