Basics and recommendations on aggregation and communication of building LCA assessment results

A Contribution to IEA EBC Annex 72

February 2023

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Authors

Vanessa Gomes, UNICAMP, Brazil (vangomes@unicamp.br)

Maristela Gomes da Silva, UFES, Brazil

Lizzie Monique Pulgrossi, UNICAMP, Brazil

Contributing Authors

Maria Balouktsi, KIT, Germany
Thomas Lützkendorf, KIT, Germany
Rolf Frischknecht, TREEZE, Switzerland

Imprint:

Published by 2023 Verlag der Technischen Universität Graz, www.tugraz-verlag.at

Editors: Rolf Frischknecht, Thomas Lützkendorf, Alexander Passer, Harpa Birgisdottir, Chang-U Chae, Shivakumar Palaniappan, Maria Balouktsi, Freja Nygaard Rasmussen, Martin Röck, Tajda Obrecht, Endrit Hoxha, Marcella Ruschi Mendes Saade

DOI: 10.3217/978-3-85125-953-7-01

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The official reports from IEA EBC Annex72 are available at following website:
https://annex72.iea-ebc.org/publications

Funding
The work within Annex 72 has been supported by the IEA research cooperation on behalf of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology via the Austrian Research Promotion Agency (FFG, grant #864142), by the Brazilian National Council for Scientific and Technological Development (CNPq, (grants #306048/2018-3 and #313409/2021-8), by the federal and provincial government of Quebec and Canada coordinated by Mitacs Acceleration (project number IT16943), by the Swiss Federal Office of Energy (grant numbers SI/501549-01 and SI/501632-01), by the Czech Ministry of Education, Youth and Sports (project INTEREXCELLENCE No. LTT19022), by the Danish Energy Agency under the Energy Technology Development and Demonstration Programme (grant 64012-0133 and 64020-2119), by the European Commission (Grant agreement ID: 864374, project ATELIER), by the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) in France (grant number 1704C0022), by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Affairs and Climate Action (BMWK, the former Federal Ministry for Economic Affairs and Energy (BMWi)) in Germany, coordinated by the project management agency PTJ (project numbers 03SBE116C and 03ET1550A), by the University of Palermo - Department of Engineering, Italy, by the Research Centre for Zero Emission Neighbourhoods in Smart Cities (FME ZEN) funded by the Norwegian Research Council (project no. 257660), by the Junta de Andalucía (contract numbers 2019/TEP-130 and 2021/TEP-130) and the Universidad de Sevilla (contract numbers PP2019-12698 and PP2018-10115) in Spain, by the Swedish Energy Agency (grant number 46881-1), and by national grants and projects from Australia, Belgium, China, Finland, Hungary, India, The Netherlands, New Zealand, Portugal, Slovenia, South Korea, United Kingdom, and the United States of America.

Preface

This publication is an informal background report. It was developed as part of the international research activities within the context of the project IEA EBC Annex 72. Its contents complement the report “Context-specific assessment methods for life cycle-related environmental impacts caused by buildings” by Lützkendorf, Balouktsi and Frischknecht et al. (2023). The sole responsibility for the content lies with the author(s).

Together with this report, the following background reports have been published on the subject of “Assessing Life Cycle Related Environmental Impacts Caused by Buildings” (by Subtask 1 of IEA EBC Annex 72) and can be found in the official Annex 27 website (https://annex72.iea-ebc.org/):

- Survey on the use of national LCA-based assessment methods for buildings in selected countries (Balouktsi et al. 2023);
- Level of knowledge & application of LCA in design practice: results and recommendations based on surveys (Lützkendorf, Balouktsi, Röck, et al. 2023);
- Basics and recommendations on modelling of processes for transport, construction and deconstruction in building LCA (Soust-Verdaguer et al., 2023);
- Basics and recommendations on influence of service life of building components on replacement rates and LCA-based assessment results (Lasvaux et al., 2023);
- Basics and recommendations electricity mix models and their application in buildings LCA (Peuportier et al., 2023);
- Basics and recommendations on influence of future electricity supplies on LCA-based building assessments (Zhang 2023);
- Basics and recommendations on assessment of biomass-based products in building LCAs: the case of biogenic carbon (Saade et al., 2023);
- Basics and recommendations on influence of future climate change on prediction of operational energy consumption (Guarino et al., 2023);
- Basics and recommendations on discounting in LCA and consideration of external cost of GHG emissions (Szalay et al., 2023);
- Documentation and analysis of existing LCA-based benchmarks for buildings in selected countries (Rasmussen et al., 2023);
- Rules for assessment and declaration of buildings with net-zero GHG-emissions: an international survey (Satola et al. 2023).

Summary

The practice of aggregating LCA-based building assessment results of multiple midpoint indicators into single-score environmental performance indices is gaining ground, at least for comparing assessment results and for communicating with non-LCA specialist groups of actors, like financial institutions. Indeed, interpreting contradictory results of individual impact indicators is a challenging task, and a single environmental index delivers a clearer message on a building's overall performance. This report helps to provide an improved understanding of the possibilities and limitations of partial or full aggregation of environmental performance assessment results.

To illustrate application, the environmental single scores of five case buildings with varied constructive characteristics were obtained through selected aggregation methods and different impact categories groupings. In general, the performance ranking was maintained, regardless of the aggregation approach used. However, rank reversals are possible, particularly when ecotoxicity categories are considered. This exercise also highlights the importance of standardly reporting not only the same impact categories but also the same building components and of including building services in the analysis, for metals directly influence ecotoxicity results. There is no single best method for aggregating the environmental assessment results of buildings.

If required to facilitate performance communication and report single score building results - in regions or countries with data available to allow weighting - LCA practitioners should choose weighting approaches that ensure coherence to the weighting logic, the underlying regional references used and the problem at hand. The weighting factors shall be thoroughly justified. Sensitivity/uncertainty analyses shall be carried out to assess results robustness, to detect potential ranking reversal risks. Such analyses are also useful to consider the effect of different discount rates and geographic-driven weighting factors on the aggregated result when applying monetization approaches. In all cases, weightings and overall aggregation procedure shall be transparently described, and the result of selected indicators (at the minimum GHG emissions) published in addition to the aggregated assessment result. In selected cases, in which partial aggregation is an alternative to full aggregation, it is recommended that they shall be based on endpoint categories.

A detailed summary of this report is available in the following publication: Gomes et al. (2022)[1].

[1] See: https://doi.org/10.1088/1755-1315/1078/1/012093

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Abbreviations

Abbreviations	Meaning
ADP	Abiotic Depletion Potential
AHP	Analytic Hierarchy Process
AP	Acidification Potential
AWARE	Available Water Remaining
BAFU	Bundesamt für Umwelt
BDP	Biodiversity Damage Potential
BE	Belgium
BRE	Building Research Establishment
CED	Cumulative Energy Demand
CEN	European Committee for Standardization
CH	Switzerland
CML	Centrum voor Milieuwetenschappen - Leiden (Center of Environmental Science)
CTU	Comparative Toxic Unit
DALY	Disability Adjusted Life Year
DM	Determination Method
DSF	Depleted Stock Fraction
DTT	Distance-to-Target
EBP	Environmental Building Performance
EC-JRC	EU Commission's Joint Research Centre's Institute for Environment and Sustainability
EN	European Standard
EP	Eutrophication Potential
EPD	Environmental Product Declaration
eq.	equivalent
FAETP	Freshwater Aquatic Ecotoxicity Potential
FW	Fresh Water
GDP	Gross Domestic Product
GHG	Green House Gases
GWP	Global Warming Potential
HTP	Human Toxicity Potential
HWD	Hazardous Waste Disposed
IBO	Austrian Institute for Healthy and Ecological Building
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardization
LCA	Life Cycle Assessment

LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
MAETP	Marine Aquatic Ecotoxicity Potential
MJ	Mega-Joule (10E+6 Joule)
MMG	Milieugerelateerde Materiaalimpact van Gebouw(element)en
NHWD	Non-hazardous waste disposed
NL	Netherlands
NMD	National Environmental Database
ODP	Ozone Depletion Potential
PEF	Product Environmental Footprint
POCP	Photo-Oxidant Creation Potential (Photochemical oxidation)
POP	Persistent Organic Pollutants
PPP	Purchasing Power Parity
RoW	Rest of World
RTI	Radiotoxicity index
RWDHL	Radioactive waste disposed – high level
Sb	Antimon
SBK	Stichting Bouwkwaliteit (Foundation for Building Quality)
TETP	Terrestrial Ecotoxicity Potential
TNO-MEP	TNO shadow prices (Harmelen, A.K. van, et al., 2004)
UBP	Umweltbelastungspunkten (environmental damage in eco-points)
UK	United Kingdom
WTP	Willingness-to-Pay

1. Introduction

Within the framework of an environmental performance assessment, Life Cycle Assessment (LCA) results are available for several impact categories among other information like inventories and/or aspects. Often, drawing the correct conclusions based on a broad variety of environmental impact and/or aspect-related indicators can be challenging. Sometimes, assessment methods choose to select a single LCA indicator perceived as the most important to focus on. Indeed, optimization towards one variable is much more straightforward than doing the same for more than a dozen indicators, and this partly explains the popularity of single-issue approaches like carbon footprint. However, some assessment methods support their users in interpreting disparate LCA results by applying aggregation methodologies to:

a. combine the assessment results of numerous indicators using weighting factors to form an overall result (or several partial results/scores), which is dimensionless. Benchmarking happens at a mid-point level, i.e., a score is assigned to each indicator based on whether given benchmarks were fulfilled (assessment for individual indicators) and then the scores are weighted and combined to produce an overall single score. This type of aggregation is typical for environmental performance assessment as part of sustainability assessments; and
b. derive a fully aggregated indicator with a unit of measurement (e.g., eco-points) and check the fulfilment of benchmarks set at this aggregated level.

A difference between cases (a) and (b) is that in the former all individual indicators are determined and assessed first and then aggregated, while in the latter only the aggregated indicator is used for the assessment. In that case, all initial information is already transformed into this individual aggregated indicator[2]. Special cases combine aggregated indicators with a few other essential indicators (see Switzerland with its KBOB recommendation 2009/1 on Eco-points, Primary Energy and Greenhouse gas emissions).

Aggregating indicator results into single indexes involves the optional LCIA steps of normalization and weighting (ISO, 2006). In general and simple terms, each indicator result is normalised, i.e. divided by normalisation factors connected to reference information which expresses the total impact of a certain region in a reference year. Then, the normalised values can be multiplied by a weighting factor assigned to each indicator. Once they are all expressed on the same basis, they can be added up into a single value. The weighting applied may be equal for each indicator.

Various options are available for both normalisation and weighting. The purpose of weighting is to ensure that the focus is on aspects considered or perceived most relevant. However, while normalisation can be science-based, this is often not the case for weighting schemes, which inherently involve value choices that depend on policy, value systems, and cultural and other preferences (Sala, Cerutti, & Pant, 2018). This clouds its application for many multi-criteria approaches, including LCA. Additional controversy arises when the partial results are usually no longer visible at the first look, and whether insufficiently robust indicators should be included in external communications or in a weighted result until their robustness is improved (Sala et al., 2018).

Several concepts are applied to weighting across impact categories in LCIA (Figure 1), but distance-to-target (DTT), 'monetization', and the social and expert panel-based methods are most often used (Finnveden, 1996), also within the building sector. Some methods opt for equal weights to aggregate environmental indicators (see e.g., IBO (2011)). Each approach has advantages and drawbacks, and the fittest approach is defined by the application conditions and by preferences of individuals or organisations.

[2] In some assessment schemes, such as the KBOB recommendation 2009/1, the initial information, the life cycle inventories, as well as the life cycle inventory results remain accessible.

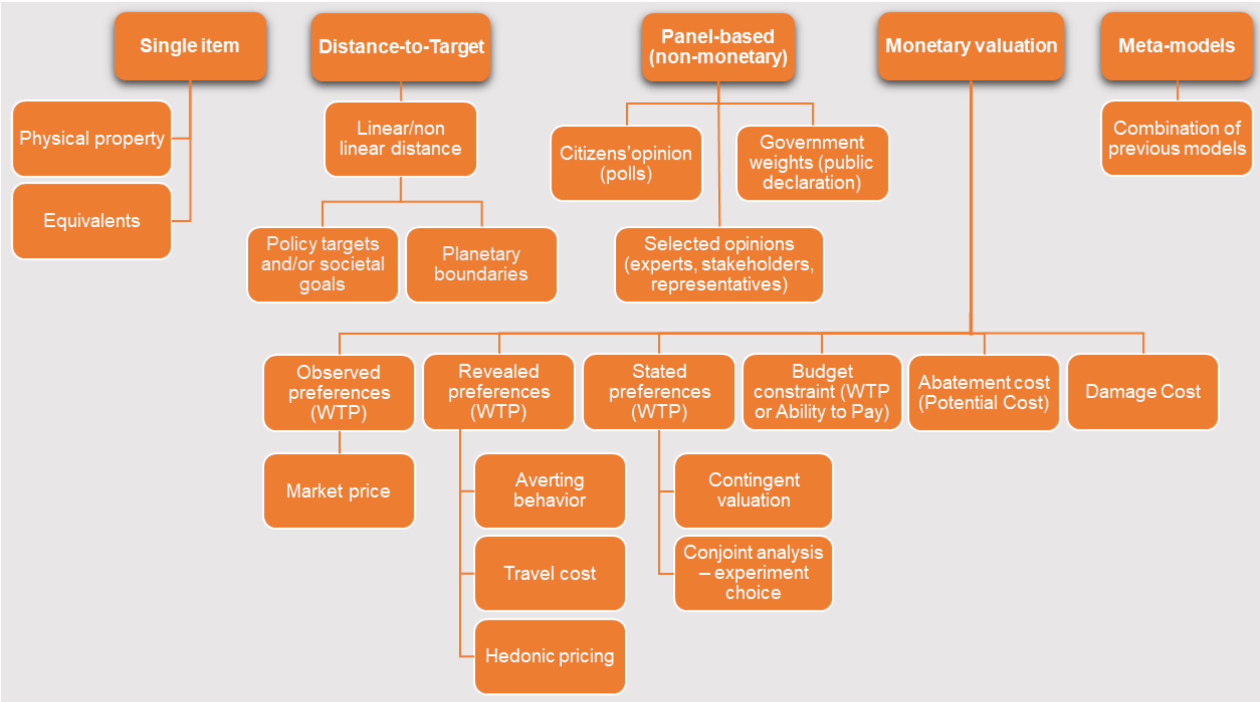

Figure 1: Overview and taxonomy of weighting approaches used in LCIA (Sala et al., 2018)

1.2 Distance to Target

Distance to target (DTT) methods are widely used in LCIA. The ecological scarcity method formed the basis for developing eco-factors for Switzerland (Ahbe, Braunschweig, & Müller-Wenke, 1990; BAFU (Hrsg.), 2021), Germany (Ahbe, Schebek, Jansky, Wellge, & Weihofen, 2014), the European Union and its member states (Ahbe, Weihofen, & Wellge, 2018; Muhl, Berger, & Finkbeiner, 2019).

