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Net zero emission buildings: next generation of benchmarks and calculation rules

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Abstract. The definition of ambitious life cycle-based benchmarks and target values to limit the GHG emissions of buildings is seen as one of the most important steps in pushing the construction and real estate sector in significantly reducing its contribution to global warming. Especially target values are no longer only developed from a bottom-up perspective. There is now an interest by governments and sustainability assessment system providers in supplementing bottom-up approaches with science-based top-down approaches as part of their responsibility to respect planetary boundaries. The creation of GHG emission budgets in combination with target values, as well as the introduction of strict enough legal binding requirements already today is critical for achieving a climate-neutral building stock. Achieving these tasks requires tackling still open methodological issues. Following the work of IEA EBC Annex 72 and current developments in Germany, the paper presents main questions, key steps, modelling aspects that can cause variation and uncertainties, as well as clarifies key terms and definitions. It is highlighted that although a net zero emission requirement is a universal benchmark, information on system boundaries and calculation rules are still necessary to provide evidence of its fulfilment.

Keywords: buildings, target setting, GHG emissions, planetary boundaries, remaining budget

1. Introduction

The necessity of a drastic reduction in global greenhouse gas emissions (GHGe) is nowadays widely acknowledged. The goal is to reach a state of climate neutrality. Achieving this goal is less tied to some specific, politically defined point in time and more to the scientifically determined remaining budget for GHG emissions which is expected to be used up soon.

However, there are already different definitions of climate neutrality worldwide but also inside Germany. Similar to definitions of sustainability, the German energy agency dena distinguishes between "strong" climate neutrality (GHG emissions and reductions are balanced) and "weak" climate neutrality (the purchase of emission credits is permitted) [1]. The German Federal Environment Agency UBA assumes that in order to prove climate neutrality, in addition to GHGe, all other impacts of human activity on the climate must also be taken into account, e.g. surface sealing by roads and settlements. Among other options, the use of the term greenhouse gas neutrality is recommended [2] – a term also used for the determination of requirements for the national building stock. In Germany, the proportion of energy-related GHGe for the area of action “construction, maintenance and operation” of buildings is 40% when considered across sectors. This corresponds to the share found in international studies [4], while the share particularly for the manufacturing of building products for new construction, replacements add refurbishment is around 10%.

To achieve a climate neutral building stock by 2045 or sooner, buildings should either cause no GHG emissions or offset or neutralise them with approved options. In Germany, for example, this requires that the previous requirements for limiting the “consumption of primary energy, non-renewable” in operation be supplemented by limiting “GHGe, expressed as global warming potential” and expanding the system boundary to cover the whole life cycle. Both the operational and embodied GHGe must then be calculated, assessed and reduced. The relative and absolute importance of embodied impacts is increasing. In the case of energy-efficient buildings, the share of embodied GHGe is already over 50% [5]. In Europe, several initiatives now require the calculation and reporting of GHGe over the entire life cycle of buildings, including LEVEL(s) [6], the draft EPBD [7] and the TAXONOMY [8]. So far, however, no benchmarks have been specified. In several European countries including Germany [9], the introduction of requirements to limit life cycle GHGe of new buildings or refurbishments is currently being discussed with the aim of achieving net GHG neutrality.

The analysis of worldwide activities, guidelines and roadmaps as part of the project IEA EBC Annex 72 [21] has shown that many methodological issues need to be clarified in the context of the development, application and interpretation of benchmarks and target values. The aim of this paper is to map, particularly for top-down targets, the most significant methodological issues and available options. It is important to not focus one-sidedly on aspects of climate protection. Measures to reduce GHGe must themselves be subjected to a sustainability assessment and moreover, other environmental goals, e.g. the conservation of natural resources, must be pursued in parallel. The paper therefore discusses the possibilities of transferring the presented procedure on development, application and communication of GHGe target values to other environmental aspects in future, such as resource conservation.

