Innovative Renewable Energy
Series Editor: Ali Sayigh

Ali Sayigh *Editor*

Renewable Energy and Sustainable Buildings

Selected Papers from the World Renewable Energy Congress WREC 2018

Springer

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Series editor

Ali Sayigh
World Renewable Energy Congress, Brighton, UK

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ISSN 2522-8927 ISSN 2522-8935 (electronic)
Innovative Renewable Energy
ISBN 978-3-030-18487-2 ISBN 978-3-030-18488-9 (eBook)
https://doi.org/10.1007/978-3-030-18488-9

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Introduction

At the Congress, 21 plenary papers, 8 keynote papers and 140 technical papers were presented. The opening address was given by H E Dr. Altwaijri, director general of the ISESCO and WREN honorary chairman, representing 54 countries, who presented his excellent talk 'Leading Role of ISESCO in the field of Renewable Energy and the Promotion of the Concept of Green and Sustainable Cities in the Islamic World'.

The message from Professor Ali Sayigh to the participants at the opening was:

On behalf of the World Renewable Energy Network and Congress, I welcome you all to our 28th anniversary Congress at the University of Kingston, London, UK. Once again, it gives me very great pleasure to welcome our permanent member of WREN Council, H E Dr. Altwaijri, our honorary chairman, and the rest of my distinguished colleagues from more than 60 countries.

WREN, with your continued support, has managed to change the equation of 'energy from fossil-fuel' to 'renewable energy fuel'.

Recently, the second largest exporter of oil, the Kingdom of Saudi Arabia, embraced renewable energy on a very large scale. Their present power capacity is 77 GW, and they are planning projects of renewable energy to generate 200 GW by 2030.

In Europe, the EU has set an energy consumption target of 32% from renewables. However, this figure is considered by many to be too low since renewables already nearly meet this amount and bearing in mind that the target did not include biomass.

Meanwhile, China has already reached its 2020 carbon emission reduction goal 2 years ahead of its target. India is another country which contributes on a large scale to global pollution but now aims to install 100 GW of renewables by 2022. Many countries in the world are now embracing renewable energy not only because it is clean and cost-effective but also because it reduces energy imports and creates local jobs.

While the outlook for renewables is in many places very encouraging, there was a feeling of dismay at the recent withdrawal by the US from the Paris Agreement on Climate Change to be effective in 2020. Nevertheless, many States in the US will continue to implement their own renewable energy policies and place the US among the leading renewable energy producers.

Now, it is up to you, the participants in this Congress, to continue to spread and develop all forms of renewable energy and to commit yourselves to the very urgent reduction of the climate change effect. It goes without saying that this goal includes the improvement of energy efficiency and energy conservation through recycling and sustainable development. I urge you to do this not primarily for the sake of renewable energy industries but more importantly for the future welfare of our fragile environment.

Our thanks to all the sponsors and to the staff and students of Kingston University for their generous support and help. My thanks and gratitude to the Technical Committee and our publishers, Springer (USA) and EDP (France), who are attending the Congress in person.

Special thanks to ISESCO and their Director General, Dr. Altwaijri, who is WREN honorary chairman and main supporter of WREN during the last 18 years. My thanks to Dr. Doukas and the European Commission in supporting WREN Congresses over the last 4 years. Last, but not least, our thanks to the Institute of Engineering and Technology, in particular to Mrs. Jones in sponsoring WREN Congresses over the last 5 years.

I wish you a great success in your research and utilization of green energy and seize this opportunity to network and learn from each other while you are in London. Wishing you a very enjoyable time.

One of our pioneers and invited speakers to WREC-18, Prof. David Elliott, Open University, has written a summary of the event which was published by Physics World (IoP); the link is https://physicsworld.com/a/specialists-gather-at-world-renewable-energy-congress/.

This could be an introduction to WREC-18:

‘World Renewable Energy Congress: 18 in the UK’

The World Renewable Energy Congress (WREC) is a long-running biannual gathering of academics and practitioners, linked via the World Renewable Energy Network (WREN) . Although UK-based, its biannual sessions, and other regular sub-gatherings, are held all over the world. This year, however, for its 18th session, WREC returned (for a second time) to Kingston University in suburban Surrey. Big hitters included David Renné, president of the International Solar Energy Society, who offered an inspiring *Overview of pathways to 100% Renewable Energy*, and Rainer Hinrichs-Rahlwes, vice president, European Renewable Energies Federation (EREF), and board member of the German Renewable Energy Federation (BEE), looking critically at *Europe’s 2030 Targets*: the EU is trying, he said, but needs to do better.

