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Carbon Footprint Assessment of a Residential Development Project

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Abstract—**Buildings account for roughly one third of all green house gas emissions globally. Identifying the sources of these emissions and understanding their relations to the construction phase is essential in climate change mitigation. This study evaluates the carbon emissions caused by a residential construction project in Finland. The research method is modified tiered hybrid life cycle assessment. The study shows that the carbon emissions of a 220 homes development project are around 60 000 tons of which 90 percent initiates from actual buildings and ten percent from the supporting infrastructure. The sources of the carbon emissions are divided into numerous categories without any single dominant category. Thus, reducing the emissions requires a holistic management approach, as there are no single dominant materials in terms of carbon emissions. Also, the costs were found to poorly correlate with the carbon emissions, which implies that the traditional cost management strategy used in project management cannot directly deal with carbon management challenge. In addition, the results indicate that because of the rapid and high carbon spike of construction, the construction phase emissions are much more significant regarding the climate change than their share of the buildings' life cycle emissions would suggest. The study also shows that a generic LCA data model can be used to roughly estimate the emissions of a development project, but that a more detailed project specific data is needed for more accurate results. The difference between a generic and a project specific model were calculated to be roughly 20 percent. The results of the study may be applied to the evaluations of similar construction projects. The research method may also be used in future research as well as in further development of hybrid LCA methods.**

Index Terms— **life cycle assessment (LCA), residential area constructions, EIO-LCA, hybrid LCA.**

I. INTRODUCTION

Climate change seems unavoidable. The EU has adopted a target of limiting the temperature rise below 2.0 Celsius degrees [1]. Of the emissions sources, buildings account for over one third of all the green house gas (GHG) emissions [31]. According to recent research, buildings also provide the most profitable mitigation possibilities [27]. Even though the share of carbon dioxide (CO2), the most important green house gas in the atmosphere, is still relatively low, the concentration is growing as the decay is slow. Due to this, attention should be paid to the time perspective in addition to the volumes of greenhouse gas emissions (GHG's). Thus, understanding the problem and the underlying causes together with prevention and minimization of the effects belong to the most significant global challenges in the near future [3].

Buildings' share of the Finnish carbon footprint is estimated to be 30 to 40 percent [7]. Use phase dominates the buildings' life cycle emissions with the share of nearly 90 percent [5]. The share of the construction phase is a bit less than ten percent [5]. Although construction phase's share of the total life cycle emissions is relatively small, construction phase causes significant carbon emissions in a short time horizon. In order to practice effective environmental management, developer companies have to recognize the most important materials and functions that cause carbon emissions in the construction projects. This study reveals these materials and functions plus models the life cycle wide emissions for each of them.

Carbon footprint has been established as the common way to examine GHG emissions related to certain processes or goods. Determination of the carbon footprint is based on a life cycle assessment where climate change is the only effect group [4]. Previous research reveals that most of the carbon emissions caused by people is heavily connected to the residential energy consumption, construction, travelling-related infrastructure and establishment issues [5, 6, 7]. Finding out quantities and sources of these carbon emissions is essential in order to reduce the carbon emissions and slow down climate change.

Life cycle assessment (LCA) is a method used for measuring the comprehensive environmental effects of objects and actions. Besides the direct environmental effects, LCA also measures the indirect effects beginning at the acquisition of raw materials and ending at the disposal of the product [8, 18]. In previous research, LCA has been the tool for measuring and comparing the environmental effects of different material and product options, building types, energy options etc. [8, 9, 10, 11]. In addition, LCA has quite recently been used more and more to study the activities in society that cause carbon emissions and the relative shares of these activities [4, 7, 12]. Some of the previous research has focused on comparing the different LCA methods and their applicability in various conditions [13, 14, 15].

While the LCA method has previously been utilized in construction research, gaps in the knowledge related to the emissions of construction can still be identified. Several studies concerning life cycle wide environmental loads of the specific construction materials exist [16, 17]. In addition, the GHG emissions from construction of different building types have been studied. However, few studies with life cycle perspective on environmental effects of whole residential areas exist. Besides the construction of residential buildings, the constructions of communal buildings and infrastructure also have significant impact on the carbon footprint of a

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typical residential area.