2. Benchmarks and target values: Basics and perspectives

2.1. Importance of target paths

Target values are defined through the process of target-setting. Target values can serve as general goals in a system of performance levels, i.e. a benchmark system in the context of certification or a funding programme, or as project-specific goals given in the early stages of a building design process (i.e. client’s brief). Target values can also give direction to the further development of legal requirements. The stricter the targets are, the more the preservation of legal certainty in the long run is ensured, as legal requirements tend to progressively become tighter. It is useful for a benchmark system to include more than one target value, and particularly include a system of target levels, where short-, medium- and long-term targets are provided at the same time to describe a “path” (also called “roadmap”). The indication of medium and long-term targets allows industry and construction companies to adjust to more stringent requirements at an early stage. At the same time, funding programs can be geared towards medium to long-term target values. In the field of climate protection, it is common to specify targets for defined time periods or target years, e.g. “Until 2030” or “In the year 2050”.

Examples of such roadmaps already exist in Europe and given future limit values can be seen as today’s targets. For example, both Denmark and Sweden have timetables in place for a progressive tightening of CO2e requirements in their building regulations and in the voluntary sustainability class [10, 11]. Another example is RIBA’s voluntary performance targets for embodied carbon (among others) as part of its 2030 Climate Challenge [12]. Its aim is to align with the future legislative horizon and set out a challenging but achievable trajectory to realise the significant reductions necessary by 2030 for a realistic prospect of achieving net zero carbon for the whole UK building stock by 2050. An overview of roadmaps with net zero targets is provided by Prasad et al. [13]. Common points among all these roadmaps are that they recommend achieving net zero operational GHG emissions, at least for the new buildings, in the short-term while requiring achieving in parallel significant reductions (40-60%) in embodied emissions. In the case of a net zero target in the whole life, some consider it feasible already for the medium-term (2040), while others see it as long-term target.

2.2. Top-down vs bottom-up targets: What's the difference?

The generation of benchmarks and/or target values can follow a top-down or bottom-up approach. Bottom-up derived target values are based on best practices, as well as technical and/or economic feasibility to ensure that they are attainable. Such target values are dependent on the economic cost optimum of a certain moment and technology and are therefore subject to dynamic development resulting from technical progress and changing economic boundary conditions. In general, bottom-up approaches usually are either based on a statistical evaluation (percentile method) of a sample of buildings (real or virtual) to derive different types of values (limit, reference or target values) or an analysis of archetypes or on theoretical values, such as technical and economic optimum values. It is important to highlight that most countries' responsible institutions and organizations still rely on bottom-up approaches to define the strongest 'possible' requirement level for different types of buildings [14].

However, target values can also be derived following a top-down approach. This means that target values are based on global environmental goals or national policy targets translated to individual buildings or to the national, regional or institutional building stock, and are therefore not dependent on the current status of the building stock or what is nowadays technically and economically feasible. A target value derived from such an approach serves more as a benchmark of what is regarded as political necessity (politically defined target). Triggered by the emerging scientific discourse on planetary boundaries (i.e. quantitative thresholds for nine Earth-system processes whose transgression could seriously compromise our well-being) [15], and the need to define a global safe operating space (SOS) within which social and economic development should be coordinated, governments and other institutions are now interested in supplementing bottom-up approaches with science-based top-down approaches as part of their responsibility to protect the natural foundations of life [10]. For the built environment and particularly the goal to reduce GHG emissions, this means that the scientifically defined global CO_2 emission budgets for the 1.5°or 2° scenarios [16], are scaled down to the life-cycle of individual buildings.

There is no doubt that the definition of ambitious environmental target values for the full life cycle of buildings is one of the most important steps in pushing the construction and real estate sector in significantly reducing its environmental impacts. Yet, since science-based targets are not geared towards technical and/or economic feasibility to achieve them, but on a top-down scientifically justified necessity to preserve Earth systems, their immediate adoption would result in socio-economic consequences. In this context, science-based targets can be part of a reduction path, giving time to the industry to adapt.

