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Applying the Life Cycle Assessment Approach to a Case Study with the Environmental Impacts Assessment of the Insulation Materials

Ahmed AbdelMonteleb Mohammed Ali
Associate Professor, Department of Architecture, College of Architecture and Planning, Qassim University, Qassim, 52571, Saudi Arabia
Email: ahm.ali@qu.edu.sa, TEL: +966532490093
Associate Professor, Department of Architectural Engineering, Faculty of Engineering, Assiut University, Assiut, 71515, Egypt
Email: ahmed.abdelmonteleb@aun.edu.eg, TEL: +201005490811

ABSTRACT
Insulation materials are essential for minimizing energy use, enhancing thermal comfort, and minimizing greenhouse gas emissions in buildings. However, the insulation materials sector may have a considerable environmental impact. Many literature reviews and numerous studies have addressed the insulation material and its thickness from the perspectives of energy efficiency and thermal performance inside buildings, regardless of the environmental impacts of the insulation materials industry. Therefore, the research problem in this article is to observe the environmental burdens of the insulation materials industry. The scientific methodology used in the research is the life cycle assessment (LCA) methodology based on the ISO14040 series standards. Using the LCA approach, the research compares the environmental impact of four widely used insulation materials: extruded polystyrene, expanded polystyrene, rock wool, and glass wool. Without considering the use and end-of-life disposal stages (the system boundary of this study), the LCA approach assesses the insulation materials from the cradle to the gate, including raw material extraction, production, and transportation. The study analyzes the Ibny Baitak project in New Assiut City as a case study to apply the LCA of the insulation materials scenario.
Extruded polystyrene, rock wool, and glass wool have the lowest impacts, according to the study's findings, while expanded polystyrene is the most harmful. Concerning the midpoint result, the XPS recorded 4.35 kgCO_2eq, and the EPS pointed to 3.96 kgCO_2eq. As for the endpoint result, the XPS insulation material has recorded the highest adverse impact compared to other materials by 1.61 mt. The EPS came in the second rank by 1.24 mt, then the rock wool by 0.55 mt, and finally, the glass wool by 0.33 mt.
The results imply that a building's environmental effect over its lifetime can be considerably impacted by the material used for insulation. The study's findings can help architects, engineers, and construction professionals choose the best insulation for energy-efficient buildings. Considering the LCA approach is very important to consider in all manufactured materials. Thus, the industry and stakeholders should consider environmental concerns besides energy efficiency when choosing insulation materials for construction projects.

KEYWORDS
Life Cycle Impact Assessment, BIM, Insulation Materials, New Assiut City

1. Introduction
Using insulation materials in the construction industry is crucial to improve energy efficiency and reduce greenhouse gas emissions by improving the thermal performance inside the buildings. However, the production and installation of insulation materials can also have a significant harmful emission [1]–[3]. Several factors contribute to the environmental consequence of the insulation materials industry, including raw material extraction, production, transportation, use, and end-of-life disposal. Therefore, evaluating the environmental impacts of insulation materials throughout their life cycle is essential to make informed decisions about their selection for building projects.
Life cycle assessment (LCA) is a frequently used technique for assessing a

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product's environmental impacts [4]. LCA is a thorough method used to assess how procedures and products affect the environment at every stage of their life cycle, from the extraction of raw materials to the disposal of trash [5]. LCA considers various environmental effects of primary products and byproducts, including greenhouse gas emissions, energy use, water use, and toxicity [6]. This study employs the LCA approach to evaluate the environmental impacts of several insulation materials commonly used in the construction industry. The study compares the different insulation materials: extruded polystyrene, expanded polystyrene, rock wool, and glass wool. The literature review summarized that the most common insulation materials are polyurethane, polystyrene, glass wool, rock wool, cellulose, and flax. However, the problem addressed in this study is to compare the environmental impact of four commonly used insulation materials in Egypt: extruded polystyrene, expanded polystyrene, rock wool, and glass wool. LCA will be applied to these materials. These materials were chosen because they represent various insulation types commonly used in the construction industry in Egypt.

The following compares these materials with different characteristics and environmental effects [7].

- Polystyrene is used to create polystyrene (XPS), a closed-cell foam insulation material. Because XPS has a high compressive strength and is moisture-resistant, it can be used in below-grade applications. However, the high energy requirements for XPS synthesis and the need for petroleum-based raw materials add to the material's comparatively significant environmental implications [8]–[11].
- Another foam insulation product made from polystyrene is expanded polystyrene (EPS). EPS is portable and offers effective thermal insulation. The significant energy consumption and reliance on petroleum-based raw materials needed to produce EPS add to the material's comparatively high environmental influences [12].
- Rock wool is a type of insulation created from unprocessed basalt rock. The melted and spun fibers from the pebbles are then used to create insulation bats or boards. Rock wool is fire-resistant and has thermal solid and acoustic insulation qualities. The manufacture of rock wool has a lesser impact than polystyrene foam insulation since it uses less energy and petroleum-based raw ingredients [13].
- An insulation substance formed from glass fibers is called glass wool. Glass wool is fire-resistant. It has strong thermal and acoustic insulation qualities. Glass wool manufacture has a lower effect than polystyrene foam insulation since it uses less energy and petroleum-based raw materials [13].

Overall, the entire life cycle of insulation materials should be assessed, including raw material extraction, production, transportation, usage, and end-of-life disposal. However, this study has focused only on the cradle-to-gate stage till the manufacturing process of the insulation materials. The individual application and environmental factors, including energy efficacy, environmental impacts, and cost-effectiveness, should be considered when selecting an insulation material.

2. Literature Review

A. Martínez-Rocamora, J. Solís-Guzmán, and M. Marrero [14] have analyzed 20 LCA databases and categorized them based on their geographic scope, material type, and level of detail. The authors have suggested that the availability of LCA databases focused on construction materials is essential for evaluating the building materials and promoting sustainable building practices. Regarding the LCA application, C. Ingrao, A. Messineo, R. Beltramo, T. Yigitcanlar, and G. Ioppolo [15] have analyzed the LCA application to evaluate the energy efficiency and environmental performance of buildings. The authors have suggested that LCA can be useful for designers, builders, and policymakers to make informed decisions about building materials, design, and operation.

Concerning the combination of building information modeling (BIM) and LCA methodologies, S. Seyis [16] has analyzed the use of BIM and LCA to improve the sustainability of buildings. The author has found that integrating BIM and LCA can help optimize building design, reduce material waste, and improve energy efficiency. Besides that, S. Su, Q. Wang, L. Han, J. Hong, and Z. Liu [17] have proposed the BIM-DLCA (Building Information Modeling-Dynamic Life Cycle Assessment) model to evaluate the environmental effect of buildings throughout their life cycle. The model integrates BIM and LCA methodologies to provide a comprehensive assessment, considering the dynamic changes in building design and operation over time.

Considering the LCA of the insulation materials, Pedroso et al. [2] have aimed to analyze the environmental consequences of shielding products used in external thermal insulation composite systems. Also, S. Layachi et al. [12] have investigated the impact of incorporating expanded polystyrene (EPS) beads into lightweight earth blocks. The results have highlighted that adding EPS beads to the earth blocks significantly improves their thermal insulation properties and reduces their density, making them lighter and easier to handle. Vo et al. [18] have discussed the advancements made in thermal insulation using extruded polystyrene (XPS) foams. The article also discusses the recent developments in XPS foam technology, such as nanotechnology, which has significantly improved the thermal insulation properties of XPS foams. Dombayci [19] has investigated the optimum insulation thickness for external walls of buildings. The study uses a life cycle assessment (LCA) to compare different insulation thicknesses, considering the materials used, manufacturing, transportation, installation, use, and end-of-life disposal. The results show that increasing insulation thickness beyond the optimum level can increase the environmental impact due to the additional materials and energy required for its production and installation. With a complete assessment, Al-Homoud [20] has compared the thermal insulation performance and cost of different insulation materials, including mineral wool, expanded polystyrene, extruded polystyrene, polyurethane, and cellulose.

