buildings

MDPI

Annex

Annex 1 – Mapping Approach of the SBA from IFC 2x4 to LCA

Table S1 shows new property sets specified in IFC4 that are able to handle some information that is relevant for the sustainability assessment of buildings according to metrics (environmental indicators), as provided by the Sustainable Building Alliance (SBA). The properties can be applied for the whole life cycle or only a single life cycle phase. Hereby, indoor environment quality indicators are not represented. [1,2]

Table S1. IFC 2X4 environmental property set suitability for SBA environmental metrics calculation [1,2].

SBA metric	IFC 2X4 corresponding property	Comments
Use of non-renewable primary energy	NonRenewableEnergyConsumption: Quantity of non-renewable energy used	in kWh/m²
Water consumption	WaterConsumption: Quantity of water used expressed	in m³/time unit
Thermal comfort	No Pset_IEQ_space exist	Notions related to thermal comfort are covered: Pset_SpaceThermal Pset-Space_ThermalLoad Etc.
Indoor Air Quality	No Pset_IAQ_space exist	IAQ is not taken into account explicitly (it could be proposed but there is not yet an agreed way of doing it)
Global Warming Potential (GWP)	ClimateChange: Quantity of greenhouse gases emitted	in kg eq CO_2/m^2
Hazardous Waste	HazardousWaste: Quantity of hazardous waste generated	in t/m²
Non hazardous Waste	NonHazardous Waste: Quantity of non-hazardous waste generated	in t/m²
Inert Waste	InertWaste: Quantity of inert waste generated	in t/m²
Nuclear Waste	RadioactiveWaste: Quantity of radiactove waste generated	in t/m²

Annex 2 - Current shortcomings with low prioritization within Ökobau.dat

Annex 2 provides for further details on shortcomings of the Ökobau.dat that have been assigned a low prioritization (“B” or “C”) and occurrence (“C”). They are highlighted in light grey within the following tables of Annex 2.1 to Annex 2.3. Shortcomings with a high prioritization (“A”) and occurrence (“A” or “B”) are already explained in detail within the corresponding publication of this Annex.

Annex 2.1

Identified end user related shortcomings are summarized within Table S2.

Table S2. End user related shortcoming—Examples and their prioritization for solution-oriented handling.

Examples (End user related shortcomings)	**Prioritization** A = High B = Medium C = Low	**Occurrence** A = General B = Frequent C = Rare
Incorrect linking of life cycle inventory data with environmental information of the use phase	A	A
Incorrect comparison on material level	A	B
Application of inappropriate End-of-Life scenarios on material level	B	B
Incorrect application of generic and EPD datasets	B	B
Wrong interpretation of LCA results on building level	C	B
Application of inappropriate useful service lives on material level	C	C

<u>Application of inappropriate End-of-Life scenarios on material level:</u> The selection of a correct and technical feasible End-of-Life scenario on material level depends as well on the position and installation method of the material itself. Depending on the possibility for a type wise separation of materials, End-of-Life scenarios need to be adjusted. An example is a polyethylene (PE) foil on which the later basement plate is poured. Typically, the End-of-Life scenario for the PE foil would be combustion in a waste incineration plant, including credits for the energy produced (electricity and heat). However, the PE foil is inseparably connected to the concrete floor slab. Thus, in practice, it is not possible to recycle it thermally. It would have to be dumped without gaining any credits. Here, the question raises how the constructive context of components and material could be specified and represented to differentiate the explained spatial context and installation method.

<u>Incorrect application of generic and EPD datasets:</u> An incorrect selection and use of environmental datasets from the Ökobau.dat database within building life cycle assessment studies often occurs. This is due to as the Ökobau.dat is not able to provide environmental information on a 1:1 basis for all existing construction products in Germany. End users are therefore enforced to work with estimates or do choose mistakenly an EPD data from another manufacturer, when no specific or other generic information is available. In order to choose a dataset correctly with regard to the construction project phase that is to be assessed, it is important to know what types of construction product life cycle assessment data exist and for what purpose they are applicable. Especially, the before mentioned safety margins and their potential influence on the overall building LCA results have to be kept in mind when deciding for or against the application of specific environmental profiles.

