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Environmental Impact Assessment of Renovated Multi-Apartment Building Using LCA Approach: Case Study from Lithuania

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Abstract: In Europe, more than 75% of buildings are energy inefficient according to current energy standards. These buildings account for 40% of total energy consumption. Therefore, addressing the energy efficiency of existing buildings through various renovation measures remains of critical importance. In this study, two differently renovated multi-apartment buildings were selected to evaluate its environment impact using life cycle assessment. The buildings were built during the early 1980s, which did not meet the current energy efficiency standards. In recent times, these buildings were revised by Governmental agencies through the modernization process. The aim of the assessment is to study the environmental impacts associated with different renovation measures that has been carried out. This assessment covers the impact of new materials added, and the operational energy use. The study reveals that renovation stage accounts for 19% CO_2 emission. The renovated buildings with renewable measures have a significant impact over climate change than the conventional renovation measures. Moreover, the potential savings in thermal energy used for space heating and domestic hot water preparation are 25% and 40% after conventional and renewable measures renovation, respectively. It was concluded that the total climate change potential could be reduced from 12% and 48% by retrofitting combined with renewable energy measures.

Keywords: residential buildings; multi-apartment buildings; renovation; environmental impact assessment; life cycle assessment

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1. Introduction

With rising focus on the building sector, the 'renovation wave' of the European Green Deal initiated, in view of the full decarbonization by 2050 that remains a strategic domain for Research and Innovation [R&I] [1]. In Europe, 85% of building stock were built before 2001 that exist today and will be standing in 2050. This means that a large share of today's building stock was built without any energy performance requirement—35% and 40% of the building stock was built before 1970 and 1960 which implies almost 75% of it is energy inefficient according to current building standards [2–4]. Overall, buildings are responsible for about 40% of the EU's total energy consumption, and for 36% of its greenhouse gas emissions from energy [5]. Energy poverty remains a major challenge for millions of Europeans. Therefore, addressing the criticality of energy inefficiency in existing residential buildings is of crucial importance for the legislators and the policy makers in Europe. Regulatory instruments such as European Performance Building Directive (2010/31/EU) [6] focus on enhanced insulation and heating, ventilation, and air conditioning (HVAC) system, and the efficient use of renewable energy.

In fact, renovation will be the key strategy to reduce the environmental impacts from the existing buildings [7]. However, we need to understand that renovation/refurbishing/

retrofitting often requires new materials, equipment, or energy input. Moreover, renovation increases the service life of the building, therefore, it is important to consider the environmental impacts not only of the renovation (use stage) and the operational phase of the building but also the whole phase of building in a holistic perspective. Life Cycle Assessment (LCA) is a versatile tool, used for different assessments, such as embodied impacts, emissions, usage of natural resources of a product, or service for their entire life cycle [8]. Moreover, studies also conclude that most of researchers focused primarily on the operational energy of the buildings [9–11].

For example, in Lithuania, the buildings were built during the late 20th century with 60% and 40% of the population dwelling in multi-family and one/two family buildings, respectively. However, most of the buildings were constructed using the old standards with little maintenance [11]. The energy systems were also developed during the Soviet times, the electricity supply was based on large-scale generators from nuclear fuel and gas supplied through pipelines, but often were poorly maintained and managed. Thus, the dwellings are in poor technical condition, and lack of proper insulation has led to huge loss of energy and incurred high costs.

To improve the energy efficiency, living conditions, and to reduce fossil fuels and CO_2 emissions in housing, Lithuania has revised their multi-apartment buildings in 2013, jointly with the Ministry of Energy and Environment. The Energy Performance Buildings Directive (EPBD) project was launched with the aim to ensure financing and upgrading the multi-apartment buildings by providing loans and state aid to the owners for implementing energy saving measures [12]. Principally, the renovation was implemented by both structural and technical measures, mainly aimed at heat energy savings. These types of renovation can be categorized based on the percentage of the energy savings attained, such that a retrofitted building reaps the benefit of longer lifespan with improved quality of the original building.

Over the decade, numerous studies were carried out to evaluate the renovation of buildings and its environmental impacts. According to Villegas et al., the cold condition has significant contribution to energy impact during the renovation process. The study conducted with multi-family housing in Sweden, where renewable energy dominates, shows that operational phase, building materials, and building installation have the greatest impact [13]. Moreover, the choice of building refurbishment measures could possibly affect the building in terms of emissions, fuel use, etc. For instance, the building envelope measure decreases the emission of GHGs more than retrofitting a ventilation system [14]. Choosing a proper heating system for a residential building plays an important role in saving the maintenance cost, efficiency, environmental aspects, and the comfort level of the building [11,15]. So, the indoor comfort and reduced energy costs are among the most important attributes while choosing a renovation measure.

Residential buildings that were constructed between 1960 and 1990, majorly constitutes of brick, wood, and concrete materials [16]. Wood and bricks are most common materials in detached and attached buildings, while concrete in multi-apartment Nordic residential buildings [17]. These buildings have similar issues in terms of climatic and geographic conditions; hence, the studies have focused much on energy renovation in the existing buildings. Review of literature studies reveals that different level of renovation measures [16,18,19] is commonly practiced across different countries to achieve energy efficiency. Arguably, the renovation measures are still questioned for their execution potency. Few researchers have studied the challenges of renovation projects [11,20], and energy performance of t residential buildings; even so, the evaluation of life cycle assessment in renovation projects is relatively small. In line with this context, the paper attempts to investigate environmental impacts of different renovation scenarios of multiapartment buildings using life cycle approach. Moreover, this paper discusses current renovation scenario in Lithuania, and presents different evaluation results of renovated buildings and its environmental impacts. The study adopts quantitative approach with actual data from renovated projects and other literature sources. Selected multi-apartment buildings with two scenarios: renovation with conventional and renewable energy measures were taken as an object to carry out environmental impact analysis. The buildings were assessed in two stages: 1) pre- renovation, and 2) post- renovation covering different lifecycle phases such as construction, transportation, use, and disposal.

2. Materials and Methods

2.1. Life Cycle Assessment

LCA is a methodology to estimate and evaluate the environmental impacts throughout the product life cycle. LCA considers all attributes of natural environment, resources, and human health [21]. Based on the procedure and recommendations indicated in ISO 14040 and ISO 14044, the LCA tool can scrutinize environmental inputs/outputs of all lifecycle stages including raw materials extraction, manufacturing, transportation, use, maintenance, recycling, and disposal. There are four main steps in the LCA which are indicated below [22–24]:

1. Goal and scope of the study defines the purpose and sets a boundary for the assessment;
2. Life-cycle inventory (LCI) is the data collection to achieve the intended goal of the study. The process involves accounting of various input-output data related to the analysis/service which helps carry out impact assessment;
3. Life-cycle impact assessment (LCIA) contains category definition, classification, characterization, and weighing as main elements with different set of procedures;
4. Life-cycle interpretation is to examine the results to determine the conclusions that can be made based on the inventory results that are consistent to the goal and scope of the study.