This paper distinguishes between two types of top-down science-based targets; (1) the (net) zero targets and (2) the budget-based targets. (Net) zero GHG emission target (for the whole life) is the ultimate target while targets based on 'allowable' budgets are needed as interim targets for the transition period before countries' building stocks need to be net zero. This is the case for the following simple reason: If one country was to begin reducing the building stock's GHG emissions to zero e.g. by 2045 only in 2040, the total amount of GHGs emitted would be significantly higher than the GHG budget to which the construction and real estate sector in this country is entitled. Therefore, for a Paris-compatible GHG emission reduction within the available time, it is not only the date by which net zero is achieved that is critical, but also the total amount of GHGs emitted by this sector/ area of action over this period.

This distinction in analysis was necessary as the target of net zero carbon/GHG emissions, also called carbon neutrality or climate neutrality, is seen as a special type of top-down benchmark as it additionally involves balancing and/or offsetting of the residual emissions.

3. Key methodological issues

3.1. General aspects for all kinds of benchmarks: Basics

Overall, at the most essential level, benchmarks can be categorised with respect to system boundaries, i.e. (a) building elements covered in the building model and (b) life cycle stages covered in the life cycle model. Life cycle-based assessment methods, and consequently benchmarks, differ in these scopes.

Concerning the completeness of the building model, variations are significant with the most important being the inclusion/exclusion of mechanical, electrical and plumbing (MEP) services such as

HVAC-systems. For example, based on limited studies that have been carried out so far, MEP could account for nearly 40% of embodied GHG emissions of certain types of new-build projects [16].

In relation to the life cycle model, the determination of GHG emissions associated with a building's life cycle usually includes two parts—an operational part and an embodied part. Based on the modular framework provided by the ISO/TC 59/SC 17 and CEN TC 350 standards to maps the environmental information according to buildings' life cycle stages (A-C and D) (see [17] for an overview of the new structure) the operational part corresponds to module B6. When it comes to the services included under B6, the minimum scope is to focus on regulated building-related energy use (B6.1). Benchmarks may additionally include non-regulated building-related energy use such as indoor transportation (B6.2) and user-related energy use (B6.3), which can account for a significant share of the total operational energy consumption. Especially for net zero GHG emission definitions a full B6 scope to deal with questions of the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity is important. It also reduces the systematic deviations between the calculated energy needs and the real consumption measurement. In the case of B7 (operational water) and B8 (mobility), these have been rarely included in net zero approaches up to now [17]. All these variations in life cycle scope and their effect on creating benchmarks make clear descriptions necessary.

The same applies to the modules comprising the embodied part: while a focus on upfront emissions is expected since they are occurring 'today', the inclusion/exclusion of the replacements of building components (B4), can have a considerable effect since, depending on the replacement rate, this can be comparable to the construction-related embodied part [18]. This choice becomes even more important in the case of net zero GHG emission buildings where the deployment of photovoltaic systems (PVs) is a common measure to achieve this target.

These two system boundary choices are not particular to net-zero or budget-based approaches. How are handled in such targets is part of the discussion in the following two sections.

3.2. The budget-based intermediate target

The growing understanding of climate change being a survival issue for humanity has recently led not only to more far-reaching efforts but also to a wider acknowledgement that solely focusing on marginal improvements is no longer sufficient to stay within the planetary boundaries. How much more effort is needed to be consistent with planetary boundaries until full decarbonisation can only be deducted through the development of top-down interim targets following a budget approach. Overall, top-down carbon budgets are increasingly being used to guide political decision-making. Although a positive development (transparency/comparability), these budgets are still politically defined and not science-based, leading to an ambition gap.

Science-based budget approaches are particularly important for clearly demonstrating the urgency of immediate actions. Starting from the remaining global environmental budgets, it is possible to determine budgets for individual countries and their national building stock as well as individual building types. There are several different approaches for downscaling a given remaining global budget to single countries and industry sectors [19], as well as several studies attempting to downscale to individual buildings to support the design of new single buildings, or the refurbishment of existing ones [20].

A non-binding subdivision of the budget into an embodied and an operational part can further help the design process. Different decision choices are possible at every downscaling step allowing for different configurations. This leads to high variations in target details. Figure 1 provides an overview of the key choices surrounding budget-based target approaches (as identified in the Annex 72 project [21]), in the form of a decision tree. Especially, in budget-based approaches, there is no strict 'right' or 'wrong' approach (i.e. configuration) that shall be applied, but the modelling choices depend on stakeholder's viewpoint on framework assumptions as well as ethical questions [20]. While one can say that the choices leading to a smaller budget for individual buildings are more ambitious, how realistic they are is another issue to examine as budget-based targets are not dependent on technical feasibility considerations (among others). At the minimum, transparency is needed.

