Refurbishment or Replacement of Buildings – What is Best for the Climate?

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Abstract

Norwegian Bank “SpareBank 1 SMN” in 2008 decided to reestablish their headquarters in Trondheim. The key question addressed in the process, was whether to rehabilitate the existing building or demolish it and construct a new one. Becoming aware of the environmental issues related to the decision, a project was set up to assess the consequences for green building. The analysis concluded that from a climate point of view the most favourable strategy was to replace the existing construction and build a new one.

A hybrid LCA approach was used as the assessing tool, and in the paper we discuss the methodological challenges facing analyses addressing the issue of comprehensive analytical approaches in order to inform decisions in this respect. The paper shows the usefulness of life cycle models as input to a decision making process in a feasibility phase of the project. In addition, data availability and methodological issues are discussed in some detail.

Keywords

GHG emissions, LCA, refurbishment, building, feasibility phase

Introduction

The building sector’s share of final energy consumption worldwide is estimated as high as 30-40 percent (WBCSD 2009, European Commission 2007). Consequently it represents a major target for improvements. The sector is generally addressed by most environmental policies (EUs Energy Performance Directive).

In 2008, the Norwegian Bank “SpareBank 1 SMN” decided to reestablish their headquarters in Trondheim, Norway. As a consequence of a more offensive regulation and focus on energy and reduction of GHG emissions in the building sector, the bank established an environmental strategy for the construction project where environmental considerations should be an integral part of decision made in the process.

The old facilities were regarded as increasingly inadequate, not very functional or usable with respect to changes in the performance of bank services today and in the future. The existing headquarter building was from the early 70s. The challenge was to decide whether they should rehabilitate the existing building or demolish it and construct a new building.

SpareBank 1 SMN has been concerned with their responsibility for the building's environmental load over its entire life cycle. Thus, it was appropriate to use life cycle assessment (LCA) as the methodological approach.

The aim of this LCA project was bipartite. Firstly, to document the GHG emissions from the two alternative solutions, and secondly, to gain experiences from using LCA methodology as a basis for decision making in a feasibility phase.

Methodology

LCA

The LCA-methodology has been developed during the last 20 years and is adapted by the ISO community available as standards ISO-14040-44. In addition, standards for communication of results from LCAs are developed as Type III declarations or Environmental Product Declarations. These standards address all products and there are ongoing processes adjusting the methodology to building products and constructions, ISO 21930 and CEN TC350. A closely related standard to ISO 14000-series has been developed – *ISO 15686 Buildings and constructed assets – Service life cycle planning*. This standard is intended to complement the ISO14000-series by describing how environmental standards may be implemented in building projects.

Several studies have used life cycle assessments to measure the impacts of energy consumption in different building stocks in a quantitative way (UNEP, 2007). The use of LCA as the assessing tool has become commonly used in this respect.

One important result from the LCA analyses is that energy use for operation contributes to 80-90 percent of the total during the lifespan (Rønning et al. 2001, Vold et al. 2006, Fernandez 2007, Rønning et al. 2007, Dimoudi and Tompa 2008). But, when assessing low energy buildings the embodied energy is significant and may be the dominant factor (Thormark 2002, Thormark 2006).

The undertaking of LCA analyses of buildings needs methodological considerations on two dimensions. The first one relates to the question of which emissions should be included, i.e. the activity of boundary setting to decide which emissions that belong to the building being scrutinized. The second dimension is related to the actual data collection and which figures should be used for emissions from basic technologies such as electricity generation and various infrastructures. These dimensions are of course entangled as the first dimension will decide which data to be collected and the second dimension will decide whether the actual data to fulfill the system boundaries are at all available.

Regarding boundary setting an array of different tools exist for building components, whole buildings and whole building assessment frameworks. The tools cover different phases of a building's life cycle and take different environmental issues into account (Haapio and Viitaniemi 2008a).

Currently most of the building environmental assessment tools are used towards the end of the design process to evaluate the environmental results (Haapio and Viitaniemi 2008b).

Boundary setting by using a merge of LCA and LCC

ISO 15686-6 gives a comprehensive illustration of the system to be included in an environmental assessment of a building construction, but it is not very clear how the scenarios for *Construction, Use, Maintenance* and *End of life* given in figure 1 should be described or what kind of data should be included.

