Celal Bayar University Journal of Science

Fired Clay Brick or Autoclaved Aerated Concrete as Walling Materials in Terms of Sustainability

Saniye Karaman Öztaş[1*], Sinan İriş[2]

[1]Gebze Technical University, Department of Architecture, Kocaeli, TURKEY
[2]Izmit Municipality, Kocaeli, TURKEY
*saniyekaraman@gtu.edu.tr
*Orcid: 0000-0003-1955-0013

Received: 26 August 2019
Accepted: 15 June 2020
DOI: 10.18466/cbayarfbe.610833

Abstract

The construction sector is a significant contributor to harmful environmental impacts throughout the entire building life cycle. The fact that a large amount of and a wide range of materials used in construction makes their environmental impacts important. In this context, Environmental Product Declarations (EPDs) contribute to compare the environmental impacts of the building materials with the same functional unit for the same processes. Fired clay brick (FCB) and autoclaved aerated concrete (AAC) are commonly used materials for the exterior walls in Turkey. In this study, it was aimed to analyze the environmental impacts and identify environmental hot spots to improve the sustainability of the two materials in the scope of the "cradle-to-gate". EPDs and local data obtained from two factories through mutual interviews were used. The environmental impacts of FCB caused by raw materials acquisition and transportation are less than AAC. On the other hand, the manufacturing of FCB is an energy-intensive process because of the firing and firing temperatures compared to the manufacturing process of AAC. It is thought that the results of this study can be useful to improve the sustainability of the materials and to select sustainable building materials.

Keywords: Aerated concrete, brick, cradle-to-gate, sustainability.

1. Introduction

Sustainable materials are often regarded as materials that are natural and offer specific benefits to the users in terms of low maintenance, energy efficiency, the improvement of occupant health and comfort, the increase of productivity whilst being less harmful to the environment [1]. Many methods have been developed to assess the environmental impact of materials and components in the construction sector. Life Cycle Assessment (LCA) is a methodology that assesses the environmental impact of products and processes throughout the entire life cycle and is defined in ISO 14040 (2006) [2]. Environmental Product Declarations (EPDs) based on LCA according to EN 15804 (2012) are a voluntary, transparent and well-structured way of presenting basic and verified environmental information of a product or product group [3]. The environmental information of an EPD including all life cycle stages shall be subdivided into the information groups. Only the declaration of the product stage modules, A1- A2 and A3, is required for compliance with EN 15804. The declaration of the modules including other life cycle such as construction stage (A4-5), use and exploitation (B1-7) and end of life (C1-4) is optional. A1 module includes raw material extraction and processing, processing of secondary material input, A2 module includes transport to manufacturer and A3 module includes manufacturing. As per ISO 14025 (2006), type III EPDs present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function [4]. There are many Type III EPD programs in the world. Each program develops its own product category rules (PCRs) and classifies PCRs of the product differently.

As per Bribian et al., the public institutions must urge the manufacturers of materials to use EPDs or type III ecolabels based on the real impact of every product. Otherwise, the impacts of the materials can only be estimated approximately using existing inventories that are difficult to adapt to the reality of a specific geographical area [5]. As per Ding, the environmental profile of sustainable materials is largely unavailable or incomplete, and that is particularly serious in developing countries [1]. In this context, a more widespread use of EPD must be regarded as the most practicable way toward a sensitive choice of materials at the working plan and construction stages, otherwise designers have no access to the necessary information for whatever environmental evaluation [6].