Wherever it is held, WREC always attracts significant international participation, including from **Africa**, with, this year, a range of technical papers being presented, for example, on mini-grids and rural electrification. At the more general policy level, David Elliott, Open University, and his colleague Terry Cook relayed some ideas from their new book (https://www.palgrave.com/gb/book/9783319747866) by focussing on the impact of market-based private investment approaches to renewable development in Africa. The new 'trade not aid' approach being adopted by the EU aims to stimulate private sector investment to create new markets, something that China was already good at, although often with less emphasis on the social and environmental aspects.

There were also several good presentations on developments in **Asia**, including one on the state of play with offshore wind in Japan. It was reported that were or had been ten projects, 40MW in all, including some 2MW floating systems and some now at 5 and 7MW. But though the potential was very large (100s of GW for both offshore and onshore wind), there were problems with developing wind power in Japan. It has cumbersome EIA procedures (they can take 4 years) and three separate regional electricity supply bodies in the East and six in the West, making grid integration of outputs from onshore wind, which is mainly in the North, hard. Floating offshore projects might however circumvent some of the bureaucratic issues and supply power direct to load centres like Tokyo.

Integration is clearly an increasingly important issue, with storage being part of that. Controversially, WREN Director Donald Swift-Hook argued that **energy storage** was mostly irrelevant and that renewables were best seen as direct (fossil) fuel savers. So, if they were available, and especially at increasingly low cost, then just use them. Other times, use gas! Turning surplus renewables into gas (PtG) would evidently be too expensive. So post-generation storage of renewable outputs was basically not needed or viable: 'Commercial storage of energy on a power system works by arbitrage, buying cheap electricity [typically in the middle of the night] and selling it when electricity is dear [during the day-time or evening]. If fuel saving renewables are stored, the round-trip losses from putting their electricity into store and taking it out again wastes some of the fuel already saved. There is no difference in fuel costs around the clock, so storing electricity from renewable fuel savers cannot be arbitraged or commercially justified'.

Reinhard Haas, from the Energy Economics Group at the Technical University of Vienna, also looked at the storage issue, in the context of dealing with surplus outputs from renewables, and their short- and long-term variations. Batteries were OK for short-term balancing, and they reduced the strain on the grid. But pumped hydro was needed for longer-term storage—though its cost would rise as new sites became scarce. However, power-to-gas (PtG hydrogen/methane) would get cheaper. *But* there are diminishing returns—each storage success makes it less economically attractive to store more! Or as Haas put it: 'Every additional storage unit makes this one and every other less cost-effective'! That's the so-called principle of self-cannibalism in energy economics, which, as far as I can see, means that the cheaper anything gets, the less profit can be made from going for more of it. But that's surely only if the market remains the same size—if it's expanding, so will the opportunity to make profits from meeting it. However, Haas says that while local batteries might do well for short-term storage, ‘in a dynamic market framework the costs of all centralized long-term storage technologies will finally be too high to become competitive’, and he sees competition with demand response options and demand-side management challenging storage as well.

So, decentralized batteries apart, his final conclusion is quite grim, almost as grim as Swift Hook’s, ‘with respect to all centralized long-term storage technologies, the future perspectives will be much less promising than currently indicated in several papers: new long term hydro storages will not become economically attractive in the next decades [and] for PtG-technologies it will become very hard to compete in electricity markets, despite a high technological learning potential’, though Haas does say that ‘for hydrogen and methane there might be prospects in the transport sector’.

There were, as ever, many papers on specific technical and operational issues and developments (over 170 in all), with the **PV solar** field heavily represented, including one from Oman, on the impacts of dust, and a nice historical one on the use of PV by the US Vanguard satellite—a lot to take in but with some overall very positive messages. For example, it was suggested that PV may surpass 1TW globally by 2022. It was also suggested that new luminescent wavelength downshifting materials could boost PV productivity significantly. That would make PV more valuable in less sunny areas—the paper on that came from Ireland. Arguably, it might then be clearly even more preferable to biomass in land use terms. It was claimed that given the low-energy conversion efficiency of bio-photosynthesis compared to PV cells, PV could already generate 40–80 times more power output/acre than biomass crops. Of course, the difference would be less if it was biomass *waste* that was being used, an issue also well covered at WREC. However, overall PV does seem to be romping ahead in many areas, both at the large and small scales, with, for example, PV being used in refugee camps and in Afghanistan’s reconstruction and hybrid PV thermal playing a role in desalination.

