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Environmental life cycle assessment of rockwool filled aluminum sandwich facade panels in Turkey

Emrah Yılmaz *, Batuhan Aykanat, Bekir Çomak

Düzce University, Faculty of Engineering, Department of Civil Engineering, 81600, Düzce, Turkey

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ABSTRACT

As composite materials combine multiple outstanding characteristics together such as lightweight, high resistance and durability, their consumption in the industry has been growing rapidly. This consumption causes environmental concerns due to raw material, energy and natural resource requirements through entire life cycle of composite materials in stages such as production, transportation, usage and disposal. Thus, assessment of environmental impact of composite materials gains more importance. This study provides a comprehensive life cycle inventory (LCI) data for the production process of 50 mm, 60 mm and 80 mm thick rockwool filled aluminum sandwich (RWFAS) facade panels. Environmental impacts of RWFAS panels from cradle to gate (optional) have been calculated by SimaPro software in accordance with ISO14040 and ISO14044 standards by life cycle assessment (LCA) method. As a result of the study, it was found that the most important environmental impacts have been caused by the production stage, and most of these impacts have been due to the use of aluminum sheet in the production process. When all panels were compared, it was determined that 80 mm thick RWFAS panel had the highest values in all environmental impact categories when compared with other sandwich panels.

1. Introduction

The increasing energy supply shortage require taking measures in the construction sector as well as in every other field. Every year, construction activities cover 40% of the energy consumed globally. About 80% of the energy consumed in buildings is used for heating purposes. Therefore, a great deal of energy can be saved, especially by making thermal insulation [1,2].

In Turkey, 17.5 million m^3 per year of thermal insulation products are used. 90% of this is used for the insulation of the buildings and the rest for the insulation of the installations. Insulation panels containing rock wool, glass wool, EPS, XPS and PUR/PIR are produced in Turkey in accordance with the TS EN 14509 standard [3]. In addition, as looking at the leading manufacturers of the sector, it is seen that all of them have increased their stone wool and XPS capacities in recent years. Therefore, in the future, it is predicted that the rock wool insulation material will further reduce the usage rates of other insulation materials. It is seen that the usage rate of rock wool insulation material in Turkey is higher than the usage rate in Europe (Fig. 1) [4].

In recent years, instead of conventional materials, researchers are interested in (composite) materials which combine multiple characteristics together and find place in innovative and practical application areas. Composite materials are new materials of interest with outstanding characteristics which are obtained as a result of the combination of characteristics of different materials [5,6]. Use of

* Corresponding author.
E-mail address: emrahyilmaz@duzce.edu.tr (E. Yılmaz).

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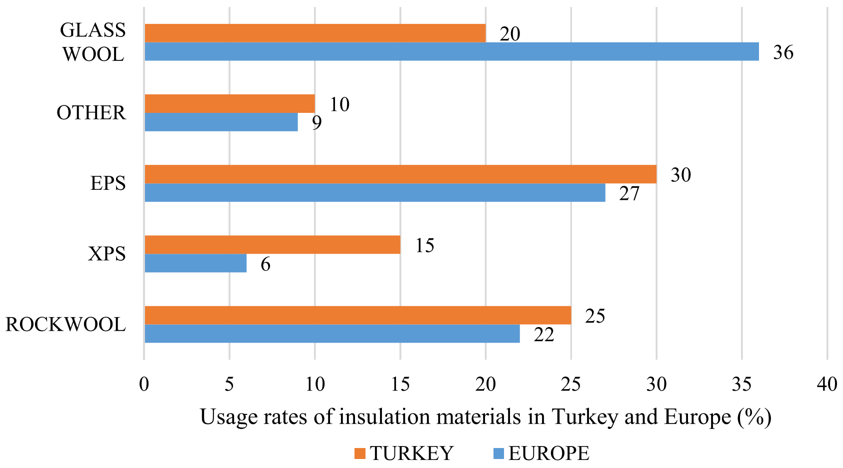

Fig. 1. Usage rates of insulation materials in Turkey and Europe.

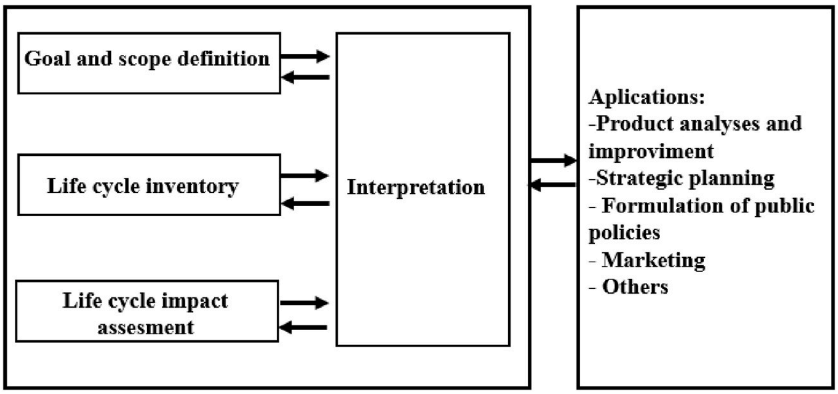

Fig. 2. LCA stages.