The paper studies the life cycle wide environmental effects of Nupurinkartano residential area construction project in southern Finland with two different LCA-methods. The purpose of the paper is to provide an estimate for the carbon emissions caused by a residential area construction project, and to test the applicability of LCA method in the selected framework. Furthermore, the results of the paper provide a possible comparison of different LCA-methods in modeling emissions of construction projects. The hybrid LCA-tool built for the study can also be used in forthcoming research as well as a basis for future hybrid LCA-tools.

II. METHOD AND RESEARCH DESIGN

The research method used in the case study is life cycle assessment (LCA). The model presented is an application of tiered hybrid LCA. In addition, an input-output life cycle assessment is utilized in the early phases of the study.

The LCA methods are divided into three categories. Of these process LCA is the traditional method used in life cycle assessments [8, 18, 19]. Process LCA is often considered to produce the most accurate results, especially on homogenous and distinctive cases such as construction projects [15]. The reason for accurate modeling results lies in the initial information that is usually locally and temporally correct. The boundary definition of the process LCA assessments sets a significant challenge in conducting accurate life cycle wide modeling [18]. The process chain has to be cut in some point and the processes that are left outside the assessment might have relevant impact on the results [18]. Process LCA is also a time consuming and an expensive way of conducting life cycle research [15]. The initial process data used in the modeling may also be challenging to obtain and the programs used in the modeling process are usually expensive [15].

The second method, input-output life cycle assessment IO-LCA connects the monetary costs of the products or actions with environmental impacts through output matrices for certain input that utilize industry average data [13]. The IO-LCA-method was invented by the Nobel Prize winner Wassily Leonthief in the 1970s. The IO-LCA has several advantages compared to process LCA method. IO-LCA-tool uses national economy wide input-output matrices to calculate direct and indirect environmental impacts for each monetary investment. Consequently this characteristic of the method nullifies the truncation problem of the process LCA. Conducting an IO-LCA is also time efficient compared to process-LCA [8]. However, IO-LCA method also carries a few disadvantages. There are only a couple of national models available which in addition are several years old. IO-LCA also uses an aggregated national sector for each object or assessment and characteristics of the specific processes cannot be taken into consideration. Consequently, the IO-LCA modeling tool is not suitable for comparing different objects inside the sectors.

Hybrid LCA models are designed to combine the most suitable characteristics of both IO-LCA and process LCA models. They allow both an avoidance of the truncation error of process LCAs and a reduction of aggregation error inherent in IO-LCAs [18]. The hybrid LCA's can be further categorized as tiered hybrid LCA, -input-output-based hybrid LCA and integrated hybrid LCA. The specific properties of these are discussed in detail in Bilec et al. (2006) and Joshi (1999) [15, 26].

In this study an IO-LCA based application of tiered hybrid LCA is used. The application of IO-LCA method used is the economic IO-LCA (EIO-LCA) which is provided by the Carnegie-Mellon University [2]. A free-access version of this modeling tool is available at the Carnegie-Mellon University's web page. The model is based on US Industry, the reference model of the most recent version being from the year 2002.

The hybrid model utilized is based on the results of an initial direct IO-LCA-modeling. The hybrid model consists thus of an EIO-LCA basis with the most important materials or functions based on the carbon emissions sources replaced by local and current process data.

The case study of the paper is Nupurinkartano residential area that will be built in Espoo, a city located in southern Finland. The development of the area started in 2004 by conducting a planning and various reporting. Nupurinkartano residential area is intended to accommodate 550 to 600 people. The residential area is planned to consist of 219 houses that will for the most part be terraced houses, semi-detached houses and detached houses. The sizes of the houses will be from 70 to 160 m2. The residential area consists of approximately 54 hectares. Total permitted building volume for the area is about 35400 m2. The characteristics of the residential area are shown in Table I.

There were three phases in the study. The first phase was a direct input-output life cycle assessment of the carbon emissions with the EIO-LCA tool [2]. First only one single general construction sector was utilized for the whole project in order to get a rough estimate of the amount of carbon dioxide emissions caused by the construction project. In the second phase, the costs were allocated more precisely between different EIO-LCA sectors. The initial data of the project were received by e-mail from the developer company [28]. The data included total costs of the construction project sorted by the materials and the functions. Twelve most important materials were specified as were services' and energy's part of the total costs. All the costs are presented in the Table II in the Results-section. The total construction costs of the buildings of Nupurinkartano are 69.39 million euro and the total costs of the infrastructure are 6.93 million euro according to the cost data. Constructions materials' and equipment's share of the building costs was approximately two thirds. Construction work accounts for approximately one third of the costs. Energy's share of the costs is almost irrelevant. Construction work also includes the costs of the subcontractors used in the project.