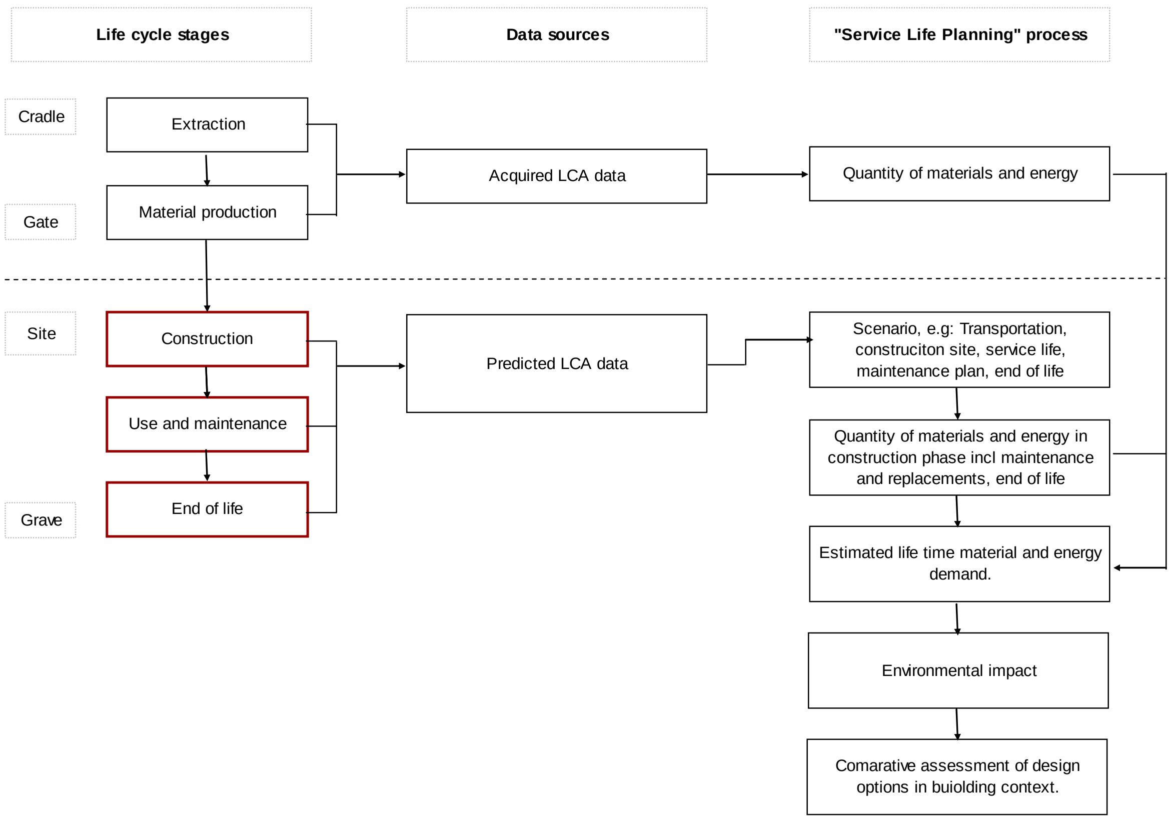

Figure 1 The relation between Life Cycle phases, data sources and Service Life Planning. (ISO 15686-6:2004).

On the other hand the methodology Life Cycle Costing (LCC) for constructions is used for estimating the total costs over the construction's anticipated functional lifetime. This methodological approach includes a description of scenarios missing in Life Cycle Planning. Instead of calculating the environmental loads from the construction elements, one takes into consideration the loads over the entire life cycle. It incorporates the initial capital costs, the demolition costs and the entire annual costs for Managing, Operation, Maintenance and Development (MOMD) (Lindberg, 2002).

When it comes to making environmental considerations the focus has up to now been predominantly on the LCA stages above the dotted line in figure 1. In other words – the individual materials or building elements have been environmentally assessed – but the combination of them and the effect the material choice have on e.g. operation, maintenance and development are rarely assessed.

Data availability

Calculating life cycle emissions can be approached methodologically from two different perspectives: bottom-up, based on Process Life Cycle Assessment (PLCA) or top-down, based on Input-Output Life cycle Assessment (IOLCA) analysis. Generally, input-output LCA has its advantages when applied for macro or meso levels such as industrial sectors or larger product groups, while process LCA has advantages when looking at micro systems; a particular process or individual product. Hybrid approaches link process information collected in physical life-cycle inventories with monetary flows in economic models.