Fired clay brick (FCB) and Autoclaved Aerated concrete (AAC) are commonly used as walling materials in construction. Clay brick is known for their durability, and when used in a well-built structure, it can last for hundreds of years with little maintenance. While brick has a relatively high embodied energy, this can be offset by its durability. Less waste and emissions are generated in brick manufacture than in the production of Portland cement, which releases almost one ton of CO_2 for every ton produced [7]. The production of brick seriously pollutes the environment and is very energy consuming, but bricks have a low maintenance level and are very durable, in most cases outlasting all other materials in a building [8]. The major challenges in producing alternative bricks material include conservation of topsoil, reduction of greenhouse gases emission during production and transportation and improving energy efficiency by the production of lower embodied energy material [9]. Aerated concrete, also known as Autoclaved Aerated concrete and which competes with brick as external walling material is non-organic, non- toxic, airtight material that generates no pollutants or hazardous waste during the manufacturing process. AAC is used in external walls because of its insulation properties. The superior properties of AAC are lightweight, high compressive strength, high thermal capacity, high fire, water resistance and workability [10]. There are a number of studies considering the comparison of environmental impact assessment of fired brick and AAC as walling materials. In the study of Nadoushani and Akbarnezhad, embodied energy, embodied carbon, resource sustainability, heating and cooling load were focused for five different facade material alternatives including brick and AAC [11]. Jayawardana et al. studied low embodied carbon building strategies for the cradle-to-gate system boundary. Selected materials were clay brick, AAC block, cement block, compressed stabilized earth brick, fly ash brick and precast concrete panel for the same functional unit (kg) [12]. In the study of Shulka (2014), burnt clay brick and ACC were compared in terms of renewable resources, use of waste product, energy efficiency and water conservation, durability and life span, recycle and reuse, local availability, and cost benefit [13].

The level of environmental impact caused by building materials may vary from country to country, and also from production plant to production plant. This is because of the differences in the technology and methods used in the production process of building materials [14]. In this regard, the declaration and assessment of environmental data can contribute development of the sustainability of building materials. Therefore, it was aimed to evaluate the environmental impacts of FCB and AAC as exterior walling materials using environmental data from different countries and local data in this study. EPDs and on-site field data were used to compare environmental impacts of the two materials.

2. Materials and Methods

2.1. Cradle-to-gate Process of FCB and AAC Manufacturing

According to TS EN 771-1+A1 (2015), FCB is defined as a masonry unit obtained from clay or other clay soil by adding sand or other powder additive or by firing at a sufficiently high temperature to obtain a ceramic bond without adding [15].

The main raw material used to produce fired bricks is clay. The clay is extracted from quarry with the help of construction machinery and transported to the manufacturing area. In the raw material preparation process; the clay stored in the factory is transported to the bunker. Elimination and moistening of the clay, separation of stone pieces in the crusher and discriminator provide a homogenous raw material. Raw material preparation process affects the quality of the product and the raw material gains strength. In the manufacturing process, clay is grinded in the rolls, transferred to bunker and annealed. Then, clay is transferred from bunker to vacuum extrusion machine and formed in extrusion. This process is completed by transferring of raw bricks coming out of extrusion by conveyor, placing on shelves and transporting of brick cars to drying area by manpower, forklift or tractor. Natural and/or artificial drying are performed to remove the raw bricks from moisture and to participate in the firing stage.

Bricks are fired at 900 – 1000 °C in the kilns. At this temperature, the structural properties of the bricks completely change. Raw brick becomes a hard and high strength material by losing its softness and flexibility. There are different kiln systems used for brick firing such as intermittent kilns (clamps, scove, scotch, down-draught kilns) and continuous kilns (zigzag, Hoffman, tunnel, vertical shaft brick kilns). The bricks are stationary, and the fire is moving in Hoffmann kilns, while the bricks are moving, and the fire is stationary in the tunnel kiln system [16]. Finally, stacked bricks are strapped, covered, and packed (Figure 1).

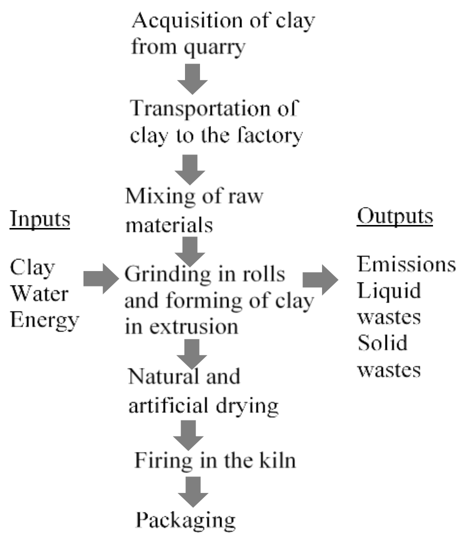

Figure 1. Cradle-to-gate process of FCB manufacturing.