TABLE I CHARACTERISTICS OF THE RESIDENTIAL AREA

Costs of buildings	69,39 M€
Costs of infrastructure	6,93 M€
Residents	550 - 600
Houses	219
Sizes of houses	70 m^2 - 160 m^2
Permitted building volume	35400 m^2

Choosing the most appropriate sector for each material or function is an essential phase in the EIO-LCA modeling process. The EIO-LCA tool then provides the life cycle wide carbon emissions for each sector according to the invested monetary value.

The third phase of the study was a hybrid LCA modeling of the construction project. EIO-LCA modeling forms the basis of the hybrid model but the EIO-LCA foundation is enhanced with process data for the most significant materials and functions. According to the EIO-LCA modeling, the most relevant single materials and functions of the project were energy, concrete and steel not only because they cause the most carbon emissions but also have the highest carbon intensity of all the materials and functions. Thus, these categories were enhanced with local process data. Two different methods were used in replacement of EIO-LCA data with process LCA data. Energy was modeled by the means of only replacing the first tier emissions with local and current process data and the EIO-LCA part of the indirect emissions of energy production process were left inside the model. Concrete and steel were modeled by replacing the whole EIO-LCA part with local and current process data. The methods used are described in detail later in the study.

The emissions for the energy used in the construction project were modeled using the local power company Fortum's reports of the year 2009. The study assumes that energy used at the construction site is produced locally. Suomenoja power plant in the city of Espoo generates electricity and district heat using coal and natural gas as a fuel. Heat is produced as electricity's by-product. Joint production of electricity and heat covers 80 percent of Espoo's need for district heat [20]. According to the developer company the total need of the electricity for the construction of buildings in Nupurinkartano is about 11765 MWh. Suomenoja power plant produced 2714 GWh of electricity and heat in the year 2009 [21]. The total CO2-emissions of Suomenoja power plant were 817 000 tons [22]. Thus, by the means of energy method, the carbon intensity of the power generation is a little over 300 grams of carbon dioxide per kilowatt-hour generated. Accordingly, the total carbon emissions caused by the energy production process are 3542 tons.

These are the direct carbon emissions caused by the energy production process. In order to include also the indirect emissions, the higher order tiers of the supply and production chain were added from EIO-LCA sector "Power generation and supply".

The initial EIO-LCA modeling of the construction project revealed that concrete and steel are the most relevant construction materials regarding carbon emissions. Process information of concrete and steel were acquired using the environmental reports of Rakennustietosäätiö RTS [17]. Process information includes the life cycle emissions of the products beginning from the acquirement of raw materials and ending at the gates of the manufacturing factory. Concrete and steel products were divided into subcategories by the developing company and every subcategory was paired up with an appropriate environmental report. The environmental reports of concrete and steel products are based on the products of typical Finnish manufacturers. The amounts of steel in wall elements and hollow-core slabs were estimated according to Lounamaa (2010) and the amount was reduced from the concrete steels in order to avoid double counting [16]. Initial data of concrete and steel materials and their respective carbon emissions are presented in the Table II in the Results-section.

III. RESULTS

The total emissions of the whole construction project are 60542 tons of carbon dioxide based on the hybrid LCA model. Buildings' share of these emissions is 55267 tons and infrastructure's share is 5275 tons. Thus, the buildings' share of total carbon emissions of the construction project is 91 percent and infrastructure's share is nine percent. The carbon emissions of the construction project are presented in Fig. 1. The most significant sources of buildings' carbon emissions were concrete (6121 tons, 11 percent), energy (4195 tons, eight percent) and steel (3513 tons, six percent). Brickwork and timber also had moderate carbon emissions of 4460 and 3650 tons. HEVAC material caused 1580 tons and also windows and doors 1120 tons of carbon emissions. The residual six important construction materials only caused five percent of buildings' total carbon emissions. Costs and emissions of all materials and functions are shown in Table II.