In the building sector PLCAs have been the most usual approach. This approach is calculating emissions from the inputs by its masses, which represents challenges for several reasons. Firstly, the construction sector in Norway does not have a tradition to evaluate their projects on mass basis, only in economical terms. Thus, one does not have key figures or experienced based calculations to lean on. Secondly, in a feasibility phase one doesn't know which materials will be chosen. And last but not least, there are not environmental data available for all building materials and components.

The combination of LCA and input-output models has shown value as a complementary tool to traditional inventory methods in LCA. Especially in US one see the approach of IOLCA and Hybrid LCA utilized when analyzing a construction project (Guggemos and Horwath 2005, Sharrad et al. 2008) to overcome the lack of data and to include embodied emissions.

Case specific methodology

The methodology used in this case is a merge of the Life Cycle Costing methodology - LCC and Life Cycle Assessment – LCA (Rønning et al., 2007) where LCC methodology was the basis for define the life cycle scenarios and system boundaries (figure 2)

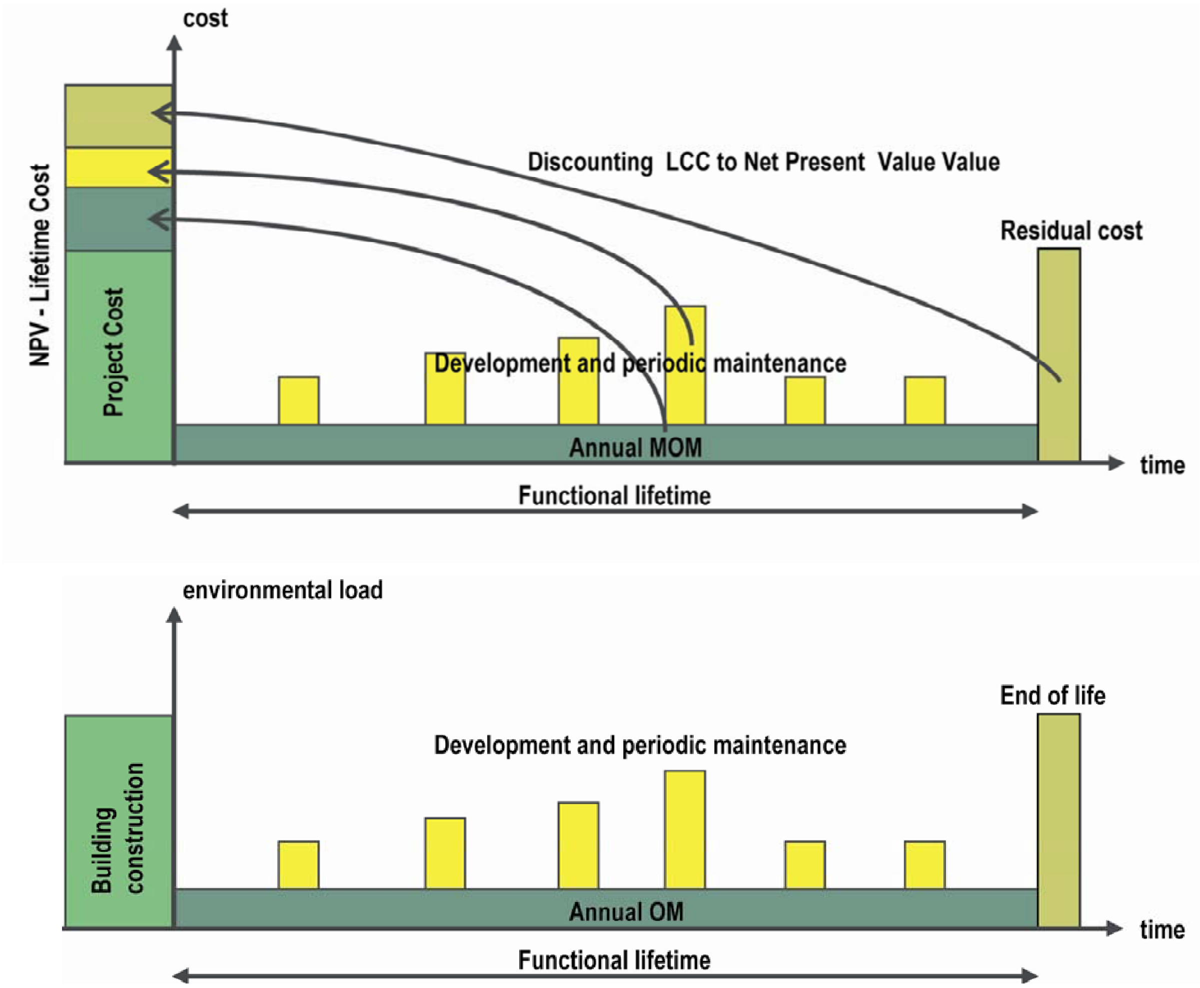

Figure 2 Life Cycle Cost theory and Life cycle phases of a building (Rønning et al., 2007).