Starting with the allocation of a chosen global emission budget to a country (Step 1), different choices are at play. First, there are different options for the global remaining budget, ranging from about 400 to about 2500 $GtCO_2$ depending on the temperature threshold (2 or 1.5 °C), the likelihood of staying under this threshold (50% or 66%), and whether the pathway will be achieved with or without negative technologies [15, 20]. Even if choosing the pathway without negative technologies as the most ambitious one, the choice of the strictest target (66%, 1.5 °C) over the commonly used (66%, 2 °C) would lead to about 70% smaller budget downscaled to the building level, making it one of the largest sources of uncertainty. The next choice is the effort sharing principle used to downscale the global budget to a single country/region level. There is a wide literature about this topic [19] and this choice is subject to questions of equality, capability and historical responsibility among others. Within the specific effort-sharing principles themselves further methodological choices arise, such as whether the current or future population is applied when applying an equal per capita (EPC) principle (this can have an effect on countries' budgets which expect rapid populations changes), or which year should be the 'start' of historical responsibility (1850 as the start of the industrial revolution, 1970 as the beginning of the decade in which scientists increasingly published about global warming, or 1990 as the year of first IPCC Scientific Assessment Report?). It is important to note that such questions are typically asked on a national government level. Therefore, benchmark developers particularly for buildings, use the per capita budgets defined by governments and do not derive such budgets themselves. However, they should be able to understand the rationale behind the assumptions on which national budgets are based and the potential uncertainties associated with current scientific models leading to their future revision.