<u>Wrong interpretation of LCA results on building level:</u> The interpretation of LCA results on building level is a challenge for LCA practitioners as well. Besides subjective influences, one reason for this is also the quality of environmental data applied from the Ökobau.dat. LCA users often compare two building designs. Per se, the design with the lowest environmental impact is hereby often considered as the best option without further questioning why. Neither the type of environmental data used nor respective uncertainties within the environmental impacts are re-considered for this decision. As mentioned above, generic LCA data carry a safety margin of 10%, 20%, or 30%; EPD data mostly do not. Depending on the type of environmental datasets used, deviations may occur in the LCA results for different life cycle phases, such as manufacturing, repair, and End-of-Life. But, even in case of small deviations (e.g. less than 5%) the building design with higher environmental impacts might be compatible to the building design with lower environmental impacts.

<u>Application of inappropriate useful service lives on material level:</u> In many cases, the useful service lives of building products or materials are not adjusted to the position and installation method (exposure conditions) of the product or material itself. These factors have a significant

influence on the durability [3]. An example is the useful service life for door fittings, which varies depending on whether the door is an internal or external one [4]. Another example is the positioning of external wall insulation as insulation core or as composite thermal insulation system. Table S3 summarizes these results and presents two additional examples.

Table S3. Examples for useful service lives depending on position or installation method [4].

Building product or material	Position or installation method	Useful service life In [years]
Doors	Interior	≥ 50
	External	40
Door fittings	Interior	30 to ≥ 50
	External	25 to 30
Mineral plaster	Interior	40 to 45
	Exterior	≥ 50
External insulation	Core insulation	≥ 50
	Composite thermal insulation system	40

Furthermore, the international standard ISO 15686 Part 1 [5] and Part 8 [6] provide for principles of service life planning, prediction, and estimation that end users are mostly not aware of [7]. These principles does the Ökobau.dat not include so far.

Annex 2.2

Identified content related shortcomings are presented within Table S4.

Table S4. Content related shortcoming—Examples and their prioritization for solution-oriented handling.

Examples (Content related shortcomings)	**Prioritization** A = High B = Medium C = Low	**Occurrence** A = General B = Frequent C = Rare
Insufficient, inconsistent, incorrect or confusing documentation on:		
• The declared unit, reference flow or functional unit	A	B
• The use of datasets with reference “according to EnEV” and without	A	B
• The calculation rules for determining average values for the foreground system	A	C
• Allocation rules	B	B
• Consideration of uncertainty	B	B
• Technical fore- and background system description	B	B
• The independent external review	B	B
• The transport losses for energy use data free ex-consumer	B	C
• Naming / nomenclature	B	C
• The completeness of the LCA product model	C	A
• The traceability of the dataset subtype (category A and B according to [8]	C	B
Inclusion of technological advances during update for:		
• The background energy system in general	A	A
• Specific foreground production processes	A	B
Incompleteness of data basis - Missing datasets for:		
• Generic building construction products	A	A
• Technical building equipment	A	A
• The non-energy use phase	B	A

Examples (Content related shortcomings)	**Prioritization** A = High B = Medium C = Low	**Occurrence** A = General B = Frequent C = Rare
• Life cycle module A4	C	A

In addition, Table S5 points out which datasets are mostly concerned with regard to insufficient, inconsistent, incorrect or confusing documentation.

Table S5. Datasets concerned with regard to documentation shortcomings.

Examples (Content related - Documentation shortcomings)	**Datasets** **mostly concerned**
Insufficient, inconsistent, incorrect or confusing documentation on:	
• The declared unit, reference flow or functional unit	Energy use
• The use of datasets with reference "according to EnEV" and without	Energy use
• The calculation rules for determining average values for the foreground system	Generic
• Allocation rules	Generic
• Consideration of uncertainties	Generic
• Technical fore- and background system description	Generic
• Independent external review	Generic
• Transport losses for energy use data free ex-consumer	Energy use (generic)
• Naming / nomenclature:	Selected
• Completeness of the LCA product model	Almost all
• The traceability of the dataset subtype (category A and B according to [8]	EPD