composite materials as well as conventional materials becomes widespread due to their advantageous characteristics such as light-weight, high resistance, durability, output elasticity, cost and low heat conduction [7,8]. When composite materials are classified according to their compositions, they are placed in two main groups as composites with phases (i. filled composites, ii. reinforced composites) and layered composites (i. laminates, ii. sandwich structures) [9]. Sandwich structures are multi-layered composite materials that were designed and produced to establish a balance between the need for having a light-weight and resistance for life-time loading conditions that were required in Britain and United States during the IInd World War [10]. The coatings of sandwich structures, which are generally composed of a low density core and two hard coatings, are thinner than the core and core thickness is rarely more than 50 mm in typical applications [11]. Today, such a relationship of light-weight and high resistance continues to exist as a requirement in several industries and demand for such materials increase in time. Sandwich structures find many different application areas in aviation, automobile, railway industries, maritime engineering, wind-energy systems, biomedical fields and construction industry [11,12].

Construction industry has the highest energy consumption and consumes more than one third of the entire energy produced throughout the world. Most of this consumption happens during the transformation of raw materials into construction materials, and this causes about 50% of global CO_2 emissions [13]. The concept of sustainability becomes popular as environment-friendly, new, alternative materials are produced and new strategies of production are investigated in order to decrease the impacts that cause environmental pollution produced during the production of construction materials [5]. These innovative approaches pave the way for the efficient use of energy for construction industry and construction of environment-friendly buildings.

One of the scientific methods to assess the environmental impact of these constructions from material production stage to construction and user stages or from disposal treatment stage to their end-of life stage is Life Cycle Assessment (LCA) method [14]. LCA can be used effectively in the construction industry to investigate and decrease the environmental impacts that occur in entire life cycle of buildings [15].

LCA is a method used to assess the potential environmental impacts and resources of the entire process throughout the life cycle from raw material supply, production and usage stages to waste management [16,17]. LCA, which is an approach to compare the environmental impacts of materials, is also a standardized method to provide a sound scientific base for environmental sustainability

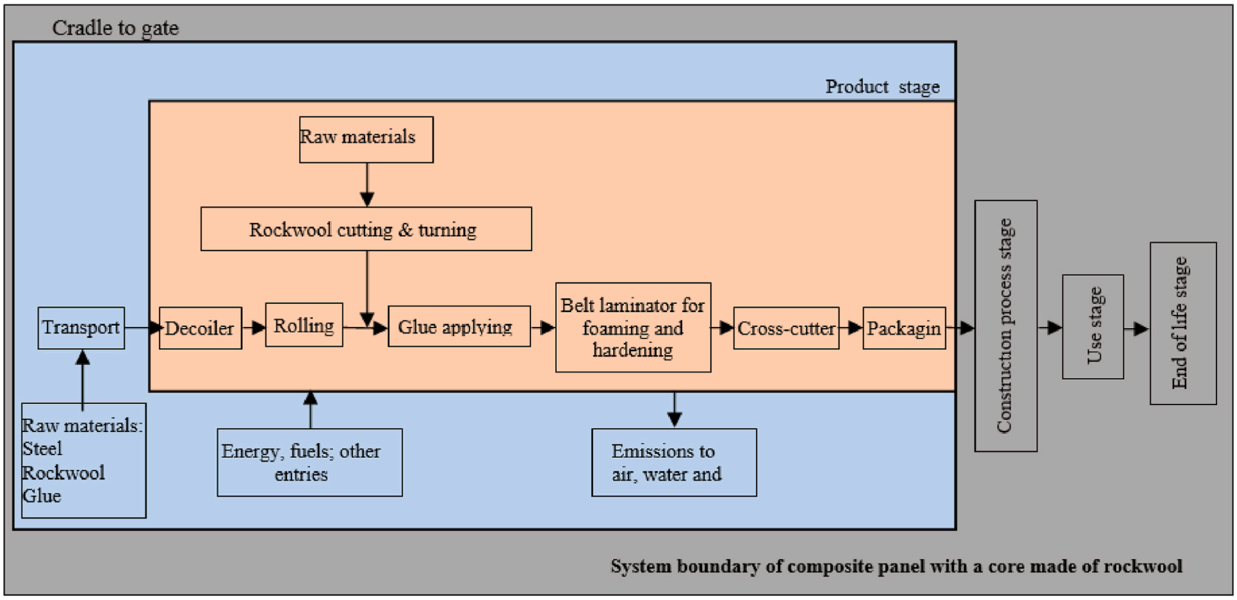

Fig. 3. System boundaries including the production stage from cradle to gate for the proposed study.

[14]. Also, it can be used for assessment of environmental impacts of composite materials related with recyclability [18].