As per TS EN 12602 (2016) about aerated and foam concrete construction materials and elements, the AAC and foam concrete are defined as porous light concrete obtained by reducing the weight of the mixture prepared with a finely ground silica aggregate and an inorganic binder by the addition of a pore-forming agent and obtained by steam curing [17].

Quartzite stone, the main raw material of AAC, is extracted from quartzite quarry and transported to the manufacturing site. In the raw material preparation process, quartzite stone becomes sludge after being reduced to very small dimensions with the help of crusher and mixed with water. The quartzite slurry is then transferred to silos and mixed to remain homogeneous. Cement, lime, gypsum and aluminum powder, the other raw materials of AAC, are transported to the manufacturing site and the raw materials which are brought to a certain consistency are mixed. The prepared raw material mixture is poured into the molds and AAC swells to the extent of molds by waiting for a certain period. In this process, lime reacts chemically with water, resulting in high amounts of heat and calcium hydroxide. When the aluminum powder is added to the released calcium hydroxide, hydrogen gas is released, and the material swells twice as much. The released hydrogen gas forms the porous structure of AAC.

The blocks which are cut with the help of steel wires are kept in autoclaves at 8 - 12 bar pressure at 170 - 200 ° C for about twelve hours. As a result of autoclaving, the hydrogen gas in the pores flies as vapor, the air fills into the pores and the AAC becomes the final form. AAC extracted from autoclaves are separated from each other by a mechanical system and transferred to the packaging area. Life cycle phases for the "cradle-to-gate" system boundary is presented in Figure 2.

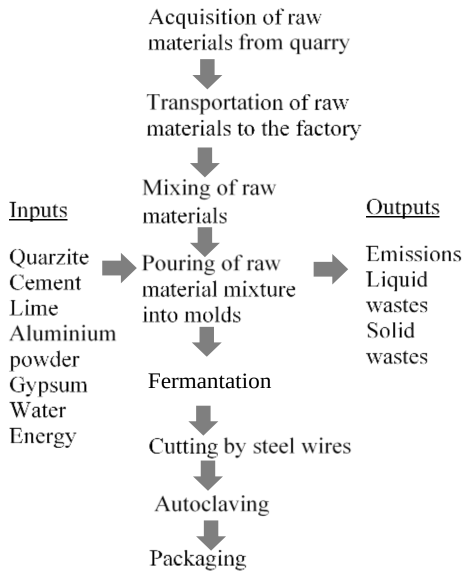

Figure 2. Cradle-to-gate process of AAC manufacturing.

2.2. The Environmental Data Comparison based on EPDs

In this study, EPDs were used in environmental data assessments and comparisons for cradle-to-gate process of FCB and AAC. The environmental data were obtained from eight EPD documents that manufacturers in different countries declare through different or the same program operators.

According to ISO 14025 (2006) and ISO 14040 (2006), the requirements for the comparability for Type III EPDs are indicated below [2, 4].

- the functional unit is identical
- the description of data is equivalent;
- the criteria for the inclusion of inputs and outputs are identical;
- the data quality requirements including coverage, precision, completeness and representativeness,
- consistency, reproducibility, sources and uncertainty are equivalent;
- the units are identical.

Therefore, the environmental impacts of FCB and AAC with EPD were assessed by considering the same functional units and the same boundaries (Table 1). Conversion factors that are in the EPDs of the AAC were used in converting "m^3" to "tons". EPD of the FCB-1 includes average environmental data of 46 brick plants in UK, while AAC-1 and AAC-2 include average data of 3 brick plants. AAC-3 includes average environmental data of members of the Aircrete Products Association (APA) in UK. All EPDs in the scope of the study are developed in accordance with ISO 14025 and EN 15804: 2012.

2.3. The Environmental Data Comparison based on Case Studies

Local environmental data were collected by on-site field data obtained from an FCB factory and an AAC factory during October 2018- February 2019 in Kocaeli/Turkey. Environmental data were obtained through the mutual interviews in these factories.

