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Research Article

Environmental Sustainability Assessment of Cold Storage Panel Production

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ABSTRACT

Today's ever-increasing environmental sustainability concerns have led to a major shift in construction sites and industrial sectors. In this context, the choice of construction materials for important structures such as cold storages plays an important role in terms of both environmental impacts and energy efficiency. The aim of this study is to evaluate the environmental loads of cold storage panels with thicknesses of 80 mm, 100 mm, 120 mm, 150 mm, 180 mm and 200 mm. In order to reveal the production inputs that cause these loads, the environmental effects were examined specifically for the 100 mm thick cold storage panel. Environmental impacts were analyzed using the Life Cycle Assessment (LCA) method in accordance with the ISO 14040/44 methodology as a system boundary "cradle to gate". This study focused on three different environmental impact categories of cold storage panels produced in Türkiye: global warming potential (GWP), cumulative energy demand (CED) and water footprint. In the evaluation of environmental impacts, production inventory information obtained from the panel manufacturer was used. For analyses, Simapro v. 8.5 LCA software was used. Analysis results show that the carbon footprint of a 100 mm thick cold storage panel is 46.1 Kg CO_2eq., and its water footprint is 27.1 m^3. Additionally, the use of galvanized sheet metal in cold storage panel production is a hot spot in terms of global warming effect. It has been determined that the largest share in the water footprint belongs to polyurethane used as insulation material. Additionally, according to the CED, non-renewable fossil and non-renewable nuclear were determined to be the most affected categories, and the use of galvanized sheet metal and polyurethane were determined to be the most important hot spots in terms of non-renewable and renewable resources. To help improve the environmental performance of the cold storage panel, it is recommended to use bio-based and less environmentally impactful raw materials in production and to measure their environmental impact on a life cycle basis from cradle to grave.

Keywords: *Life cycle assessment, Cold storage panel, Global warming, Water footprint, Environmental sustainability*

Soğuk Hava Deposu Paneli Üretiminin Çevresel Sürdürülebilirlik Değerlendirmesi

ÖZET

Günümüzün giderek artan çevresel sürdürülebilirlik endişeleri, inşaat alanlarında ve endüstriyel sektörlerde büyük bir değişime yol açmıştır. Bu bağlamda, soğuk hava depoları gibi önemli yapılar için

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inşaat malzemeleri seçimi hem çevresel etkiler hem de enerji verimliliği açısından önemli bir rol oynamaktadır. Bu çalışmanın amacı, 80 mm, 100 mm, 120 mm, 150 mm, 180 mm ve 200 mm kalınlıklardaki soğuk hava deposu panellerinin çevresel yüklerini değerlendirmektir. Bu yüklere ana katkıyı sağlayan üretim girdilerinin ortaya konması için 100 mm kalınlığına sahip soğuk hava deposu paneli özelinde çevresel etkiler irdelenmiştir. Çevresel etkiler, Yaşam Döngüsü Değerlendirmesi (LCA) yöntemi ile ISO 14040/44 metodolojisine uygun olarak sistem sınırı "beşikten kapıya" şeklinde analiz edilmiştir. Bu çalışma, Türkiye'de üretilen soğuk hava deposu panellerinin küresel ısınma potansiyeli (GWP), kümülatif enerji talebi (CED) ve su ayak izi olmak üzere üç farklı çevresel etki kategorilerine odaklanmıştır. Çevresel etkilerin değerlendirilmesinde panel üreticisi firmadan temin edilen üretim envanteri bilgilerinden faydalanılmıştır. Analizler için Simapro v. 8.5 LCA yazılımı kullanılmıştır. Analiz sonuçları, 100 mm kalınlığındaki bir soğuk hava deposu panelinin karbon ayak izinin 46,1 Kg CO_2 eşd., su ayak izinin ise 27,1 m^3 olduğunu göstermektedir. Soğuk hava deposu panel üretiminde galvaniz sac kullanımının küresel ısınma etkisi açısından sıcak nokta olduğunu göstermektedir. Su ayak izinde en büyük payın yalıtım malzemesi olarak kullanılan poliüretana ait olduğu tespit edilmiştir. Ayrıca CED'e göre yenilenemeyen biyokütle ve yenilenemeyen nükleerin en çok etkilenen kategoriler olduğu, galvaniz sac ve poliüretan kullanımı yenilenemeyen ve yenilenebilir kaynaklar açısından en önemli sıcak noktalar olduğu belirlendi. Soğuk hava deposu panelinin çevresel performansının iyileştirilmesine yardımcı olmak için üretimde biyo bazlı ve daha az çevresel etkiye sahip hammaddelerin kullanılması ve bunların çevresel etkilerinin yaşam döngüsü temelinde beşikten mezara ölçülmesi tavsiye edilir.