The initial one-sector EIO-LCA modeling of the construction project, where all the costs were allocated to one construction sector in the EIO-LCA model, resulted in 49020 tons of carbon emissions. Buildings' share of the emissions was approximately 91 percent and infrastructure's share was nine percent. The more disaggregated EIO-LCA modeling, where the costs of the construction project were divided into 13 most important materials and functions, sub-contraction and others, and matched with the EIO-LCA sectors, resulted in 70800 tons of carbon emissions. Buildings' share of the total carbon emissions is 93 percent with allocated EIO-LCA method.

According to the allocated EIO-LCA modeling, the most significant building materials were concrete and steel. Concrete used in the construction project caused 7060 tons of carbon emissions. Correspondingly steel used in the project is a source for 6420 tons of carbon emissions. Furthermore, energy used in the construction project caused very relevant carbon emissions of 11200 tons. These three functions combined caused over one third of the total carbon emissions based on the allocated EIO-LCA modeling.

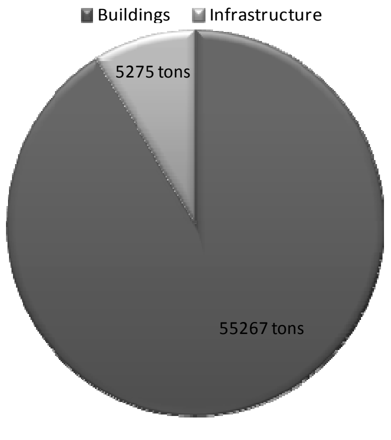

Fig. 1 Total emissions of the construction project

TABLE II :INITIAL DATA AND CARBON EMISSIONS OF THE STUDY

Buildings

Material or function	EIO-LCA sector	M€	Total t CO_2e
Timber	Sawmills and Wood Preservation	4,96	3650
Concrete	**Concrete pipe, brick and block manufacturing**	**3,68**	**7060**
Steel	**Iron, steel pipe and tube manufacturing from purchased steel**	**3,16**	**6420**
HEVAC-material	Iron and Steel Mills	2,72	1580
Brickwork (bricks + plaster)	Brick and Structural Clay Tile Manufacturing	2,22	4460
Electric material	Miscellaneous electrical equipment manufacturing	1,92	729
Windows and doors	Wood Window and Door Manufacturing	1,88	1120
Energy	**Power generation and supply**	**1,2**	**11200**
Furniture	Nonupholstered Wood Household Furniture Manufacturing	0,97	475
Water insulation	Paint and Coating Manufacturing	0,71	763
Domestic appliance	Household Refrigerator and Home Freezer Manufacturing	0,59	460
Plastic pipes and basins	Plastics Pipe and Pipe Fitting Manufacturing	0,51	716
Heat insulation	Industrial Process Furnace and Oven Manufacturing	0,47	237
Subcontractors	Other nonresidential structures	26,40	16200
Others	Residential permanent site single- and multi-family structures	18,00	11900
Total		**69,39**	**66970**

Infrastructure

Material or function	EIO-LCA sector	M€	Total t CO_2e
Other construction components	Nonresidential maintenance and repair	3,66	2280
Mixed used streets' construction components	Museums, historical sites, zoos and parks	0,32	157
Construction components of water supply and sewage	Water, sewage and other systems	1,17	2090
Contractor's costs	Residential permanent site single- and multi-family structures	0,89	589
Designing	Architectural and engireening services	0,42	78
Investor's and owner's tasks	Management of companies and enterprises	0,47	81
Total		**6,93**	**5275**

Concrete products:	**Modeling method**	**Volume (m^3)**	**Density (kg / m^3)**	**Mass (kg)**	**CO_2 (g / kg)**	**CO_2 (t)**
Wall elements	Local process data based on public reporting	6 262,3	2 400,0	15 029 520,0	250	3 757,4
Hollow-core slabs	Local process data based on public reporting	2 419,1	1 358,5	3 286 324,5	140	460,1
Beams, pillars ja prestressed concrete	Local process data based on public reporting	81,0	2 520,0	204 120,0	220	44,9
Bars	Local process data based on public reporting	877,5	400,0	351 000,0	265	93,0
Ready-mixed concrete	Local process data based on public reporting	6 427,0	2 400,0	15 424 800,0	110	1 696,7
Patio tiles	Local process data based on public reporting	257,6	2 239,0	576 766,4	120	69,2
Total		**16 324,5**		**34 872 530,9**		**6 121,3**