<u>The calculation rules for determining average values for the foreground system:</u> EPD datasets contain information if and how average values have been calculated, e.g. based on averaging of production across all plants (production mix). The generic datasets mostly do not include information on how or where average values have been derived from for the foreground system (e.g. market mix vs. production mix). According to the general principles for the acceptance of LCA data [8], this calculation must be provided

<u>Allocation rules:</u> Information on the allocation procedures and rules carried out within the product foreground system are missing for generic datasets. This information is necessary if e.g. production of by-products is to be considered. The documentation of allocation for generic datasets is required according to ISO 14040/14040 [9,10] and according to EN 15804 [11] for EPD datasets.

<u>Consideration of uncertainties:</u> The background document on the adaptation of the Ökobau.dat to the European standard EN 15804 [11] recommends setting up requirements for the quality assurance of generic data and their verification. These requirements may relate to pre-verification, time representativeness, technological representativeness, geographical representativeness, plausibility checks, completeness, consistency, and uncertainty. It suggests documenting the results of a sensitivity analysis in case different generic data (sources) may be selected. Such a sensitivity analysis could e.g. state for parameter and modeling uncertainties, but seems not to be included so far within the documentation.

<u>Technical fore- and background system description:</u> Information on the technical fore- and background system is provided on a very general basis and is partly irrelevant for the specific dataset. This complicates understanding for the end user what information is actually relevant. An example is the dataset "Underfloor heating with copper pipes". The technical foreground

description includes irrelevant information such as the assumption that 95% of large technical appliances (such as boilers, air conditioning, ventilation systems, or elevators) are recycled.

Independent external review: Generic datasets do not undergo an independent external review, but a quality check [9]. Nevertheless, generic datasets state an independent external review by the the GaBi user forum, the GaBi user community and the GaBi bug forum within the tab "Modeling and Validation". By mistake, the impression is created that an independent external review according to EN ISO 14025 [12] or EN 15804 [11] has been carried out. An improved wording would be "dependent internal review".

Transport losses for energy use data free ex-consumer: The documentation on generic datasets for the energy use free ex-consumer, partly do and partly do not include transport losses from the supply at the power plant to the consumer. This may lead to confusion as to whether the dataset may be indeed characterized as "free ex-consumer" or whether additional transport losses have to be included manually.

Naming/nomenclature: Some of the nomenclatures of the datasets may be confusing for the end user. This is even enforced, if these datasets are also less plausible classified within the structure of the Ökobau.dat. Examples are the datasets for the photovoltaic systems. They are classified under "9. Others" – "9.2 Energy carriers – provision free ex-consumer" – "9.2.05 Electricity". Their classification seems to indicate only the reporting of environmental impacts for the use phase. In contrast, their nomenclature indicates the reporting for the systems themselves. Furthermore, the dataset does not only represent a cradle to gate inventory, as referenced within the technical description, but a cradle to grave inventory. This inventory includes once credits within the life cycle module D and once it does not. The functional unit (declared unit or reference flow) may be confusing as well, as it relates to one square meter of surface area.

Completeness of the LCA product model: Inconsistent, here partly missing, statement within the tab "Modeling and Validation" on the completeness of the product model. The statement is necessary for an improved understanding of data quality. The statement is only provided within the tab "Process Information" under description.

The traceability of the dataset subtype (category A and B according to [8]: EPD data are characterized as specific, average, or representative ones. Furthermore, they may be distinguished into EPD data with an EPD program under operation (subtype category A) or without (subtype category B) according to general principles for the acceptance of LCA data [8]. The subtype category A or B are only limited traceable and may only be figured out, when checking the type of validation within the tab "Validation and Modeling". For example, an "accredited third party verification by IBU" points to EPD data from subtype category A.

Content related shortcomings with regard to the incompleteness of the data basis and missing environmental information are summarized and explained in the following paragraphs.