The following papers have been published to study the effect of the insulation thickness on the thermal comfort inside the building. Bolattürk [21] has examined the optimum insulation thickness for building walls in the warmest zone of Turkey. The results show that the optimum insulation thickness varies depending on the orientation of the walls and the type of insulation material used. Hasan [22] has presented a method for optimizing building insulation thickness using life cycle cost analysis. The results have revealed that the optimum insulation thickness varies depending on the climate, type of building, and energy prices. Çomakli et al. 2003 [23] have inspected the optimum insulation thickness for external walls in buildings. The results show that the optimum insulation thickness varies depending on the material used and the climate. Ismail et al. [24] have presented a simplified model metric for quantifying the thermal resilience of office buildings during power outages. Dombayci et al. [25] have researched the optimization of insulation thickness for external walls in buildings using different energy sources. The findings have presented that the optimum insulation thickness varies depending on the type of insulation material used and the energy source. Kurekci [26] has investigated the optimum insulation thickness for building walls in all provincial centers of Turkey. The outcomes have highlighted that the optimum insulation thickness varies depending on the orientation of the walls and the type of insulation material used. Yu et al. [27] have considered the optimum insulation thickness for external walls in buildings in China's hot summer and cold winter zones. The results show that the optimum insulation thickness varies depending on the material used and the climate.

Tettey et al. [28] have investigated the impact of different insulation materials on the primary energy consumption and carbon dioxide emissions of a multi-story residential building. The results have demonstrated that vacuum insulation panels and cellulose insulation have the lowest primary energy consumption and carbon dioxide emissions, while expanded polystyrene has the highest. Su et al. [29] have presented a life cycle inventory comparison of different building insulation materials and uncertainty analysis. The results have revealed that cellulose insulation has the lowest impact, while expanded polystyrene and extruded polystyrene have the highest. Schiavoni et al. [30] have provided a review and comparative analysis of insulation materials for the building sector. The authors have suggested that the selection of insulation materials should consider a balance between thermal insulation performance, cost, and the specific requirements of the building and its location. Llantoy et al. [31] have presented a comparative life cycle assessment (LCA) of different insulation materials for buildings in the continental Mediterranean climate. The study has highlighted the importance of considering the environmental effects of insulation materials when selecting them for buildings and the need for a comprehensive life cycle assessment.

In conclusion, the literature review highlights the importance of considering the total environmental impact of insulation materials. Reviewed studies have shown that the environmental impacts of insulation materials can vary significantly depending on the raw material components, manufacturing process, transportation, installation, use, and end-of-life disposal. Also, many researchers have studied the energy efficiency of using insulation materials. That is why this research will focus on further assessing the environmental burdens of the insulation materials industry [7].

3. Study Area

This article will take the New Assiut City (NAC) in Assiut, Egypt, as a case study, as it is a new city with significant challenges to offer the best quality of the building and services for the residents. Thus, this section deals with a presentation of the NAC.

3.1. NAC description:

Presidential Decree No. (194) of 2000 was issued to establish the NAC as a third-generation city. The establishment of the city was within the framework of the Egyptian state's efforts for urban expansion to achieve several development goals, the most important of which is to accommodate the increasing population numbers to relieve population pressure and redistribute the population within the territory of Assiut Governorate, and at the same time maintain the agricultural area, and raise the standard of living of the region's population. By providing adequate housing for the population, especially for low-income people, in addition to providing new job opportunities from industrial projects, which will be established in the city, stimulating immigration to the new city, and reducing immigration outside the governorate, the following is a brief description of the new city of Assiut in terms of the general location, city area, general planning of the city, and finally the components of the city [32].

3.2. NAC Location

The NAC is located east of the Nile on the (Cairo - Sohag) desert road, at its intersection with the (Hurghada - Assiut) road, and about 15 km from Assiut city, as shown in Figure 1.

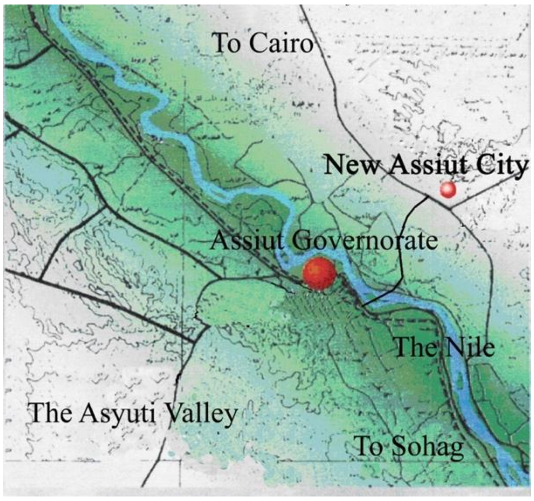


Figure 1 Relationship between Assiut City and NAC

3.3. NAC master plan

The urban block of the city consists of 2 residential neighborhoods separated by a primary service axis (city center), in addition to the third district (the future extension area), the industrial zone, and the regional area, as shown in Figure 2.

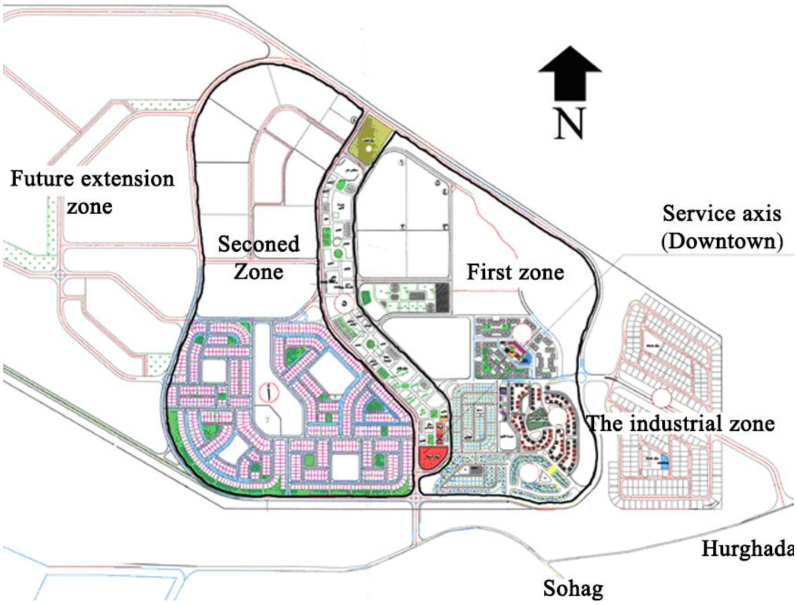


Figure 2 NAC master plan

3.4. Monitoring and analysis of the reality of the housing project Ibny Baitak in NAC:

Within the framework of the National Housing Project program, the Ministry of Housing, Utilities, and Urban Development adopted the idea of introducing a new type of housing under the name of the "Build Your Home" project Egyptian governments, as presented in Figure 3, as one of the projects aimed at reducing slums in existing cities and providing adequate housing for low-income young citizens [32].