Anahtar Kelimeler: *Yaşam döngüsü değerlendirmesi, Soğuk hava deposu paneli, Küresel ısınma, Su ayak izi, Çevresel sürdürülebilirlik*

I. INTRODUCTION

Nowadays, the rapid increase in global population, rising living standards, industrialisation and urbanisation processes have increased energy consumption, making environmental sustainability concerns an important agenda item [1]. In this context, the implementation of energy efficiency and environmental sustainability principles has become an important goal in energy intensive sectors. Cold storages represent an important area that strongly influences energy consumption [2]. Cold storages are structures with cooling and heat insulation system for perishable food products such as fruits, vegetables, seafood and frozen foods. These structures play an important role in storing these food products under specially favourable conditions to prevent their spoilage throughout the year [3].

Sandwich panels of different thicknesses are used to provide thermal insulation of cold storages. These sandwich panels have a wide range of uses in cold storage where the temperature must be constant, in production facilities where the temperature must be high, in clean rooms where hygiene conditions must be high (electronic, health and nuclear facilities), in medicine and vaccine warehouses, in vehicles and containers used in cold chain transport [4–6].

These sandwich panels are composite materials produced by adding insulation materials such as expanded polystyrene (EPS), extruded polystyrene (XPS), rock wool (RW), polyurethane (PU) and polyisocyanurate (PIR) insulation foams between two galvanised and painted metal sheets to provide the best thermal insulation [7–10]. Sandwich panels have many features that make them applicable for different purposes such as ease of installation, low thermal conductivity coefficient, sound and moisture insulation, acoustic and noise control feature, energy saving and fire safety [11,12]. PU core sandwich composites are preferred as a widely used building material, especially in the construction of cold storages, due to their many advantages such as cost effectiveness, lightness, stability and energy efficiency [13]. With the effect of increasing global warming, cold storage areas will be needed more. Therefore, the cold storage industry is growing rapidly and the environmental impact of the materials used in this field is becoming more important.

Life cycle assessment (LCA) method is used to assess the environmental impacts of products/services in the most comprehensive way throughout their entire life cycle, from raw material procurement to waste disposal [14–17]. Today, the sustainability and environmental impacts of industrial and commercial activities are becoming increasingly important. In this context, the construction industry plays a critical role in assessing the environmental impact of building materials, especially cold storage panels.

In this study, three different environmental impact categories such as global warming potential (GWP), cumulative energy demand (CED) and water footprint of PU core sandwich panels of different thicknesses used in cold storage production were analysed and the main factors (hotspots) contributing to the impacts were identified.

II. MATERIALS AND METHODS

A. COLD STORAGE PANEL PRODUCTİON

The production process of cold storage panels starts with the application of sheet metal, membrane, ctp or pvc-like materials on the line with a decoiler. Then, to increase the adhesion of the insulation material, the surface tension is increased by electron bombardment using the corona unit. If forming is required, the desired pattern is applied to the material through rollers and the insulation filling material is added between the two layers. The layered material is pressed, polymerised at a certain temperature and then adhered. In addition, a male-female structure is formed with side moulds and the seating detail of the panel is formed. The product coming out of the press is completed and cut to the desired dimensions and taken to the cooling unit to lose its temperature. Finally, it is stacked in the desired quantities, packaged and made ready to be shipped to the end user.

