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# Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design☆

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ABSTRACT

Due to the growing threat of climate change, we are challenged to find improved assessment practises to recognize solutions for sustainable urban development. The focus of the study is on the life cycle design of a district energy system for a new residential development in Finland. This study analyses LCC (life cycle costs) and carbon emissions (LCA (life cycle assessment)), i.e., the "viability" of different energy systems through a methodological life cycle framework. By combining LCC and LCA, a LCM (life cycle management) perspective is portrayed to support decision-making on a long-term basis. The comparable energy design options analysed are (1) district heating (reference design), (2) district heating with building integrated photovoltaic panels, (3) ground source heat pump, and (4) ground source heat pump with building-integrated photovoltaic panels. The results show that the design option with the highest initial investment (4) is in fact the most viable from a life cycle perspective. This study further strengthens the connection between cost savings and carbon emissions reduction in a life cycle context. Thus, by implementing LCC and LCA analysis in an early design phase, justified economic and environmental design decisions can be identified to develop more sustainable urban areas.



## 1. Introduction

It is often stated that the three dimensions of sustainable development (economic, environmental and equity) tend to contradict each other in urban planning [1,2]. Finding solutions that would support progress in all three of these aspects is thus a big challenge. Godshalk (2004) has further studied the value conflicts within sustainable development between ecology, economy and equity. He has boldly suggested that ecology (i.e., the environment) and economy should be the primary values, and that equity should be seen as a secondary objective in order to enhance urban planning [3]. While opposite opinions exist as well (e.g., in the Nordic countries, the social aspect of urban development is mandated by legislative processes), focussing on these two aspects certainly forges the way in the search for viable sustainable solutions.

The focus in environmental sustainability in urban development has lately been dominated by climate change. The spotlight in research and policy-making is on cities, especially on residential buildings and transportation due to their dominant role in global growth [4,5]. Demographic changes indicate that by the year 2050, 70% of the world's population will live in cities [6]. In terms of emissions and energy consumption, cities produce about 80% of all GHG (greenhouse gas) emissions and consume 75% of energy globally [7]. Simultaneously, the global building stock is responsible for approximately 30–40% of energy use and carbon emissions [8]. In Europe, the major share of these emissions actually derives from heating alone [9].

It seems that residential development could present a grand opportunity to decrease energy demand and reduce carbon emissions cost-effectively with combining existing knowledge and technology [10,11]. The highest economically feasible mitigation potential is suggested to be found in the residential and commercial sector; a possible 29% reduction is insinuated in relation to the projected emission baseline for year 2020 [6].

Public and private acquisitions in present development can be argued to be made predominantly based on short-term investment values and not from a life-cycle driven perspective [12]. This may lead to development potentially conflicting with all the sustainability dimensions.

By employing a life cycle perspective through LCM (life cycle management); LCC (Life cycle costing) and LCA (life cycle assessment) have been introduced to provide information for managing sustainable development. Hence, the life cycle perspective (or life cycle thinking) does not get the required attention [13]. Klöpffer, W.



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(2008) and Finkbeiner et al. (2010) have introduced a tool for LCSA (life cycle sustainability assessment), which is defined as: LCA + LCC + SLCA (LCA = Environmental Life Cycle Assessment, LCC = Life Cycle Costing, SCLA = Social Life Cycle Assessment) [14,15]. Connecting both environmental and economic aspects would further strengthen the importance of the concept life cycle management in the early design stages of urban development [16].

When combining economic and ecological dimensions, they can be claimed to complement each other in residential development. Lower energy consumption equals lower running costs. When this thinking is extended throughout the life cycle of a new residential development, the savings might be significant compared to the initial investment. According to McKinsey & Company (2009), the built environment sector has an excellent economic potential to reduce GHG emissions by the year 2030 [17]. Accordingly, only the power generation sector has more potential. Energy efficiency as a category has the most abatement opportunities, in which building insulation possesses a significant role [17]. The study suggested that minor design changes in construction have a significant carbon reduction impact with a payback-time close to zero for both carbon emissions and the respective operational costs.