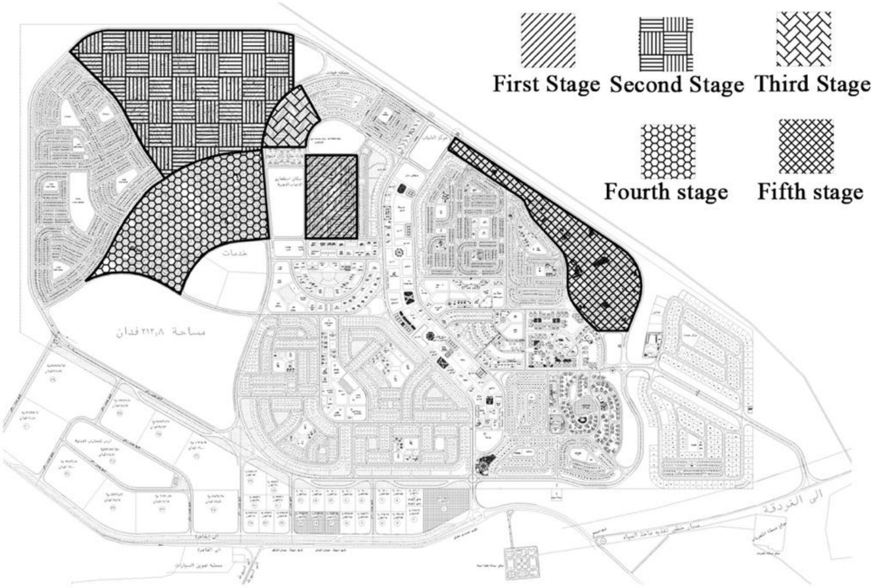


Figure 3 Ibny Baitak project zones in NAC

3.5. Housing style and architectural models of the Ibny Baitak project in NAC

As has previously indicated, the project is a residential block; the beneficiary citizen builds a housing unit on them with a construction rate of 50% of the block so that the area of the housing unit is (63m^2) consisting of two bedrooms, a hall, a kitchen, and a bathroom, with a stair with an area of (12m^2) to be a flat floor (75m^2). This article will take the model (Z) as the case study to apply the LCA scenarios because this model has the most significant number of blocks in the Ibny Baitak project with 56.45% of total models, as mentioned by [33], [34]. Figure 4 presents the facades and section of the selected model (z) to be the case study of this article.

(a) Northern facade

(b) Southern facade

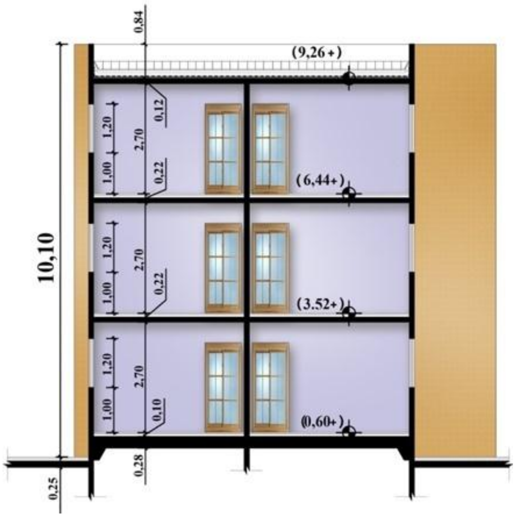


Figure 4 Facades and section of the model (z) [33], [34]

4. Material and methods

The scientific methodology used in the research is the LCA methodology based on the ISO14040 series standards. As well as the BIM has been used to collect case study data. Then, these data have been dropped into the life cycle inventory phase to calculate the life cycle environmental impacts of the four insulation materials. Therefore, the method of gathering and evaluating data will include the usage of the Ecoinvent database [35] and Revit.

4.1. Life Cycle Assessment approach

The LCA method can compare the environmental effects of various insulation materials, such as glass wool, expanded polystyrene, rock wool, and extruded polystyrene. The extraction, production, and transportation of raw materials and other factors all impact how environmentally friendly insulation products are. The insulating material selected can considerably influence the environmental effect of a building's life cycle. Therefore, it is crucial to consider the environmental effects and energy efficiency of insulating materials when choosing them for construction projects. As shown in Figure 5, the International Standards Organization (ISO) is a well-known standards body. (1) ISO 14040: Principles and framework [36], (2) ISO 14041: Goal definition and inventory analysis [37], ISO 14042: Life-cycle impact assessment [38] and ISO 14043: Life-cycle interpretation [39].

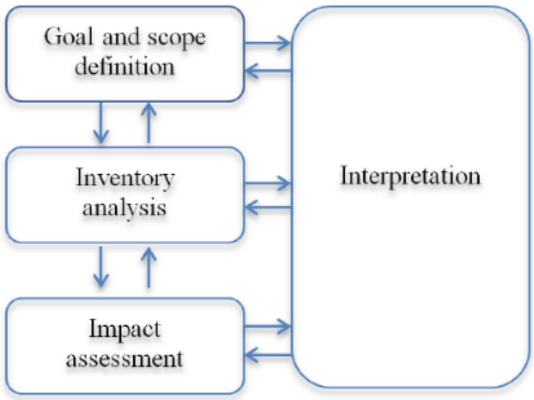


Figure 5 Life cycle assessment framework [40]

Following a thorough comparison, Ali et al. [41] and Al-Ghamdi [42] have presented their findings. It was shown that the LCA tool used most frequently is PRe SimaPro. As a result, the academic PRe SimaPro V9.5 license was utilized to access all open-license Ecoinvent datasets.

4.1.1. Goal and scope definition

The goals and scope of the LCA research are established at this point, as seen in Figure 6. Extruded polystyrene, expanded polystyrene, rock wool, and glass wool are the four insulation materials the study will assess for their impacts. The scope of the study establishes the functional unit, system limits, and data needs. According to the study, functional units of various insulation materials used in an LCA should be carefully selected. According to what is stated, the functional unit for this inquiry is 1 kg for the various types of insulation.