PUR and PIR are used as insulation materials in cold storage panels consisting of painted galvanised sheet, stainless steel or PVC film laminated inner and outer surface layers. These panels, which have the flexibility of production in the desired length between 2 m and 12 m, can be produced between 80 mm and 200 mm in thickness, depending on the climatic conditions in which they will be used. As seen in Figure 1, the panel connection detail has a tight fitting detail to prevent thermal bridges.

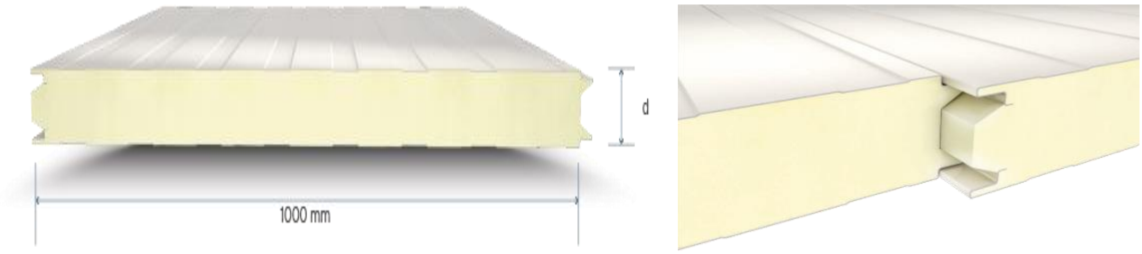

Figure 1. *PUR/PIR insulated cold storage panel [18]*

Table 1 shows that the heat permeability coefficient (U value) of PU and PIR insulated cold storage panels of different thicknesses, produced in accordance with the TS EN 14509 [19] standard, varies between 0,27- 0,11 W/m^{2}K depending on the panel thickness. According to TS EN 13501-1 [20], the flammability classes of cold storage panels are B-s2; d0 and B-s1; d0, respectively [18].

Table 1. Physical properties of PUR/PIR insulated cold storage panels [18]

Product	**Core Thickness** **d** mm	**Outer Sheet Thickness** $\mathbf{t_{No}}$ mm	**Inner Sheet Thickness** $\mathbf{t_{Ni}}$ mm	**Min. Length** **m**	**Max. Length** **m**	**Heat Transfer Coefficient** **U** W/m^2K	**Thermal Resistance** **R** W/m^2K
PU and PIR insulated cold storage panels	80		0,40	2	12	0,27	3,68
	100	0,50	0,45			0,22	4,61
	120	0,60	0,50			0,18	5,52
	150	0,70	0,60			0,15	6,88
	180	0,80	0,70			0,12	8,25
	200		0,80			0,11	9,16

A. 1. LCA Method

This study was carried out through life cycle assessment, which is widely used to determine the environmental impact of products/services. The following sections are structured according to the ISO 14040 framework [21], [22], [23], [24], [25], [26].

A.1.1. Goal and scope definition

The primary purpose of this research is to calculate the cradle-to-door environmental impacts of cold storage panels with different thicknesses produced and widely used in Türkiye, taking into account global warming potential, water footprint and cumulative energy demand, and to identify hot spots. This evaluation was made in line with the data obtained from a company with an annual sandwich panel production capacity of approximately 13.5 million m² in Türkiye. As a functional unit, 1 m^2 cold storage panel produced in Türkiye was selected. System limits for 1 m^2 cold storage panel production are shown in Figure 2.