WREC was held in the midst of the sweltering UK summer, and interestingly, there were some timely papers on **cooling and ventilation**, including, significantly, some from China, where, with a rapidly growing more affluent urban population, this is becoming a major issue. Much of the Middle East and Africa also has increasing air con demand, and this will rise everywhere as climate change increases. Fortunately, some new technologies are emerging which may help, including systems using high heat capacity phase-changing materials. As some papers from the UAE noted, they can also be used with concentrating solar power systems. So maybe high temperatures are not always a problem—although I still would not like to be trapped on the 100th floor of a Dubai high rise when and if the currently still mostly fossil-derived power supply fails and there are no lifts or air con. But it was good to hear that some progress is being made on greening buildings and power there!

However, as everywhere, there is a lot more to do. As Prof. Ali Sayigh, the indefatigable chair of WREC, put it, ‘many countries in the world are now embracing renewable energy not only because it is clean and cost effective but also because it reduces energy imports and creates local jobs…Now it is up to you, the participants in this Congress, to continue to spread and develop all forms of renewable energy, and to commit yourselves to the very urgent reduction of the climate change effect’.

Chapter 19
Measure the Embodied Energy in Building Materials: An Eco-Sustainable Approach for Construction

Francesca Scalisi and Cesare Sposito

19.1 Introduction

According to the definition of the Bruntland Commission, the sustainable development consists in satisfying the current needs without compromising the possibility of future generations of satisfying theirs [1]. The term sustainability, initially used to define fairest economic development dynamics, has quickly become of common use and was, then, used to identify not only the development methods but also each action or situation in which this model is applied and put into effect, starting from sustainable production and sustainable market to the sustainable building: a building that does not use polluting materials and prefers natural organic materials, recycled materials and components, that limits the use of fossil fuels and that reduces the production of waste and energetic consumption during operation.

Therefore, energy and environment are the two subjects which architecture and building need to take into account as the building sector is responsible for 40% of global energy consumption and 30% of greenhouse gas emissions [2]. The total energy used in the life cycle of a building is determined by the sum of the embodied energy and the operational energy [3–5]. The definition of operational energy is clear, it defines the quantity of energy requested during the operation of buildings in heating, cooling or ventilation, the production of domestic hot water and illumination [6]. The embodied energy can be generically defined as the energy used in the production stage of the material [7], even if an accurate definition should consider the whole life cycle of the material, with an analysis cradle-to-grave that includes

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A. Sayigh (ed.), *Renewable Energy and Sustainable Buildings*, Innovative
Renewable Energy, https://doi.org/10.1007/978-3-030-18488-9_19

the energy needed for the extraction of raw materials, processing and transport, periodic energy for maintenance and final energy for disposal [8, 9]. The analysis cradle-to-grave is very complex, mostly because finding the data related to periodic energy for maintenance and final energy for disposal is difficult. Most of the studies on energy efficiency of buildings focuses on the reduction of operational energy, as it affects the most the total energy consumption of a building [10].

Opting for high-performance solutions and using high-performance materials definitely allows to create buildings classified as "Nearly Zero Energy Buildings". This might activate an increase of consumption, creating the "Jevons Paradox" [11]. The economist William Jevons observed that technological improvements that increase a resource's efficiency can cause an increase of this resource's consumption instead of its decrease, because higher efficiency results into a decrease of costs and, therefore, a growth in consumption.

And this paradox is followed by another, according to which the necessity of using high-performance materials to get energy efficiency during operation causes the rise in the necessary embodied energy to create those materials.

The acknowledgment of the idea of a higher embodied energy could be justified only by a significant decrease of energy during the operation of the building, thanks to which a positive balance between embodied energy and operational energy is maintained [12–14].

Many studies question this balance, arguing that the extreme growth of embodied energy is not always adequately compensated by the decrease of operational energy, since embodied energy might represent almost half of the total energy used in a building life cycle and, sometimes, it exceeds operational energy [15–18]. In this sense, the research for efficiency in the operational phase can be counterproductive for the total energy consumption because it doesn't supply enough advantages from a sustainable environmental point of view [11].