The impact assessment consists of three mandatory elements: life cycle inventory, classification and modelling of impact indicators (characterization). Different methods of LCI have different results and the uncertainties/limitations have influence on study results. Characterization can be quantified with midpoint and endpoint approaches. Midpoint categories are classified based on different topics such as global warming, acidification potential and so on. On the contrary, the endpoints are classified into resources, human health, and natural environment [24,25]. Over the years, the methodological development has evolved strong and widely practiced in research, industry, and policy [26]. LCA is combined and applied in different system levels, as well as in other existing assessment tools such as risk assessment, material flow analysis, energy analysis, and so on [21,24]. Some research projects recommend that sustainability assessment methods should be integrated with other existing tools and indicators to enable the decision-making process [26]. Therefore, LCA is constantly deepening, broadening, and evolving to achieve a comprehensive solution for diverse users.

Within the last decade, research on LCA has increased in construction sector covering construction process to manufacturing of building materials. However, the methodology of LCA in construction industry is still fragmented due to the nature and complex of the buildings [27]. CML method at endpoint and midpoint levels were used to fulfill this assessment. The results were presented based on three categories: impacts by materials, impacts by building, and impacts by indicator. The LCA database Ecoinvent v3.6 [28] was applied as the background source for life cycle impact analysis and the potential impacts were calculated using the LCA software SimaPro 9.1 [29]. In this research, LCA methodology was used to evaluate the environmental impacts associated with the building throughout its life cycle and the study of the identified buildings was carried out following the guidelines indicated in the European standards series—ISO 14040 and ISO 14044 [22,23].

2.2. Research Object

Renovation projects of two municipally approved multi-apartment buildings were used as the primary data source for this study. Those two multi-apartment residential buildings situated in Kaunas Municipality. The multi-apartment buildings composed of prefabricated concrete large panel elements which is identical in terms of appearance and the building space. The buildings were built during the early 1980s and were renovated in 2015. Both buildings consist of 54 apartments each. Each of them was constructed using reinforced concrete panels, which form the walls, the plinth, and the roof. The total useful floor of a building is 3469.24 m^2. The spacing details of the multi-apartment building are presented in Table 1.

Table 1. Details of gross external area of the building.

Total Area of the Facade Walls of a House	**3658.87 m^2**
Area of the ground plinth	174.36 m^2
Area of the roof covered with bitumen roll	742.90 m^2
Total area of the multi-storey house window and balcony doors	112 m^2

To understand the two objects clearly, these two apartments will be termed as Building A (Figure 1) and Building B. Building A has been modernized by insulating walls and roofs, replacing new plastic windows. Building B has been renovated identically as Building A, with additional hot water, solar collectors, and heat pump installations (refer to Figure 2).

Figure 1. Renovated multi-apartment building (Building A).

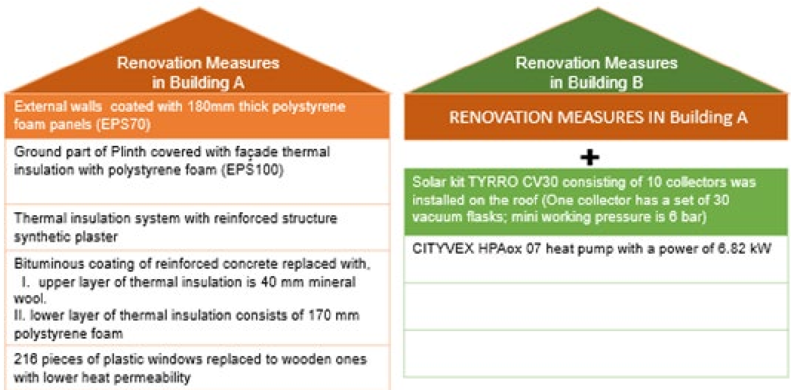

Figure 2. Renovation measures carried out in Building A and B.

Major renovation in the multi-apartment buildings (Building A and Building B): the exterior walls of reinforced concrete was covered with 180 mm thick polystyrene foam panels EPS70. These panels are covered with decorative gypsum plaster (Figures 3 and 4).

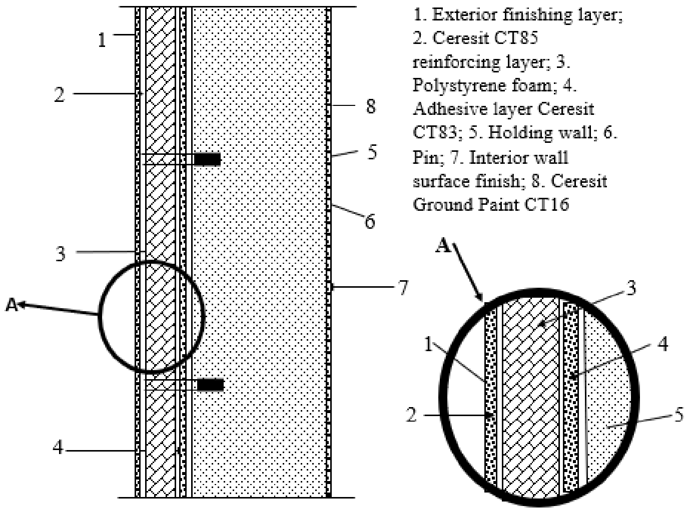

Figure 3. Installation of Ceresit VWS system with polystyrene foam thermal insulation material [30].

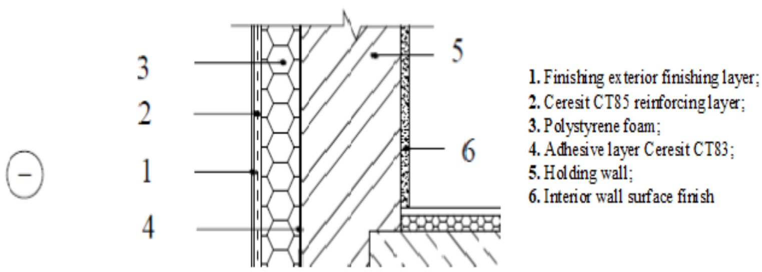

Figure 4. Installation of Ceresit system with polystyrene foam insulation material on the plinth [30].

In addition, the ground part of the plinth is covered with a facade thermal insulation system Etics Ceresit Ceretherm Popular (facade polystyrene foam EPS100). The thermal insulation system is covered with reinforced structural synthetic plaster (Figure 3). The old bituminous coating of the reinforced concrete roof has been replaced with new thermal insulation materials. The upper layer of thermal insulation is 40 mm rockwool Dachrock mineral wool. The lower layer of thermal insulation consists of 170 mm polystyrene foam. All the windows and balcony doors have been replaced with new plastic windows with lower heat permeability. The number of replaced apartment and other premises windows is 216 pieces. The total area of the replaced windows and doors is 112.1 m^2.