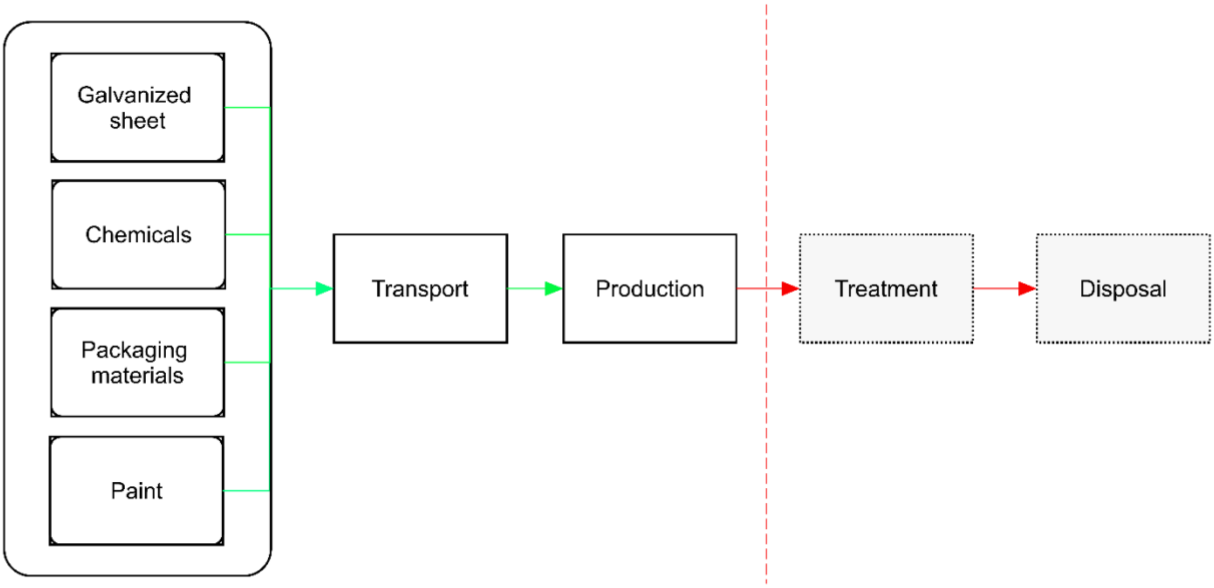

Figure 2. *System limits of cold storage panel production*

A.1.2. Life cycle inventory

Primary data such as the materials used in cold storage panel production, the quantities used per unit product, transportation distances, and energy consumption were obtained from the sandwich panel manufacturer in Türkiye in 2021 and the inventory summary is summarized in Table 2. Ecoinvent v. 3.5 database was used for background inventory data [27]. For the electricity used in cold storage panel production, the Turkish electricity grid mix was selected.

Table 2. *LCI data for panel production, functional unit - 1 m^2 cold storage panel*

Inputs	Unit	80 mm	100 mm	120 mm	150 mm	180 mm	200 mm
Lower and upper sheet weight	g	8320	8320	8320	8320	8320	8320
Polyol	g	1100	1360	1625	2020	2420	2685
Isocyanate	g	1860	2310	2760	3435	4110	4560
Catalyst	g	23	29	34	42	51	56
Additive	g	22	27	32	40	48	54
Pentane	g	55	68	81	101	120	134
Air	nl	1,5	1,5	1,5	1,5	1,5	1,5
Foil, tape, film (packaging)	g	50	50	50	50	50	50
Paint	g	50	50	50	50	50	50
Energy to produce	kWh	0,16	0,20	0,24	0,26	0,28	0,31
Transport, 3.5e7.5 t truck	kg.km	36,94	36,94	36,94	36,94	36,94	36,94
Transport, >32 t truck	kg.km	960	960	960	960	960	960

A.1.2. Life cycle impact assessment

Life Cycle Impact Assessment (LCIA) is a mandatory LCA step in which the potential environmental impacts of the product or process throughout its life cycle are measured within the scope of collected LCI data [28]. This study focused on three main environmental impact categories: global warming potential (GWP), water footprint and cumulative energy demand.

First used as a method to assess GWP was the IPCC 2013 approach, developed by the Intergovernmental Panel on Climate Change (IPCC), which includes the IPCC's climate change factors over a 100-year time horizon. [29]. Secondly, the Available WAter REmaining (AWARE, v1.02) method recommended by WULCA was preferred for LCIA water footprint. [30]. Finally, the LCIA was performed using the Cumulative Energy Demand 2018, v1.11 (CED) published by ecoinvent version 2.0 and based on the method extended by PRé Consultants [27].