19.2 Methods to Measure Embodied Energy

It is necessary to consider the data on embodied energy since the start of the decision-making process, fundamental to facilitate optimal project choices for the environment. But the calculation for embodied energy is complex, especially for two reasons: the lack of data and the conflicting measurement methods.

Langston and Langston [19] state that measuring operational energy is less complicated than establishing the embodied energy: a complex operation requiring a longer time.

The calculation of embodied energy has two fundamental steps: the choice of the system limit and the method according to which the data in the system was elaborated.

The first one represents one of the most important and controversial points, because establishing the limit of the system determines the amount of information provided: it is quite clear that the limit should always be cradle-to-grave, in order to

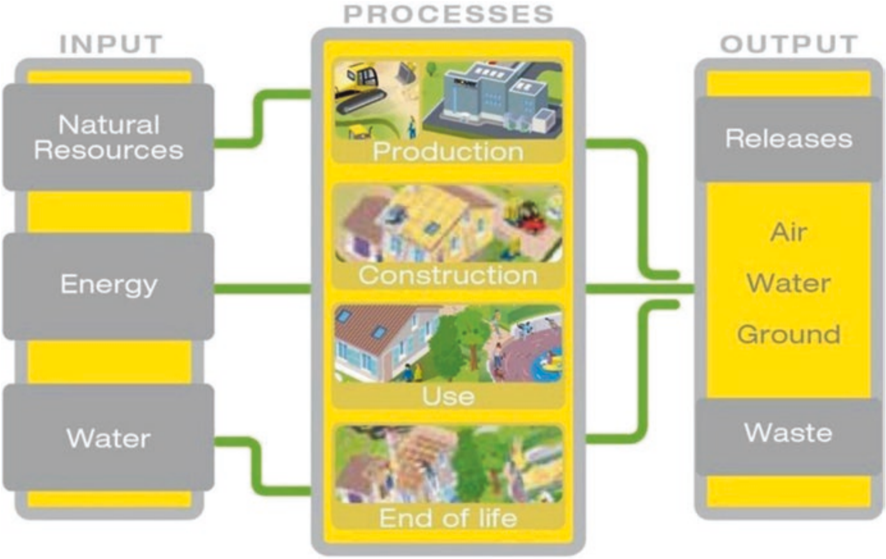


Fig. 19.1 Flow diagram of the life cycle (Source: EPD® Isover Saint-Gobain)

understand the whole life cycle, but basically the most used system limit is cradle-to-gate. This idea will be extensively analysed in the following paragraphs, while now, we will focus on the measurement methods of embodied energy (Fig. 19.1).

The measurement of embodied energy is complex and until now a generally accepted method has not been defined to distinctively measure it [19–22]. The main methods used to measure embodied energy are process analysis, input-output analysis and the hybrid method.

Process analysis allows to identify and quantify direct and indirect energy required by the work processes. Even if it is highly demanding, the process analysis is really widespread because it allows to get accurate and specific results. It consists in the decomposition of the production process of a good in individual activities and quantification of energy fluxes necessary to its realization. The final value of used energy is known as process energy requirements (PER) [9].

The input-output analysis is a macroeconomic technique created in the 1970s by the Nobel Prize Leontief. Through the cross-sector matrix the energy directly and indirectly used in the economic system is measured. The limit of this approach is to get data grouped in a sector in which different goods and/or services are produced. The analysis carried out with this technique was born from the need of putting into the final balance also the items usually ignored in the process analysis, that is the effect of the services indirectly involved in the production and all the works preceding the point to which the process analysis might decide to stop. The final quantity of energy calculated with the input-output analysis is known as gross energy requirements (GER) [9, 23, 24].

The hybrid method has the main characteristics of the two aforementioned methods, since it is a process analysis that uses the input-output analysis when acquiring some data is extremely complex [25].

The use of more sustainable building materials and building techniques is an important contribution to the eco-efficiency in the building industry, therefore, to a more sustainable development [26]. An appropriate building materials choice can cause a 17% reduction of the energy used in the construction of a building [27], and it can reduce the CO_2 emissions by 30% [28]. Having reliable databases with updated data on embodied energy is an efficient help to whoever wants to make aware project choices, aiming to protect the environment.

One of the best known and used databases is the Inventory of Carbon and Energy (ICE) created by Hammond and Jones from Bath University [29]. The measurement method used is input/output and the system limit is cradle-to-gate, even if for some materials the consumed energy during the delivery of the products to the building site was considered. In Table 19.1 some of the materials of the ICE are listed.