In distance to target (DTT) methods like the ecological scarcity, critical flows are derived from statistics and policy targets. Weights stem from how far society's activities are from achieving the desired targets. The underlying assumption is that a correlation exists between the seriousness of an effect and the distance between the current and target levels. So, if for achieving a sustainable society impact "A" must be reduced by a factor of 2, and impact "B" must be reduced by a factor of 6, then impact "B" is regarded as three times as serious. An outstanding example in this group is the Swiss eco-factors 2021 method (UBP'21) (BAFU (Hrsg.), 2021), which has been generally applied in Switzerland's policymaking for years and in several applications, including in the building sector. Expressing policy targets in quantitative terms is not always straightforward, though (Castellani, Benini, Sala, & Pant, 2016).

1.3 Monetization

Another way to derive weighting factors in LCA of buildings is through the 'monetary valuation' or 'monetization' of impacts (Pizzol et al., 2016). Monetization is the practice of determining the economic value of non-market goods - i.e., goods for which no market exists - by converting measures of social and biophysical impacts caused by releases of environmentally harmful substances or the use of natural resources into monetary units, based on consideration of external effects that lead to associated (external) costs to society (Arendt, Bachmann, Motoshita, Bach, & Finkbeiner, 2020).

Monetary valuation is applied in cost-benefit analysis to enable the cross-comparison between different impacts and/or with other economic costs and benefits. Such application suggests a great potential to be also applied in the weighting phase of LCA (Pizzol et al., 2016). Indeed, valuing health and environmental impacts as external cost in monetary units for policy-oriented decision support has found increased acceptance worldwide over the past years (Sonnemann, G.; Tsang, 2019).

Monetization is most often based on 'prevention' (aka. 'control or abatement') or 'damage' cost methods. Prevention cost methods value an impact based on marginal cost to securing the relevant policy target for an impact. Doing so requires policy objectives clearly expressed quantitatively (e.g., emission concentration in the air), and cost-effectiveness analyses of all potential prevention measures to enable ranking in monetary terms per prevention (control or abatement) unit, like €/kg emission. The costs of the least cost-efficient measure to meet a given target indicates the value that society is willing to pay or impose on citizens or firms to control that environmental problem (De Nocker & Debacker, 2018). In the construction context, this kind of approach has been used e.g., in the Netherlands by the Dutch Ministry of Public Works' DuboCalc (for infrastructure works), for comparing the environmental profiles of buildings using GreenCalc, and for LCA of buildings and parts using the Dutch Determination Method (Stichting Bouwkwaliteit, 2019).

As quantitative policy objectives are not always available, and at times defined more on political than on scientific grounds (Castellani et al., 2016), damage cost methods are sometimes preferred, like in environmental priority strategies – EPS (Steen, 1999), the Uniform World Model – UWM (Rabl, Spadaro, & McGavran, 1998), the Environmental prices handbook 2017 (CE Delft, 2018), and – specifically in the building sector - the Belgian 'Environmental Material Performance of Building Elements' (MMG) assessment framework (Debacker et al., 2012; Allacker et al., 2020) version valid until July 2021 (MMG2014).

Damage cost methods calculate how emissions or use of resources damage human health and the economy, in terms of additional costs, loss of ecosystem services, reduced income or loss of well-being for current or future generations. Ecosystem damage valuation is based on two elements: first, the damages on nature (say, biodiversity losses) are quantified, then, a value for the loss of biodiversity is needed. Such valuation attempts to estimate the 'demand function' for environmental quality, which is usually determined by how much of their income people are willing to give up for one additional unit of environmental quality or their 'willingness-to-pay' (WTP) for damage avoidance.

Similarly, two elements are needed for human health damage valuation: first, the damages on human health are quantified in terms of, e.g. disability-adjusted life years (DALY). Second, a value of life needs to be determined to monetize the damages, expressed in monetary units/DALY for a certain region. Individual indicators results are hence aggregated by multiplying their respective characterization values (e.g., *X* kg CO_{2eq} or *Y* DALY) by a monetization factor (e.g., *Z* €/kg CO_{2eq} or *W* €/DALY) that indicates the extent of the damage to the environment and/or humans - or the external environmental cost - in monetary terms.

MMG2014 (De Nocker & Debacker, 2018), for example, uses valuation procedures to express eutrophication impacts in €/kg $(PO_4)3-_{eq}$ that combine various costing methods: willingness to pay for eutrophication impacts avoidance; impacts on biodiversity estimated by fate and impact modelling; and 'restoration costs' and 'prevention costs' to meet the objectives for freshwater quality, as required by the European water framework directive. To account for spatial variability, the value is adjusted for differences in GDP per capita (PPP) between Europe and the rest of the world. That same assessment framework expresses impacts on human health in CTUh (comparative toxic units human health) according with the USEtox method (Rosenbaum et al., 2008). Quantification of loss of life expectancy considers that 1 CTUh cancer case equals 11.5 DALY. The valuation follows Equation 1.

Costs of 1 CTUh cancer = (medical care + loss of production)* + loss of life expectancy** **Equation 1**
= €51,429.60* + (11.5 x €53,363.50***)
= €665,11

Where:

* Estimated based on an EU study (Luengo-Fernandez, Leal, Gray, & Sullivan, 2013)
** Loss of life expectancy = number of DALY x Value of a life year lost / DALY
***W-Europe estimate, assuming 1 DALY related to cancer corresponds to 1 YOLL (year of life lost)

1.4 Panel Approach

Finally, in a panel weighting exercise, a number of experts express their perceived severity of a given impact relatively to others in the local/regional/national/global context. In LCIA, a panel approach has been used, for instance, in damage-oriented (endpoint) methods like eco-indicator 99 (Goedkoop & Spriensma, 1999) and ReCiPe (Goedkoop et al., 2013), which combine a series of individual midpoint indicators into three standardized endpoints - human health, ecosystems quality, and resource scarcity - based on scientific factors. As such, value judgment is applied close to the end of the cause-effect chain. In the context of building LCA, the panel-based approach has been used by UK's BRE EN Ecopoints (Abbe & Hamilton, 2017) to convey single-scores of normalised values of indicators mostly based on EN15804+A1.

2. Weighting Approaches Used in Single Score Results of Buildings LCA

2.1 Swiss Eco-factors (UBP) (distance-to-target method)

The Swiss Eco-factors (UBP) according to the ecological scarcity method were first published in 1990 (Ahbe et al., 1990) and last updated in 2021 (BAFU (Hrsg.), 2021). Based on Swiss environmental policy, it allows for a complete picture of the environmental impacts of the use of energy and material resources, land and freshwater use, of emissions in the air, water bodies and soil, of the deposits of residues from waste treatment, of traffic noise and of marine fish (wild catch), expressed in eco-points. It meets the requirements of a true and fair view in terms of environmental information (BAFU (Hrsg.), 2021).

The ecological scarcity method uses the information on the current annual emissions of pollutants and extraction of resources (current flow, see equation below) in or of a country (here Switzerland) and the maximum allowed annual emissions and extractions (critical flow, see Equation 2) according to environmental legislation in that country.

