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Development of an advanced methodology for assessing the environmental impacts of refurbishments

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Abstract. The refurbishment of the building stock is one of the key tasks for reducing the future environmental emissions in building sector. The assessment of the environmental impacts (EI) of refurbishments with LCA methodology remains a challenge. In the current practice, the refurbishment is threated as the beginning of the new lifecycle and all the impacts associated with the previous life cycle are generally neglected. The exclusion of materials and components used prior to the refurbishment produces a data gap at the end-of-life since information about materials that remained in the building after the refurbishment are missing. Furthermore, no information about what impacts have already been considered in the past bears the risk that some of the impacts are double-counted. In order to overcome these problems, an advanced methodology for the assessment of the embodied impacts in the case of refurbishment was developed that combines two sub-methodologies that can also be used separately. The first sub-methodology is used for remodelling the input data in order to make them time corresponding. The second sub-methodology is used for the assessment of the EI in the residual value of building materials and components and is including the allocation of EI between the life cycle before and after the refurbishment. The combination of the two sub-methodologies enables a more realistic and accurate assessment of the environmental impacts. The methodology is illustrated on the case on the case of a façade refurbishment. Five different allocation approaches are investigated and the residual value is calculated after a selected time period before and after the refurbishment. For all the inputs time-corresponding data is modelled and used. The study showed that for the life cycle before the refurbishment the EI and the residual value are generally higher if time-corresponding data is used since the EI of the electricity mix are higher. It turned out that the use of different allocation approaches is favouring either the use of recycled or reused materials or the recycling of the materials at the end. The PEF and the cut-off approach with module D are both enhancing the circular economy. It can be assumed that they are likely to prevail in the future.

Keywords: LCA, refurbishment, allocation, module D, dynamic LCA

1. Introduction

It is anticipated that 80% of the entire building stock that will be used in 2050 has already been built [1]. This means that the already existing buildings will be responsible for a large share of greenhouse emissions in the future [2]. Therefore refurbishment of public and private buildings is an important measure and has been identified as a key initiative to drive energy efficiency in the construction sector in the European Green Deal, which is a set of policy initiatives of the EU with the overarching aim of achieving climate neutrality of the EU by 2050. A strategy called "renovation wave" aims to double annual renovation rates in the next years [3]. Besides the increase of the refurbishment rate it is important that the quality of the refurbishment measures is improved. The study of Steininger et al. [4] highlights that the climate neutrality can only be achieved by deep refurbishments of the building envelopes, the substitution of their heating systems or a combination of both actions. Less ambitious refurbishment actions will not bring the desired results.

Consequently, also the environmental impacts of the refurbishment measure have to be assessed correctly. However, the interpretation of the current standards for the calculation of environmental impacts with the LCA leaves many opportunities to calculate the associated environmental impacts. In the current practice, refurbishment is considered as the beginning of the new life cycle and all the impacts associated with the previous life cycle are generally neglected. The recognition of the allocation need between the life cycle before and after the refurbishment is seldom observed.

It was also observed, that the information used for the LCA should be time-corresponding since the production processes are not static but change over time. For example, the electricity mix is changing on an hourly basis so some of the research studies propose using the hourly electricity mix for the assessment of the environmental emissions [5,6]. The energy or electricity mix can have a strong influence on the results [7,8]. Therefore, it should be encouraged that the datasets of the materials used should also be modelled with energy or electricity mixes that correspond with the time of production.

To overcome this shortcoming, a new advanced methodology was developed that allocates the impacts between the life cycle before and after the refurbishment. It consists of two sub-methodologies that can also be implemented separately. The first methodology is used for remodeling data in order to make the input data time-corresponding. The second methodology enables the calculation of the residual value of components and materials before and after a refurbishment.

2. **Methodology**

The methodology is a combination of two sub methodologies that can also be used separately. The first sub- methodology is used for remodeling the input data in order to make them time corresponding. The second sub-methodology is used for the assessment of the EI in the residual value of building materials and components and is including the allocation of EI between the life cycle before and after the refurbishment.