19.3 TC 350 Standards

In 2011–2012 have been published the standards developed by CENT TC 350, a Technical Committee developing the standards that can define a harmonized methodology to assess the environmental performance and the costs of the life cycle of buildings. It is made up by three Working Groups: WG1—Environmental Performance of Buildings, WG2—Building Life Cycle Description, WG3—Product Level. The purpose of the latter is to define the Product Category Rules (PCR) to elaborate the Environmental Product Declaration (EPD) for building materials. The Environmental Product Declaration (EPD) is a voluntary-based technical document verified by a certification body that accompanies the marketing of a product. The TC 350 Standards define the impact from cradle-to-grave of buildings and products using as measurement method the process analysis.

The TC 350 Standards for building products, in compliance with EN 15804: 2012 are divided in four stages:

Product stage, construction stage, use stage, end-of-life stage, and an optional module reuse-recovery (D).

In the table of the Fig. 19.2 the mandatory and optional stages are listed, according to the considered system limit.

Product, construction, use and end-of-life stages are strictly linked to the building. As a matter of facts, the type of building in which a product must be installed will establish the scenarios of the building's life cycles, and these will determine the scenarios that must be evaluated for the installation, the usage pattern and the end of life, but the final disposal will depend on the product.

In the analysis cradle-to-gate only the product stage (A1–A3) is considered and, therefore, is mandatory. In the analysis cradle-to-gate with options the product stage (A1–A3) is mandatory while all the other stages are optional. In the analysis cradle-to-grave all the stages are mandatory but D is optional.

Table 19.1 Inventory of Carbon and Energy (ICE) of Bath University [29]

Materials	EE—MJ/kg	EC—$kgCO_2/kg$	Materials	EE—MJ/kg	EC—$kgCO_2/kg$
Aggregate	0.10	0.005	General insulation	45.00	1.86
General sand	0.10	0.005	Lead virgin	49.00	2.61
Rammed soil	0.45	0.023	Stainless	56.70	6.15
General concrete	0.95	0.130	Natural latex rubber	67.60	1.63
General stone	1.00	0.056	General paint	68.00	3.56
General plaster (gypsum)	1.80	0.12	Polyurethane	72.10	3.00
Marble	2.00	0.112	General Carpet	74.40	3.89
Common Brick	3.00	0.22	PVC general	77.20	2.41
Typical cement	4.6	0.83	Expanded Polystyrene	88.60	2.50
Plasterboard	6.75	0.38	PVC Injection Moulding	95.10	2.20
General timber	8.50	0.46	ABS	95.30	3.10
General steel Recycled	9.50	0.43	Polycarbonate	112.90	6.00
General ceramics	10.00	0.65	Polypropylene, Injection Moulding	115.10	3.90
Lead Recycled	10.00	0.53	Synthetic rubber	120.00	4.02
General glass	15	0.85	Nylon 6	120.50	5.50
Paperboard	24.80	1.32	Nylon 6.6	138.60	6.50
Linoleum	25.00	1.21	Epoxide Resin	139.30	5.91
Fibreglass	28.00	1.53	Aluminium Virgin	218	11.46
Aluminium Recycled	28.8	1.69	Titanium virgin	361 to 745	–
General steel virgin	35.30	2.75	Titanium recycled	258.00	–

Miscellaneous		
PV Modules	Embodied Energy—MJ	Embodied Carbon—kg CO_2
	MJ/sqm	kg CO_2/sqm
Monocrystalline	4750 (2590 to 8640)	242 (132 to 440)
Polycrystalline	4070 (1945 to 5660)	208 (99 to 289)
Thinfilm	1305 (775 to 1805)	67 (40 to 92)