Additional renovation in Building B: in addition to the hot water preparation, PV collectors and air-water heat pumps are installed. Solar kit Tyrro CV30 consisting of 10 collectors was installed on the roof. One collector has a set of 30 vacuum flasks. A single collector's width is 2.5 m; height 1.98 m, weight 114 kg; the absorber area is 2.40 m^2. The maximum working pressure is 6 bar. The heat from the solar collector is taken to the solar module that heats up the return heat from the heat station. The hydro module ensures the circulation of a solar coolant. The solar heat exchanger is hydraulically connected to the inside of the heat pump system and to the pipeline to the heat substation. Building B has a Cityvex HPAox 07 heat pump with a power of 6.82 kW. The heat pump consists of external and internal units. The external unit consists of a compressor, a heat exchanger (evaporator) and a fan. The internal unit consists of a heat exchanger (capacitor).

2.2.1. Goal and Scope

The residential building consists of a modernized and refurbished system with four inhabitants, including the construction, maintenance, and operational energy. The study aims to evaluate the environmental impacts of the renovated multi-apartment buildings by identifying and analyzing potential environmental impacts before and after renovation process. Functional unit (FU) is a basic unit for both quantification and comparison. Different studies have focused on different FU, based on their requirements and nature of the study. For instance, the studies conducted on single family housing adopted usable living area in square meters (m^2) as FU with 50 years' service life [31–35]. Therefore, based on the characteristics of the building, the functional unit is taken as entire building with a service life of 40 years.

The system boundaries are product life cycle stages and components reviewed during the life cycle assessment. The other characteristics such as water consumption, indoor air quality, acoustics, and economic value, are not considered in this study for the functional unit. The adopted renovation process of the building boundary was based on Vilches et al. [7] the author studied the possibility of the refurbishment process itself with different system boundaries (Figure 5), considering standard building assessment modules for Life Cycle Assessment according to EN15804:2012.

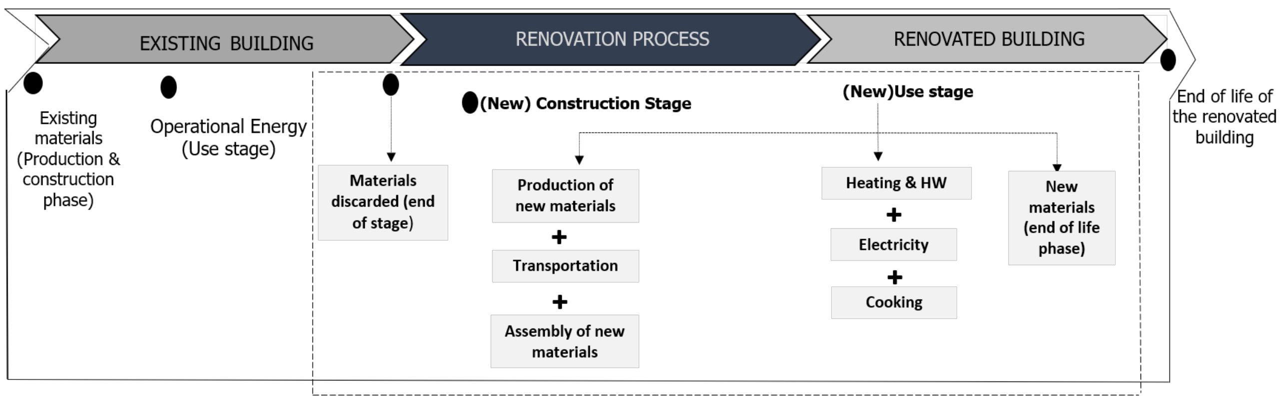

Figure 5. Detailed schematic diagram of system boundaries of the existing building (dotted lines considered as system boundaries for Life Cycle Assessment (LCA) evaluation).

Figure 5 represents the system boundaries of the object under investigation which has been represented in detailed manner as a schematic diagram. The system boundary of the existing building includes:

- the main building (new) materials used during the renovation of the building
- processes and energy consumption required to produce newly added construction materials during renovation
- thermal energy consumption for the heating of building premises and hot water preparation during the life cycle of the building, i.e., average heat energy consumption for 40 years
- disposal of the (old) construction materials replaced during the process of renovation (end of stage).

During the process of renovation, no materials were discarded from the building except for the doors, ventilators, and wooden window frames. While considering transport, it has two aspects—(i) transportation of materials to site (including the human resources), and (ii) transportation of materials from different regions (import). In this case, transportation within the country is only considered to analyze the overall impact. Therefore, import of materials is beyond the scope of this study. Nonetheless, it was difficult to accumulate data of 40 years old building, as the information was limited. Therefore, the data is modelled with Ecoinvent 3.6 database and different literatures [13,16,28,34].

2.2.2. Life Cycle Inventory

The survey of input and output data for the processes were performed in relation to three life cycle stages: construction (during renovation), operational phase (use), end of life stage of the replaced materials. Initial inventory and data for each unit process was collected from the approved renovation project. The missing dataset was adopted from different literatures [13,16,33,35] as a reference data. Moreover, Simapro 9.1/Ecoinvent 3.6 [28,29] database for Life Cycle Inventory for further calculations. Building materials and assemblies include primary materials used during the renovation. In Table 2, all used data are compiled and presented. The collected data were fed into SimaPro 9.1 software, to design the material flow.

Table 2. Estimation of collected quantities of the selected residential building [30].

Contents	Quantity	Units
Estimation of Building materials—Before Renovation		
Concrete	1098.16	ton
Window frame(wooden)	112	m^2
Bitumen adhesive compound	1114.35	kg
Glass (density 2580 kg/m^3)	4	m^2
Reinforcing Steel	2196.65	ton
Clay bricks	13,000	kg
Stone wool	10,261	kg
Paint	3572	kg
Cement cast plaster flooring	4970	kg
Polystyrene Foam	13,179.25	kg
Estimation of New Materials—Added During Renovation		
Window frame (PVC)	112	m^2
Gypsum plasterboard	32,007.47	kg
Thermal plaster (outdoor)	20,058.3	kg
Glass fiber reinforced plastic, polyester resin	38,528	kg
Heat distribution equipment	1	p
Photovoltaic panel	495	m^2
Heavy fuel oil	38,528	kg
Paint	1572	kg
Transportation of materials to construction site via road (truck or carrier)	20	km
Energy for construction	113.189	MJ
Water	109,820	kg
Machine operation	5	hr
Use Stage—Before Renovation		
Electricity consumption	960.48	Mwh
Water Consumption	1750	m^3
Natural Gas consumption (cooking)	19.9	kwh/m^2
Heat energy consumption for SH and HW preparation	590	Mwh
Use Stage—After Renovation		
Electricity consumption	314	Mwh
Water Consumption monthly	1750	m^3
Natural Gas consumption (cooking)	19.9	kwh/m^2
Heat energy consumption for SH and HW preparation	352.47	Mwh
Heat energy consumption for SH and HW preparation (without solar panels)	444.42	Mwh
Discarded Materials (End of life)		
Polystyrene	100	kg
Rockwool	100	kg
Windows (Wooden)	7.8	ton
Doors	2	ton
Glasses	2.6	ton
Steel and other (non) metals	80	ton
Other debris	0.5	ton
Transportation output of building = 30 km to disposal site after 40 years of lifespan		
Disposal Scenario: Landfill = 20%, Disposal = 20%, Reuse = 60%		
80% of the building materials will be recycled and the remaining will be incinerated		

2.2.3. Life Cycle Impact Analysis

Furthermore, Life cycle impact assessment (LCIA) aims to connect the different or each LCI result as per the process flow or the intervention of the product or service defined corresponding to the environmental impact. Each impact is classified into different categories and the category indicator which helps to connect and interpret the result corresponding to the impact categories.