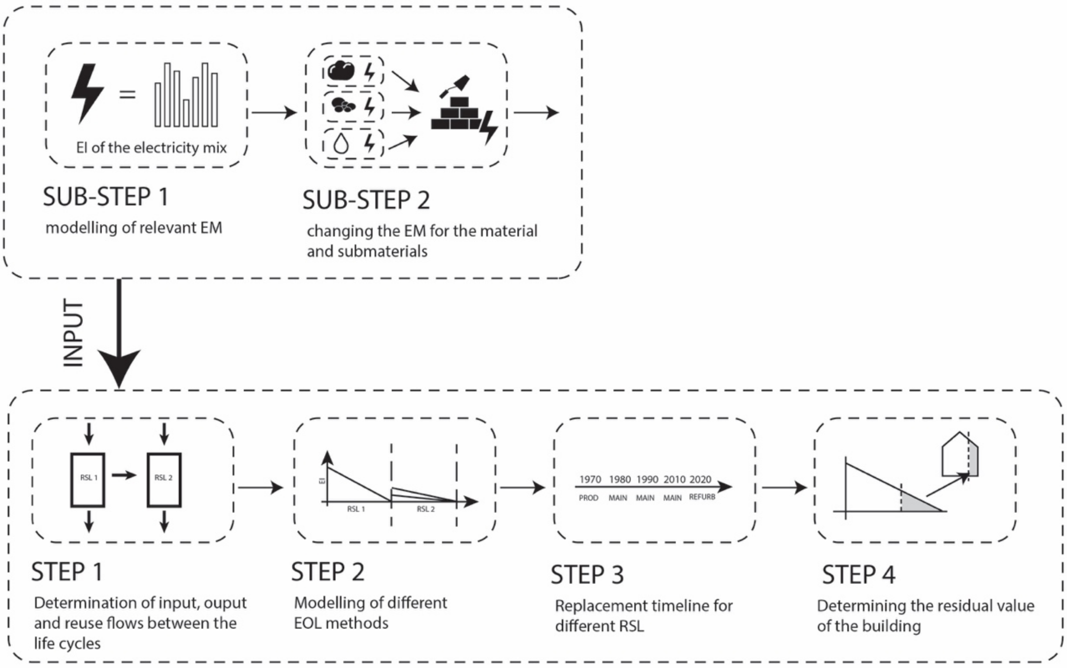

Figure 1. Combination of the methodology for the time-accurate determination of materials manufactured in the past and the methodology for the allocation between the life cycle before and after the refurbishment into a single methodology

The input data is remodeled in two sub-steps. In sub-step 1 the electricity mixes have to be remodeled for the selected time period. In the second sub-step, the LCI of the datasets are remodeled by replacing the electricity mix in the datasets with the electricity mix the electricity mix obtained in the previous phase. The remodeling of the input data is more precisely explained Potrc Obrecht et al. [12].

In the first step, all the relevant flows between the life cycles before and after the refurbishment are determined. Then the environmental impacts are assessed. In this step different allocation approaches were used, namely: the cut-off, cut-off with module D, avoided burden, 50:50 and the product environmental footprint (PEF). Step 3 is the development of maintenance scenarios with the selected reference service life (RSL) database. The environmental impacts of the maintenance scenarios are also calculated with time-corresponding data (calculated with the procedure described in the sub-steps). In the fourth step, the residual value is estimated. This part of the methodology is explained in detail in Potrc Obrecht et al. [16].

This approach is presented on 1 m2 of exterior wall of the case study of a multi-residential building. A comparison between the materials with the current materials and the materials with the exchange electricity mix is presented. The case study is a typical residential building from the period between 1971 and 1980. According to Slovenia's long-term renovation strategy, this kind of building has the greatest potential for the mitigation of GHG emissions with refurbishment measures [9]. The building was selected in the international Tabula project [10,11] and is presented in **Table** and Figure 2.