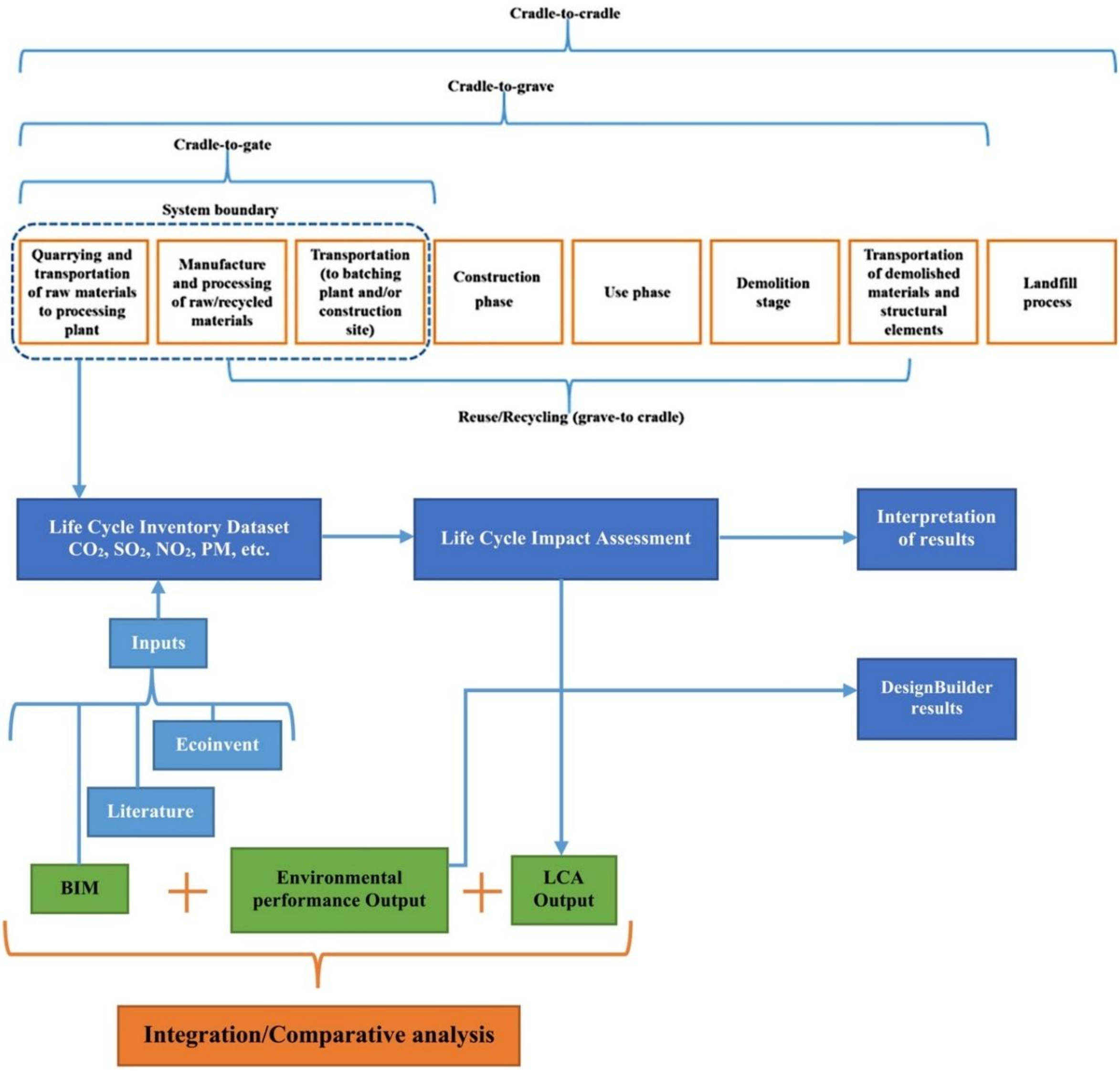


Figure 6 System boundary of LCA application in this study

Figure 7 displays the specific system boundaries of the insulation industry in more detail. This study will concentrate on the (cradle to gate) border, which includes (1) raw material extraction and continues through (2) raw material transportation and storage and (3) production and packing.

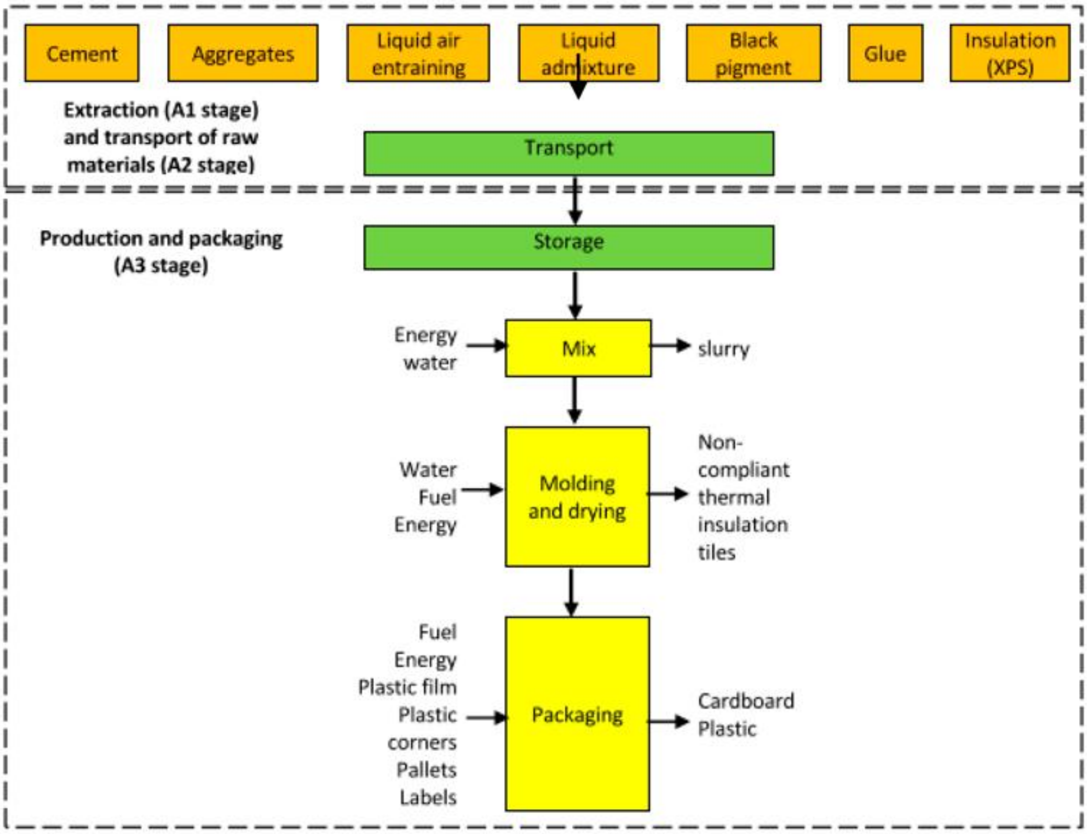


Figure 7 System boundary of the insulation material industry [1]

All materials have been built in SimaPro, as seen in Figure 8. The network flows of the production processes for rock wool, glass wool, expanded polystyrene, and extruded polystyrene are illustrated in Figure 9.

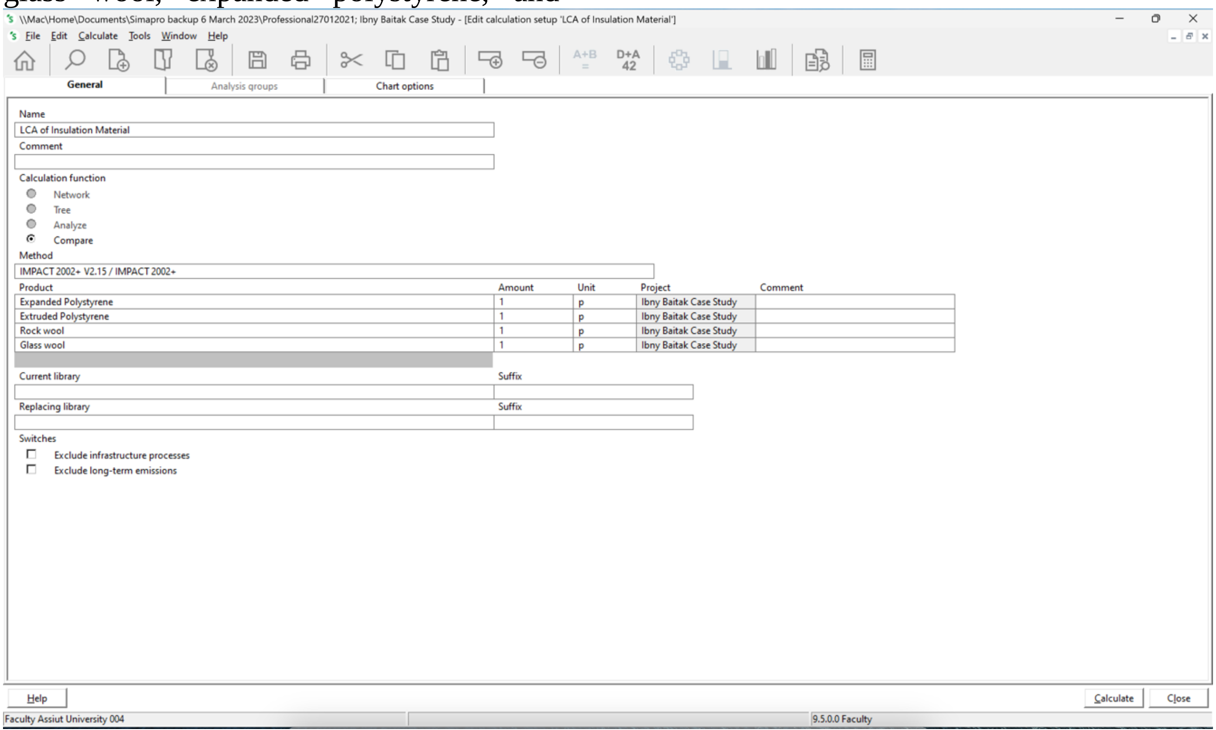
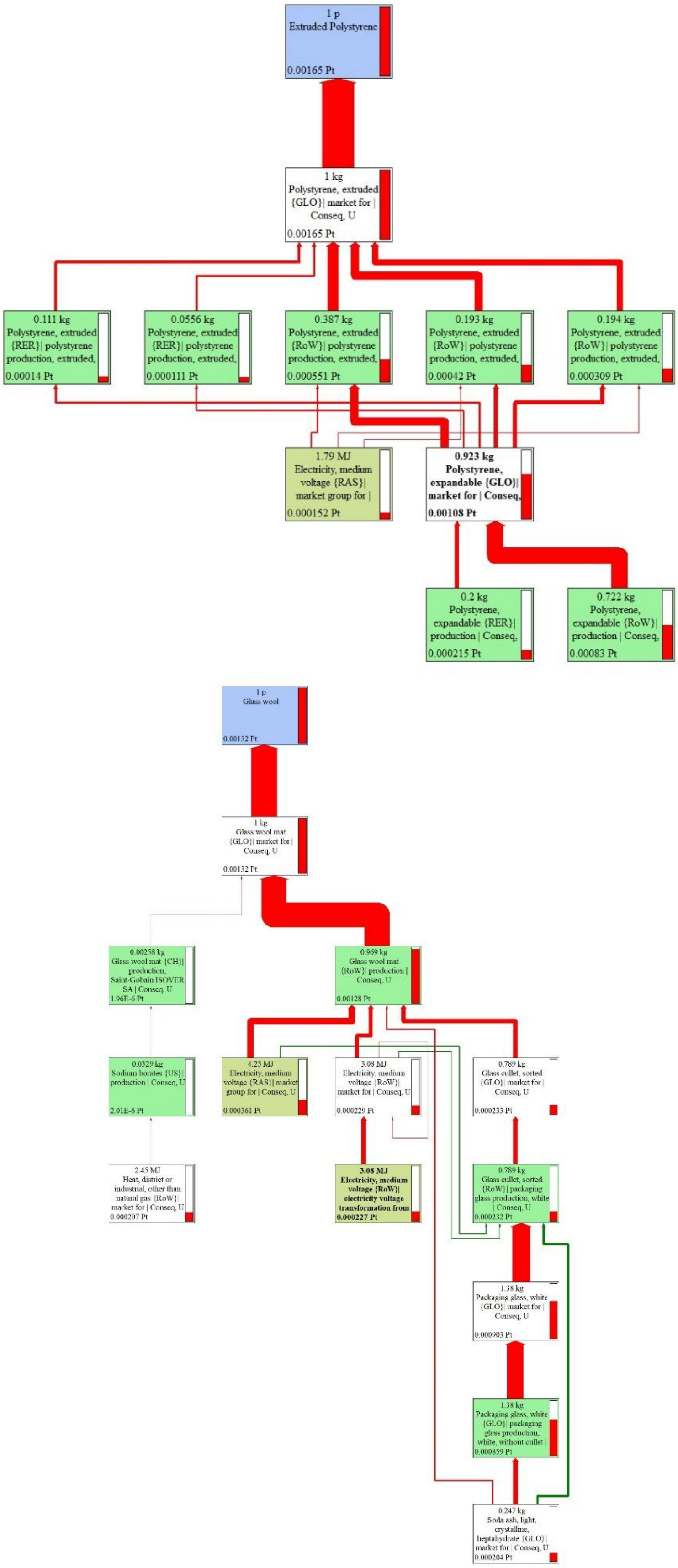