Usually, two main schools of thought are available to estimate the environmental impacts [36]:

- The classical impact assessment method, CML 2000 methodology is used to access and quantify the potential indicator that falls in the midpoint categories such as global warming, ozone layer depletion
- Damage related methods, such as ReCiPe, Eco indicator 99, etc., help to model the cause-effect relationship of damage and quantify the endpoint.

Climate change, human toxicity, acidification, eutrophication, ozone depletion, and resource depletion are the commonly used impact categories in building sector [9,31–33,35,37–39]. CML methodology was commonly used to evaluate the different phases of both single and multi-family building stocks [31,32,40]. This method is used with midpoint indicators that help to quantify the abundant results of the life cycle inventory to several most important indicators [41]. Several studies also focus on cumulative energy demand to evaluate the energy and resource utilized in the entire process or product [33,42,43]. With relevance to the study, the following impact factors such as global warming potential (GWP), human toxicity (HT), acidification (AP), eutrophication (EP), photochemical oxidation (POCP), resources (abiotic) depletion (ABP) were assessed (shown in Table 3), as the above factors have the greatest impacts on the environment [31].

Table 3. Environmental impact categories.

Environmental Impact Category	Compartment	Indicator Reference Unit	Damage Category	Method
Global Warming Potential (GWP)	Stratosphere	kgCO2 eq.	Climate Change	IPCC
Photochemical Oxidation (PCOP)	Air and land	kgC2H2 eq.	Human Health, Ecosystem Quality	CML
Acidification (AP)	Land and water	kgSO2 eq.	Ecosystem Quality	CML
Eutrophication (EP)	Land and water	kgPO4 3- eq.	Ecosystem Quality	CML
Human Toxicity (HT)	Ground level	kg1,4-DB eq.	Human Health	IMPACT 2002+
Fossil Depletion (ABP)	Land	MJ or kg crude oil-eq.	Resources	Cumulative Energy Demand

2.3. Energy Consumption

The energy life cycle analysis of a building includes two types of energies—(i) energy consumed in the production of building materials, transportation, construction, and demolition of the building and treatment of the resulting waste; (ii) energy used for heating or cooling the building's indoor air, as well as electricity [44].

The multi-apartment residential buildings consume the most amount of heat energy in Lithuania, i.e., 54% of final heat energy consumption. Heat production in households mainly use firewood and wood waste accounted for 72.4%, natural gas—14.8%, liquefied petroleum gas and gas oil—1.67%, solid fuels (coal, peat, briquettes)—7.48%, as per 2015 data [45].

The main objective was to analyze the energy efficiency of the selected buildings with two scenarios: renovation with conventional and renewable energy measures. During the building's life cycle, most of the energy (about 80–90%) is used for heating the building using conventional heating methods [10]. The district heating systems majorly depends on natural gas to provide heating solution to the connected multi-apartment buildings.

There are two types of estimation to calculate heat in building's premises—(i) absolute heat energy cost of the entire area of a dwelling per year; (ii) relative heat cost required to heat 1 m^2 of building space per month or year.

According to Lithuanian Energy standards, the selected building was certified as "Class E" of energy certification before the renovation process. After renovation, the building was graded as "Class C" since all the renovated apartment buildings should reach a minimum of Class C [30]. The classification of energy performance ranges from class G to A++ corresponds to poor energy performance and higher energy performance (i.e., equals to nearly zero energy building). A comparison of total energy consumption and the energy consumption for heating was obtained during the certification [12].

3. Results

3.1. Environmental Life Cycle Assessment

3.1.1. Impacts by Materials

Materials play an important role in determining the environmental impact of the buildings. During the process of renovation, there could be a significant number of environmental impacts due to the inclusion of new materials or new products (e.g., Photovoltaic collectors) [7]. The impact assessment has been conducted using Simapro 9.1 and the indicators has been chosen correspondingly to study the potential impacts. The featured graph below (Figure 6) performed with CML 3.3—classic method with 8 impact indicators [41] which includes Global Warming Potential (GWP100a) as per IPCC. The environmental impact distribution of newly added materials during the process of renovation as shown below (Figure 6) for the selected categories such as ABP, GWP100a, ODP, HT, POCP, AP, and EP.

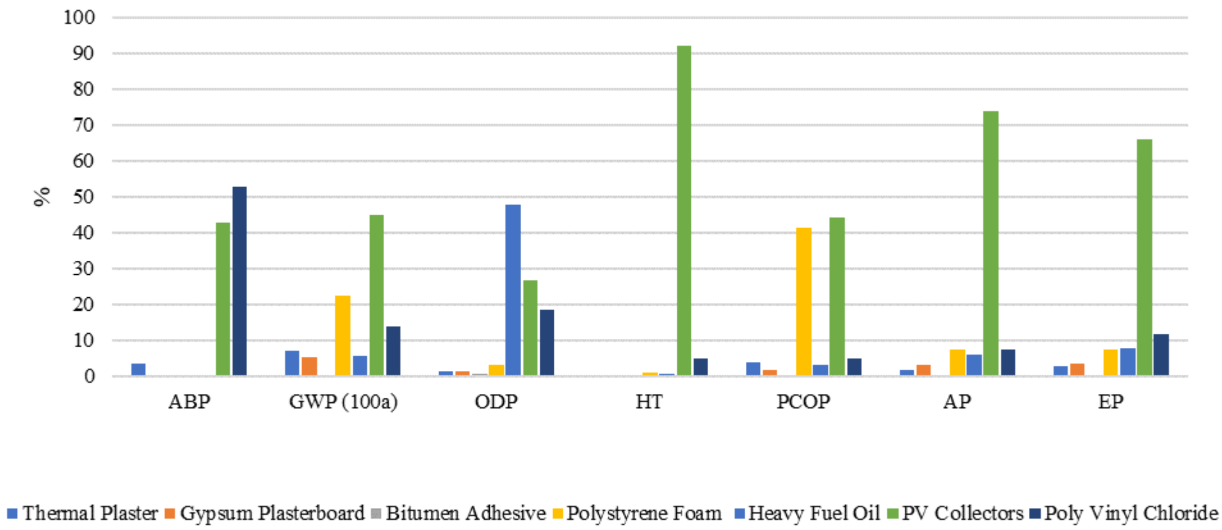

Figure 6. Distribution of the environmental impacts of new materials.