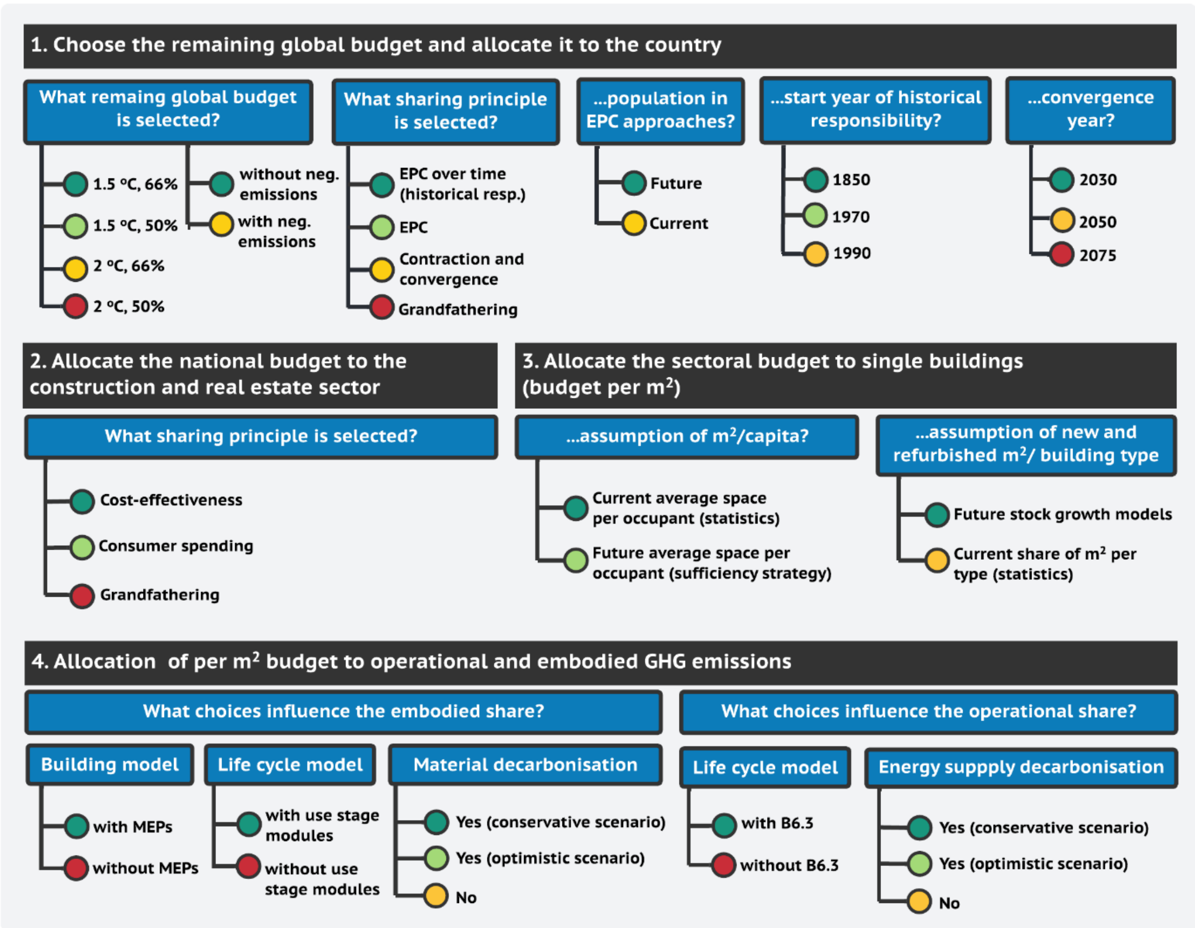

Figure 1. Overview of the key decision steps and choices surrounding budget-based target approaches Note: The options are listed from most ambitious (dark green) to least ambitious (red).

The question of which effort-sharing principle to apply arises also when allocating the national budget to a specific sector (Step 2). Like the allocation of global budgets to countries, the allocation of a budget to sectors or areas of activity does not follow scientific principles. One may choose to either maintain the size of the previous proportions of the sectors/industries and set identical specifications for a percentage reduction (i.e. grandfathering) as a more simplified approach or to look for the options with the most favourable ratio of cost and benefit (i.e. cost-effectiveness) and imposing more stringent budgets on sectors where mitigation efforts may be more cost-effective to implement, among others. Attempts to develop science-based budgets for the full supply chain of a country's real estate sector are seen in Switzerland and Germany [22, 23].

When it comes to deriving budgets per building type or m^2 for individual building types (Step 3), different approaches exist which have been analysed in Habert et al. [20]. To assist designers in identifying hotspots, budgets need to also be divided into life cycle stages, or broadly operational and embodied GHG emission budgets (Step 4). Again, this is a process subject to many assumptions. For example, when it is assumed that the energy supply will be decarbonised by e.g. 2040, then a bigger proportion of the remaining budget is allocated to embodied part compared to following a grandfathering approach where the budget is allocated in analogy to current average embodied/operational GHG emission share per building type (which share is influenced by the selected system boundaries as discussed in Section 3.1).

3.3. Net zero GHG emissions target

The meaning of 'net zero GHG emissions' varies across countries and actors [17]. Subtle differences in the specific details of approaches determine whether net zero GHG emission targets are truly ambitious and contribute to deeply decarbonize the building stock, or whether they cause minimal or no impact at all. These significant differences complicate the comparison of targets and have implications for the additionality of reductions, as well as the integrity of claims. Figure 2 provides an overview of the key distinctions of the net zero GHG emission approaches identified from an analysis performed within the EBC Annex 72 project [21], in the form of a decision tree (i.e. five steps to establish net zero targets). It becomes clear that there is a wide depth and breadth of net zero emission reduction concepts. Mapping and understanding these variations can support the further development of the country-specific assessment approach or definition of net emission buildings and increase target transparency with the aim of achieving greater credibility and ambition.

Starting from the definition of the life cycle scope (Step 1), the range covered under the term 'net zero GHG emission' can be from solely covering the regulated operational part (typically B6.1) to covering the full life cycle (denoted as 'complete operation' + 'complete embodied'). Consensus is needed in connection with reflecting in the term used system boundary scopes other than whole life, e.g. focus on only operational GHG emissions or only upfront GHG emissions. In other words, this huge variation calls for a simplified system of names and/or codes combined with publicly available definitions and system boundaries intending an essential level of transparency.