For every environmental pressure, the eco-factor expresses the distance to target and is defined as follows:

$$\text{Eco-factor} = \underbrace{K}_{\substack{\text{Characterization}\\ \text{(if applicable)}}} \cdot \underbrace{\frac{1 \cdot \text{UBP}}{F_n}}_{\text{Normalization}} \cdot \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \cdot \underbrace{c}_{\text{constant}} \qquad \text{Equation 2}$$

Where: K is the characterization factor of a pollutant or a resource
Flow is the load of a pollutant, quantity of a resource consumed or level of a characterized environmental pressure
F_n is the normalization flow: Current annual flow, with Switzerland as the system boundary
F is the current flow: Current annual flow in the reference area
F_k is the critical flow: Critical annual flow in the reference area
c is a constant (10^{12}/a)
UBP is ecopoint, the unit of the assessed result

Environmental pressures may be individual substances emitted to air, water or soil, radioactive and non-radioactive wastes deposited underground, individual resources extracted, or characterised flows to and from the environment. Characterization factors are determined for pollutants and resources that can be allocated to a specific environmental impact (e.g., global warming potential to quantify the greenhouse gas emissions). Here, the effect of a certain pollutant (e.g., the global warming potential of methane) is placed in relation to the impact of a reference substance (carbon dioxide). Table 1 shows the environmental impacts for which characterisation is used. All other emissions of pollutants and resource extractions are normalised and weighted directly, i.e., without characterisation.

Table 1: Characterization methods used in the 2021 version of the ecological scarcity method (BAFU (Hrsg.), 2021)

Environmental impact	Abbr.	Eco-factor (UBP/ref. unit)	Reference unit	Source for characterisation model
Global warming potential	GWP	1000	kg CO_2-eq.	(IPCC, 2013)
Ozone depletion potential	ODP	25'000'000	kg R11-eq.	(UNEP, 2007)
Acidification potential	AP	8'300	kg SO_2-eq.	(Guinée et al., 2001)
Ecotoxicity potential of heavy metals emitted to air		59'000'000	kg Cd-eq.	(Fantke et al., 2018)
Carcinogenic potential of PAH, dioxin, furan and benzene emissions to air	CTU	$2.6 * 10^{11}$	CTUh	(Fantke et al., 2018)
Carcinogenic potential of radioactive emissions to air		110'000	GBq C-14-eq.	(Frischknecht, Braunschweig, Hofstetter, & Suter, 2000)
Human toxicity potential of heavy metals emitted to surface water		6'200'000	kg As-eq.	(Fantke et al., 2018)
Carcinogenic potential of radioactive emissions to surface waters		29'000	GBq U-235-eq.	(Frischknecht et al., 2000)
Carcinogenic potential of radioactive emissions to seas		150'000'000	GBq C-14-eq.	(Frischknecht et al., 2000)
Oestrogenic potential of endocrine disruptors		8'700'000'000	kg E2-eq.	(Rutishauser et al., 2004)
Bioconcentration factor of persistent organic pollutants	POP	59'000'000	kg 2,4,6-tribromphenol-eq.	(Ruiz, Ng, Scheringer, & Hungerbuhler, 2012)
Human toxicity potential of heavy metals emitted to soil		2'800'000	kg Zn-eq.	(Fantke et al., 2018)
Impact potential of plant protection products		280'000	kg glyphosate-eq.	(Fantke et al., 2018)
2000-watt society primary energy resources		8.3	MJ oil-eq.	-
Biodiversity damage potential through land use	BDP	630	m^2.a settlement area-eq.	(Chaudhary & Brooks, 2018; Chaudhary, Verones, De Baan, & Hellweg, 2015)
Freshwater consumption	AWARE	22	m3 water-eq.	(Boulay et al., 2017)
Abiotic depletion potential	ADP	150'000	kg Sb-eq.	(van Oers, Guinée, & Heijungs, 2019)
Depleted Stock Fraction	DSF	1000	kg PS-eq.	(Hélias, Langlois, & Fréon, 2018)
Radiotoxicity of radioactive waste	RTI	54'000	cm^3 HAA-eq.	(NAGRA, 2014)

2.2 The Determination Method – NL (monetization, prevention costs approach)

The 'Determination Method of Environmental Performance of Buildings and Civil engineering works'– together with the National Environmental Database (Nationale Milieudatabase – NMD) and the calculation rules – is managed by the Stichting Bouwkwaliteit (SBK - Building Quality Foundation), in the Netherlands. The NMD database was set up to provide a uniform calculation of the environmental performance of buildings and civil engineering works in the Dutch context. It contains products and activities cards that refer to environmental profiles drawn up in accordance with the Determination Method. These product cards and environmental profiles are used in the various tools to calculate the environmental performance of buildings and civil engineering works.

The Determination Method calculates the material-related environmental performance of buildings and civil engineering works over their entire life cycle in a clear and verifiable manner. The method serves both as PCR that gives instructions for drafting EPDs and the resulting basic profiles and product cards, in a format compatible with EN15804+A1:2013 and suitable for inclusion in the National Environmental Database, and as the calculation rules setting for the computational tools.

The 'Determination Method of environmental performance of buildings and civil engineering works' (Castellani et al., 2016), hereafter 'Determination Method', focuses on the environmental performance of an entire building (or infrastructure work) – the unit to which the performance relates (i.e., the functional equivalent) - instead of on that of individual products. The design and the intended service life define the building products and installations used and the number of replacements over the service life (NMD Foundation, 2020).

The method is structured after the EN 15804:2012 + Amendment A1 standard (CEN, 2013), developed for product-level environmental product declarations (EPDs). Specific rules for drafting and using EPDs for the material-related assessment at building and civil engineering structure level are considered for the Dutch context. The method's monetization approach uses weighting factors (Table 2) to convert the calculated emission values into monetized costs or 'shadow prices', as developed in the RWS report by TNO-MEP (Harmelen, 2004), which supposedly represent the estimated costs that actions to prevent or solve the impact in question would have, i.e., the highest permissible cost level for the government (prevention cost) per unit of emission control.

Each characterized effect score is multiplied by the weighting factor for the corresponding unit, without prior normalization. Once all emission values are collectively expressed in monetary terms, they can be added up into the Environmental Building Performance (EBP), a single score expressed in €/m²GFA*year of lifespan. These weighting factors are determined on a member state level and indicate the (relative) severity of the environmental effects in the country (NMD Foundation, 2020). Only the factor for abiotic depletion (€ 0.16) differs from the original RWS report by TNO-MEP (Harmelen, 2004), which set it to zero.

Until January 1st, 2021, the building environmental profile comprised eleven environmental impact categories (or 'set 1') in accordance with EN 15804+A1 (Table 2). In July 2020, the Determination Method was updated and included a new set of indicators - 'set 2' (NMD Foundation, 2020) to align with EN15804+A2 (CEN, 2019) (Table 3), but the corresponding weighting factors were not found in the searched literature at the time of writing.