In this study, aluminum and rockwool containing composite facade panels were compared by demonstrating their environmental impacts from cradle to gate (optional) with tangible data. Data of the rockwool filled aluminum sandwich (RWFAS) facade panels for which the life cycle analyses would be performed within the scope of the study are obtained from a leading production site in panel production in Turkey.

2. Life cycle assessment (LCA)

By this method, in every stage of life cycle from cradle to grave, environmental impacts including those resulting from production, transportation, use of consumer and disposal of wastes after usage are analyzed in detail [19,20]. LCA is composed of four stages as follows: a) Goal and Scope Definition, b) Inventory Analysis, c) Impact Assessment and d) Interpretation of Life Cycle [17] (Fig. 2).

At first, the researcher establishes the goal, boundaries and restrictions of the study. The main goal gives information about functional unit, system boundaries, data categories, data quality descriptions, assumptions and restrictions, critical revisions, and type and format of the report needed for the study [17]. Inventory Analysis is the second stage of LCA. It includes collection of data and calculation methods. As these data would comprise a basis for the study, this is accepted as the most important and time-consuming stage. It is also associated with determination of scope stage as it includes collection of data [17,21,22]. In such cases, data collection technique or method for determination of goal and scope of the study might be changed [23]. Life cycle impact assessment methods aim to transform each collected data to a corresponding environmental impact [24,25]. Last stage of LCA is an interpretation which aims to analyze the results and reach a conclusion by describing the boundaries and giving recommendations. These recommendations are based on the results of previous stages of the study [21].

3. LCA of rockwool composite facade wall panels

In this study, life cycle assessment (LCA) methodology was applied for calculation of environmental impacts as described in ISO14040 standards [17] series. SimaPro 9.1 software was used accordingly for modelling inventory data related with sandwich panels. Environmental impacts were calculated using the CML-IA baseline method.

3.1. *Defining the goal and scope*

The aim of the study is to determine the environmental impacts of rockwool filled aluminum sandwich facade panels with different thicknesses (50 mm, 60 mm and 80 mm) and also to compare the environmental impact of sandwich panels with different thicknesses. In this study, the functional unit is defined as “1 m^2 sandwich panel with insulation”.

3.2. *System description*

The study describes a section of the life cycle which is from cradle to gate (optional) and considers the objectified environmental impacts. For each panel systems with different thicknesses, it contains system boundaries, raw material supply, production and disposal of sandwich panels. As system boundaries include the definition of unit processes and entry-exit sections, system boundaries of rockwool filled aluminum sandwich panels are given in detail in Fig. 3.

Table 1
LCI of rockwool filled aluminum sandwich panels.

1 m^2 Rockwool Filled Aluminum Sandwich Panel			
Materials	50 mm	60 mm	80 mm
Aluminum sheet *(g)*	3128	3128	3128
Rockwool *(g)*	4900	5900	7900
Isocyanate/Glue *(g)*	294.6	294.6	294.6
Polyol/Glue *(g)*	263	263	263
Film coating *(g)*	7.5	7.5	7.5
Side band *(m)*	2	2	2
Packaging foil *(g)*	13.5	13.5	13.5
Paint *(g)*	35	35	35
Electricity consumption (kWh)	0,89	0,89	0,89

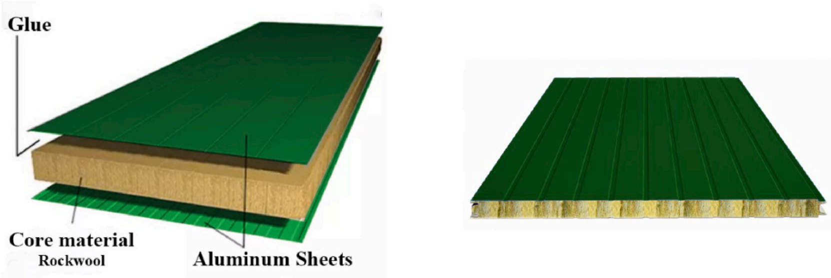

Fig. 4. Rockwool filled aluminum sandwich panel.

In the disposal scenario stage, it was assumed that 70% of the panels that have completed their lifespan will be subject to separation process and 30% will be sent to the solid waste landfill. It has been accepted that 89% of the galvanized sheet, which is one of the raw materials in the panels to be decomposed, is collected for recycling, 10% is reused, and the remaining 1% is stored in solid waste landfills, as modeled in the LCA study. In addition, the distance to the area to be sent for disposal of the panels that have completed their useful life is determined as 100 km on average [26].

3.3. *Life cycle inventory (LCI) analysis*

LCI data for rockwool filled aluminum sandwich (RWFAS) panels are provided by face to face meetings with related company experts, expert recommendations and observations. Table 1 gives information about the raw materials and their amounts used for 50 mm, 60 mm, and 80 mm thick 1 m^2 RWFAS panel production. Images of RWFAS are given in Fig. 4.