Steel products:	**Modeling method**	**Mass (kg)**	**CO_2 (g / kg)**	**CO2 (t)**
Concrete steels (element steels excluded)	Local process data based on public reporting	492 774,6	6 400	3 153,8
Plates and section wires	Local process data based on public reporting	347 652,4	1 150	399,8
Steel pipe beams, pillars and profiles	Local process data based on public reporting	55 435,5	1 070	59,3
Total		**895 862,5**		**3 612,9**

Energy:	**Modeling method**	**M€**	**Amount (MWh)**	**CO_2 (g / kWh)**	**CO_2 (t)**
Suomenoja Power Plant	Local process data based on public reporting		11765	301,06	3542
Indirect emissions of electricity production	EIO-LCA: Power generation and supply	1,2			653
Total					**4195**

Process data was adopted into the carbon emissions modeling of energy, concrete and steel based on the allocated EIO-LCA modeling results. Local process data was used in order to enhance the initial model. Direct carbon emissions of the energy generation process were 3542 tons. The total indirect carbon emissions for the electricity production were 653 tons. Thus, the total life cycle wide carbon emissions caused by the electricity used in construction project are 4195 tons.

Energy used in the construction project is the most significant source of carbon emissions according to both hybrid LCA and allocated EIO-LCA modeling. Its share of the buildings' carbon emissions is approximately 8 percent using the hybrid LCA modeling and 17 percent with the EIO-LCA modeling. Concrete's share of the buildings' carbon emissions is approximately 11 percent with both modeling methods. Corresponding carbon emissions for steel are seven percent with hybrid LCA method and ten percent with allocated EIO-LCA method. Costs and carbon emissions related to the buildings' construction are presented in Fig. 2. Fig. 2 only includes the most important construction materials and functions. Fig. 2 allows the observation of the significance of different building materials and their relative shares from the point of view of both costs and carbon emissions.