III. RESULTS AND DİSCUSSİON

Environmental impact results of cold storage panels with different thicknesses obtained using IPCC 2013, CED and AWARE impact assessment methods are given in Table 3.

***Table 3.** Environmental effects of cold storage panels of different thicknesses.*

Impact category	**Unit**	**80 mm**	**100 mm**	**120 mm**	**150 mm**	**180 mm**	**200 mm**
GWP	kg CO_2eq	41.8	46.1	50.4	56.8	63.3	67.7
Water footprint	m^3	23.9	27.1	30.4	35.2	40	43.2
Cumulative Energy Demand (CED)							
Non renewable, fossil	MJ	607.4	686.9	766.9	886.5	1006.6	1086.7
Non-renewable, nuclear	MJ	49.0	59.1	69.2	84.3	99.5	109.6
Non-renewable, biomass	MJ	0.2	0.2	0.2	0.2	0.2	0.2
Renewable, biomass	MJ	9.1	11.1	13.1	16.0	19.0	20.9
Renewable, wind, solar, geothe	MJ	9.0	9.6	10.2	11.1	12.0	12.6
Renewable, water	MJ	14.4	16.3	18.3	21.2	24.1	26.1
Total		689.1	783.3	877.9	1019.3	1161.5	1256.2

When Table 3 is examined, it is seen that as panel thicknesses increase, global warming potential (GWP), cumulative energy demand and water footprint also increase. The main reason for this increase in the values in the environmental impact categories is thought to be due to the increase in the amount of raw materials used in production as panel thicknesses increase.

In this study, the global warming potential, water footprint and cumulative energy demand of the 100 mm thick cold storage panel, which is the most produced of these panels, are discussed in Figure 3, Figure 4 and Figure 5 superlatively in order to have a clearer understanding of the production inputs that contribute to the total environmental impacts of panels with different thicknesses.