Table 2: Indicators describing environmental impact and respective weighting factors ('set 1') within the Dutch Determination Method (Stichting Bouwkwaliteit, 2019)

Environmental indicator	unit	€/unit	
Climate change - GWP 100 yr	kg CO_{2eq}	0,05[3]	
Ozone layer depletion - ODP	kg CFC_{11eq}	30,00	
Photochemical ozone creation - POCP	kg $C_2H_{4\ eq}$	2,00	
Acidification – AP	kg SO_{2eq}	4,00	
Eutrophication – EP	kg $(PO_4)_{3eq}$	9,00	
Human toxicity - HTP	1,4-DCB_{eq}	0,09	emissions
Ecotoxicological effects, aquatic (freshwater) – FAETP	1,4-DCB_{eq}	0,03	
Ecotoxicological effects, aquatic (marine) – MAETP	1,4-DCB_{eq}	0,0001	
Ecotoxicological effects, terrestrial – TETP	1,4-DCB_{eq}	0,06	
Depletion of abiotic resources (excluding fossil energy carriers) - ADP	kg Sb_{eq}	0,16	raw materials[4]
Depletion of fossil fuels - ADP_{ff}	kg Sb_{eq}[5]	0,16	

[3] Each country has its own damage cost values: the Dutch DM factor is about 25% of the German Federal Environment Agency (UBA) estimate, for example.
[4] The factor for abiotic depletion was set as € 0.16 in the DM, whereas the RWS report set it as € 0.
[5] If 'depletion of fossil energy carriers' is available in MJ, the conversion factor of 4.81E-4 kg of antimony/MJ can be used [CMLIA, Part 2b: Operational Annex, page 52], as indicated in Stichting Bouwkwaliteit (2019).

Table 3: Indicators describing environmental impact ('set 2', valid after January 1st, 2021) within the Dutch Determination Method (NMD Foundation, 2020).

Impact category	Indicator	Unit
Climate change - total	GWP - total	kg CO_{2eq}
Climate change – fossil	GWP – fossil	kg CO_{2eq}
Climate change - biogenic	GWP - biogenic	kg CO_{2eq}
Climate change – land use and change to land use	GWP - luluc	kg CO_{2eq}
Ozone layer depletion	ODP	kg CFC_{11eq}
Acidification	AP	mol $H+_{eq}$
Freshwater eutrophication	EP-freshwater	kg $(PO_4)_{3eq}$
Seawater eutrophication	EP-seawater	kg N_{eq}
Land eutrophication	EP-land	mol N_{eq}
Photochemical ozone formation	POCP	kg $NMVOC_{eq}$
Depletion of abiotic raw materials - minerals and metals	ADP minerals and metals	kg Sb_{eq}
Depletion of abiotic raw materials - fossil fuels	ADP-fossil	MJ, net cal. val.
Water use	WDP	m^3 world $_{eq}$ deprived
Fine particulate emissions	Illness due to PM	Illness incidence
Ionizing radiation	Human exposure	kBq $U235_{eq}$
Ecotoxicity (freshwater)	CTU ecosystem	CTUe
Human toxicity – carcinogenic	CTU human	CTUh
Human toxicity – non-carcinogenic	CTU human	CTUh
Land use-related impact/soil quality	Soil quality index	Dimensionless

2.3 Belgian MMG Assessment Framework (monetization, damage costs approach – up to July 2021[6])

The Belgian MMG assessment framework follows a hierarchical structure in its calculation model, which allows four levels of analysis: materials (e.g., bricks and mortar), work sections (e.g., a masonry wall), building elements (external / internal wall) and whole buildings (Allacker et al., 2020). This way, a simplified evaluation of at building level can be obtained as the sum of material impact of their building elements, as only databases for selected material, work section and element levels are operational.

The MMG assessment framework considers indicators for environmental impacts and external environmental costs. In the MMG2014 version, valid until July 2021, 14 environmental indicators are divided in two subsets (De Nocker & Debacker, 2018). The seven mandatory environmental impact categories for EPDs expressed in the CEN/TC 350 standard EN 15804+A1 (CEN, 2013): Climate change, ozone depletion, acidification for soil and water, eutrophication, photochemical ozone creation, depletion of abiotic resources (elements and fossil fuels) are called 'CEN indicators' (Table 4). Other seven indicators (named 'CEN+') are aligned with recommendations by the ILCD Handbook (EC-JRC, 2011) and the Product Environmental Footprint (PEF) Guide (EC, 2013). Categories like terrestrial and marine ecotoxicity are not yet translated to environmental costs, due to the lack of reliable monetary values in the literature.

The request of Belgian authorities for aggregated building score outputs stem from the inherent difficulty to make decisions when multiple individual impact scores are offered. As the CEN/TC 350 standards do not consider weighting nor aggregation, the MMG developers opted for an environmental external cost-based weighting method (Allacker et al., 2020). Three optional aggregated environmental scores, expressed in

[6] With the update to CEN/TC 350 standard EN 15804+A2 (CEN, 2019) in July 2021, the MMG assessment approach changed, mainly to be in line with end the European initiatives for LCA of buildings and building products, and to support integration of specific B-EPD data in the TOTEM tool. The current framework considers 19 impact indicators grouped in 12 main impact categories and moved from the previous monetisation approach to adopt the JRC's PEF weighting procedure (Sala et al., 2018). For each individual environmental indicator, the characterised values are first normalised by dividing them with their respective normalisation factors. These factors represent the global impact per capita for a given reference year and allow to express all the results in a dimensionless unit. The normalised results are then multiplied by their respective weighting factors to reflect the perceived relative importance of the environmental impact categories considered. After weighting, the results of the different environmental indicators can be summed up to obtain a single overall score. For details, please see Lam & Trigaux (2021).

monetary value (€) are used: for CEN indicators, for CEN+ indicators, and for an overall single score, which is the sum of both.

Information on damage costs is available for most impact categories, though at different amount and quality. Categories such as terrestrial and marine ecotoxicity are not yet translated to environmental costs, while others like land use impacts on biodiversity, ecotoxicity require proxies such as the costs of typical measures, amount of environmental taxes, or restoration costs (e.g., ecosystems and biodiversity) or configure multi-source and multi-effect problems (e.g., acidification, ozone formation, particulate matter) that complicate prevention cost assessment for single effects, whose targets often reflect short term compromises instead of long term policy objectives, and are seldom used as indicators for social costs (De Nocker & Debacker, 2018).

For most impact indicators, MMG's central estimate is based on damage cost approach and a 3% p.a. discount rate is applied, whilst the low and high estimates account for uncertainty and information from other sources and methods, including that based on prevention costs. External environmental costs may vary regionally, meaning that weight sets derived for Belgium might not apply to other locations. Hence, monetary values have been determined for three regions – Flanders/ Belgium, Western Europe. As most processes related to the life cycle of building products are related to Western Europe (Table 4), only those values are considered for the publicly available version of the method. The monetary values for Flanders/Belgium and the 'rest of the world' are determined for sensitivity analyses sake. MMG explicitly declares that Worldbank's purchasing power parity (PPP[7]) is used to adjust monetary values for differences in GDP/capita between Western Europe and the 'rest of the world' (RoW= 40% of Western Europe values) in cases like acidification of land and water sources, eutrophication, human toxicity and particulate matter impacts (De Nocker & Debacker, 2018).

[7] PPPs enable to compare the output of economies and the welfare of their inhabitants in 'real' terms, as they control price level differences across nations. The PPP concept is used by multilateral institutions like the UN, Worldbank and IMF, policymakers and private sector agents, among others.