Regarding the establishment of specific reduction requirements (Step 2), a matter of differentiation is whether a net zero approach requires to pursue all available options to reduce operational and embodied GHG emissions (i.e. energy efficiency measures, low carbon products, circularity, etc.) by setting stringent benchmark values (binding or guiding), before purchasing renewable energy (on-site and/or off-site) or offsets to ultimately bring the emissions balance to zero. In some cases, there are also side requirement in place to limit or to avoid non-energy related GHG-emissions caused by F-gas from construction products or refrigerants. Many approaches adopt such hierarchy of actions, but there are some frameworks that do not [17]. It is evident that this hierarchy ensures that net zero GHG emission buildings put minimal emissions into the atmosphere, before even the balancing takes place, and such approaches are considered more ambitious.

Side requirements can be in place not only for efficiency, but also for increasing renewable energy supply (Step 3). All approaches have such requirements in place and their strictness depend on whether on-site technologies are prioritized over off-site technologies (i.e. the approach requires to first look to identify how much electricity can be generated from on-site renewable sources based on the available surface area, level of shading, etc.), and whether off-site renewable sources of direct ownership or with additionality (i.e. physical PPAs) are preferred over other options. Not all renewable energy procurement contracts guarantee the same quality of renewable energy. A “renewable energy hierarchy” is provided in a recent guide by World Economic Forum [24].