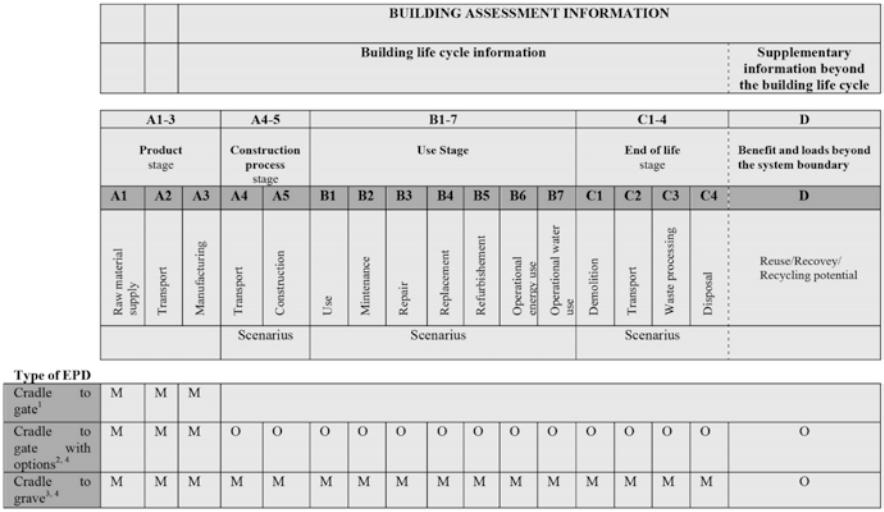
The product stage includes the supply of all material and energy, the disposal of final waste during the production stage. In detail, it includes:

A1—extraction and processing of raw materials, including processing of secondary materials

A2—transport of raw materials and secondary material to the producer

A3—manufacture of the construction products, and all upstream processes from cradle to gate

The construction stage also includes the waste handling and the disposal of final waste. The transport and installation of the building process depend from the context of the building in which the building product is used. Specifically, it includes (Fig. 19.3):



	BUILDING ASSESSMENT INFORMATION																
	Building life cycle information																**Supplementary information beyond the building life cycle**
	A1-3			**A4-5**		**B1-7**							**C1-4**				**D**
	Product stage			**Construction process** stage		**Use Stage**							**End of life** stage				**Benefit and loads beyond the system boundary**
	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
	Raw material supply	Transport	Manufacturing	Transport	Construction	Use	Mintenance	Repair	Replacement	Refurbishement	Operational energy use	Operational water use	Demolition	Transport	Waste processing	Disposal	Reuse/Recovey/ Recycling potential
				Scenarius		Scenarius							Scenarius				
Type of EPD																	
Cradle to gate[1]	M	M	M														
Cradle to gate with options[2, 4]	M	M	M	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Cradle to grave[3, 4]	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	O

M = Mandatory O = Inclusion Optional

[1]for a declared unit, [2]for a declared unit or functional unit, [3]for a functional unit

[4]Reference Service Life to be included only if all scenarios are included

Fig. 19.2 Information modules for construction products, adapted from EN 15804:2012

Fig. 19.3 Flow diagram of the life cycle (Source: EPD® Gyprom Saint-Gobain)

A4—transport of products from the manufacturer to the construction site
A5—the installation/construction of the building

The use stage can be divided into two groups: use stage related to building fabric (B1–B5) and use stage related to the operation of the building (B6–B7).

The use stage related to building fabric includes the following steps:

B1—use of the product, service or appliance installed
B2—product maintenance
B3—product repair
B4—product replacement
B5—product renovation

The module B1 refers to the releases into the environment. At product level, the maintenance (B2) includes all the operations for maintenance of the product installed in a building during the service life of the product. The impacts of this stage are directly linked to the context of the building and must be evaluated with well-defined settings. This is true also for the repair (B3), replacement (B4) and renovation (B5). The evaluation should include production, transport, energy and water use and any associated wastage and end-of-life processes.

The use stage related to the operation of the building must include the use of energy and water during the operation of the product, including the production and transport of any waste in the location produced by energy/water use. It includes, specifically:

B6—use of operational energy
B7—operational water use

As listed in the EN 15804: 2012, the end-of-life stage of a construction product begins when it is replaced, dismantled and does not have any function. Specifically, it includes:

C1—demolition of the building/construction product
C2—transport of demolition waste including the end-of-life construction product in the waste treatment plant
C3—waste treatment operations for reuse, recovery or recycling
C4—disposal and linked processes

During the end-of-life step, everything coming out from the system (that is the building) is considered waste until it gets the status of end-of-waste. The end-of-waste status is reached if one of these materials or products meet one of these requirements: it is commonly used for specific purposes; there is a market or a demand for it; it meets technical requirements for specific purposes; its use will not lead to negative effects.

The module D refers to the possible reuse/restoration/recycling.

19.4 EDP Analysis

The implementation of EPD according to these standards can be a valuable contribution for building professionals in search of reliable data on embodied energy of materials. Even if there are several doubts [30, 31]: first, the voluntary nature of this tool and the steps envisaged according to the system limit, which leaves a wide margin of discretion on what must be the steps considered (apart from the mandatory requirement in each step, if the limit of the chosen system is cradle-to-grave).