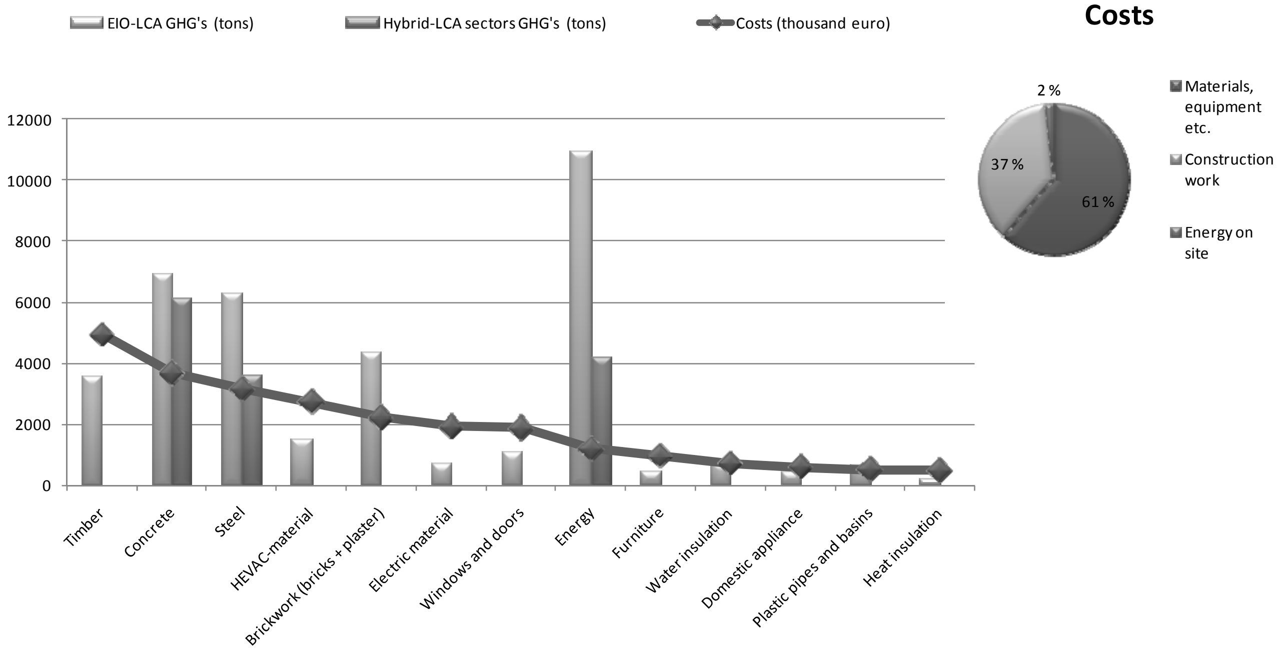

Fig. 2 Costs and emissions of the most significant construction materials

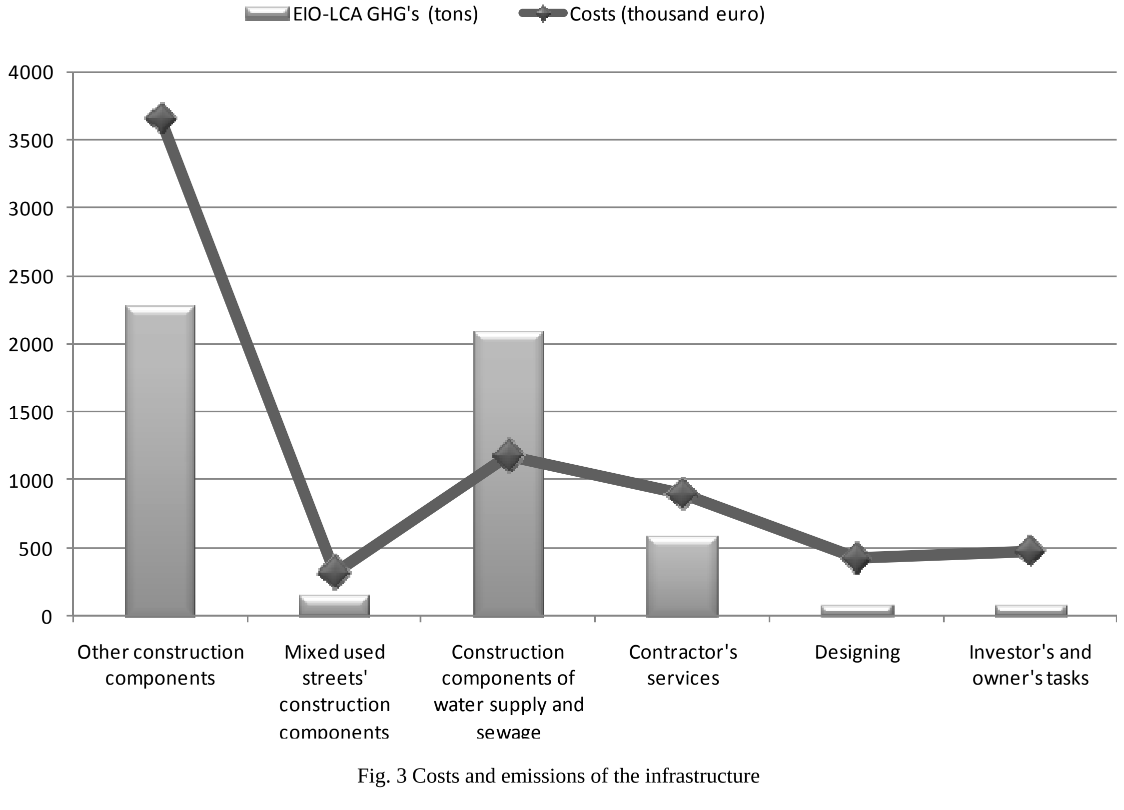

Fig. 3 Costs and emissions of the infrastructure

Infrastructure's share of the construction project's carbon emissions is nine percent according to the hybrid LCA modeling and seven percent when modeled with the allocated EIO-LCA method. Construction components of water supply and sewage and other construction components had by far the most significant emissions. Other construction components caused carbon emissions of 2280 tons. Corresponding carbon emissions of water supply and sewage components were 2090 tons. The EIO-LCA input contractor's costs had an output of 589 carbon dioxide tons. The residual three functions only account for six percent of the infrastructure's carbon emissions. Costs and carbon emissions related to infrastructure are presented in Fig. 3.