4. Results and discussion

In line with the findings obtained with the inventory analysis for RWFAS panels (50 mm, 60 mm and 80 mm thick), SimaPro software was used and life cycle impact assessment was performed. As a result of the assessment, by using a 100 years-old basic model of IPCC (IPCC 2013) [27], the impacts of 50 mm, 60 mm and 80 mm thick RWFAS panels on climate change are given in Fig. 5, Fig. 6 and Fig. 7, respectively.

In Fig. 5, it can be seen that for 50 mm thick RWFAS panel, during its life cycle from cradle to gate (optional), 92.2% of the climate change impacts have been due to the production stage, while 7.8% of them have been due to the disposal stage. Main contributions of production stage can be listed as follows; aluminum sheet (77.4%), rockwool (9.51%), glues (4.25%), power (0.82%), and packaging (0.22%).

In Fig. 6, it can be seen that for 60 mm thick RWFAS panel, during its life cycle from cradle to gate (optional), 92.9% of the climate change impacts have been due to the production stage, while 7.1% of them have been due to the disposal stage. Main contributions of production stage can be listed as follows; aluminum sheet (76.4%), rockwool (11.3%), glues (4.19%), power (0.8%), and packaging (0.21%).

In Fig. 7, it can be seen that for 80 mm thick RWFAS panel, during its life cycle from cradle to gate (optional), 91.5% of the climate change impacts have been due to the production stage, while 8.5% of them have been due to the disposal stage. Main contributions of production stage can be listed as follows; aluminum sheet (72.3%), rockwool (14.3%), glues (3.96%), power (0.75%), and packaging (0.19%).

As a result of the assessment, characterization results for production stage and end-of-life disposal stage are given in Table 2 and Fig. 8. Characterization results of 1m2 RWFAS panels are compared in Fig. 8.

In Table 2; ADP:Abiotic depletion potential (from fossil sources), ADPF: Abiotic depletion potential (from non-fossil sources), GWP: Global warming potential, ODP: Ozone depletion potential, HTP: Human toxicity potential, FAETP: Freshwater aquatic ecotoxicity potential, MAETP: Marine aquatic ecotoxicity potential, TETP: Terrestrial ecotoxicity potential, POCP: Photo-oxidant creation