Table 1. Element list for the reference building

REFERENCE BUILDING	
Component	**Area [m2]**
Foundation slab	506.5
Exterior walls	1241.9
Windows	267.9
Slabs	2532.5
Inner walls	4216
Roof	646.6

Figure 2. Illustration of the reference building

In the second part, the difference in the results after the allocation of the impacts is presented. The results of the last step are presented in this part.

3. Results

The environmental impacts of the first life cycle can be calculated with the static data or semi-dynamic (time-corresponding) data. Table 1 indicates how the environmental emissions would change if the environmental emission of the material were calculated with time-corresponding data (semi-dynamically).

In this case, the environmental emissions of the current electricity mix were exchanged with the EI of the electricity mixes for the 1970, the year in which the case study building was built. The 1970 electricity mix has higher emissions and consequently, the materials produced with this mix also have higher emissions.

Table 2 shows that the individual materials have from 3.2 to 14.1 per cent higher GWP impacts if they are calculated with the 1970 electricity mix instead of the current electricity mix. Furthermore, 1 m2 of the exterior wall has 5.1% higher emission than if it were calculated with the current electricity mix.

Table 2. The difference between the GWP impact of the materials for 1 m^2 of exterior wall calculated for different years

	CONCRETE BLOCK		ADHESIVE MORTAR		BASE PLASTER		COVER COAT		PAINT		**EXTEROR WALL**	
year	1970	2020	1970	2020	1970	2020	1970	2020	1970	2020	**1970**	**2020**
GWP (kg Co2 eqiv.)	58.5	56.3	35.9	33.8	6.0	5.6	3.1	2.7	0.7	0.7	**104.2**	**99.1**
relative	103.9%	100.0%	106.3%	100.0%	106.0%	100.0%	114.1%	100.0%	103.2%	100.0%	**105.1%**	**100.0%**

Table 3 and Figure 2 show how the residual value changes if time-corresponding data is used. In the life cycle before the refurbishment the EI are generally higher if time-corresponding data is used for the assessment. The differences between the different allocation methods are small since mostly virgin materials were used at the beginning. The only difference emerges in the case of the 50:50 and PEF allocation methods because of the benefits of reusing the mortar and bricks. After 30 years, the residual value is about 4% higher, while after 50 years the residual value is 2.7% higher.

After the refurbishment the residual values calculated with time-corresponding data are smaller since the replaced materials have lower EI because they are produced with environmentally friendlier electricity mixes. In the second life cycle the differences between the different allocation approaches are bigger since the EI of the reused materials (mortar and brick) are allocated in a different way. After 30 years, the residual value is 10% lower for the cut-off and cut-off with module D approaches, 4% lower for the avoided burden approach and 6% lower for the 50:50 and PEF approaches.

Table 3. The difference between the use of static and time-corresponding data for the assessment of the residual GWP EI after 30 and 50 years for the life cycle before (LC1) and after refurbishment (LC2)

			EXTERIOR WALL			
			LC1		LC2	
			30 years	50 years	30 years	50 years
GWP (kg CO2 eq)		static	60.1	36.0	41.7	13.1
	CUT-OFF	time-corresponding	62.5	37.0	37.6	9.6
		static	60.1	36.0	41.7	13.1
	CO-D	time-corresponding	62.5	37.0	37.6	9.6
		static	60.1	36.0	98.1	46.8
	AVOIDED	time-corresponding	62.5	37.0	93.9	43.4
		static	61.8	37.0	71.3	30.8
	50:50	time-corresponding	64.2	38.0	67.2	27.4
		static	61.8	37.0	69.6	29.8
	PEF	time-corresponding	64.2	38.0	65.5	26.3