IV. DISCUSSION

The purpose of this study was to estimate the carbon emissions of a residential construction project in Finland. The research method used in the study was an application of EIO-LCA based tiered hybrid LCA. The case project of the study is Nupurinkartano residential area in the city of Espoo, Finland. The residential area consists of detached and semi-detached houses and is planned to accommodate 550 to 600 inhabitants.

The total carbon emissions of the residential construction project are 60542 tons with the hybrid LCA method, 49020 tons with single sector EIO-LCA and 70800 tons with allocated EIO-LCA method. The one sector EIO-LCA modeling only uses "Residential permanent site single- and multi-family structures" sector for buildings and "Nonresidential maintenance and repair" sector for infrastructure. The total carbon emissions of the construction project with hybrid LCA modeling are 24 percent higher than the results of allocated one sector EIO-LCA modeling and 17 percent lower than the results of allocated EIO-LCA modeling.

The main reason for the difference is the local energy provider's carbon profile, which is better when compared to the correspondent EIO-LCA sector. Emissions of the building materials are caused by numerous sources and most of them are not very significant on their own. Most important single sources of carbon emissions are energy (eight percent), concrete (11 percent) and steel (six percent). These sources also have the highest carbon intensities among the construction materials. Besides these, also brickwork causes significant emissions and has high carbon intensity.

Identified uncertainties of the IO-LCA method include temporal bias plus accuracy and aggregation problems [18]. The modified tiered hybrid LCA method used in the study was created in order to obtain more accurate results compared to the initial EIO-LCA modeling. EIO-LCA, that formed a foundation of the hybrid LCA model, is the most disaggregated IO-LCA method because it has most sectors available [2]. Almost every input-output table also assumes that imported products are produced domestically [18]. In most scenarios carbon intensity of foreign production does not correspond to the domestic production and resulting emissions might be biased. Suh et al. (2004) discusses the problem in detail [18]. In this study the coverage of the process data in the hybrid LCA model diminishes the bias significantly.

The EIO-LCA foundation of the hybrid LCA model provides a way to avoid the truncation problem and process-LCA data improves the accuracy of the model. The results of hybrid LCA modeling were approximately 14 percent lower than the allocated EIO-LCA results. However, the sectors covered with process data, concrete, steel and energy, were found to produce 42 percent less emissions than the results of the EIO-LCA modeling. The model might thus be further improved by replacing more significant EIO-LCA sectors with process data.

The purchasing power parity (PPP) tables were used to avoid biases caused by temporal factors such as inflation and currency rate differences between the present Finnish economy and the US industry 2002 model. The purchasing power parity 2005 table is provided by The World Bank. Weber et al. (2007) used the similar correction in their study [24]. The PPP USA–Finland coefficient is 0.98 [23].

Comparing the EIO-LCA sector results with the local and actual process data is a suitable way to analyze EIO-LCA tool's applicability to the Finnish environment. Carbon emissions of materials and electricity obtained with process data were lower than EIO-LCA results in all cases. EIO-LCA carbon emissions of concrete products were 13 percent higher, steel products 74 percent higher and electricity 262 percent higher than the process data results. One of the reasons behind the big differences in results lies in the composition of EIO-LCA sectors that are different between the US and the Finnish economies.

The EIO-LCA modeling represents a major part also in the results of hybrid LCA modeling by the overall share of 77 percent. The selection of EIO-LCA sectors for the most essential functions and materials has significant consequences on the results. The processing level of certain sectors is essential when making decisions on the sectors. Concrete products may be modeled for example with two sectors. "Cement manufacturing" has a low processing level and is very carbon intensive compared to "concrete pipe, brick, and block manufacturing" sector which was used in the study. "Cement manufacturing" sector results six times higher carbon emissions than "concrete pipe, brick and block manufacturing" sector. However, concrete materials used in the construction projects such as Nupurinkartano usually have a higher level of processing than "cement manufacturing" sector has.

There are also two possible EIO-LCA sectors for steel materials. "Iron, steel pipe and tube manufacturing from purchased steel" is a sector that was included in the study. An alternative is "iron and steel mills" which has a lower processing level and thus higher carbon intensity. Using the "iron and steel mills" in the EIO-LCA modeling would have almost doubled the carbon emissions caused by steel materials.