The existing literature presents some examples of combining the economic and ecological dimensions of life cycles. Carlsson Reich (2005) attempted to combine economic LCC with environmental LCA in the case of municipal waste management systems. The environmental effects were monetized in order to introduce a common unit to measure both life cycle costs and environmental effects [18]. The methodology enabled the analysis, but issues of consistent methodology between economic assessments and environmental LCAs remained. Heijungs et al. (2012) introduce a way of calculating economic and ecological life cycle costs in one assessment model [19]. Similarly, Junnila (2007) has presented a combined LCC and LCA framework for life cycle management of energy-consuming products [20]. Lijing Gu et al. (2008) have created a method where LCA and LCC are combined for addressing the life cycle green costs of buildings. LCA of different building design options was analysed and converted into LCC costs for emissions. Afterwards the emission costs derived from LCA were added to the conventional LCC outcome [21]. Brown et al. (2011) have proposed a life cycle management approach for large-scale development resorts, where LCC and LCA are combined in order to create designs that provide environmental benefits with low operational costs [22].

The purpose of this study is to examine whether a residential development can in practice deliver the claimed sustainable viability, i.e., simultaneous environmental and economic benefits. The study combines LCC and LCA in a case of a residential district energy system area in Finland aiming to identify the actual technologies that could provide the highest sustainable viability and assesses the emissions and relative mitigation potentials associated with the different technologies.

Additionally, this study examines whether investments in modern energy systems are feasible in both the economic and ecological perspective. Thus, the LCC and LCA analyses are carried out separately. Combining LCC and LCA brings added value to life cycle management. By enhancing the position of life cycle management, profound sustainable solutions can be identified and implemented.

The study suggests that investments in new technology in heat and electricity production provide savings in costs and GHG emissions. However, the break-even points of the investments occur significantly sooner ecologically than economically.

The structure of this paper is as follows: The research methods are presented in Section 2, followed by a detailed description of the research process in Section 3. The results of the study are presented in Section 4. The implications and uncertainties related to the results are discussed in Section 5. Finally, conclusions of the study are presented in Section 6.

In order to avoid misinterpretation, the terms *life cycle viability* and *life cycle affordability* are defined. Life cycle viability (in urban development) is defined as merging economic and environmental sustainability [23]. Life cycle affordability is defined as a calculated net present value measure (€/m$^2$/a) representing overall cost-efficiency during a defined time period.

## 2. Research methods

The research methods applied in this study are life cycle costing (LCC) and environmental life cycle assessment (LCA). It is important to note that the LCC and LCA methods function similarly, although they quantify their outcome with different measures: LCC is for purely economic assessments, whereas LCA is for environmental assessments.

### 2.1. Life cycle costing (LCC)

LCC is a valuable financial approach for evaluating and comparing different building designs in terms of initial cost increases against operational cost benefits with a long-term perspective. The key incentive for applying an LCC analysis is to increase the possibility of cost reductions for the operational phase, even if an additional increase in the initial investment is necessary [24]. By applying an LCC perspective in the early design phase, decision makers are able to obtain a deeper understanding of costs during the life cycle for different design strategies. Buildings are a long-term investment associated with environmental impacts over a long duration [25,26]. Fundamental environmental responsibility aims for a long-term view and with that an understanding that initial design decisions have a significant impact over a building's life span [25].

LCC is defined as "a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors, both in terms of initial costs and future operational costs" (Standardized Method of Life Cycle Costing for Construction Procurement ISO15686, 2008) [27]. It is important to notice that traditional LCC is purely economical and does not take into account environmental aspects [24]. Earlier development has focused on developing LCC methodology for the construction industry and placing LCC in an environmental context [28]. Sterner E. (2002) developed an LCC model to calculate the total energy costs for buildings [29].

The LCC theory foundation is properly developed by Flanagan et al. (1989) and Kirk & Dell'Isola (1995) along with essential decisions and activities to undertake an LCC analysis [30,31]:

- **Defining alternative strategies to be evaluated** – specifying their functional and technical requirements
- **Identifying relevant economic criteria** – discount rate, analysis period, escalation rates, component replacement frequency and maintenance frequency
- **Obtaining and grouping of significant costs** – in what phases different costs occur and what cost category
- **Performing a risk assessment** – a systematic sensitivity approach to reduce the overall uncertainty

In order to compare different alternatives, a derived indicator consisting of net present cost of all relevant life cycle costs is calculated. The LCC annual equivalent is defined as €/m$^2$/a (net present cost) for the chosen evaluation period (Standardized Method of Life Cycle Costing for Construction Procurement