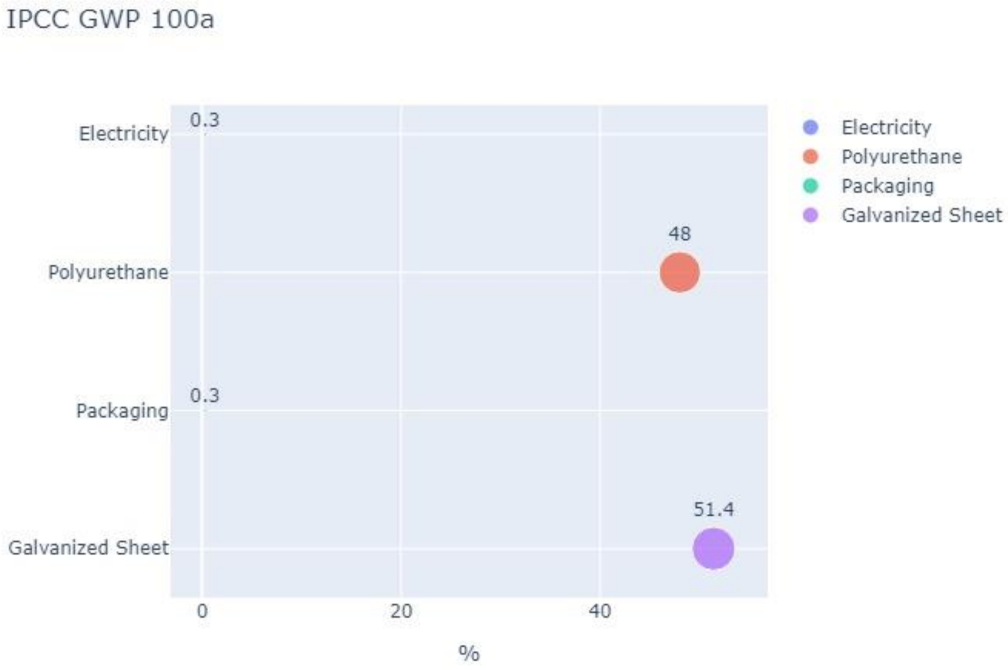

***Figure 3.** Global warming potential results (100 mm)*

The main contributors to the effects of production inputs of the 100 mm thick cold storage panel on the total global warming potential are shown in Figure 3. The total GWP of this panel is calculated as 46.1 kg CO_2eq. Galvanized sheet has the highest contribution rate at 51.4%, accounting for more than half of the total GWP. It is thought that the high additive rate of galvanized sheet is related to the use of energy-intensive technologies in production processes.

The use of polyurethane in the production of 100 mm thick cold storage panels provides the second highest contribution, contributing 48% to the total GWP of the panel, with 22.1 kg CO_2eq. It is seen that the electricity and packaging materials used in panel production make a low contribution of 0.3% to the total GWP.

The main contributors to CO_2 emissions account for 99.4 per cent of total emissions. For the cold storage panel, the main environmental impacts arise from the use of galvanized sheet and polyurethane, and this is followed by the electricity consumption required for packaging and panel production.

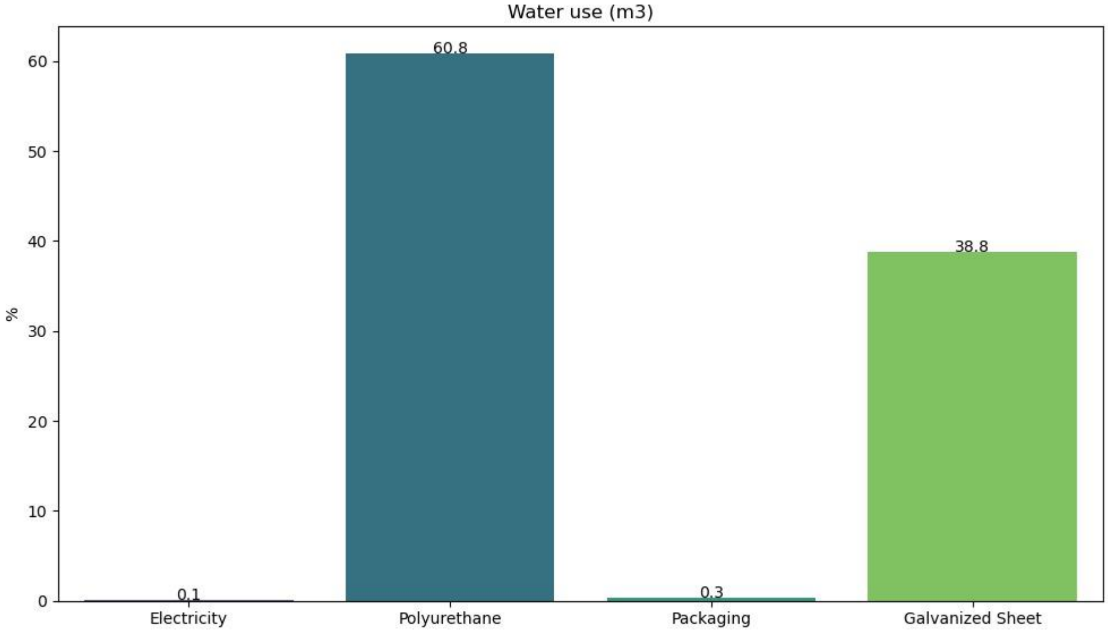

Figure 4. *Water footprint results (100 mm).*

Figure 4 shows the water footprint results according to the components of the 100 mm thick cold storage panel. The total water footprint of the 100 mm thick cold storage panel is calculated as 27.1 m^3. Polyurethane, used as an insulation material in the production of this panel, has the highest contribution rate to the water footprint (60.8%) with 16.5 m^3This suggests that polyurethane production has a significant impact in terms of water consumption.