Hoffman and tunnel kiln are the most commonly used kilns respectively in Turkey. In this study, at the fired brick plant which is built on a land of 96,000 square meters and has a production area of 41,000 square meters, Hoffman kiln is used, natural and tunnel drying are performed. The factory produces 80 thousand fired bricks per day and 280-300 days of production are carried out during the year. It has ISO 9001 and TSE certificates.

Table 1. The environmental data for FCB and AAC based on EPDs.

			Brick EPDs				**AAC EPDs**			
			FCB- 1	**FCB- 2**	**FCB- 3**	**FCB- 4**	**AAC- 1**	**AAC- 2**	**AAC- 3**	**AAC- 4**
Product			generic brick	gray brick	extruded brick	yellow brick	AAC	AAC-non reinforced	AAC	AAC
Country			UK (46 plants)	Denmark	Norway	Denmark	Turkey (3plants)	Germany (3plants)	England	Germany
Program operator			Bre	Epd-Denmark	IBU	Epd Denmark	IBU	IBU	IBU	IBU
The period of validity			2019- 2024	2018-2023	2014-2019	2018-2023	2015-2020	2014-2019	2017-2022	2017- 2022
Functional unit			1tonne	1 tonne	1 tonne	1 tonne	1 tonne	1 tonne	1 tonne	1 tonne
Boundary			cradle-to-gate	cradle-to-gate	cradle-to-gate	cradle-to-gate	cradle-to-gate	cradle-to-gate	cradle-to-gate	cradle-to-gate
Product content			clay-shales (92%), sand (6%, inorganic additive (2%)	grey clay (70%), red clay (5%), yellow clay (%13), sand (%4), water (%8)	clay (89 %), sand (5.4%)sawd ust (2.4%),cha motte (2.2%)	yellow clay (49%), red clay (35%), sand (%8), water (%8)	quartzite (45-65%), cement (15-30%), gypsum (2-5%), lime (6-20%), aluminum (0.05-0.15%)	sand (40-72 %), cement (9-45%), caustic lime (10-20%), gypsum (2-5%), aluminum (0.01-0.4).	PFA (61%), other aggregates (14%), cement (14%), quick lime (8%), water (3%)	sand (50-70%), cement (15-30%), lime (10-20%), gypsum (2-5%), aluminum(0.05 -0.1%)
Environmental Impact Categories	GWP	kg CO_2 eq.	213	243	277	305	418	479	168	381
	ODP	Kg CFC11 eq.	0,00001	4.69E-8	10.3E-8	7.14E-8	0,00001	0.67E-8	7.10E-7	0.036E-8
	AP	kg SO_2 eq.	3.49	1.31	0.62	0.80	1.20	0.57	0.20	0.41
	EP	kg $(PO_4)^3$ eq.	0.107	0.124	0.08	0.077	0.22	0.074	0.019	0.053
	POCP	kg C_2H_4 eq.	0.177	0.066	0.113	0.040	0.089	0.052	0.06	0.038
	ADPE	kg Sb eq.	1.24E-4	0.39E-4	0.66E-4	4.83E-4	1.83E-4	5.32E-4	2.87E-4	10.21E-4
	ADPF	MJ	2370	3310	3393	3340	2336	2609	1200	2280
	PERT	MJ	120	259	1155	257	30,25	454,86	192	827.64
	PENRT	MJ	2430	3410	3431	3450	3326	2902	1290	2485
	FW	m^3	0.861	31.1	1.093	49.4	1.21	1.22	0.52	0.56
	HWD	kg	1.39	0.34E-3	0.115	3.41E-4	0.30	0.29	0.01	0.091E-4
	NHWD	kg	5.41	4.58	3.19	6.46	1.22	22.61	8.02	33.06
	RWD	kg	0.0069	0.0506	0.015	0.0250	-	0.1064	0.035	0.0731

(Captions: GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non-fossil resources; ADPF = Abiotic depletion potential for fossil resources; PERT = Total use of renewable primary energy resources; PENRT = Total use of non-renewable primary energy resources; FW = Use of net fresh water; RWD = Radioactive waste disposed; HWD = Hazardous waste disposed; NHWD = Non-hazardous waste disposed.)