Figure 8 Calculation setup of the four insulation materials in SimaPro



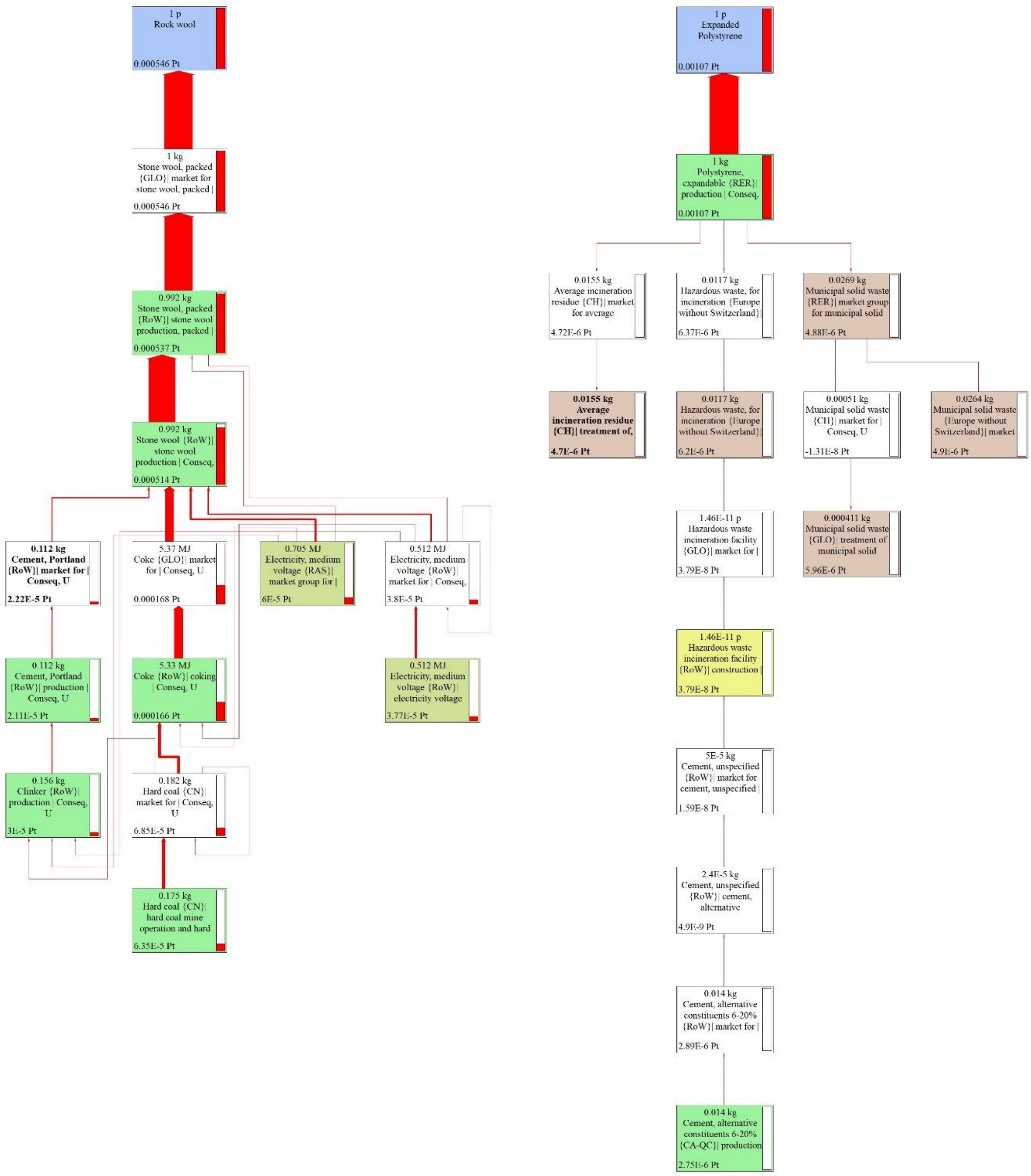


Figure 9 Network flow of the four insulation materials studied in SimaPro

4.1.2. Life cycle inventory

At this stage, all inputs and outputs related to the various types of insulation material are identified and quantified. Each phase of the product life cycle, including production and transportation, comprises the raw materials, energy used, emissions produced, and waste produced. Because there are not many LCA and LCI applications in Egypt, this study has had to rely on a few hypotheses from the literature review to make up for the lack of data for the input materials. A wide range of LCA applications for building materials was compared by Rocamora et al. [14]. Ecoinvent V3 [35], depicted in Figure 10, is the database version used for this inquiry. The global market sector in the Ecoinvent (SimaPro-based) database was specially chosen to be more compatible with Egyptian production techniques.