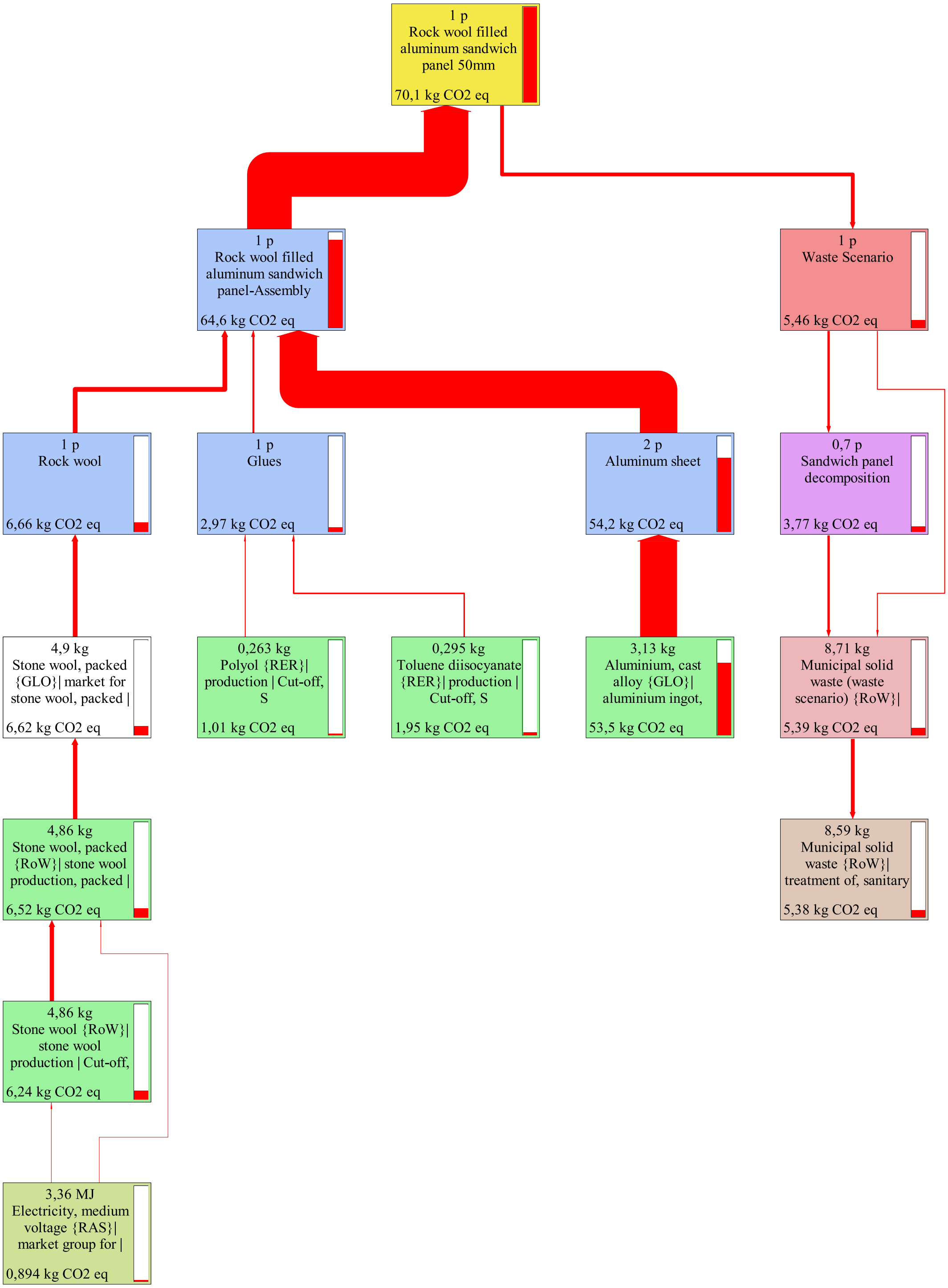

Fig. 5. Impacts of 50 mm thick RWFAS panels on climate change.

potential, AP: Acidification potential, EP: Stated as Eutrophication potential.

In Table 2 and Fig. 8, it can be seen that in all RWFAS panels the impact categories in production stage had more environmental impact than the impact categories in disposal stage.

The environmental impacts of RWFAS (50 mm, 60 mm and 80 mm) panels due to the production stage have been found as follows: FEATP 74.5%, 76.1% and 72.2%, respectively, EP; 80.7%, 82.3% and 79.6%, respectively, TETP; 90.9%, 91.6% and 90%, respectively, GWP; 92.1%, 92.8% and 91.5%, respectively. The ratio of impacts due to disposal stage have been found as follows: FEATP 25.5%,

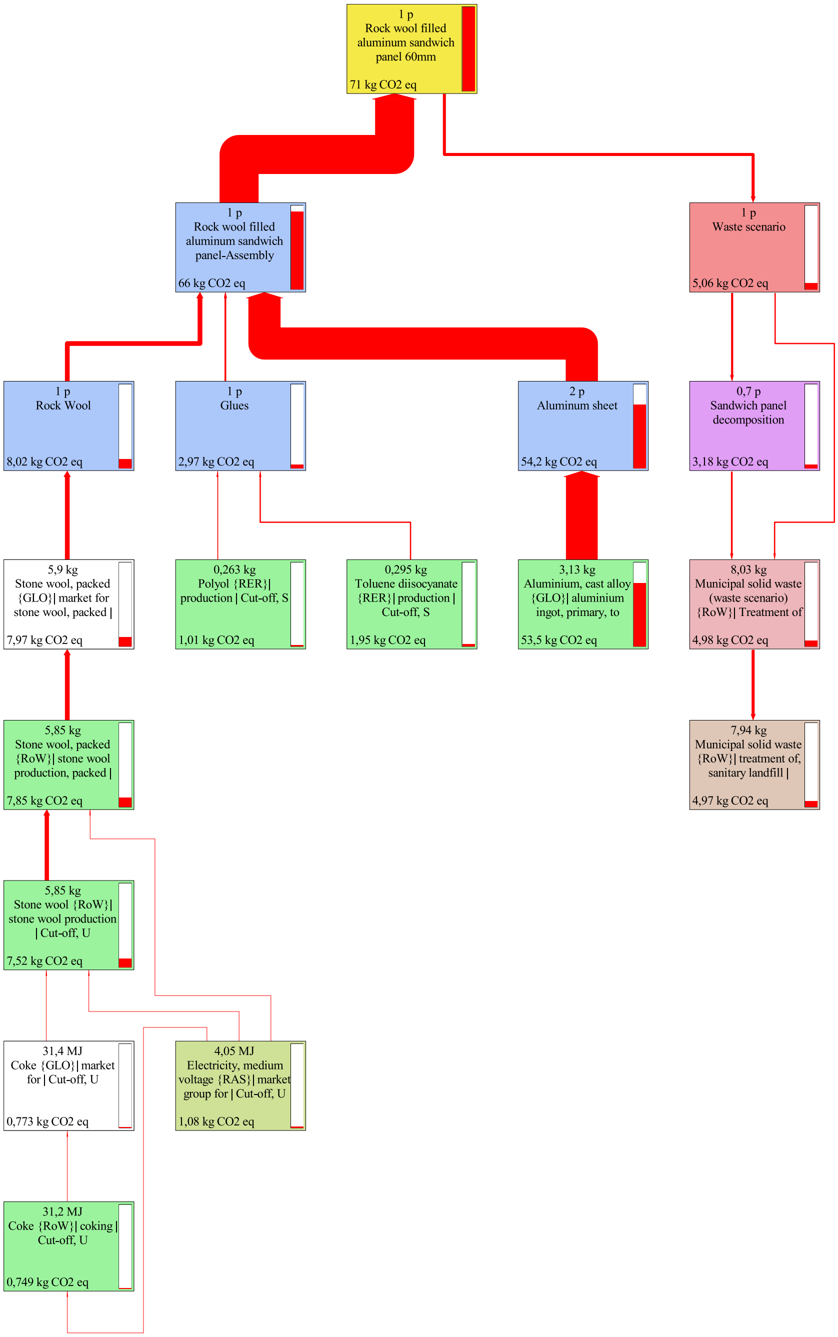

Fig. 6. Impacts of 60 mm thick RWFAS panels on climate change.