The comparison is based on calculations of greenhouse gases related to the phases Building construction (cradle to gate for building materials and components), Operation, Maintenance and Development during the life span of 60 years of the two alternatives. Demolition - or End of Life – was not included in the comparison, but is included in the general model.

The two alternative cases are defined as follows:

New construction:

- Existing building is demolished completely and new building is constructed
- New building has good adaptability

Refurbished construction:

- Demolishment of all interiors excluding primer building components and building envelop and rebuilding.
- Medium adaptability.

The total energy demand for the existing building is relatively high, 524 kWh/m^2. The goal for the new or refurbished construction was a net energy demand on 85 kWh/m^2. The existing construction is considered to have low adaptability and area effectiveness. Thus, the comparison must take into consideration a relatively extensive refurbishment including upgrading of the existing building.

While the new construction's condition with respect to operation, maintenance and development was assumed to be **"**well adaptable", the refurbished construction's state was defined as "medium adaptable". Due to the low adaptability for the refurbished construction the energy consumption after refurbishment would probably be reduced to 300 kWh/m^2. Those assumptions influenced the results significantly. In table 1 assumptions regarding MOMD is given.

Table 1 Assumptions regarding MOMD

		Units	New construction	Refurbished construction
General assumptions	Gross area	m^2	12 740	12 069
	Number of work places		600	500
	Service life	years	60	60
Demolishing/constuction	Share demolished/rebuilt		Whole construction	All interior excl. building envelop and primer building elements
Energy use	Net energy demand	kWh/m^2	100	300
	Purchased electicity[1]	kWh/m^2	85	174
	District heating2	kWh/m^2		126
Inspection technical equipments	Building condition		Good condition and good routines	Medium condition and routines
	Cost	NOK/m^2 per yrs	60	90
Cleaning	Building condition		Good condition and good routines	Good condition and good routines
	Cost	NOK/m^2 per yrs	70	70
Maintenance and development	Building condition		Good adaptability	Medium adaptability
	Cost	NOK/m^2 per yrs	1 500	4 500
	Cycle	years	every 7th	every 7th

[1] Nord-el mix (Nordic el production, loss included)
[2] FREVAR: Emissions per kWh produced + 10% loss

In the feasibility phase no information or calculations regarding amount of materials were available. Thus, the budget estimates for the project was used as basis for calculations of GHG emissions.

In table 2 the distribution of work and material costs are given. Since the consumption of material is calculated in monetary terms, a hybrid approach to LCA was chosen in this case. Statistics Norway gives the emission intensity per sectors calculated as emissions per NOK gross product in the different sectors. These numbers were used in addition to product specific emissions in those cases where the materials were given, e.g. use of concrete.

Table 2 Estimates for materials and work cost for the feasibility project.

	Working cost	Material	as percentage of total material cost [%]				
			Wood	Heavy materials (concrete, masonry etc.)	Metals	Electrical and mechanical products	Paint and chemical products
Overhead costs							
Overhead cost rigging and operation	100						
Contract administration	100						
Supplementary work, technical disciplines	100						
Construction							
Groundwork and foundation	28,5	71,5		64	7,5		
Primary constructions	25,5	74,5	15	52	7,5		
Secundary external constructions	37	63		48	15		
Secundary internal constructions	45	55	15	40			
Surfaces	47,5	52,5	15				37,5
Complemental building components	37	63		40	15	8	
Fixed furniture	36	64	4		12	48	
HVAC installations							
Sanitary installations	60	40			10	30	
Heating	60	40			30	10	
Fire extinguishing	80	20			20		
Process cooling	65	35			20	15	
Central air treatment	20	80			70	10	
Air distribution and ducts	70	30			30		
Comfort cooling	40	60			45	15	
Electric power							
Electric power	80	20				20	
Core installations for electric power, general	50	50			25	25	
Low voltage supply	30	70			35	35	
Lighting	30	70				70	
Electric heating	60	40				40	
Backup power	30	70			50	20	
Teleprocessing and automation							
Teleprocessing and automation, general	70	30				5	25
Base installations for tele og automatic	60	40			10	30	
Integreted communication	70	30				25	5
Telefoni og personsøking	60	40				35	5
Alarm and signal systems	60	40				35	5
Sound and display systems	30	70			10	55	5
Automation	50	50				45	5
Other installations							
Transport of persons and goods	52	48		5	10	33	
Waste and vacuum cleaning	55	45			10	35	