The Poly Vinyl Chloride (PVC) material used in window frames has significant impact over 50% on ABP whereas Polystyrene foam contributes about 42% on POCP indicator. Similarly, gypsum plasterboard shows impact on GWP and POCP with 20% and 40%, respectively. The graph shows that the PV collectors has impact on HT, AP, and EP with 92%, 73%, and 66%, respectively. Moreover, thermal plaster and bitumen adhesive shows less than 10% on all impact categories.

This significant impact of PV collectors on Figure 7a–c is due to their production of PV modules, indirect emissions due to copper and aluminum parts [46]. Moreover, the installation of energy conserving devices in the building possibly contribute a significant environmental impact on various level [47], yet PV collectors are a good alternative to the conventional heat energy produced from fossil fuels. In the Figure 7a the value for PV collectors is 123,327 CO_2eq emission for the new materials added during the renovation process. Similarly, from the Figure 7a heavy fuel oil and Polyvinyl chloride shows considerable impacts on GHG emissions following to PV collectors. Figure 7b shows what impacts the PV collectors have on acidification potential that accounts for 41% (570,942 $kgSO_2$eq) of total impact. Similarly, Figure 7c presents impact on eutrophication accounting for 57% of total impact.

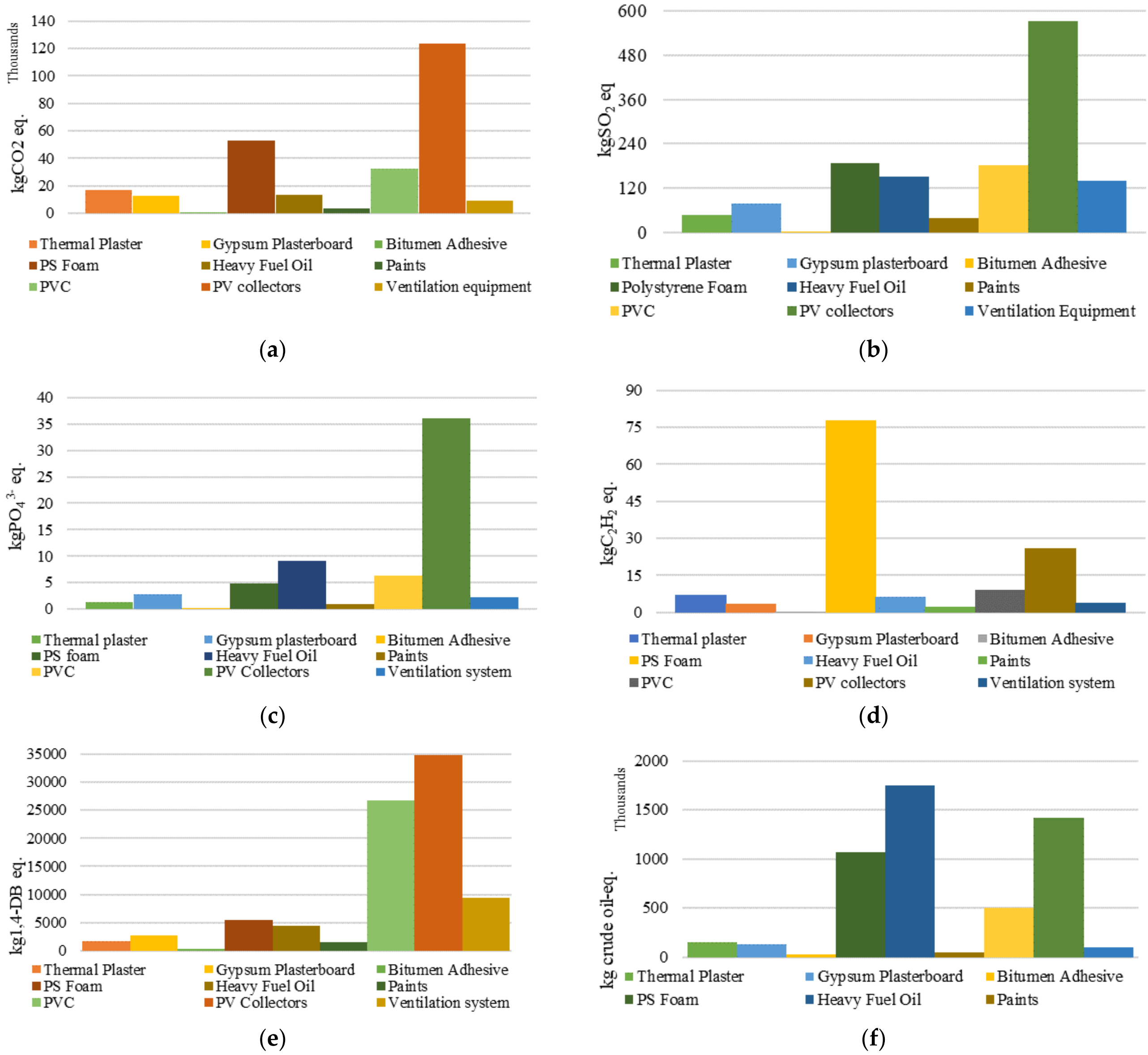

Figure 7. Characterized assessment of environmental indicators: (**a**) Global Warming Potential; (**b**) Acidification; (**c**) Eutrophication; (**d**) Photochemical Oxidation Potential; (**e**) Human Toxicity; (**f**) Fossil Depletion.

Figure 7d displays the impact on photochemical oxidation potential indicator, in which the polystyrene foam (PS foam) contributes 57% of total impact category. Figure 7e shows the effect on human toxicity, in which PVC contributes 31% (26,783 kg 1,4-DB eq) following to the PV collectors that accounts 40% of the total impact. Figure 7f displays the impact on fossil depletion in following materials such as heavy fuel oil, PV collectors, PS foam, and PVC with 34%, 27%, 21%, and 10%, respectively. The impact on heavy fuel oil could be due to the production and the extraction of petroleum fractions [48]. Overall, the results show that addition of new materials into buildings have considerable impact based on different indicators measured. Nevertheless, it is interesting to observe PV collectors contributes highest level of impacts on different mid-point indicators, however the overall reduction of energy consumption (i.e., performance) in the building after the installation measures is notable. Additionally, PV modules itself does not produce any emissions on a daily basis and reduces material usage during construction [46].

3.1.2. Impacts by Buildings

The impact of the buildings on the environment has been assessed by calculating the quantities of the main building materials and the thermal energy consumption during the operation of the apartment (estimated life cycle of the building is 40 years). Three scenarios were modelled using Simapro 9.1 to evaluate and compare the impact of the multi-apartment buildings.