23.9% and 27.8%, EP, respectively; 19.3%, 17.7% and 20.4%, respectively, TETP; 9.1%, 8.4% and 10%,respectively, GWP; 7.9%, 7.7% and 8.5%, respectively (Table 2).

In Fig. 8, it can be seen that 80 mm thick RWFAS panel had the highest values in all environmental impact categories when compared with other sandwich panels. That is because that the rockwool amount needed for the production of this panel is more than that of other panels.

The construction sector is responsible for the consumption of approximately 40% of the world's energy and materials, 17% of water resources and the formation of approximately 50% of greenhouse gas emissions [28–31]. Therefore, the ADP, GWP and FATEP impact categories are considered to be more important than the other impact categories.

Normalization results at production stage and end-of-life stage are given in Table 3 and Fig. 9. Normalization results of 1 m^2 RWFAS panels are compared in Fig. 9.

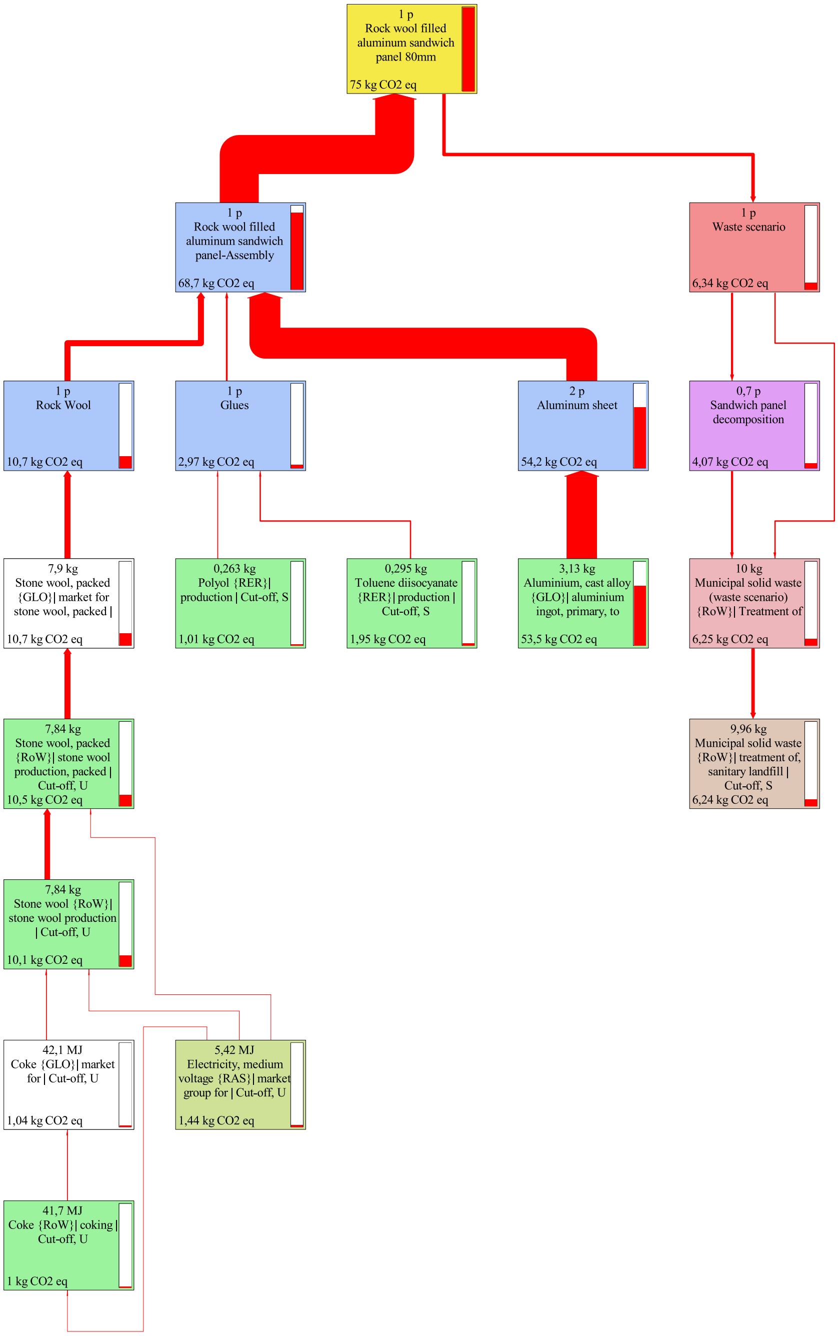

Fig. 7. Impacts of 80 mm thick RWFAS panels on climate change.