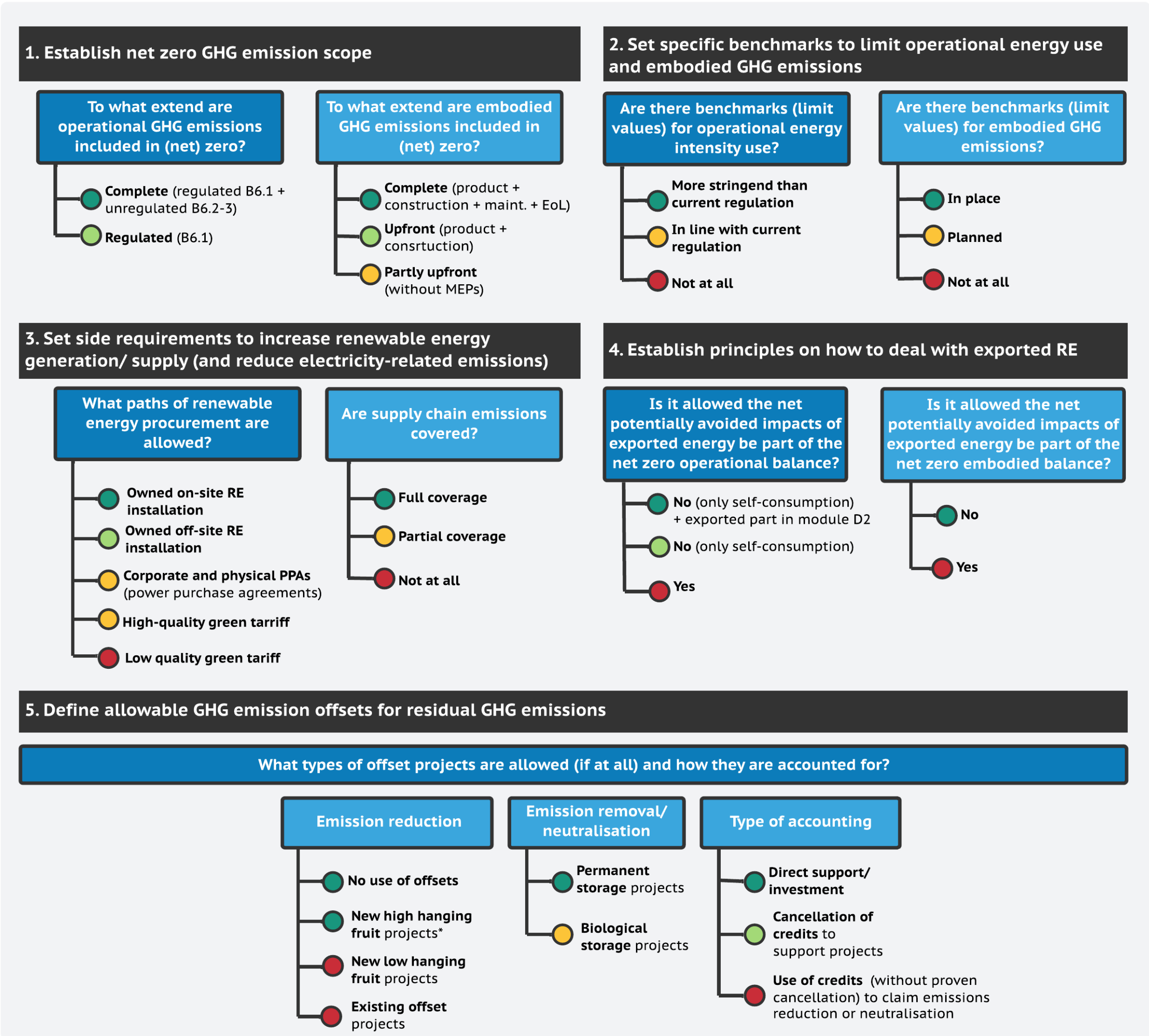

Figure 2. Overview of the key decision steps and choices surrounding net zero GHG emission approaches. Note: The options are listed from most ambitious (dark green) to least ambitious (red)

Another important variation of approaches is the options used to achieve a ‘balance’ (Steps 4 & 5), when this is necessary. A first typology dealing with this question has been provided by Lützkendorf and Frischknecht [25]. In some markets, climates and building typologies, achieving absolute zero operational GHG emissions is feasible without the use of offsets when only the direct GHG emissions are considered. It is possible to design and construct buildings to be highly energy efficient and exclusively powered by renewable energy sources (on-site or off-site), with no residual emissions, i.e. completely decarbonised operationally. However, GHG emissions are possibly still emitted in the upstream and downstream supply chains of technical systems generating renewable energies (production of materials, manufacturing and maintenance of technical systems, end-of-life management) – in future this situation may change [26]. A question is whether exported energy is used as a sort of 'offset credit' by approaches to balance operational emissions outside the self-use boundary, or even embodied GHG emissions (Step 5). The use of net benefits of exported energy in the balance has so far been the most common approach as it allows to reach net zero operational GHG emission incl. supply chains or net zero GHG emission (in the whole life) without the need for carbon offsets (e.g. see [17]). However, exported energy potentially reduces the emissions elsewhere compared to an alternative energy generation or procurement scenario. There is currently a debate as to whether embodied and avoided impacts associated with exported energy shall be given for information only (e.g. in module D2 following latest developments in European standardisation in CEN TC 350 like EN 15643) or considered in the net zero balance. This involves the risk of double counting (credits for both the building under consideration and the purchaser of the exported energy) and should be therefore avoided as much as possible. This risk decreases with a transition from individual net zero GHG emission buildings as the object of assessment towards net zero GHG emission building groups and districts/neighbourhoods (expanded physical boundaries).

It becomes clear that approaches not considering exported energy in balance cannot reach net zero GHG emissions in the whole life, unless it is combined with some sort of investment in offset projects (Step 6). This investment can be direct or be in the form of certificates. Buying certificates can be considered as less binding compared to investments in projects (given that they have the same standing in terms of verification). In terms of the types of allowable offset projects, these can be GHG emission reduction projects or GHG removal projects. Prioritise carbon removal (neutralisation) offsets over reduction offsets (and over balancing approaches) can be considered as more ambitious; although the market for removal offset options is still in its infancy, the transition from reductions to removals is critical because even if the building sector would stop emitting GHG emissions right now, the quantity of emissions in the atmosphere is still vast to stop the warming trajectory [24]. If investment in neutralisation projects is not an option, high-hanging fruit reduction projects (i.e. ambitious and usually higher cost projects that address the least deployable areas of mitigation potential) should be preferred.