- a non-renovated multi-apartment building
- a renovated multi-apartment (Building A)
- a modernized multi-apartment building equipped with renewable energy sources (Building B)

A comparison of both renovated and non-renovated building was assessed using CML method for the most significant midpoint categories. An absolute environmental impact assessment result is presented in Figure 8 for the chosen potential impacts—GWP (100a), HT, PCOP, AP, EP, and their corresponding values.

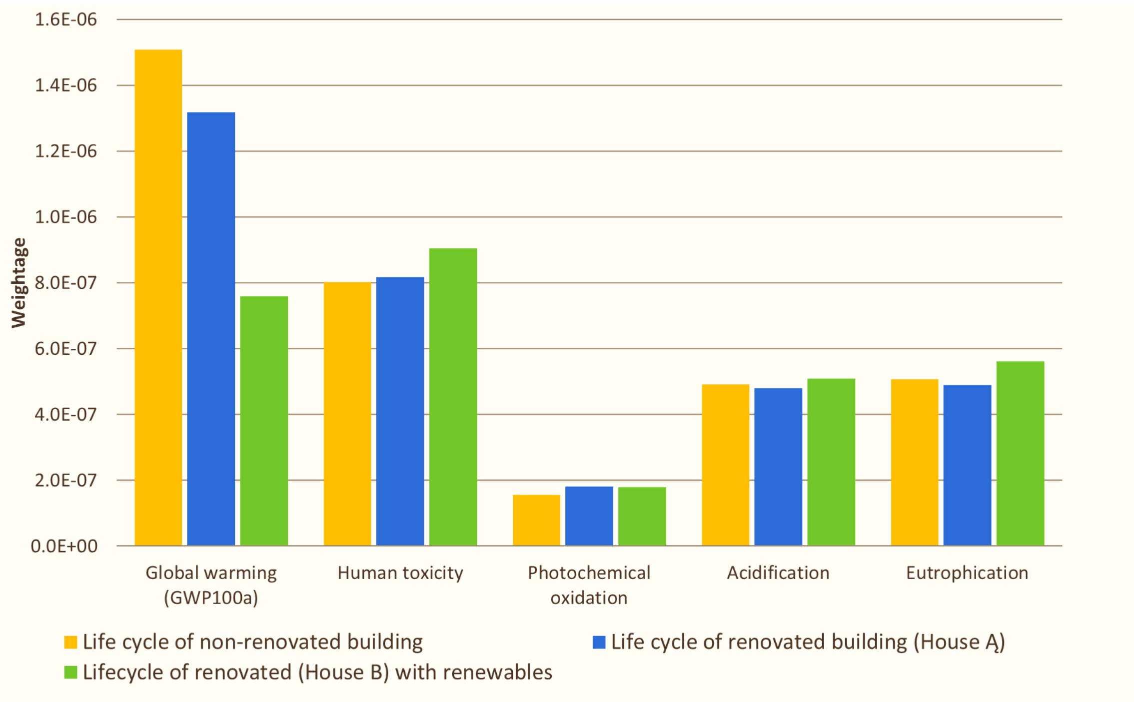

Figure 8. An absolute assessment of environmental impacts of multiapartment buildings before and after renovation.

While analyzing Figure 8, it was noted that overall, construction, and operation processes (including renovation) has considerable environmental impact on AP, EP, followed by POCP. The impact of the renovated building without energy measure (Building A) in this category is:

- about 1.14 times greater than a non-renovated building (i.e., insulation of the building's facade walls, the ground part of the plinth, the roof and the windows);
- about 2 times higher than the environmental impact of a renovated building where renewable energy measures (Building B) used.

Similarly, a comparison of different renovation scenarios (both pre- and post- renovation) is presented in Figure 9 for the chosen potential impacts—GWP (100a), HT, PCOP, AP, EP, and their corresponding values.

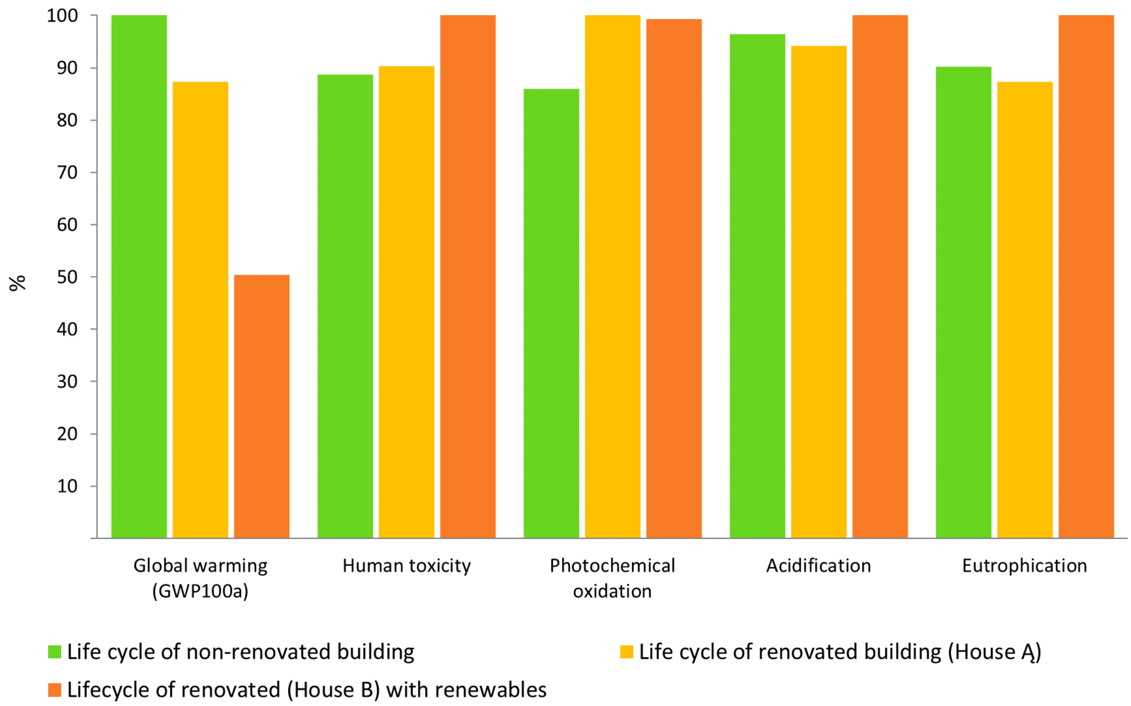

Figure 9. Comparison of environmental impact of a multi-apartment building before and after renovation.

The comparison of different renovation scenarios (Figure 9) reveals a significant impact in the GWP. The impact of the renovated building in the climate change category has been reduced to 12% after the regular renovation of the building (Building A). Renovating a residential building and installing PV collectors and a heat pump (Building B) could reduce the negative impact on climate change up to 48%. These differences are due to the energy efficiency and reduced thermal energy consumption, aiding to reduce the amount of greenhouse gas emissions from fossil fuels. Other assessed exposure categories—effects on human health, acidification, and eutrophication—have a greater negative impact on the environment when the building is renovated with renewable energy measures, i.e., PV collectors and heat pump (Building B) rather than the conventional renovation. It is interesting to note that the installation of PV collectors and heat pumps contributes to the negative impact on human health which increased by 9%, 5% in acidification, and 10% in eutrophication category. Although the installation of PV collectors in the residential buildings have substantially less impact on human health, the production of these thermal collectors technologies gives out significant effect on human health and toxicity [49]. On the other hand, there are options available to reduce energy consumption and environmental impacts associated with the production/process of PV collectors [46].