Each impact category is expressed in different units. Therefore, normalization is performed in order to make all these environmental impacts dimensionless and to be able to make a comparison. By normalization, it would be possible to compare the environmental impacts as all categories were made dimensionless.

As seen in Fig. 9, the most environmentally effective categories were MAETP, FAETP, ADPF, GWP followed by AP, EP and HTP. It can be seen that 50 mm, 60 mm and 80 mm thick RWFAS panels had about the same level of POCP, TETP and ADP category impacts.

In Fig. 9 and Table 3, it can be seen that for 50 mm, 60 mm and 80 mm thick RWFAS panels, all impact categories in production stage had more environmental impacts than the disposal stage.

Panels with the highest impact in respect of MEATP can be listed as 50 mm, 60 mm and 80 mm thick panels, respectively. When analyzed in respect of FAETP, it was observed that 80 mm RWFAS panel had the highest impact, while 50 mm RWFAS panel had the lowest impact; when analyzed in respect of EP, AP, ADPF and GWP, it was observed that 80 mm RWFAS panel had the highest impact.

Table 2
Comparison of characterization results of 1 m^2 RWFAS panels.

Impact Category	Unit	50 mm RWFAS Panel			60 mm RWFAS Panel			80 mm RWFAS Panel		
		Production Stage	Disposal Stage	Total	Production Stage	Disposal Stage	Total	Production Stage	Disposal Stage	Total
ADP	kg Sb eq	0.000169	3.17E-7	0.00017	0.00017	3.2E-07	0.000172	0.00018	3.96E-7	0.000180
ADPF	MJ eq.	620.8040	4.11	624.914	636.473	4.0189	640.4919	667.8103	4.9930	672.8033
GWP	kg CO2 eq.	64.4905	5.5	69.9905	65.8478	5.1010	70.9488	68.56234	6.3909	74.95324
ODP	kg CFC-11 eq.	20.06E-6	4.19E-8	2.1E-6	2.1E06	4.1E-08	2.18E-6	2.31E-6	5.14E-8	2.36E-6
HTP	kg DCB eq.	36.4369	1.84	38.2796	37.3906	1.7053	39.0959	39.2979	2.1050	41.4029
FAETP	kg DCB eq.	50.0826	17.1	67.1826	50.4680	15.8278	66.2958	51.2316	19.7541	70.9857
MAETP	kg DCB eq.	1.75E5	8.63E3	1.84E5	1.76E5	7.95E3	1.84E5	1.79E5	9.88E3	1.89E5
TETP	kg DCB eq.	0.1236	0.0124	0.1360	0.1252	0.0114	0.1366	0.1285	0.0143	0.1428
POCP	kg C_2H_4 eq.	0.0234	0.00118	0.02458	0.0240	0.0010	0.025	0.0252	0.0013	0.0265
AP	kg SO_2 eq.	0.3681	0.0156	0.3837	0.3780	0.0015	0.3795	0.3980	0.0018	0.3998
EP	kg PO_4 eq.	0.0946	0.0226	0.1172	0.096	0.0207	0.1167	0.1013	0.0259	0.1272

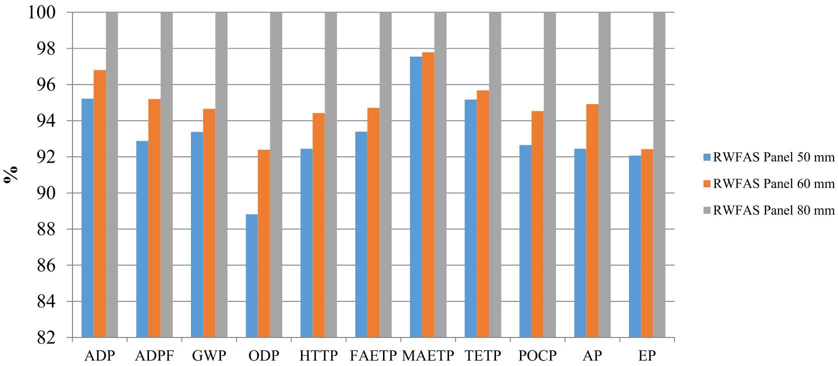

Fig. 8. Comparison of characterization results of 1 m^2 RWFAS panels.

Also, when examined in respect of HTP, POCP, ADP and ODP, it was determined that 50 mm RWFAS panel had the lowest impact.

5. Conclusion

LCA methodology was used in this study to assess and compare environmental performances of RWFAS panels with different thicknesses from cradle to gate (optional) and determine their hotspots. Technology used in the productive process is consistent with the state-of-the-art for RWFAS panel's manufacturing at a global level. This paper provides a high-quality comprehensive LCI data of sandwich panel production process, and the dataset can be used in other LCA studies on the topic.