2.4. The Environmental Data Comparison based on Case Studies

Local environmental data were collected by on-site field data obtained from an FCB factory and an AAC factory during October 2018-February 2019 in Kocaeli/Turkey. Environmental data were obtained through the mutual interviews in these factories.

Hoffman and tunnel kiln are the most commonly used kilns respectively in Turkey. In this study, at the fired brick plant which is built on a land of 96,000 square meters and has a production area of 41,000 square meters, Hoffman kiln is used, natural and tunnel drying are performed. The factory produces 80 thousand fired bricks per day and 280-300 days of production are carried out during the year. It has ISO 9001 and TSE certificates.

Celal Bayar University Journal of Science
Volume 16, Issue 2, 2020, p 109-117
Doi: 10.18466/cbayarfbe.610833

In the study, block bricks (190x135x190 mm), the most commonly used type of brick as exterior walling material in Turkey, were selected. The clay quarry is 6 km away from the factory and clay is transported by highway. Excavators and backhoe loaders are used to quarry the clay and 150-liter fuel is consumed daily. The annual raw material used for the manufacturing of bricks is approximately 39.900 m³/year.

As a result of the machines operating at full efficiency, 11.000 kWh of electricity is consumed per day. 33.32 kWh of electricity is consumed to produce 1 m³ bricks. In the factory, tunnel drying, and natural drying are both used. Extruded bricks are placed on the shelves in the tunnel drying area and then in the tunnel kiln using rail system by manpower. The heat used for drying in the tunnels is obtained from the hard coal burned in firing process and is transferred to the drying tunnel by means of aspirators. Besides, when the air temperature is suitable, the bricks are transported to the natural drying area with the help of tractors. There are two Hoffman kilns in the factory. 0.037 kg/m^3 hard coal is consumed to produce 1 m^3 of FCB. The firing temperature is 800-850 °C.

Figure 3. Hoffman kiln in the FCB factory.

FCB is cooled with ambient air by opening the door of the kiln. Air channels are opened on the side walls of the kiln near the ceiling and air is introduced into the kiln. This air passage is carried out by the air fans in the kiln chimney, the hot gas sucked is gave out of the chimney above the furnace. FCB are loaded to the vehicle in front of the kiln and brought to the packaging area with the help of forklifts. They are packaged on pallets, stocked and made ready for distribution. During these operations, forklifts consume approximately 9.8 liters of diesel fuel per day. The amount of stretch nylon consumed for 1m³ brick is 0,7 kg. During brick production, brick losses are approximately 1.5%.

The factory with a daily production capacity of 450,000 m³ unreinforced AAC in Gebze was monitored. Quartzite, the main raw material of AAC, is extracted from the quartzite quarry, which is approximately 1 km away from the factory, with the help of construction machinery, and is transported to the crusher which enables the stone to reach smaller dimensions. The quartzite grounded with water in the mill is stored in silos as quartzite sludge after a certain time. At this stage, electricity and water are consumed. 380 kWh motor is used for the operation of the mill.

During the raw material process, lime and cement are supplied from outside the factory. The lime produced at a temperature of approximately 1100-1200 °C is transported to the factory from 40 km and kept in lime silos. Cement is brought to the factory from 164 km and 118 nautical miles. Aluminum is transported to the factory from approximately 2.000 km. A total of 157.500 tons of quartzite sand, 8.000 tons of gypsum, 96.000 tons of lime and 1.800 tons of aluminum powder are used annually in the plant. In the raw material acquisition stage, 865.5 MJ non-renewable primary energy is consumed for 1 m³ AAC production.

Quartzite sludge, lime, cement, aluminum powder, AAC powder, AAC sludge and water are mixed in the tank. It is then transferred to molds. As a result of the chemical reaction of lime with water, a high amount of heat and calcium hydroxide are released. Aluminum powder is added to the released calcium hydroxide, hydrogen gas is released, which swells the material about twice as much. After about 150 minutes, the swelling process is completed, and then wet cutting is started. The masses extracted from the molds are brought to the cutting area and AAC is cut according to the desired dimensions with the help of pressure steel wires. Electrical energy is consumed for the vehicles used in this stage. The losses resulting from the wet cutting process are mixed with water and turned into sludge and participate in production again.