Although EIO-LCA tool only has one sector for power generation, the hybrid model is exposed to particular uncertainties that are connected to electricity modeling. The method used in the study is based on the assumption that the electricity used in the construction project is produced locally. The local power company Fortum's Suomenoja power plant has a carbon intensity of 301 g/kWh which is moderately high when compared to the alternatives. Fortum's average carbon intensity of the electricity production in the year 2009 was 134 g/kWh and the average carbon intensity of Fortum's power plants in the EU region was 41 g/kWh in the year 2009 [22]. The carbon emissions of the electricity used in the construction project would only have been one seventh of the current results if Fortum's average energy production carbon intensity in the EU region was used.

Another significant factor for uncertainties in the hybrid model is the aggregated allocation of subcontractors' services. Subcontractors' services were modeled using the general EIO-LCA construction sector "Residential permanent site single- and multi-family structures". The subcontractors' services remain as a black box since materials and services cannot be distinguished from the cost data provided by the developing company. Accordingly, the carbon emissions caused by subcontractors' services may differ significantly depending on how extensive the materials' and heavy machinery's shares are compared to low carbon intensity services inside the sector. Disassembling the subcontractor's services into plain services and construction materials is essential in future development of the current modeling tool.

Although 12 most significant construction materials were identified and modeled with corresponding EIO-LCA sectors or respective process data, the residual materials still account for 20 percent of the total carbon emissions. As the 12th most significant material, namely heat insulation, only accounts for 0.4 percent of the total emissions, the materials left to the "others" category are very numerous and have very little impact on their own. However, disassembling this category might give future research valuable information of the construction project materials.

The buildings' total emissions of 55267 tons together with the building volume of 35400 square meters means that carbon emissions of the construction project are approximately 1.6 tons per one square meter. Interestingly, the result greatly differs from the results of previous research. According to Lounamaa (2010) and Saikkonen (2010), residential buildings' carbon emissions are approximately from 0.4 to 0.5 tons per square meter [16, 29]. It would seem that a majority of the difference is explained by the used research method, the two mentioned studies lacking the indirect emissions from the higher order tiers. In addition, the detached building types in this study compared to apartment houses in the other two studies only explain approximately 10 percent of the difference [30].

The total amount of carbon emissions (60542 tons) is equal to the carbon footprints of 4800 people living in Helsinki metropolitan area. The amount of carbon emissions per one inhabitant in Nupurinkartano residential area is approximately 100 tons. This may be compared to the average carbon footprint of an average citizen living in Helsinki metropolitan area which is 13.2 tons [3]. For example a vacation abroad causes approximately 0.5 tons of carbon emissions [25]. Thus, each resident in the case area could travel abroad 200 times by the emission amount of the residential construction project of the case study. More similar construction projects should be modeled with the same research method in order to validate it. Modeling the past construction projects the carbon emissions of which are known could also clear up the error margins of the research method.

According to previous research, construction phase's share of the building's life cycle carbon emissions is only 10 percent, when 50 years life span assumption is made for buildings [5]. Thus, carbon savings acquired in the construction phase do not have a major role in lowering the life cycle carbon emissions of the buildings' life cycle. On the contrary, if actions made in the construction phase could lower the carbon emissions of the use phase, they should generally be adapted even if the carbon emissions of the construction phase increased.

Although construction phase's share of the total life cycle carbon emissions of the building is low, the construction phase causes a significant amount of carbon emissions in a relatively short time horizon. Since building new low energy buildings is a generally recognized way to mitigate the climate change on the building sector, a significant amount of carbon dioxide emissions is unleashed into the atmosphere before the savings in the energy consumption are even possible to achieve. The carbon emissions of the building phases alone may restrain the building sector from achieving their environmental goals in the near future as well as hinder a whole economy's ability to effectively fight the climate change.

Another factor concerning the time horizon of the carbon emissions is that the philosophy of the future green buildings is based on the low energy consumption. Energy production methods have become increasingly sustainable environmental-wise during the last decades. Assuming that the trend remains the same in the future, the competitive edge of green buildings, that is energy efficiency, gets inflated. However, the carbon emissions caused in the construction phase will be determined by current energy production technology. Carbon emissions unleashed into the atmosphere cannot be drawn back if the energy production methods in the future make the energy efficient buildings less environmentally competitive when compared to the current buildings.

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