When environmental impacts of RWFAS panel is analyzed by LCA method from cradle to gate (optional), the most important impacts were found to be due to the production stage. As aluminum production is a process that consumes many resources and energy, the main contribution to environmental impact of RWFAS panel production process has been provided by the use of aluminum sheet.

When all panels were assessed together, it was determined that 80 mm thick RWFAS panel had the highest values in all environmental impact categories when compared with other sandwich panels. The most environmentally effective categories of these panels have been determined to be MAETP, FAETP, ADPF and GWP, respectively. The use of renewable energy sources in panel production can reduce the environmental impacts mentioned above.

In conclusion, the environmental impacts of sandwich panels with different thicknesses produced with different insulation materials should also be determined. Because these panels are the fundamental construction materials to produce several different constructions and they have a widespread usage, they cause environmental impacts. To decrease these impacts, environmental impacts of alternative sandwich panels can be investigated and environment-friendly panels with the minimum impact can be used.

Table 3
Comparison of RWFAS panels in terms of life cycle stages.

Impact Category	50 mm RWFAS Panel			60 mm RWFAS Panel			80 mm RWFAS Panel		
	Production Stage	Disposal Stage	Total	Production Stage	Disposal Stage	Total	Production Stage	Disposal Stage	Total
ADP	2.00E-12	3.75E-15	2.00E-12	2.03E-12	3.78E-15	2.03E-12	2.10E-12	4.68E-15	2.10E-12
ADPF	1.97E-11	1.31E-13	1.99E-11	2.02E-11	1.28E-13	2.04E-11	2.12E-11	1.59E-13	2.14E-11
GWP	1.28E-11	1.09E-12	1.39E-11	1.31E-11	1.02E-12	1.41E-11	1.36E-11	1.27E-12	1.49E-11
ODP	2.30E-14	4.69E-16	2.35E-14	2.40E-14	4.64E-16	2.45E-14	2.59E-14	5.76E-16	2.65E-14
HTP	4.70E-12	2.37E-13	4.94E-12	4.82E-12	2.20E-13	5.04E-12	5.07E-12	2.72E-13	5.34E-12
FAETP	9.67E-11	3.31E-11	1.30E-10	9.74E-11	3.05E-11	1.28E-10	9.89E-11	3.81E-11	1.37E-10
MAETP	1.50E-09	7.40E-11	1.58E-09	1.51E-09	6.82E-11	1.58E-09	1.53E-09	8.47E-11	1.62E-09
TETP	2.55E-12	2.55E-13	2.80E-12	2.58E-12	2.36E-13	2.82E-12	2.65E-12	2.95E-13	2.94E-12
POCP	2.77E-12	1.39E-13	2.91E-12	2.84E-12	1.29E-13	2.97E-12	2.98E-12	1.62E-13	3.14E-12
AP	1.31E-11	5.55E-14	1.31E-11	1.34E-11	5.32E-14	1.35E-11	1.41E-11	6.63E-14	1.42E-11
EP	7.17E-12	1.71E-12	8.88E-12	7.34E-12	1.58E-12	8.92E-12	7.68E-12	1.97E-12	9.65E-12

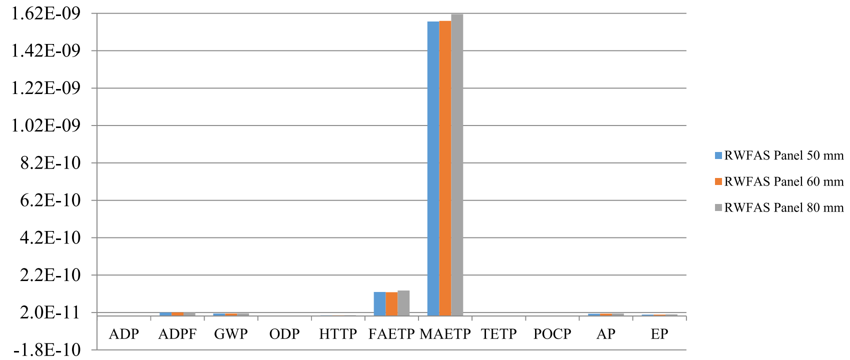

Fig. 9. Comparison of normalization results of 1 m^2 RWFAS panels.

Authorship contributions

Conception and design of study: E. Yılmaz, B. Aykanat, B. Çomak; acquisition of data: E. Yılmaz; analysis and/or interpretation of data: B. Çomak, B. Aykanat,E. Yılmaz. Drafting the manuscript. B. Aykanat, E. Yılmaz, B. Çomak; revising the manuscript critically for important intellectual content: B. Aykanat, E. Yılmaz, B. Çomak. Approval of the version of the manuscript to be published (the names of all authors must be listed):E. Yılmaz, B. Aykanat, B. Çomak.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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