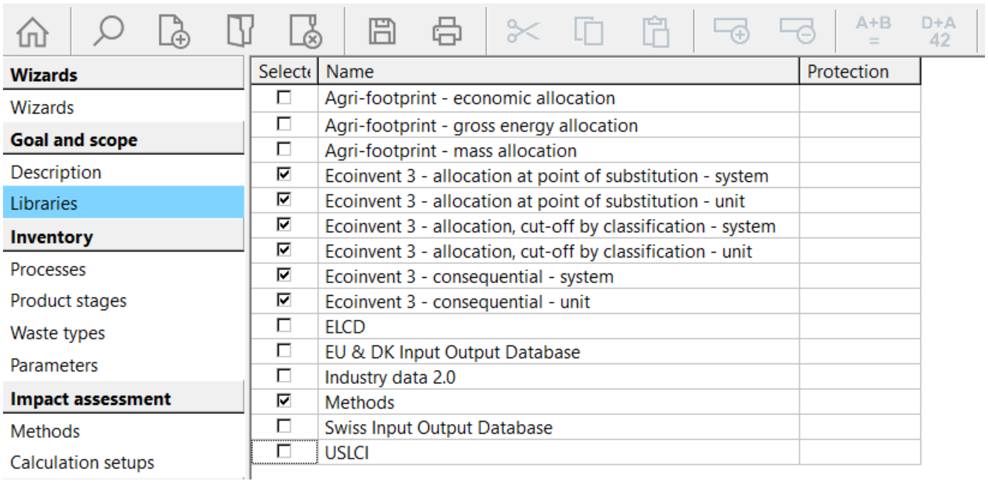


Figure 10 Ecoinvent database embedded in SimaPro V9.50

4.1.3. *Life cycle impact assessment*

The insulation materials' environmental impact is assessed using their specified inputs and outputs from the inventory analysis. It involves evaluating the effects of numerous environmental indicators, such as the potential for eutrophication, acidification, and global warming. Therefore, it distinguishes between the environmental effects of various insulation materials based on the ISO standard. This article will calculate the environmental effects using midpoint and endpoint calculations. The IMPACT 2002+ technique, which is described in Table 1, will be used in this work based on the literature review [15], [41]–[43].

Table 1 IMPACT 2002+ characterization version Q2.2 [44]

[Source]	Midpoint category	Midpoint reference substance	Damage category (end-Point)	Damage unit	Normalized damage unit
[a]	Human toxicity (carcinogens + non-carcinogens)	kg Chloroethylene into air-eq	Human health	DALY	Point
[b]	Respiratory (inorganics)	kg PM2.5 into air-eq	Human health		
[b]	Ionizing radiations	Bq Carbon-14 into air-eq	Human health		
[b]	Ozone layer depletion	kg CFC-11 into air-eq	Human health		
[b]	Photochemical oxidation (= Respiratory (organics) for human health)	kg Ethylene into air-eq	Human health		
			Ecosystem quality	n/a	n/a
[a]	Aquatic ecotoxicity	kg Triethylene glycol into water-eq	Ecosystem quality	PDF·m^2·y	Point
[a]	Terrestrial ecotoxicity	kg Triethylene glycol into soil-eq	Ecosystem quality		
[b]	Terrestrial acidification/ nutrification	kg SO_2 into air-eq	Ecosystem quality		
[c]	Aquatic acidification	kg SO_2 into air-eq	Ecosystem quality		
[c]	Aquatic eutrophication	kg PO^{4}_{3}- into water -eq	Ecosystem quality		
[b]	Land occupation	m2 Organic arable land-eq · y	Ecosystem quality		
	Water turbines	Inventory in m^3	Ecosystem quality		
[IPCC]	Global warming	kg CO_2 into air-eq	Climate change (life support system)	kg CO_2 into air-eq	Point
[d]	Non-renewable energy	MJ or kg Crude oil-Eq (860 kg/m^3)	Resources	MJ	Point
[b]	Mineral extraction	MJ or kg Iron-eq (in ore)	Resources		
	Water withdrawal	Inventory in m^3	n/a		
	Water consumption	Inventory in m^3	Human health		
			Ecosystem quality		
			Resources		

[a] IMPACT 2002, [b] Eco-indicator 99, [c] CML 2002, [d] Ecoinvent, [IPCC] (IPCC AR5 Report), and [USEPA] (EPA)
daly disability-adjusted life years, *PDF* potentially disappeared fraction of species, *-eq* equivalents, *y* year

4.2. *Building Information Modeling*

The environmental impact of insulation materials can be considered during the design and construction phases using BIM.

BIM is a digital representation of a building that facilitates collaboration and better decision-making between architects, contractors, and owners. The life cycle of a building, including the materials used and their effects on the environment, may be modeled using BIM. LCA data for various insulation materials can be incorporated into BIM to compare their impacts.

The following procedure has been used to assess insulating materials using BIM:

1. Define the project's scope, considering the building's location, size, and intended use.
2. Identify the insulation products utilized in the project, such as glass wool, expanded polystyrene, rock wool, and extruded polystyrene.
3. Gather "cradle to gate" LCA data on the manufacture, extraction, and transportation of raw materials for each insulating material.
4. Model the building in BIM software, considering the types of insulation utilized. This study will use the 2020 student-licensed version of Autodesk Revit, the most widely used BIM tool.
5. Using LCA data, compare the environmental effects of various insulation types. There are two ways to accomplish the LCA data: (1) either by exporting the BIM data to LCA software or (2) by using BIM software that contains LCA data. Senem Seyis and Shu Su et al. [16], [17], which have been reviewed, claim that LCA and BIM combined may significantly evaluate the environmental costs of material manufacturing. This study will employ this all-encompassing approach, where LCA will look at how different scenarios affect the environment. BIM will provide information on the building's components for LCA input.
6. Make informed judgments about the insulating materials to be utilized in the project based on the findings of the LCA. It can involve making design changes to reduce the environmental burdens of the insulation materials or choosing the most environmentally friendly insulation material.

5. Result and discussion

The interpretation includes identifying the study's key environmental impacts and areas for improvement.

5.1. EIA Mid-point results

In this section, the results of all scenarios will be presented by the midpoint method for single score and weighting results.

5.1.1. Single score results

Concerning the single score, Figure 11 presents the midpoint method for the insulation materials studied. The XPS insulation material has recorded the highest adverse impact compared to other materials by 1.61 mt in accordance with [12]. The EPS came in the second rank by 1.24 mt, then the rock wool by 0.55 mt, and finally, the glass wool by 0.33 mt [8]. Although the insulation materials made of polystyrene foam have good thermal insulation qualities [45], [46], their manufacture necessitates considerable energy consumption and the use of petroleum-based raw materials, which has a more significant negative impact on the environment [1], [31]. The two polystyrene-based compounds have adverse effects because of this. In contrast, mineral wool insulating materials, including rock wool and glass wool, require energy and petroleum-based raw materials, so they have low environmental effects. Glass wool is created from recovered glass fibers, and rock wool is made from basalt rock [47]. These insulation materials are fire-resistant and have thermal solid and acoustic insulation qualities. Rock and glass wool manufacturing utilizes less energy and fewer petroleum-based materials.