Calculation of the environmental profile for the whole building was based upon data from databases, NAMEA statistics (National Account Matrix including Environmental Accounts), general LCA software and the Norwegian LCC-standard. Table 3 shows the emission factors used.

Table 3 GHG emissions for different materials and working activities.

Sectors	Tonne GHG emissions/MNOK
Construction and building work activities[1]	13,7
Consultancy work[1]	1,1
Wood materials[1]	24,5
Heavy materials[2]	175,0
Metals[3]	55,6
Electrical and mechanical products[1]	3,6
Paint and chemical products[4]	42,9

1) Statistics Norway: NAMEA

2) EPD Contiga, www.epd-norge.no and cost given by Contiga

3) EPD for steel beam Contiga

4) Selvig 2007

Results

From a climate point of view the most favourable strategy is to replace the existing construction and build a new construction. The results are illustrated in Figure 3.

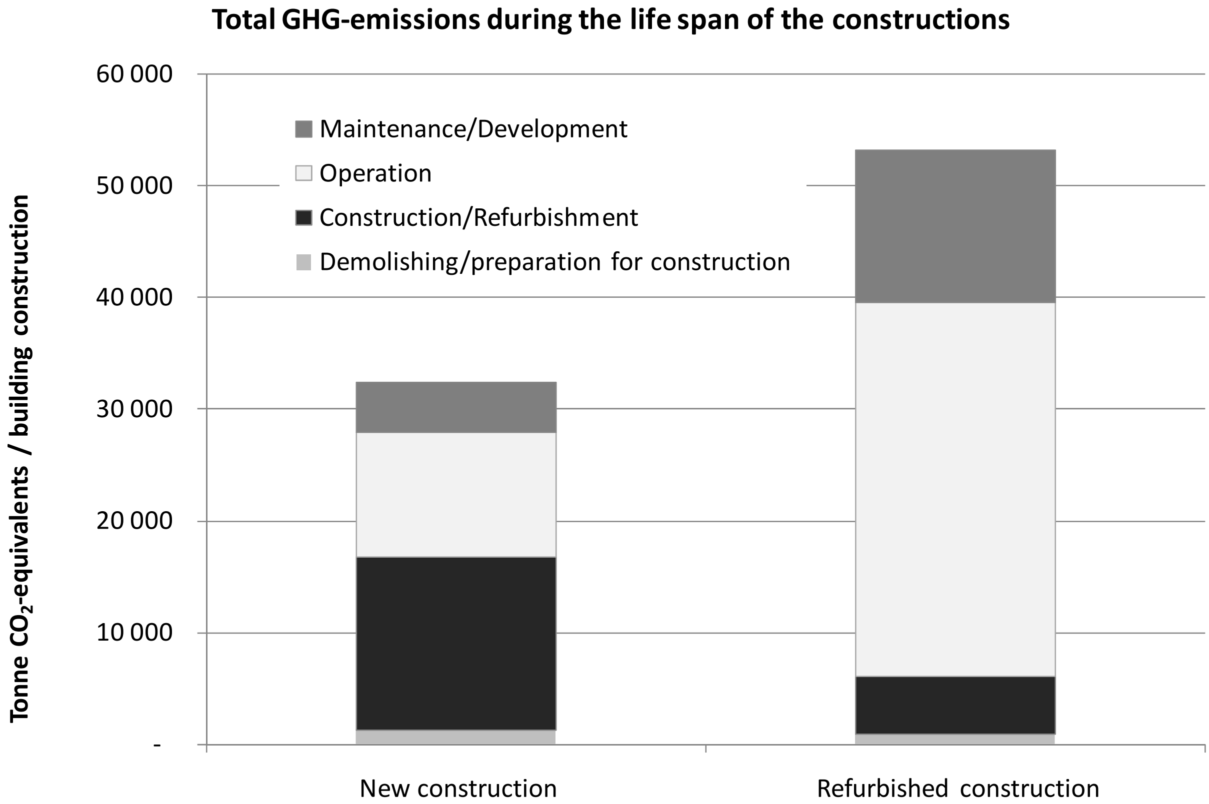

Figure 3 Total emissions of greenhouse gases given in CO_2-equivalents for new and refurbished constructions during 60 years.