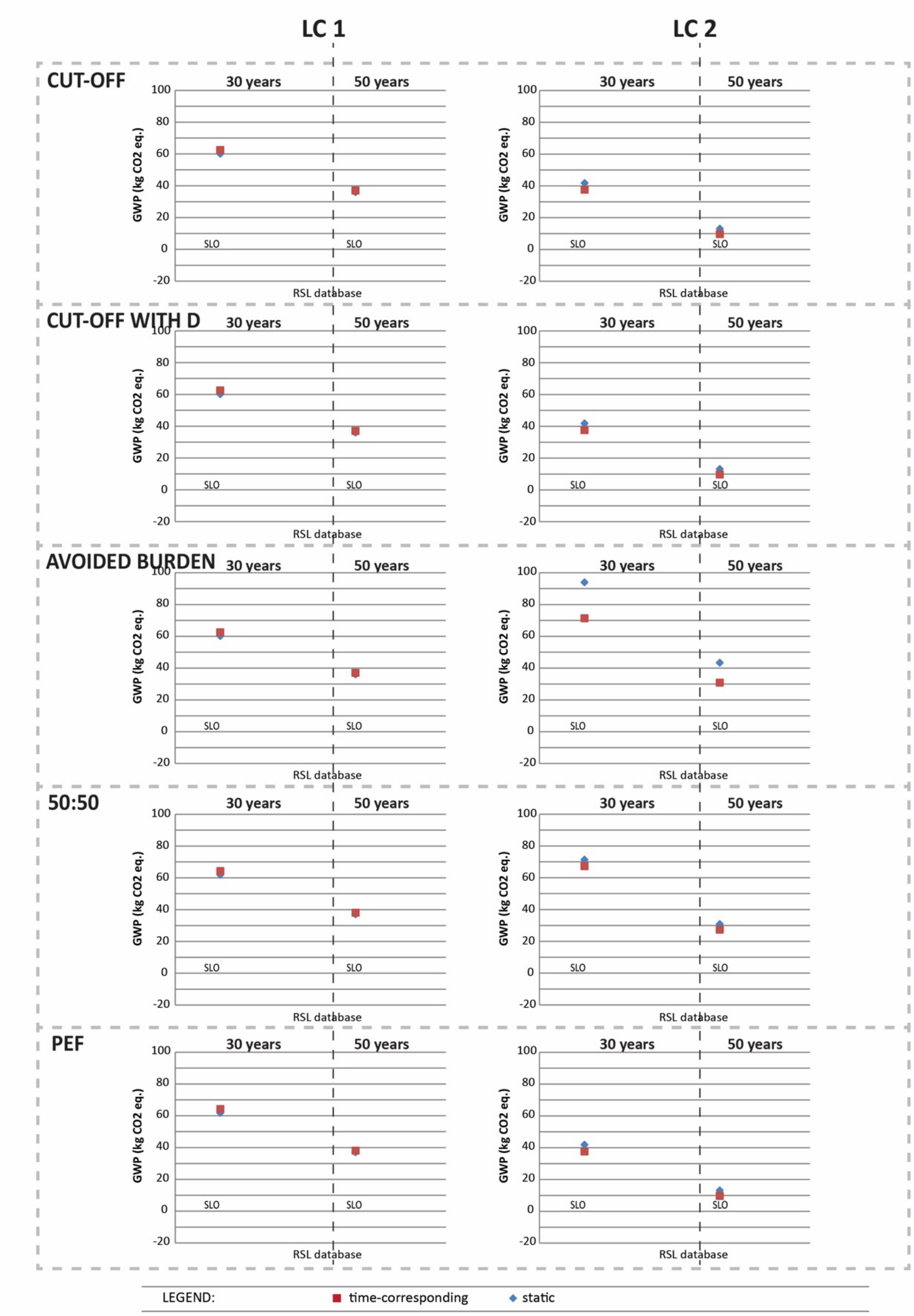

Figure 3. The difference between the use of static and time-corresponding data for the assessment of the residual GWP EI after 30 and 50 years for the life cycle before (LC1) and after refurbishment (LC2)