The existing research shows the analysis of the EPDs made by the producers on building materials, to quantify, first of all, what type of system limit was chosen. In this way, it can be understood which steps are excluded the most and if this can determine a low estimate of the embodied energy of a product.

The data in this paper refer to the existing EPDs on the International EPD® system website [32].

The geographical area of reference is Europe; on the website there are 395 EPD files divided in 24 European countries as shown in Table 19.2.

The analysis of the 395 EPD files shows that in most cases the system limit is cradle-to-gate with options, precisely in 46% of the cases; in 29% of the cases the system limit is cradle-to-gate and only in 25% of the cases the system limit is cradle-to-grave (Table 19.3).

In the case of EPDs with a system limit cradle-to-gate, the steps A1–A3 have been considered in all the files. In the files declaring that their system limit is cradle-to-gate

Table 19.2 395 EPD files divided in 24 European countries

Country	Construction products	Country	Construction products
Italy	75	Germany	5
United Kingdom	61	Hungary	5
Spain	53	Lithuania	5
Turkey	48	Finland	4
France	32	Ireland	3
Sweden	32	Luxembourg	3
Belgium	18	Czech Republic	2
Norway	14	Bulgaria	1
Denmark	9	Croatia	1
Romania	9	Netherlands	1
Switzerland	7	Poland	1
Russia	6	Portugal	1

Table 19.3 System boundaries of EPD

System boundaries	Quantity	%
Cradle-to-gate	115	29
Cradle-to-gate with options	182	46
Cradle-to-grave	98	25

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with options, it was examined which steps were considered, among the optional ones. Of course, the steps A1–A3 were considered in each file. The following steps have revealed that:

- Most of the cases have data only for the optional step A4
- A small percentage have data only for the optional step A5
- Few cases have data for steps B1–B7 and C1–C4
- The same happens for step D that is rarely considered, even in the cradle-to-grave analysis

Therefore, when in the EPD is declared that an analysis cradle-to-gate with options was made, the optional steps considered are A4 and A5, rarely the others.

In the cradle-to-grave system limit the phases are all mandatory, except for D, but it should be noted that on most of the files the values of the phases B1–B7 and C1–C4 are equal to zero or not relevant.

19.5 Conclusions

The paper has highlighted the complexity of the embodied energy measurement even if this comes with the understanding that it increasingly is a fundamental aspect of studies on energy saving in buildings. The TC 350 standards have been published, defining a harmonized methodology to assess the environmental performance and the costs of the life cycle of buildings. It represents an important tool, even if in practice it has several limits.

The analysis of the Environmental Product Declaration (EPD), made with the TC 350 Standards, shows how in practice few steps are included in their life cycle, mainly the product stage (A1–A3) and partially the construction stage (A4–A5). The impacts coming from the use stage, both the use stage related to building fabric (B1–B5) and use stage related to the operation of the building (B6–B7), are mostly omitted. It happens the same for the end-of-life settings. Rarely, they go after the end-of-life settings, with reuse, recovery or recycling (D). These results lead to some considerations that are also important challenges to be carried on in research:

- First, we should reconsider the voluntary nature of this tool that is definitely a limitation.
- If the goal is energy saving, in the interest of environmental sustainability, the data should be thoroughly as possible.
- The current lack of data prevents us from knowing the real impact of the use and end-of-life steps in energy consumption and consequently prevents us from assessing whether in the overall energy balance it is negligible.
- Many steps, especially in the cradle-to-gate system with options, are optional: it is therefore necessary to elaborate on whether this is a counterproductive choice for this tool.

– Involve more the academic world, in order to deepen the subject of research and foster debate, the building industry and end users to raise mutual awareness by offering and requesting materials and building components of certain environmental sustainability, and finally the building professions so that they can work since the creation stage with tools and data that allow to know exactly the overall energy balance of the building.

This research aims to collect data and their critical analysis, useful for evaluating future development actions and policies, but it is still in its initial stage; it will continue, first, by examining the files on the International EPD system website for non-European geographical areas. After the initial analysis on the phases of the considered life cycle, we will continue analysing more in detail the data provided for the individual stages and the type of materials in the EPDs.

The contribution, resulting from a common reflection, is to be assigned in equal part to both Authors.

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