Table 4: "CEN" and "CEN+" environmental indicators used in the MMG assessment framework, respective units and monetary values estimates for the aggregated environmental score: the square root of the uncertainty bandwidth (√BW) is used to calculate the low and high estimates from the central value for Western Europe (Allacker et al., 2020)

Environmental indicator (CEN)	unit	√BW	Estimates (€/unit)		
			Low	Central	High
Global warming	kg CO_{2eq}	2	0.025	0,05	0.10
Ozone depletion	kg CFC_{11eq}	2	25	49.1	100
Acidification for soil and water	kg SO_{2eq}	2	0.22	0.43	0.88
Eutrophication	kg $(PO_4)_{3eq}$	3	6.60	20	60
Photochemical ozone creation	kg ethene $_{eq}$	2	0	0.48	6.60
Depletion of abiotic resources: elements	kg SB_{eq}	4	0	1.56	6.23
Depletion of abiotic resources: fossil fuels	MJ, net calorific value	/	0	0	0.0065
Environmental indicator (CEN+)	**unit**	**√BW**	**Estimates (€/unit)**		
			Low	**Central**	**High**
Human toxicity: cancer effects	CTUh	4	166,277	665,109	2,660,434
Human toxicity: non-cancer effects	CTUh	5	28,816	144,081	720,407
Particulate matter	kg $PM2.5_{eq}$	2.6	12.70	34	85
Ionizing radiation: human health effects	kg $U235_{eq}$	3	3.2E-04	9.7E-04	2.9E-03
Ecotoxicity: freshwater	CTUe	5	7.39E-06	3.7E-05	1.8E-04
Water resource depletion	m^3 water$_{eq}$	3	0.022	0.67	0.20
Land use occupation: soil organic matter	kg C deficit	4	3.4E-07	1.4E-06	0.6E-05
Land use occupation: biodiversity flows, loss of ecosystems service	m^2yr	4			
• from urban			0.07	0.30	2.35
• agricultural			1.5E-03	6.0E-03	2.4E-02
• forestry			5.5E-05	2.2E-04	8.8E-04
Land use transformation: soil organic matter	kg C deficit	4	3.4E-07	1.4E-06	0.6E-05
Land use transformation: biodiversity flows	m^2	4			
• from urban land			n/a	n/a	n/a
• from agricultural land			n/a	n/a	n/a
• from forest			n/a	n/a	n/a
• from tropical rainforest			6.90	27	110

2.4 UK BRE EN Ecopoints (panel approach)

In 2015, UK BRE assembled an expert group weighting exercise to create a set of weightings for an aggregated metric (BRE EN Ecopoints) to be reported in addition to the parameters required by EN 15804 standard. The derived weightings can be used in communicating the environmental performance of construction products in BRE decision making tools and building level assessment tools (Abbe & Hamilton, 2017).

The panel assessed the relative importance of eleven EN 15804+A1 environmental indicators (CEN, 2013), preselected as representative of the overall environmental impact of the construction products assessed, whilst ensuring that it reflects the relative importance of the underlying issues within the Western European context (Abbe & Hamilton, 2017). Human and ecotoxicity impacts are excluded, and waste and freshwater use - relevant environmental pressures for construction activities - are counted in (Table 5).

Table 5: Panel-based weighting set derived for the BRE EN Ecopoints aggregation procedure (Abbe & Hamilton, 2017).

Environmental indicator	Indicator	Weighting (%)
Global warming potential (climate change)	GWP	24,1
Net use of fresh water (parameter describing resource use)	FW	15,2
Depletion potential of the stratospheric ozone layer	ODP	13,5
Acidification potential of soil and water	AP	8,4
Eutrophication potential	EP	8,2
Radioactive waste disposed – high level (parameter describing waste categories)	RWDHL	7,0
Abiotic depletion potential for non-fossil resources (elements)	ADP-E	6,6
Formation potential of tropospheric ozone	POCP	5,8
Hazardous waste disposed (parameter describing waste categories)	HWD	5,0
Abiotic depletion potential for fossil resources	ADP-F	4,0
Non-hazardous waste disposed (parameter describing waste categories)	NHWD	2,1

The characterised data for the eleven environmental indicators are referenced to the impact of one European citizen per year, using appropriate normalisation factors. The normalised impact values are then multiplied by the weighting factors for each indicator and their summation gives the single score. The highest BRE EN Ecopoints score indicate the highest environmental impacts. The derived weightings can be used in communicating the environmental performance of construction products in BRE decision making tools and building level assessment tools (Abbe & Hamilton, 2017).

In parallel, a stakeholder panel went through the same survey and procedure used for the expert panel. A multi-criteria decision-making method was used to generate the weights and subsequent prioritisation of the issues in terms of their impact. The chosen option was the analytic hierarchy process (AHP), which uses fuzzy logic to make sense of value judgements, through pairwise comparisons. A detailed description of the weighting exercise consistency, reliability, sensitivity analyses for both the expert and stakeholder panels is provided by (Abbe & Hamilton, 2017).

3. Method

The four approaches for aggregating LCA indicator values into single score results of buildings described in Chapter 2 - distance-to-target Swiss Eco-factors (UBP) 2021 (CH); monetization methods MMG2014 (BE) and Dutch Determination Method (NL); and panel-based weighting method BRE EN Ecopoints (UK) - are examined (Table 6).

Assuming a simplified evaluation at building level as the sum of material impact of their building elements, calculations were illustratively applied to five cases - concrete and masonry school building, a steel-framed laboratory, a concrete-framed and masonry residential high-rise, an office passive building, and a wood-framed building - to shed light on key points to consider when aggregating building scores. These cases had been previously assessed in accordance with the EN15804+A1 (CEN, 2019) and EN15978 (CEN, 2011) standards and using CML-IA baseline and CED methods. Hence, only the corresponding indicators values were available for use, which limited our application. Inventories, LCA assumptions and methodological decisions were the same in all cases, and are not herein detailed, given the focus on aggregation through different perspectives.

Table 6: Aggregation approaches adopted by selected methods used in the building sector

Approach	**Method**			
	UBP'21 (CH)	**MMG2014 (BE)***	**Determination Method (NL)**	**BRE EN Ecopoints (UK)**
Application		*TOTEM tool*		*BREEAM rating tool*
Weighting		damage costs	prevention costs	
Partial/total aggregation	environmental areas and total	"CEN", "CEN+" and total*	total	total
Normalization	yes	yes (Flanders, Western Europe, RoW)	no	yes (Western Europe)
Characterization	yes, for env. impacts in Table 1	yes	yes	yes

distance to target — monetization — expert/stakeholder panel

product level — element level — building level

Note: "CEN" and "CEN+" indicators refer to the terminology used by the MMG2014 assessment framework. See Table 4, in section 2.3.

4. Results

Environmental impact categories considered, indicators within them and weighting/monetization factors used in the different methods vary. Some categories – ODP, AP, EP, POCP – are most often used, but only GWP is present in all selected methods. Hence, Table 7 displays all impact factors (1 unit of impact) relatively to the impact of the emission of 1 kg $CO_{2\text{-eq}}$.

The Swiss Eco-factors method has been generally applied in the country's policymaking for long, and specifically addresses the renowned Swiss 2000-watt society goal. The Swiss Eco-factors (UBP) 2021 weighs ODP much heavier than any other approach: one ODP reference unit is about 25,000 times as serious as one GWP reference unit, which is about 25 to 42 times higher than that assigned by monetization approaches used in the building sector. It notably details assessment of impacts on human health. BRE EN Ecopoints, the panel-based method examined, weighs climate change much heavier than any other impact. Regardless of the approach chosen, panel-based weighting sets incorporate values and subjectivity. Users should be aware and encouraged to routinely carry out sensitivity analyses to test the effects of changes in the weighting set on the environmental impact scores.

Though contrasting factors across methods based on different grounds is not meaningful, comparisons within the same aggregation approach reveals variations to some extent expected, as both criticality perception translated into policy goals and mitigation valuation can vary regionally. For example, MMG2014 applies a factor to abiotic depletion potential excluding fossil energy carriers between 10 times higher than its neighbour Dutch DM, which in turn weighs acidification heavier by about the same factor. In this regard, the SBK value attributes all the prevention costs of reducing SO2 emissions to 'acidification', whereas these costs should be shared with health impacts from secondary particles. Other divergences of the kind are noticeable. The Dutch DM breaks down ecotoxicity into terrestrial, marine and freshwater, while MMG2014 considers only the latter, while distinctively attempts to address built environment specifics like land use occupation and transformation.