3.1.3. Impacts by Indicator (Single Score)

The identification of the impact category is the first step to mitigate against climate change. Figure 10 indicates the overall CO_2 emission using GWP 100a indicator. The results show different lifecycle stage of the multi-apartment building (pre- and post-renovation). The emission was estimated with best case scenario (Building B) with non-renovated building, to understand overall impact of the building in each stage in terms of CO_2 emission. The estimation of GWP results were 727 tonCO_2eq before renovation of the building and 266 tonCO_2eq during the process of renovation. This indicates that renovation phase contributes significant CO_2 emission up to 25%. Moreover, the transportation of materials to site during the construction is negligible. Likewise, the disposal score shows in negative which implies credits are adequate compared to the burden of the building's end life. In the disposal scenario, it was assumed that 60% of materials after end life was reused and 40% goes to landfill and incineration.

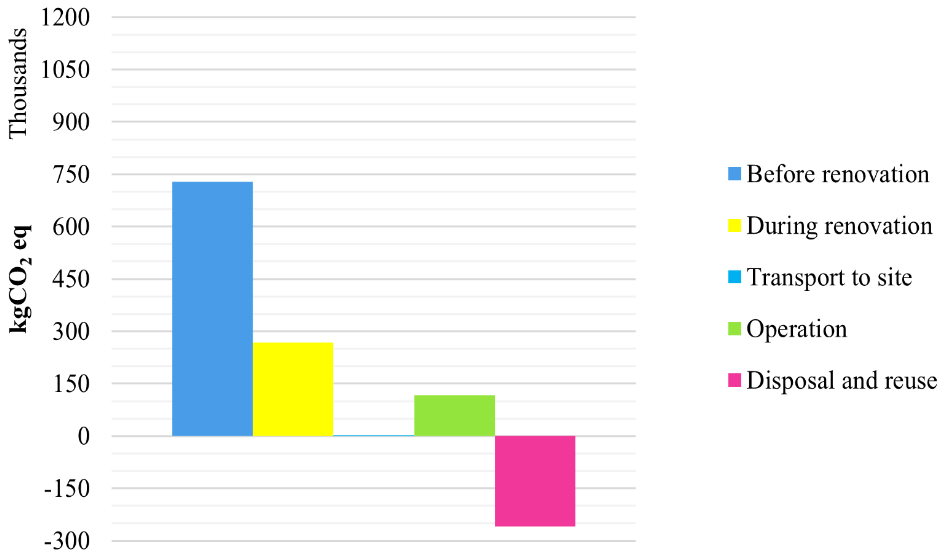

Figure 10. Global Warming Potential for overall impacts of the building (single score).

3.2. Heating Energy Consumption

The following Figure 11 represents the annual heat energy consumption and savings before and after renovation. By comparing the energy consumption of both non-renovated and renovated buildings, renovated buildings save about 20% of the annual heating energy used for space heating of the building. Moreover, Building A and Building B reduce the annual heat energy use for preparing hot water by 32% and 72%, respectively.

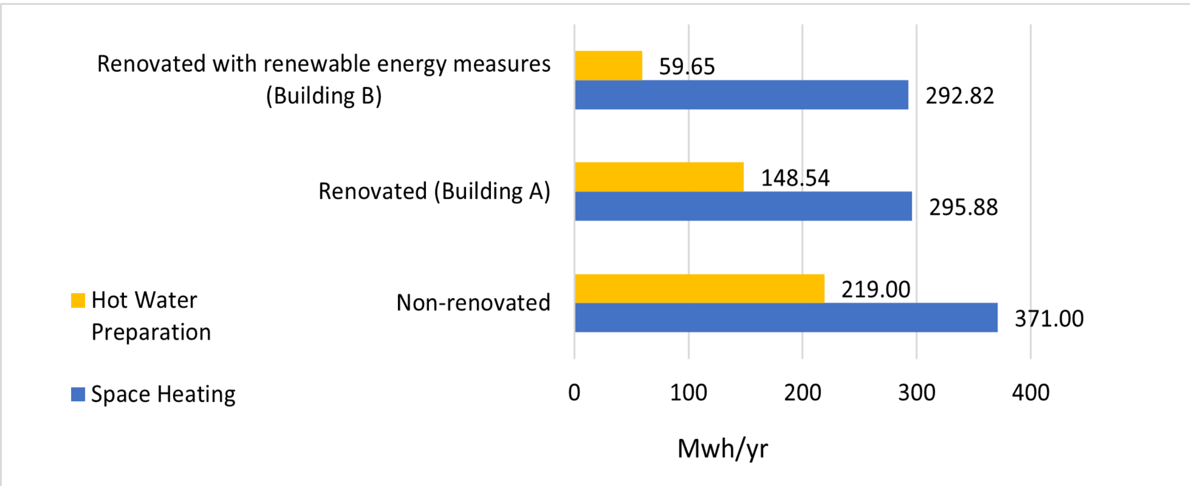

Figure 11. Annual consumption heat energy in selected building (A and B) before and after renovation.

Besides, heat energy consumption, the energy used for lighting and appliances and the natural gas used for cooking and other purposes. On average, 23.4 kWh/m^2 of natural gas used for cooking per dwelling and 32.9 kWh/m^2 of electricity used for lighting and other appliances [45]. Assuming the habit of the residents continue to be the same after and before the renovation of the building.

4. Discussion and Conclusions

This study was set to evaluate the environmental impacts of the typical multi-apartment buildings constructed before 1990, focusing on the process of renovation itself. The contributions of this study to the literature are twofold: firstly, the study includes the most widely used impact categories such as Global warming potential (GWP), Fossil depletion (ABD), Photochemical oxidation potential (PCOP), Human toxicity (HT), Acidification (AP), and Eutrophication (EP) to produce results for different materials used during the renovation process. Secondly, the study relates to the renovation processes in Lithuania, to achieve of energy efficiency of existing buildings. Although, the renovation measures have achieved the basic energy efficiency standard [12], there is a question of effectiveness of the renovation itself. Under this condition, this study could be an insight to know about the efficacy of the overall building impacts throughout the renovation process using different renovation technologies, not only from the materials point of view, but also from the energy point of view. The scope of the study covers renovation phase of the building i.e., construction and production, use, and disposal as per designated standard EN15804. The study assesses the overall impact of the building pre- and post-renovation phase of three buildings in terms of following indicators GWP, ODP, HT, AP, EP, and fossils depletion were estimated. This concludes that the renovation measures: conventional renovation and renovation with renewable energy could reduce the impact on the climate change (GWP100a) from 12% and 48%, respectively, depending on the type of renovation has been carried out. The estimated GWP results shows 266 tonCO_2eq during the process of renovation and 727 tonCO_2eq before renovation of the building. This result implies 19% of emission occurs while the renovation of the building was carried out.