Figure 3 shows the emissions related to producing and constructing the new building are more than twice the size of the refurbished construction. On the other hand the emissions related to operation, maintenance and development of the refurbished construction are three times the size of emissions related to the new construction. This is mainly explained by the low adaptability and flexibility of the refurbished construction.

This conclusion is further strengthened when comparing emissions per employee since the new construction is more area effective and makes it possible to increase the number of work places from 500 to 600. This gives a total emission per employee of app 100 vs. 50 tonne CO2 equivalents.

The demolishing pay pack time is approximately 14 years as given in figure 4.

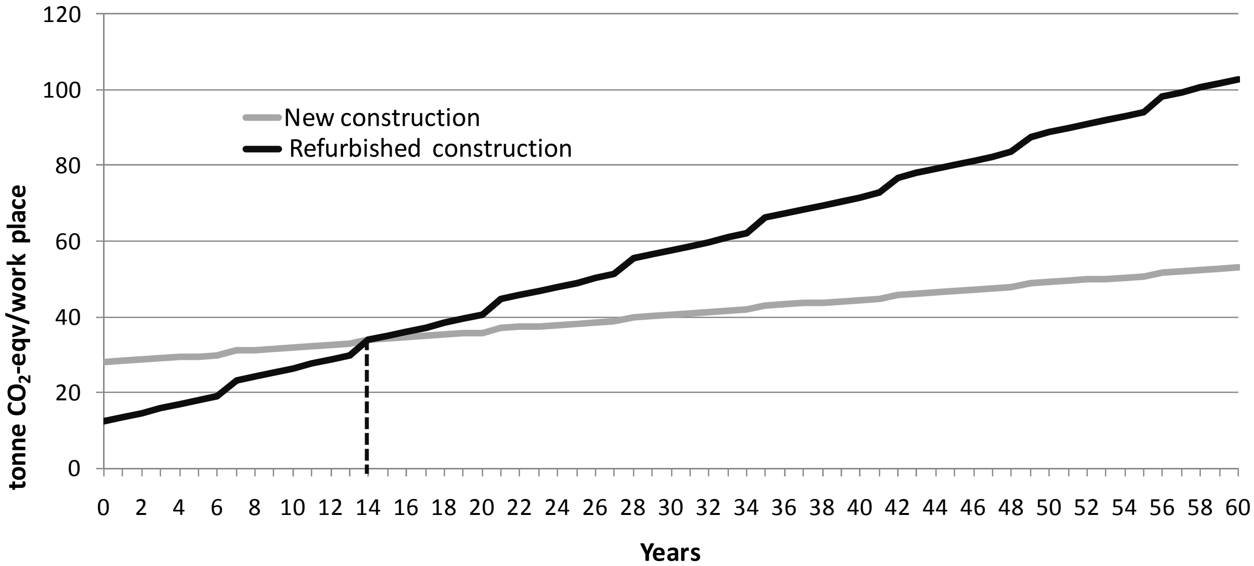

Figure 4 Accumulated emissions of greenhouse gases during 60 years given in CO_2-equivalents for the new and refurbished constructions.