It was determined that galvanized sheet metal contributed 38.8% to the total water footprint of the panel with 10.5 m^3. The contribution of the material used in packaging the panel and the energy required for production to the water footprint is 0.3% and 0.1%, respectively.

Figure 4 revealed that the main contributors to the water footprint were the use of polyurethane (60.8%) as an insulating material in cold storage panel production and the use of galvanized steel (38.8%) to form the outer shell of the panel. Electricity consumption (0.1%) and packaging (0.3%) contributed insignificantly to the total water footprint.

0.20 kWh of electricity is needed to produce a 100 mm thick cold storage panel (Table 2). Figure 5 shows the CED results of the production inputs of 100 mm thick cold storage panel production with polyurethane filling. The total cumulative energy demand of the 100 mm thick cold storage panel was determined as 783.3 MJ. By far the largest contributor to the total CED of the analysed panel is non-renewable fossil energy, followed by non-renewable nuclear energy (Figure 5).

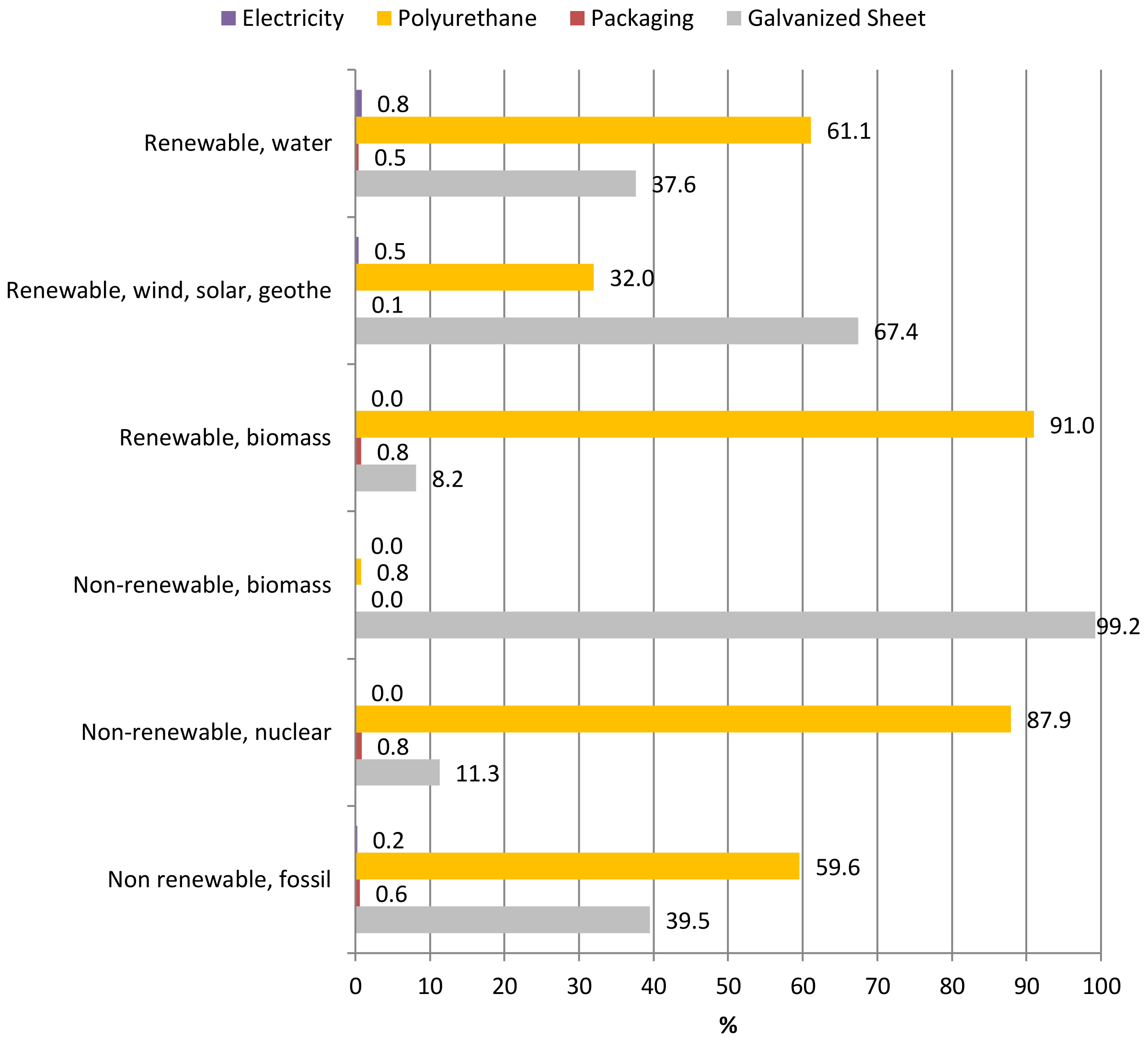

Figure 5. *Cumulative energy demand results of cold storage panel production inputs (100 mm).*

As shown in Figure 5, the use of polyurethane and galvanised sheet metal is the most effective in all effect categories in the production of 1 m^2 polyurethane insulated cold storage panel.

In particular, polyurethane (91%) and galvanised sheet metal (99.2%) are the main contributors to the renewable biomass and non-renewable biomass categories, respectively. The total renewable water impact from panel production is 16.3 MJ/m^3. As shown in Figure 5, this effect is due to the use of galvanised steel, polyurethane, electrical and packaging materials, which contribute 61.1%, 37.6%, 0.8% and 0.5% respectively.

Galvanised sheet is responsible for 67.4% and 99.2% of renewable, solar, wind, geothermal and non-renewable biomass energy from CED categories, respectively. As shown in Figure 5, polyurethane is estimated to be responsible for 61.1%, 91%, 87.9% and 59.6% of renewable water, renewable biomass, non-renewable nuclear and non-renewable fossil energy, respectively.

The high energy demand of galvanized sheet and polyurethane components, which are the materials used in the production of cold storage panels, emphasizes the importance of using renewable energy sources and energy efficient technologies in the production processes of these materials.

IV. CONCLUSION