Based on the analysis, the materials such as concrete and steel has high dominance in the building pre-renovation stage; and the materials remains the same after renovation too. The multi-apartment buildings built before 1990 constitute two main materials such as concrete and steel. Notably, the building blocks in the Baltic states (Estonia, Latvia, Lithuania) that were built between 1960 and 1990 are quite similar due to common historical relevance [16]. These buildings are large, monotonous blocks, multi-storey with prefabricated technology, constitutes of concrete and reinforcing steel could possibly be a main contributor of CO_2 emissions and on other impact categories [34]. Furthermore, the results reveal that the transportation has negligible impact over GWP indicating domestic transportation did not contribute on CO_2 emissions, however, Emami et al. [34] mentions that inbound/outbound transportation from different regions could have substantial contribution on GWP, as purchasing materials locally be relative. Although, the disposal score indicates negative, discarding of construction and demolition wastes in Lithuania is a persistent challenge [50]. This entails proper disposal of materials to improve the overall impact due to CO_2 emissions.

As expected, the chosen renovation scenarios have reduced CO_2 emission, however, there is a room for overall improvement in GHG emissions by examining closely into embodied energy of the building. This is achieved while focusing on selection of building materials [13], considering different factors such as installation, maintenance, durability, availability, cost, and so on, as it has influence the process of renovation itself [51]. Nonetheless, installation of renewable measures such as PV collectors and heat pumps have brought a huge impact on the human health and the environment and this could be due to manufacturing process or/and consumption of non-renewable energy [52]. However, Chow and Ji [46] present impact on support structures or electrical or electronic devices are negligible; so, does the disposal phase. Moreover, emissions due to operation of the PV collectors are negligible on daily basis; use of vacuum tube PV collectors exhibit remarkable performance [49]. The assessed LCA results indicate that the greatest impact was due to the supply of thermal energy in non-renovated building. However, the losses have been reduced by installing renewable energy measures in renovated multi-apartment buildings (Building A and B), where the potential savings in thermal energy used for space heating and domestic hot water preparation are 25% and 40%, respectively, after a conventional renovation (Building A) and a renovation with renewable measures (Building B), respectively. Based on the findings from the different authors [9,16,33,39,52,53] with different renovation measures (for ex., external insulation, thermal insulation, solar collectors, and heat pump etc.) achieved substantial low energy usage accordingly, which also improves both thermal comfort and energy use [53]. Improvement of ventilation and insulation of roofs and walls yield significant environmental improvement potential in both single and multi-family buildings [39]. Similarly, implementing solar collectors in addition to the conventional renovation, showed up to 70% energy reduction in a brick apartment, close to the energy efficiency requirements of new buildings [54].

The main contribution of the study is in evaluating the environmental impact assessment with life cycle approach in Lithuania for a renovated multi-apartment building. Previously mentioned, such assessment is relatively new, and this assessment was carried out for the first time. A study by Jimenez et al., [51] brought out an interesting approach on housing renovation strategies in Sweden. Similarly, Kuusk et al. [16] concluded that low-budget renovation on concrete multi-apartment buildings in Estonia had successfully reduced up to 20% of primary energy use. Moreover, Villegas et al. (2019), studied a renovation scenario from Swedish context and its trade-off between energy and materials. Similarly, Blom et al. [9] studied the environmental impacts of building and user related energy consumption in Dutch context, concluded 20–45% of environmental impact caused by household appliances. According to Vilches et al. [7] that the construction, use and retrofitting stages account for 22–31%, 60–76%, 4–9% of energy requirements for a period of 75 years, respectively. Comparing the literature from the other countries revealed a gap in analyzing renovation case studies of the residential buildings. Therefore, no such previous comparisons and benchmark exists for this study. For this study, we purposefully selected the renovated multi-apartment buildings to receive the findings whether the process of renovation is considerate or not. However, the results indicate inconsistencies while comparing two different building surveys which could be due to the selection of different system boundaries. In addition, the study shows that overall impact on climate change is less significant during the renovation process that includes the new construction materials. Nevertheless, the results are not exactly the emissions of two building scenarios since no localization was done. The actual proportions, technologies and production conditions could be different from the dataset employed from the databases even though the buildings are renovated and represent the present residential condition in Lithuania. However, this study is significant to bring out the possibility and proactiveness to consider the entire lifecycle stages while performing renovation. Despite the identified inaccuracies and limitations in the study, this analysis has provided an insight regarding the impacts of maintenance and retrofitting stage.

Various financial schemes have undertaken to modernize the buildings to ensure energy efficiency. There are several uncertainties caused during and after renovation of the multi-apartment buildings. For instance, there was no baseline information on indoor climate conditions available before renovation. Several studies have been conducted to investigate the quality of indoor climate and a comprehensive protocol was developed to assess the impacts of indoor quality according to health and hygiene standards. Moreover, the residents are satisfied with the decisions and the outcomes after the renovation measures in Lithuania [55].

However, considering the total number of multi-apartment buildings that are still in need of renovation is appalling. There are 37,627 multi-apartment building in Lithuania, out of which 3136 apartments were renovated until 2013. This indicates only 8.7% of apartment buildings are renovated thus far. As per 2020 data, 1543 apartment buildings are under renovation currently [56]. This shows that the rate of renovation per year is less than 5%. Whilst recalling the EU Green deal and the renovation wave, it is binding for Lithuania and similar countries to double the renovation rates in forthcoming years. This calls for a massive renovation of multi-apartment buildings across the country.

When considering a renovation, benefits from energy savings might be uncertain or poorly understood or explained and it is often difficult to measure the monetize as renovating can be costly and hard to organize, mobilizing finances can be difficult and can burden up the environment at local and regional level [57]. Therefore, this is the point where the question arises on necessity and quality of the process. As per EU's 'renovation wave', delivering the depth and volume of renovation should foster innovation and sustainability to increase the quality and reduce costs [1]. This COVID crisis made us realize a large number of homes require deep renovation. Therefore, renovation of buildings does not just end with environmental aspects but also the functional aspect and comfort of the user. In this regard, evaluating renovation projects in holistic perspective is important. This study aimed in evaluating the potential environmental impacts associated with renovation process and technologies used. This study is a small part of a broad spectrum where more studies related to environmental impact of construction materials and process is highly recommended, particularly in Eastern European countries similar to Lithuania. Likewise, studies covering the consumer/builder awareness, functionality, thermal comfort, choosing sustainable materials, cost analysis, return of investment shall be studied further to have better understanding of the renovation process. Therefore, to achieve acceptable results, a larger number of studies should be studied and assessed.

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