4. Discussion

The assessment of the EI with time-corresponding data can lead to great differences in results. In the presented sub-methodology, the focus was on the use of time-corresponding electricity mixes. In the study of Obrecht et al. [12] it was found out that the contribution of the electricity mix to the overall EI of materials can be as high as 20 per cent. Thus, the change of the electricity mix over time can have a great impact on the total EI of materials and therefore it is advised that precise and time-corresponding electricity mixes are used in the calculations. It is assumed that the differences in results would be even higher if the electricity mix were modelled on an hourly, monthly or seasonal basis. However, the remodelling of the input data for the calculation of the embodied impacts of the building is a demanding process which requires a lot of input information and work. For the calculation of the operational impacts of the buildings the use of time-corresponding electricity mixes is recommended, since it can have a high impact on the overall impacts, especially in case of building with higher operational energy demand.

The division of the impacts of the life cycle before and after the refurbishment has also proven to be a challenging task [13–16]. It is seldom discussed for buildings since the service life of buildings is very long. Each of the allocation approaches has its strengths and weaknesses (see Table 4) and therefore the choice of the right allocation approach depends on the scope of the study. However, since only the PEF and the cut-off with module D approaches promote the idea of circular economy, it is likely that they will prevail in the future. Also for the proposed methodology we are convinced that the cut-off with module D will be the dominant one in the future since there is a strong demand to improve the circular economy in the construction sector and it encourages the renovation due to the fact that all the impacts are allocated to the first life cycle. Other approaches, discussed in the study, are less appropriate since they are not so frequently in use and more (50:50) or they are more suitable for products with a shorter service life (avoided burden).

Table 4. Positive and negative aspects of the individual allocation approaches and their ability to contribute to the circular economy

Allocation approach	Positive	Negative	Circular economy
Cut-off	• Rewards the use of recycled materials • Easy application • Reduces uncertainty associated with future recycling	• Neglects all benefits of creating recycled materials at the EoL	no
Cut-off with module D	• Rewards the use of recycled materials • Rewards the creating recycled materials in module D	• The quality of the secondary materials is not taken into account	no
Avoided burden	• Rewards the creating recycled materials	• Neglects the benefits of using recycled materials	no
50:50	• A compromise between the cut-off		yes

	and avoided burden approach		
PEF	• A compromise between the cut-off and avoided burden approach • Introduces factors for the quality differences between primary and secondary materials	• The quality factors are not available	yes

The use of time-corresponding data leads to differences in results on such a scale that it should not be neglected. The use of time-corresponding input data in the methodology for the assessment of the EI and residual value before and after the refurbishment has proven to be a very demanding and time-consuming task. A lot of work and information is required. The development of a tool that would reduce this work would be welcome. The presented methodology can act as a framework for this tool.

The input data for the life cycle before the refurbishment can be made based on realistic data, while the EI for the life cycle after the refurbishment is mostly based on scenarios and predictions. This increases the uncertainty of the results for the life cycle after the refurbishment. However, since the European countries are obliged to plan and report the development of electricity mixes, it is assumed that this reduces the uncertainty at least on the conceptual level.

5. Conclusions

The use of time-corresponding input data for the assessment of EI and the residual value for the life cycle before and after the refurbishment would increase the representativeness of the results. Therefore, the methodology for modelling time-corresponding input data and the methodology for assessment of EI and the residual value including allocation between the life cycle before and after the refurbishment were combined. In the presented case of the exterior wall the differences were in the range from 4 to 11 per cent. For the life cycle before the refurbishment, the EI and the residual value are generally higher if time-corresponding data is used, because the EI of the electricity mix are higher, while for the life cycle after the refurbishment they are generally lower. The differences in the results are on a scale that should not be neglected. However, since this entails a lot of input information and work, it would be welcome if a tool were made available.

The presented work can be used as a framework for the development of such tool. A tool would facilitate the calculation process and make it possible that such a process would be performed also by designers. It would be recommended that such a process would be performed before the beginning of a refurbishment process since it would allow to identify with components are still not amortized and should be handled with additional care. Another advantage could be if the methodology would be used as part of the certification that would be used to evaluate the appropriates of the refurbishment and would include also other aspects like functionality. Earthquake resistance, etc.

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