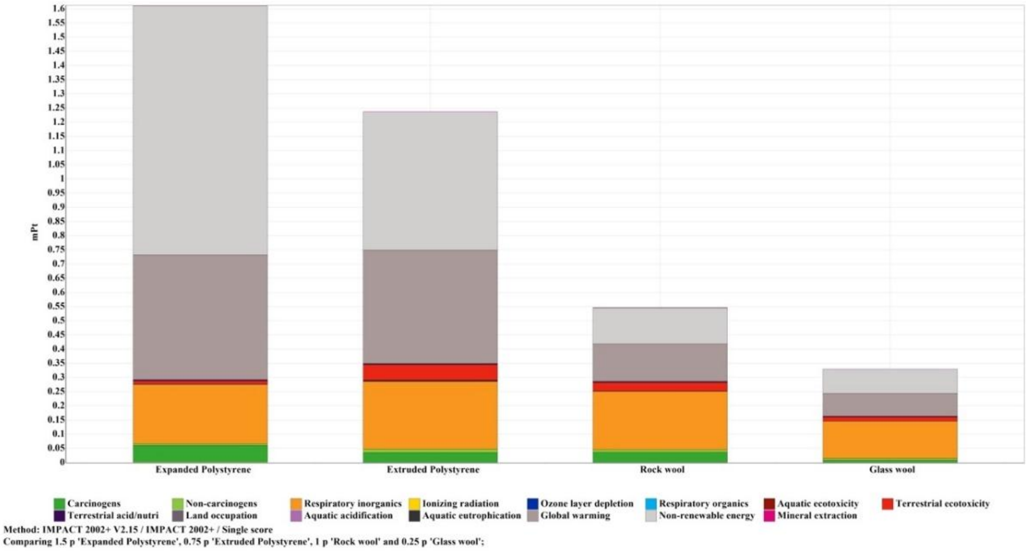


Figure 11 Single score result of LCA on the insulation materials by midpoint method

5.1.2. Weighting results

Comparing the environmental impacts among the four insulation materials, Figure 12 highlights the weighting comparison result. The main impacts are respiratory inorganics, global warming, and non-renewable energy for all insulation materials. Some LCIA techniques have embraced Disability Adjusted Life Years (DALY) as a measure of human health environmental impact to incorporate varied points linked to damages to human health, as mentioned by Dastjerdi et al., Li et al., Shi et al. and Hu et al. [48]–[51]. The highest percentages were for both polystyrene materials in agreement with [12]; expanded then the extruded insulation. For the XPS by 4.35 $kgCO_2eq$, 133.54 Mj primary and 1.48E-06 DALY. As for the EPS by 3.96 $kgCO_2eq$, 74.09 Mj primary and 1.69E-06 DALY. One of the leading manufacturing distinctions between the two polystyrene materials is that XPS is formed with gas added [8], whereas EPS is produced by inflating gas-filled beads [12].

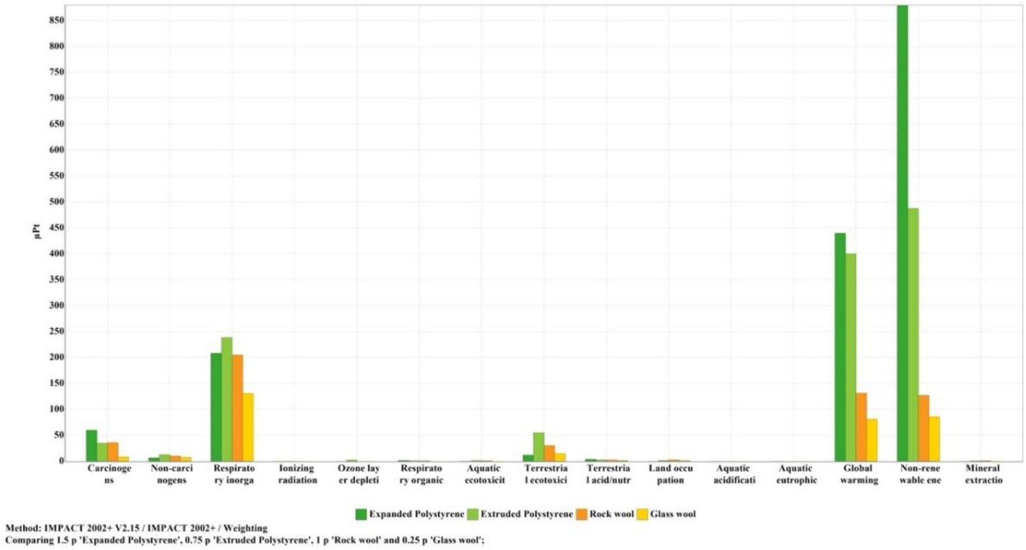


Figure 12 Weighting result of LCA on the insulation materials by midpoint method

5.2. EIA Endpoint results

In this section, the results of all scenarios will be presented by the endpoint method for single score and weighting results.

5.2.1. Single score results

Figure 13 presents the single score results, considering the endpoint results. Resource depletion is the highest impact recorded in the insulation materials, specifically in the XPS and EPS, due to the petroleum-based raw materials added to the material [8]–[11]. The XPS had 0.88 mt, EPS had 0.49 mt, rock wool had 0.13 mt, and glass wool had 0.09 mt—the rock and glass wool have low values. Then, climate change is the second environmental impact, with 0.44 mt for XPS and 0.40 mt for EPS. Finally, the human health impact was recorded to be 0.29 for XPS and 0.28 mt for EPS.

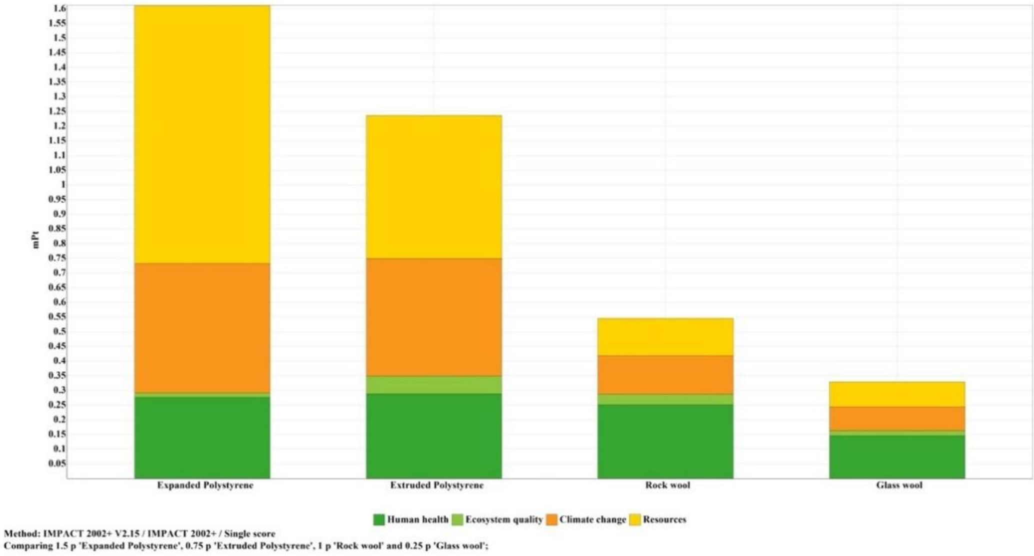


Figure 13 Single score result of LCA on the insulation materials by endpoint method.

5.2.2. Weighting results

Figure 14 depicts the result by endpoint method. The ecosystem quality has negligible numbers among all insulation materials studied. The ecosystem is a geographical region where plants, animals, and other organisms, as well as weather and landscape, work together to create a life bubble, according to the LC-Impact database [52], which has discussed this phenomenon. Also, the ecosystem consists of habitat, species, and resource indicators. So, these parameters are out of the insulation material industry scale.