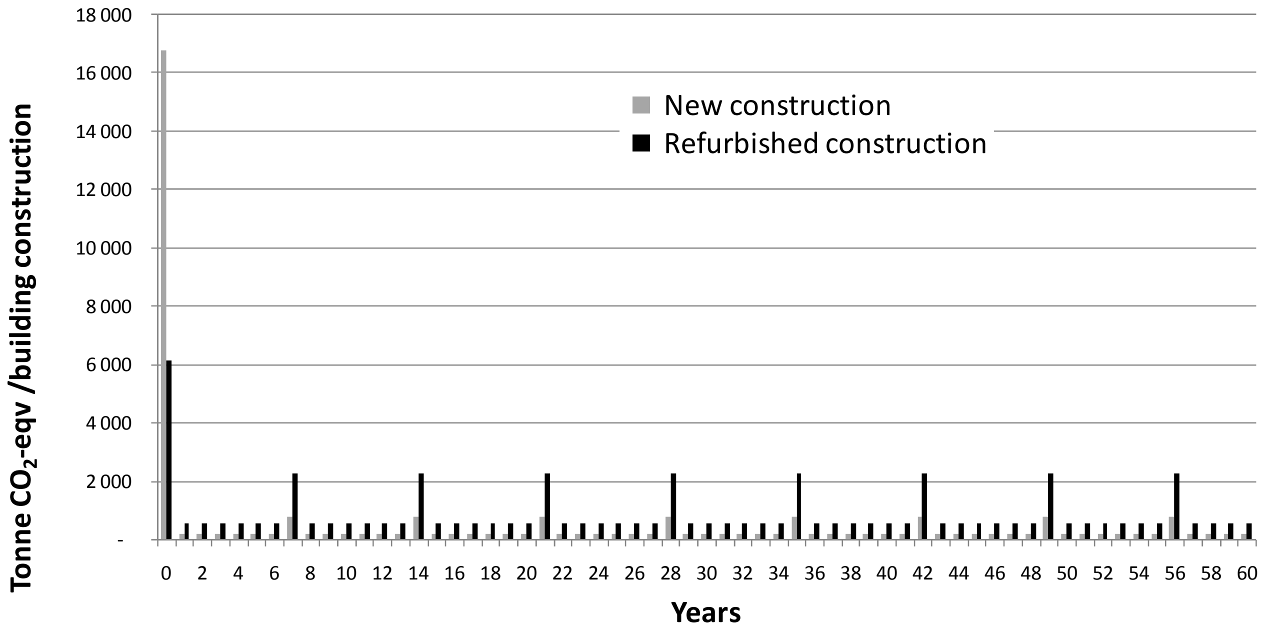

Figure 5 GHG emissions given as tonne CO2-equivalents distributed per year of operation during 60 years life span for new and refurbished building construction

SpareBank 1 SMN has documented as much as 99% of the demolished materials including furniture and fixtures have been delivered to reuse or recycling.

Discussion and conclusions

The methodology in this study has been used to evaluate the environmental consequences of the decisions made in a feasibility phase of the project. In that respect the data used – a sort of hybrid LCA combined with the scenario strategies in LCC methodology – were suitable to distinguish between the two alternatives. The results from the simulation of the two alternatives were considered to be suitable to advice the decision made by SpareBank 1 SMN. In addition, the results confirm the findings in previous studies that one can accept a heavier environmental load in the construction phase if the way the combination of building materials and solutions are affecting each other increase the adaptability of the construction and therefore reduce the emissions during the life time of the building.

The results are sensitive to the estimates done, especially the merge of data for investment planning and material flow data. On the other hand the estimates are in the same order of magnitude for the two different cases.

Currently most of the building environmental assessment tools are used towards the end of the design process to evaluate the environmental results (Haapio and Viitaniemi 2008). In the building sector PLCAs have been the dominated approach. That is probably one of the reasons why the majority of the LCAs document or evaluate environmental results and are not used as a decision tool in the design or feasibility phase.

Official Input-Output Tables (IOTs) cover the entire economy using detailed government statistics that are often inaccessible to the general public. Therefore the annual NAMEA figures were used in this study. The weakness of these figures is the lack of complete embodied energy data from the entire value chains related to a given sector. Still it gives a satisfactory basis for an analysis of the feasibility phase of a construction project.

SpareBank1 experienced that the results contributed to increased knowledge of the different choices in a feasibility phase may have on the life cycle activities in a buildings life span. Thus, when it comes to actual choices of material and technical solutions the service lives of different building products and components, and their effect on a building and its service life need to be analyzed more thoroughly. Hence it is not clear which materials or combinations of materials can achieve the best performance, in terms of lifecycle energy use and CO_2 emissions and the overall composition of the building (Fernandez 2008, Rønning et al. 2007). By composition is meant choosing and designing everything from situation, the structure, the shape, the predominant materials and the material details.

Evidently, there are challenges regarding calculating and demonstrating the differences between alternative building solutions for the operation phase. In order to create a facilitating and useful design tool for architects and developers that will constitute a valuable addition to existing tools, those challenges have to be addressed.

The results from this study were one of the main inputs to the decision process in the pre-construction phase. SpareBank 1 SMN concluded to replace the existing building. It is already demolished and the construction of the new building has started.

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