In this study, the cradle-to-door environmental impacts of cold storage panels with thicknesses of 80 mm, 100 mm, 120 mm, 150 mm, 180 mm and 200 mm produced in Türkiye were analysed by LCA method. The quality and comprehensive life cycle inventory consists of primary data obtained directly from the company where the panel production is carried out. Environmental impacts of cold storage panels and significant environmental hotspots have been identified using IPCC 2013, AWARE and CED methods. In order to have a clearer understanding of the production inputs that make the main contribution to the total environmental impacts of these panels, the environmental impacts were examined specifically for the 100 mm thick cold storage panel.

LCA results showed that the environmental impacts caused by cold storage panel production are mainly due to the use of galvanized sheet and polyurethane, followed by a minor impact of electricity and packaging inputs.

In this study, it was revealed that the use of galvanized sheet metal, one of the production inputs of the cold storage panel, is an important factor in terms of the global warming effect. It has been observed that the polyurethane insulation material commonly used in the production of these panels has a significant impact on the water footprint.

Additionally, cumulative energy demand results identified non-renewable fossil and non-renewable nuclear energy as the most affected categories. In particular, the contributions of galvanized sheet and polyurethane to CED have been identified as important hotspots for non-renewable and renewable resources. CED results showed that galvanized sheet was mainly responsible for 3 of the non-renewable and renewable energy categories, and polyurethane was responsible for the other 3 categories.

This study makes a significant contribution to eliminating the lack of knowledge on the effects of polyurethane insulated cold storage panels of different thicknesses in three different environmental impact categories. In particular, it provided information about the responsibilities of the inputs required for the production of these panels on the total environmental impact of the panel. It also suggests that future research and development should focus on investigating the potential of environmentally friendly alternative materials to replace traditional raw materials used in production to improve the environmental sustainability of cold storage panels and move the industry in a greener direction.

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