4. Checklist

The previous sections make clear that it is useful and necessary to describe all types of benchmarks in detail. ISO 21678:2020 provides general "Rules for the declaration of supporting information" of benchmarks where the type of information that shall be provided by benchmark developers is listed. The information is divided into three parts, namely (A) Basic information, (B) System boundaries and methods, (C) Source and type of information. However, more details shall be provided particularly for net zero and budget-based benchmarks. Tables 1 provides an overview of the documentation requirements mentioned in the standards and Table 2 mainly lists the additional requirements needed for top-down target values.

Table 1. Typical minimum documentation requirement according to ISO 21678:2020.

Part A: Basic Information			
A.01	Name of the indicator	A.05	Reference unit
A.02	Level(s) in the benchmark system	A.06	Region/Climate zone of validity
A.03	Type of building (function and new, refurbished or in-use)	A.07	Period of validity
A.04	More detailed specification if applicable (period and pattern of use)		
Part B: System boundaries and methods			
B.01	Explanation of methods and data bases	B.03.b	Parts of operational energy use covered in detail (B6.1, B6.2 & B6.3)
B.02	Building elements/ parts covered (i.e. building model completeness)	B.04.a	Assumptions, defaults, and choices for the different life cycle modules covered
B.03.a	Life cycle stages covered (i.e. life cycle model completeness based on the modular structure in EN 15978:2021)	B.04.b	Other assumptions and choices (e.g. biogenic carbon, discounting of future emissions, etc.)

Table 2. Additional documentation requirement (in gray) for budget-based and net zero target values. (in gray). Part C is a mixture of typical requirements and additional requirements.

Part B: System boundaries and methods (additional information needs for top-down approaches)			
B.05	Assumptions and choices only relevant for top-down budget-based target values	B.06	Allowable types of balancing and/or offsetting as for the different life cycle stages and modules incl. the hierarchy
		B.07	Timing of balancing and/or offsetting for the different life cycle stages and modules
		B.08	Side requirements for allowable renewable energy procurement options incl. the hierarchy
		B.09	Emission factor of purchased green energy (provider-specific versus generic)
Part C: Source and type of information			
C.01	Source of data if bottom-up (incl. sample size and age)	C.03	Source of target if top-down (standard/ political goal/ global goal or budget)
C.02	Statistical values chosen for the representation of the benchmark (if bottom-up)		

5. Conclusions and outlook

Large differences in key details behind top-down science-based targets for buildings complicate their comparison and make the identification of truly ambitious actors difficult. For budget-based targets, their derivation requires a series of value and modeling choices which should be transparently communicated until societal consensus among the diverse stakeholders is reached on the most appropriate choices. Moreover, during their development, the choices subject to high uncertainty should be examined in the context of sensitivity analyses as well as uncertainties should be communicated to signal that care should be taken when interpreting assessment results based on comparisons with planetary-based targets. For net zero GHG emission targets, differences in their key details, especially in relation to system boundaries and allowable options to achieve a balance affect their credibility. A common framework may be provided as part of the new activity ISO/WD 14068. In the meantime, a mapping of decision steps and choices is here provided for both types of top-down targets to support the further development of the country-specific approaches and increase target transparency.

In addition to reducing GHG emissions, the conservation of natural resources is also important for sustainable development. Particularly embodied GHG emissions are closely interrelated to the issue of resource efficiency. Despite being mentioned in the relevant standards (i.e. EN 15978:2011, under revision), the indicator ADPelement has not yet established itself as an essential indicator for assessing the environmental performance of buildings. If at all, benchmarks for this indicator are based on empirical analyzes according to the best-in-class approach. Concepts and budget/target values for the raw materials use (minerals, ore, biomass, fossil energy carriers) that support a top-down approach are now available and proposed in the literature [26]. The goal is a "resource-light" society [28]. This is comparable to a "climate-neutral" society. This also raises the question of how a per capita can and should be assigned to a m² of new or refurbished buildings to support design. To identify or rule out a burden-shifting to other environmental areas when pursuing climate protection targets, it is recommended to formulate additional requirements for other indicators, including radioactive waste, particulate matter, use of resources, responsible sourcing, as well as to per m^2 benchmarks for biogenic carbon content. There is a need for further discussion and research in this direction.

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