Aggregated scores were calculated for the four individual midpoint impact categories for which all methods selected provide a quantitative assessment (GWP, ODP, AP, ADP resources); for the seven CEN midpoint categories (MMG2014 and Determination Method) (Table 8). In general, the performance ranking was maintained, regardless of the aggregation approach used. However, rank reversals are possible, particularly when ecotoxicity categories are considered (marked in yellow). Uncertainties on results of this environmental impact indicators, in LCI data and in impact and damage assessment are high, and experience with them is still limited, as disclaimed in EN 15804+A2. One possibility is to aggregate results with and without those categories for now, as recommended by (Sala et al., 2018) for PEF aggregated scores.

Table 7: Relative single score impact factor of the emission of 1 unit of an impact compared to the impact of the emission of 1 kg $CO_{2\text{-eq}}$ in the methods examined.

Environmental impact	Original reference unit	UBP21 CH	MMG2014 BE	DM NL	BRE EN Ept UK
Global warming potential	kg CO_2-eq.	1	1	1	1
Ozone depletion potential	kg R11-eq (CFC-11-eq)	25,000	982	600	0.56
Acidification potential	kg SO_2-eq.	8.3	8.60	80	0.35
Human toxicity potential	1.4-DCB-eq			1.8	
Human toxicity: non-cancer effects	CTUh		2,881,620		
Human toxicity: cancer effects	CTUh		13,302,180		
Carcinogenic potential of PAH, dioxin, furan and benzene emissions to air	CTUh	2.6×10^{8}			
Carcinogenic potential of radioactive emissions to air	GBq C-14-eq.	110			
Carcinogenic potential of radioactive emissions to surface waters	GBq U-235-eq.	29			
Carcinogenic potential of radioactive emissions to seas	GBq C-14-eq.	150,000			
Oestrogenic potential of endocrine disruptors	kg E2-eq.	8.7×10^{6}			
Bioconcentration factor of persistent organic pollutants	kg 2,4,6-tribromphenol-eq.	59,000			
Impact potential of plant protection products	kg glyphosate-eq.	285			
2000-watt society primary energy resources	MJ oil-eq.	0.0083			
Depletion of abiotic resources: fossil fuels	MJ, net calorific value		0.02		0.17
Depletion of abiotic resources: fossil fuels	kg Sb-eq			3.2	
Abiotic depletion potential (excluding fossil energy carriers)	kg Sb-eq	0.15	31.2	3.2	
Mineral resource extraction	tonnes				0.27
Non-hazardous waste disposed	m^3				0.09
Hazardous waste disposed	m^3				0.21
Radioactive waste disposed (higher level)	m^3 high level waste				0.29
Radiotoxicity of radioactive waste	cm^3 HAA-eq.	54			
Eutrophication	kg $(PO_4)_3$ - eq		400	180	0.34
Photochemical ozone creation	kg (C_2H_4)-eq		9.6	40	0.24
Particulate matter	kg PM2.5-eq		680		
Ionizing radiation: human health effects	kg U235-eq		0.02		
Terrestrial ecotoxicity	1.4-DCB-eq			1.2	
Marine aquatic ecotoxicity	1.4-DCB-eq			0	
Freshwater aquatic ecotoxicity	1.4-DCB-eq			0.6	
Ecotoxicity: freshwater	CTUe		0		
Net use of fresh water	m^3				0.63
Water resource depletion	m^3 water-eq		13.4		
Biodiversity damage potential through land use	m^2.a settlement area-eq.	0.63			
Land use occupation: soil organic matter	kg C deficit		0		
Land use occupation: biodiversity flows. loss of ecosystems service					
from urban	m^2yr		6		
agricultural			6		
forestry			0.12		
Land use transformation: soil organic matter	kg C deficit		0		
Land use transformation: biodiversity flows	m^2				
from urban land			n/a		
from agricultural land			n/a		
from forest			n/a		
from tropical rainforest			540		

Table 8: Environmental LCA single scores of five building cases, considering four categories common to all methods (or seven categories, for MMG2014, Determination Method and BRE EN Ecopoints). The higher the score, the worse (in red) is the performance.

Weighting approach	DTT	Monetization				Expert Panel	
Methods and categories weighted	Swiss Ecopoints 2021	MMG2014 (Western Europe)		Determination Method		BRE EN Ecopoints	
	4 common	4 common	7 common	4 common	7 common	4 common	7 common
Weighted score (per m²GFA·year)	UBP	€				Ecopoints	
School building, concrete-frame, masonry	51,533.15	2.57	4.93	3.63	4.77	1,178.17	3,381.32
Laboratory building, steel-framed, metal cladding	42,061.40	2.10	4.66	2.94	4.16	962.44	2,742.79
Residential high-rise building, concrete-framed, masonry	18,046.26	0.90	1.74	1.25	1.66	414.92	1,144.87
Office passive building	14,010.69	0.70	0.99	0.89	1.04	326.49	974.58
Residential building, wood-framed	8,962,94	0.45	0.66	0.60	0.72	206.69	662.94

4 common categories: GWP, ODP, AP, ADP resources | 7 common categories: GWP, ODP, AP, EP, POCP, ADP resources, ADP ffuels

The adherence of the Determination Method to the available pre-assessed indicators allowed its aggregated score to be fully calculated. When the additional ecotoxicity categories were computed, the school concrete building and the steel-framed laboratory reversed ranks. This is not an inconsistency of the method itself or of the monetization approach, as the methods general structures herein examined are not fully comparable, but rather an expression of how the buildings' materiality (considerably more steel in the lab building) is described by the ecotoxicity indicators added, which also bear high uncertainties, as previously mentioned.

5. Remarks on Discounting when Monetizing Impacts

Monetization approaches may involve discounting after conversion of impacts into financial units, a common practice in economics. Certain impacts take time to manifest themselves into damages that can emerge after years or decades, like air pollutants impacts on human health, while carbon emissions impacts will extend over generations. Hence, in the context of policymaking the costs of mitigation measures taken today are often contrasted with the benefits produced by these actions in the future. Given this short/longer-term trade-off, the way such benefits are valued – i.e., how much guarding against future damage is worth to today's society – guides current policy design and development of cost-effective solutions.

Costs and future benefits differ in their distribution over time and must be brought to a common point in time to become comparable. A centrepiece to do so is discounting, which uses discount rates to put a present value on costs and benefits that will occur at a later date. At an analytic level, the discount rate is therefore a major determinant of the valuation outcomes (i.e., present value of costs and benefits). Its choice greatly influences valuation outcomes when impacts and mitigation measures spread over very long time periods, as for climate change. GHGs long lifespan in the atmosphere requires that the damages expected of their emissions today are valued centuries into the future.

Discounting (using positive discount rates) always gives a lower numerical value to damages in the future than to those happening in the present. This means that using a high discount rate implies that people put less weight on the future and therefore that less investment is needed now to guard against future costs. Contrastingly, when using a low discount rate, more importance is given to future generations' wellbeing in cost–benefit analyses, which supports the view to act now to protect future generations. The notion of discounting ultimately represents a key ethical issue in impact valuation, and becomes critical for issues involving intergenerational equity, such as those referring to environmental degradation and, specially, climate change. Another key ethical parameter is the 'purchase power parity', which indicates if a life-year lost by any world citizen causes the same economic damage regardless of where he/she lives. There is a strong case for using 'social discount rates' (SDR) that factor in both ethical issues (intergenerational and income) equity-and age-weighting. For reflecting the perspective of society, social discount rates are lower than those used by private investors (IPCC, 2007).