Generic building construction products: Generic datasets for individual construction product categories are sometimes missing. For example, important synthetic floor coverings, such as carpets and PVC flooring, are not available in Ökobau.dat 2017. The database in 2017 only contains some EPD data on carpet tiles and rubber floorings, as well as one generic dataset for linoleum flooring. Synthetic floorings are estimated with a useful service life between 10 to 40 years [4,7]. Assuming a building assessment horizon with around 50 years, synthetic floorings have to be exchanged between two to four times. With regard to repair and their large amount of surface area covered, even simple floorings may play a role within low-energy environmental building assessment.

Technical building equipment: In addition to the lack of generic LCA datasets, EPD datasets for the technical building equipment are also missing. Currently, there is only the possibility for users to calculate the use phase of the building based on generic use datasets. Project- and product-specific adaptations with e.g. the efficiency of the equipment in according with national energy calculations according to EnEV do not take place in this way.

The non-energy use phase: Missing environmental profiles for the non-energy use phase mainly relate to the life cycle modules B2 (maintenance), B3 (repair), B4 (replacement), and B5 (refurbishment) according to DIN EN 15804 [11]. Environmental impacts connected with the facility management of the building construction products are not yet represented within the Ökobau.dat.

Non-manufacturer datasets: Furthermore, non-manufacturer EPD datasets are missing. According to the interpretation of DIN EN 15804, EPDs may be also produced by product assembling companies that only purchase other construction products and assemble them on-site (e.g. façade manufacturers). Nevertheless, environmental information on assembled products is only rare (e.g. manufacturing of heat pump datasets) or not at all to find within the Ökobau.dat. A reason for this may be the currently applied narrow interpretation of EN 15804 by specific EPD program operators.

Annex 2.3

Identified modeling and automation related shortcomings are presented within Table S6.

Table S6. Modeling and automation related shortcomings—Examples and their prioritization for solution-oriented handling.

Example (Modeling and automation shortcomings)	**Prioritization** A = High B = Medium C = Low	**Occurrence** A = General B = Frequent C = Rare
Lack of uniform structuring or material classification	A	A
Modeling of:		
• Heat pump datasets	A	A
• Solar thermal energy datasets and photovoltaics (PV)	A	A
• Air-ventilation system datasets	A	B
• Energy use datasets according to EnEV	A	B
• Life-cycle module C and D	A	B/C
Use of inconsistent definitions with regard to:		
• Impact-free waste products	A	C
Major changes in modeling between Ökobau.dat version 1.0 to 2.0 with regard to:		
• Allocation rules	A	C
Partial lack of updateability	B	A
Very simplified methodology to derive safety surcharges	C	A

Modeling of life cycle module C and D: The discussion of how to include dismantling, demolition and recycling (modules C and D) is already in “full swing” within. Especially regarding life cycle module D (benefits and loads beyond the system boundaries), there are currently a multitude of discussions ongoing. Up to now, the building materials used have been recorded over their life cycle (module A1 to A3, module B3, module C3, module C4, and module D), whereby the refurbishment/replacement was calculated using a new production and End-of-Life process of the original material. This took place on the basis of replacement and End-of-Life scenarios based on current state-of-the-art conditions and technologies. The background to this modeling was the assumption of a conservative estimate. This is correct for life cycle modules C3 and C4, but it can lead to an overvaluation of the credits for module D.

Consider, for example, the global warming potential (GWP100) of one cubic meter of structural timber (Table S7). During the growth phase of the tree (life cycle module A1 to A3) CO_2 from the environment is bound, resulting in a negative GWP value. For the processing steps of felling, transport, saw mill cutting, etc. environmental impacts are caused that lead to positive GWP values. In total, this positive GWP value does not exceed the negative one, resulting in an overall negative GWP value for the production phase. At the End-of-Life wood is combusted (life cycle module C3) and the amount of up taken CO_2 is released to the environment again (C3). Thermal incineration in a wood-fired power plant generates electricity and heat, which is subsequently used and therefore credited with the current electricity or heat mix to life cycle module D. Overall, wood, thus, has a negative global warming potential balance according to the described system limits.

Table S7. Global warming potential (GWP) of 1m³ of structural timber [13] for representative life cycle modules and thermal incineration within End-of-Life.