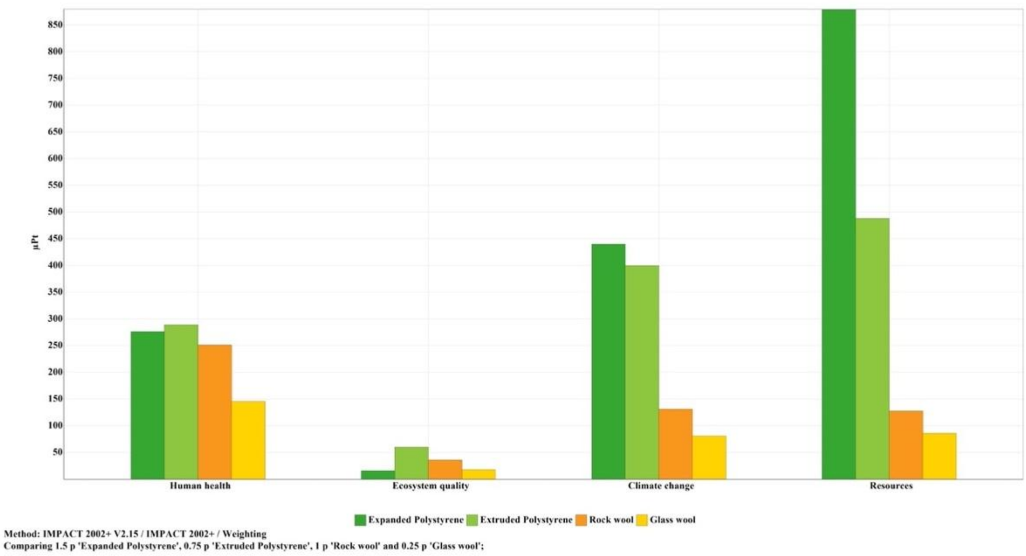


Figure 14 Weighting result of LCA on the insulation materials by endpoint method

6. Conclusion

The study has thoroughly analyzed the effects on the environment of several insulation types frequently employed in the building sector. The study employed the LCA method to assess the insulation material's life cycle. Due to the shortage of LCA applications in Egypt, the main contribution of this study is to apply the LCA to different materials in existing case studies in Egypt. This study has focused on insulation materials with the same methodology; the LCA can be applied to different materials. As well as this study has introduced the Ecoinvent database as an alternative if data is unavailable. The study's findings are in line with earlier studies that have demonstrated that the manufacture of EPS and XPS has a more negative impact on the environment than the production of other insulation materials [1], [8], [12], [31]. Despite that, the global warming and respiratory inorganic results are higher in the EPS and XPS (because of the harmful gases generated when burned and are frequently disposed of in landfills, rock and glass wool can be recycled or reused and are non-toxic.

The study's findings are a trial to prove the importance of LCA application in building materials. However, it is crucial to understand that they are based on a single case study and might not apply to all construction projects or applications of insulating materials. Additionally, this study did not consider how the longevity and upkeep of the insulating materials will affect the building's overall environmental impact.

7. Limitations and recommendations

The specific context and assumptions used in the LCA analysis may impact the study's findings. Additionally, the study does not consider how the durability and maintenance of the insulating materials will affect the building's overall environmental impact. For instance, if an insulation material needs frequent maintenance or replacement due to a shorter lifespan, this could have a more significant long-term environmental impact due to the additional resources needed. The study's focus could be broadened in future work to include a more comprehensive array of construction projects and applications for insulating materials. It might offer a more thorough understanding of how insulating materials and their uses affect the environment. Finally, since novel materials might provide more environmentally friendly substitutes for conventional insulation materials, future research might also investigate cutting-edge insulation materials and their impacts [7].

On the other hand, data availability and consistency may be challenging when conducting a comparative environmental effect assessment of insulating materials using the LCA methodology. Data on the insulation material's whole life cycle, from raw material extraction through end-of-life disposal, is necessary for LCA. Data accessibility and consistency, nevertheless, can differ between various insulation types and even between several manufacturers of the same type of insulation. The LCA approach's complexity could provide another challenge. LCA involves a thorough and multi-step examination of the environmental effects of a process or product, which calls for specialized knowledge. Life cycle inventory data is essential in LCA applications. This study has used the Ecoinvent database embedded in SimaPro as the limitation of environmental data in insulation material manufacturing. That is why it is crucial to adopt consistent data gathering and analysis procedures and to ensure that data is gathered from trustworthy sources to overcome these challenges. Involving specialists in the LCA process ensures that the analysis is carried out correctly and that the outcomes are reliable. Finally, to ensure that the study's findings are correctly interpreted, it is critical to be transparent about the constraints and presumptions used in the LCA analysis.

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تطبيق منهج تقييم دورة الحياة على دراسة حالة مع تقييم التأثيرات البيئية للمواد العازلة

أحمد عبد المنطلب محمد علي

أستاذ مشارك بقسم العمارة، كلية العمارة والتخطيط، جامعة القصيم، القصيم 52571، المملكة العربية السعودية
البريد الالكتروني: *ahm.ali@qu.edu.sa*، رقم الهاتف +966532490093

أستاذ مساعد بقسم الهندسة المعمارية، كلية الهندسة، جامعة أسيوط، أسيوط 71515، مصر
البريد الالكتروني: *ahmed.abdelmonteleb@aun.edu.eg*، رقم الهاتف+201005490811

الملخص

تعتبر المواد العازلة ضرورية لتقليل استخدام الطاقة، وتعزيز الراحة الحرارية، وتقليل انبعاثات الغازات الدفيئة في المباني. ومع ذلك، قد يكون لقطاع المواد العازلة تأثير بيئي كبير. لقد تناولت العديد من الأبحاث العلمية السابقة واالدراسات مواد العزل وسمكها من منظور كفاءة الطاقة والأداء الحراري داخل المباني، بغض النظر عن التأثيرات البيئية لصناعة المواد العازلة. ولذلك فإن مشكلة البحث في هذا المقال هي ملاحظة الأعباء البيئية لصناعة المواد العازلة. لذا فإن المنهجية العلمية المستخدمة في البحث هي منهجية تقييم دورة الحياة (LCA) بناءً على معايير سلسلة ISO14040.

باستخدام نهج LCA يقارن البحث التأثير البيئي لأربعة مواد عازلة مستخدمة على نطاق واسع: البوليسترين المبثوق، والبوليسترين الممدد، والصوف الصخري، والصوف الزجاجي (polystyrene, expanded polystyrene, rock wool, and glass wool). دون النظر في مراحل الاستخدام والتخلص من نهاية العمر (end-of-life disposal stages) (حدود النظام لهذه الدراسة)، بتقييم المواد العازلة من المهد إلى البوابة (cradle to gate)، بما في ذلك استخراج المواد الخام والإنتاج والنقل. كذلك تقوم الدراسة بتحليل مشروع ابني بيتك بمدينة أسيوط الجديدة كدراسة حالة لتطبيق تحليل دورة الحياة لسيناريو المواد العازلة.

وفقًا لنتائج الدراسة، فإن البوليسترين المبثوق والصوف الصخري والصوف الزجاجي له أقل التأثيرات، في حين أن البوليسترين الممدد هو الأكثر ضررًا. وفيما يتعلق بنتيجة نقطة المنتصف (midpoint result)، فقد سجل XPS 4.35 $kgCO_2eq$، وكانت نتيجة EPS تشير إلى 96 $kgCO_2eq$ أما بالنسبة لنتيجة نقطة النهاية (midpoint result)، فقد سجلت المادة العازلة XPS أعلى تأثير سلبي مقارنة بالمواد الأخرى بمقدار 1.61 mt. وجاء في المرتبة الثانية الصوف الصخري بمقدار 1.24 mt ، ثم الصوف الصخري بمقدار 0.55 mt، وأخيراً الصوف الزجاجي بمقدار 0.33 mt.

تشير النتائج إلى أن التأثير البيئي للمبنى على مدار عمره يمكن أن يتأثر بشكل كبير بالمواد المستخدمة للعزل. يمكن أن تساعد نتائج الدراسة المهندسين المعماريين والمهندسين ومحترفي البناء في اختيار أفضل عزل للمباني الموفرة للطاقة. من المهم جدًا أخذ منهج LCA بعين الاعتبار في جميع المواد المصنعة. وبالتالي، يجب على قطاع الصناعة وأصحاب المصلحة مراعاة المخاوف البيئية إلى جانب كفاءة استخدام الطاقة عند اختيار المواد العازلة لمشاريع البناء.

الكلمات المفتاحية

تقييم تأثير دورة الحياة، نمذجة معلومات البناء (BIM)، المواد العازلة، مدينة أسيوط الجديدة