There are two reasons for discounting the future. First, because – if the future is wealthier – society may place less weight on future net benefits, and a dollar today is worth more than a dollar received later. This is captured in the 'wealth effect' component ($\eta \times g$, or elasticity of the marginal utility times forecasted growth) in the simple Ramsey Rule for discount[8] (Equation 3).

$$\mathrm{SDR} = \delta + \eta \times g$$

Equation 3

Where:

δ is a rate of pure preference for the present (or rate of impatience)
η is the absolute value of the 'elasticity of marginal utility of consumption', i.e. the change in the value of an additional dollar as society grows wealthier, also referred to as 'intergenerational inequality aversion'
g is the is the growth rate of per capita consumption

Second, to account for people's attitudes to time: human propensity to prefer income today rather than tomorrow, expressed as the pure time preference (δ) component of the discount rate. While g is observable

[8] Please, see ISO 14008:2019 (ISO, 2019).

(ex post) and determined by the performance of the economy, δ and η require an ethical judgment (National Academies of Sciences Engineering and Medicine, 2017). In an intergenerational framework, the 'pure time preference rate' characterizes the ethical attitude towards future generations.

The Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (AR2) notes recommended, as early as 1996, a discount rate of 2-4%, by considering fair to account for a pure time preference rate equal to zero, and a growth rate of GDP per capita of 1-2% per year for developed countries and a higher rate for developing countries that anticipate larger growth rates (IPCC, 2007, p.136). ISO 14008:2019 (ISO, 2019) also suggests that the pure rate of time preference should be set to zero. IPCC's AR5 (Kolstad et al., 2014) reinforced the case for a zero or near-zero pure rate of time preference, suggesting a broad consensus, and citing 2% as the largest value among the approaches reviewed. One argument for a PTP-rate (δ) equal to 0 is that, holding consumption constant, all generations are given equal weight when calculating social welfare. That view stems from the classical impartial utilitarian philosophy, and is supported by luminaries of economics (Drupp, Freeman, Groom, & Nesje, 2018).

Despite the debate regarding the appropriate societal pure time preference rate and social discount rate to apply (De Nocker & Debacker, 2018; Sonnemann, G.; Tsang, 2019), and even on the ethical framework for intergenerational decision-making (Drupp et al., 2018), it is now widely accepted in environmental economics that SDRs must drop with time (Freeman & Groom, 2016). Governments like in the UK and France have adopted this approach to reflect uncertainty about future economic growth, fairness and intra-generational distribution, and observed individual choices (IPCC, 2007). The German Federal Environment Agency (UBA) proposes discount rates of 3% for short-term periods (up to around 20 years), and of 1.5% for claims that extend further into the future and requests a sensitivity calculation with a discount rate of 0% for cross-generational considerations (Schwermer, Preiss, & Müller, 2014, p.37).

Based on these considerations, many authors and governments propose a near zero discount rate when monetizing environmental impacts, especially for long time horizons. The monetizing approaches used for building assessments - MMG2014 and, possibly, the Dutch DM[9] - adopt a discount rate of 3% p.a.

[9] MMG2014 explicitly declares key monetization decisions, like adoption of purchasing power parity (PPP) to account for GDP/capita variation and of a social discount rate of 3% p.a. – said to be on average in line with declining rates over time used by several governments. Monetary values used by the Dutch Determination Method mainly refer to a study on shadow prices commissioned by the Dutch Ministry of Infrastructure and Environment to TNO in 2006. Shadow prices have been since updated and ultimately replaced by a thorough conceptual update: the 'Environmental prices Handbook 2017' (CE Delft, 2018). The Dutch DM 2020 supporting documentation does not mention the environmental prices concept and only provides the shadow price-based weighting set used, without explicitly declaring key monetisation decisions it relies upon. Hence, the discount rate used is herein inferred to be a 3% p.a. rate, as advised by the Discount Rate Working Group (van Ewijk et al., 2015). No reference to purchase power parity/equity weighting was found.

6. Final Remarks

Alternatives for communicating LCA results of buildings basically comprise (Ströbele & Lützkendorf, 2019):

- Focusing on one or more indicators (e.g., GWP or GWP and PE,nr), with the risk that side effects in other areas and load shifts will not be visible;
- Selecting representative indicators, based on previous studies that show that the result for one or more indicators is representative of the others and leads to reliable statements in the order and sequence of variants;
- Partial aggregation of defined indicators using specific methods; and
- Full aggregation of defined indicators using specific methods.

The last two options above (weighing of environmental impact scores into one or a few scores) are often requested by the target audiences. Using a single-score indicator to express the environmental performance makes it easier to communicate environmental performance of buildings and to compare different buildings. It also provides a comprehensive picture, which allows to identify the important environmental impacts and the most relevant building elements or construction materials. That is why some countries like Switzerland have a long-term tradition in applying single score methods in LCA which are endorsed and authorised by the Swiss Federal Administration.

Weighting factors derived from panel exercises, DTT or monetization estimates have been used to aggregate LCA results of buildings. Both prevention and damage costs monetization approaches have been used. There is no best method for aggregating impact results, though, and each approach has strengths and limitations. Expressing policy targets in quantitative terms is not always straightforward and factors for relevant categories indicators still lack. Value choice-based damage estimations often embeds personal attitude and perspectives of the decision-maker, and monetization costs are established within a virtual market, whose results can involve considerable uncertainty. Indeed, the uncertainty treatment carried out by CE Delft (2018) revealed substantial variations in monetary valuing and weighting environmental goods. Hence, if the concepts underpinning monetization are accepted – that is: financial data is comparable to environmental impacts and those impacts are mutually comparable - users should bear in mind that results can involve considerable uncertainty and take the corresponding precautions when using them.

That said, as general recommendations when pursuing to express the environmental LCA results of a building as a single score:

- Give preference to weighting schemes endorsed by authoritative bodies like national environmental agencies or ministries. Among others, this is expected to ensure that the sets of prices/costs/weights are updated every few years to reflect the latest policies;
- Where appropriate, use conversion factors that comply with scientific or engineering principles first. These normative principles apply to any level of aggregation (see also ISO 21931-1 (ISO, 2010));
- Use a method that explicitly declares all conversion/weighting factors and assumptions made. Aggregation procedures shall be transparently described in easily accessible documents;
- Always provide partially disaggregated information, the life cycle inventory result or, even better, the unit process data shall in addition to the aggregated score;
- If impact category indicators embed high uncertainty (e.g., ecotoxicity), present the aggregated result with and without those individual indicators; and
- If monetization methods are used, choose one that applies zero discount rate and world average equity weighting, in line with IPCC's recommendations. As impact assessment methods are becoming increasingly regionalized, the monetary valuation of associated impacts should also be region-specific, to deliver meaningful results.

Comparable information is not ubiquitously available, and not all countries and regions have equally developed science, targets and data. LCA practitioners carrying out studies in regions or countries with data and methods that allow weighting are encouraged to report one or more aggregated scores in addition to the detailed environmental profile, for communication's sake. Target audiences not familiar with the implications of weighting should be made aware of the controversy and objections to do so, of the uncertainties embedded, and of the fact that despite the acknowledged limitations, attempts to evolve are in course to help to fulfil their practical relevance.

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