Life cycle module according to EN 15804 [11]	**A1 to A3**	**C3**	**D** (Thermal incineration)	**Total**
GWP [In kg CO_2-Equiv. per $1m^3$]	-709	810	-364	-263

The reason for the overall total negative GWP value is that the reference year for accounting of the credits within life cycle module D is the same as for the felling of the tree (2017). In reality, however, the structural timber used in the building would remain in the building for several decades. Assuming a useful service life of at least 50 years (for example as a wooden beam ceiling) and future changes in the energy mix, the amount of credits for thermal incineration in the year 2067 would be quite different from the ones in the year 2017. Up to now, Ökobau.dat is not able to handle these dynamic boundary conditions or future changes [14].

Other modeling shortcomings within the End-of-Life phase occur due to the use of outdated End-of-Life specifications. Composite thermal insulation systems are partly considered to be thermally incinerated within life cycle module C4. However, thermal insulation materials that were built-in before the year 2014 do contain Hexabromcyclododecan (HBCD) as a flame retardant [15], decreasing the materials ability for flammability. Therefore, German waste legislation declared in the year 2017 already installed (old) thermal insulation materials (such as expanded (EPS)) as hazardous waste [16,17]. These developments seem not to be taken into account.

Use of inconsistent definitions – with regard to impact-free waste products: Overall, Ökobau.dat is a collection of different datasets from different industrial areas and it partly applies different types of modeling. An example is the classification and handling of waste materials that is not uniformly regulated within life cycle assessment. According to the current product category rules hard coal fly ash is evaluated as burden-free waste material within the Ökobau.dat [13]. However, fly ash is also considered a hazardous waste and in current research activities that were evaluated for its potential of secondary material use [18]. Fly ash is used not only within high-quality concrete as value-adding additive due to its material properties and should thus be allocated through its economic value [19].

Major changes in modeling between Ökobau.dat Version 1.0 to 2.0 – with regard to allocation: With regard to the so-called background-data or allocation principles, it seems that major changes are not adequately documented for the Ökobau.dat Version 2.0. Partly, generic data were updated according to the prevailing energy mixes in the background system, whereas EPD data were not. Differences in the background system, especially with regard to the energy mixes lead to non-plausible and untraceable differences when mixing up these data for assessment or when updating LCA results from Version 1.0. Furthermore, changes in allocation principles have an immense impact on single environmental profiles. Meanwhile, the environmental profiles for the wood chip boiler showed up with negative environmental impacts for global warming potential and non-plausible impacts for the total primary energy use for the use stage (module B6). This was probably due to changes in allocation of the upstream chain for wood products, such as the sawmill processes, which was adjusted from a physical allocation to mass to an economic allocation. Inconsistencies in mass and energy balances for the environmental profiles were the results. Within the update of Ökobau.dat in the year 2017, these inconsistencies seem to be fixed [20].

Partial lack of updateability: When using the datasets of the Ökobau.dat in external applications, the updateability of generic LCAs and EPDs is not always given. It may be the case, that after a validity of 5 years according to EN 15804, specific EPD datasets are no longer available. This may be due to a missing prioritization for update from e.g. specific manufacturers or missing financial budgets. With regard to the generic datasets, the current database provider decides whether to include datasets for update or whether just to exclude them [8]. A quality check if still main building products are available or a check on how to provide for temporary solutions (e.g. provide a generic dataset because an EPD dataset is no longer available) is not carried out. Furthermore, this shortcoming poses a great challenge to software operators, who want to enable for consistency between different versions of the Ökobau.dat for the end users.

Very simplified methodology to derive safety surcharges: The final report [21] for the adaption of the Ökobau.dat to the European standard EN 15804 in 2013 provides for some insights into the derivation of the safety margins for current generic Ökobau.dat datasets. On a random basis, missing upstream processes have been ad up or technologies have been varied. These variations have led, in some cases, to differences in environmental impacts far more than 10%. However, the safety margins are based on the assumptions that e.g. a low technological representativeness may always lead to higher environmental impacts. The possibility for any improvement in the environmental profile, as a result of improvements in technologies, seems not to appear.

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