After the cutting process, the casting trolleys are taken to autoclaves (25 x 45 m circular tubes) and cured in saturated water vapor under 12 atm pressure and 190 °C for 10 hours. As a result, the autoclave AAC reaches the final strength and volume stability. At this process, natural gas, electricity and water are consumed. AAC extracted from autoclaves are separated from each other by a mechanical system and transferred to the packaging area. Emission data has not been declared by the manufacturers for cradle-to-gate process.

Figure 4. Extraction of AAC from autoclaves and separation from each other.

Table 2. The local environmental data for FCB and AAC based on field data.

		FCB	AAC
Physical properties	Functionality	exterior wall block	exterior wall block
	Dimensions and Weight	190 mm x135 mm x190 mm	600 mm x 250 mm x 300 mm
	Compressive Strength	2.5-3 N/mm^2	1,5-5 N/mm^2
	Dry Density	600 kg/ m³	500 kg/m^3
	Thermal Conductivity	0.24-0.33 W/mK	0.085-0.16 W/mK
Raw material acquisition/ A-1	Raw Materials	clay, water and brick fracture	quartzite sand, lime, cement, aluminum powder and gypsum
	Raw Material Consumption	39900 m^3/year	149950 m³/year
	Raw Material Acquisition System	excavator- trucks system	excavator- trucks system
	Fuel Consumption	0.81 L/m³ 8.68 kWh/m³ = 31,248 MJ/m³	1.74 L/m³ (acquisition of quartzite) Total 865.5 MJ/m^3
Transportation/ A-2	Transportation Type	16-ton truck	25-ton truck
	Distance from Quarry to The Factory	6 km.	quartzite – 1 km., lime – 40 km. cement – 164 km+118 nautical miles
	Amount of Energy Consumption	32.400 l/year diesel	315.840 l/year diesel 69.5 MJ
Manufacturing/ A-3	Manufacturing Method	natural and artificial drying, firing in Hoffman kiln	swelling in molds, steam pressure 12 bar and autoclaving
	Inputs	clay, brick fracture, water, hard coal	quartzite, cement, lime, water, aluminum powder, natural gas
	Energy Consumption	1158 MJ	448 MJ
	Equipment	bunker, stone crusher, rollers, vacuum extrusion machine, vehicles	crusher, mill, quartzite sludge tank, molds, cutting machines, autoclaves, separator machines
	Firing Temperature	850 – 1000 °C	190 °C
	Wastes	0,03 m³ brick fracture	0,4 m³ AAC powder and 0,4 m³ AAC sludge
	Water Consumption	384 L/m³	402 L/m³
Packaging/ A-3	Amount of Stretch Nylon	17 mikron / 0.70 kg/m³	23 mikron / 0.79 kg/m³
	Amount of Wood Pallet	0,61 ad/m³ - 21.35 kg/m³	0,92 ad/m³ - 32.40 kg/m³

3. Results and Discussion

3.1. Results of the EPDs

In the cradle-to-gate process of FCB; the type of fuel used in brick manufacturing, the type of firing kiln, the distance between the raw material quarry and the manufacturing plant, the organization of the manufacturing area and the manufacturing method are effective in Global Warming Potential (GWP) mitigation. As per the Intergovernmental Panel on Climate Change report (2006), natural gas has the lowest CO_2 emission factor, while coal and coke have the highest greenhouse gas emissions among common fossil fuels [26].

In the cradle-to-gate process of AAC, the main raw materials such as quartzite, cement, lime and aluminum powder extracted from the quarries and distances between the quarries and the factories, high consumption of diesel fuel during quartzite mining are effective in high GWP values. Considering EPDs of the two materials, it is observed that GWP values are between 213 and 305 kg CO_2 eq. for FCB; 168 and 479 kg CO_2 eq. for AAC (Table 1). It is indicated that the total GWP value arises from onsite energy usage including the use of natural gas, electricity, coal and coke, diesel and LPG fuels for 46 UK manufacturing sites that represents 99% of UK brick production. The second highest contributor is from the emissions released from the clay raw materials on firing. The other input processes have relatively low contributions to the total GWP value [18]. Brick manufacturer in Norway declared that the value of GWP is mainly produced by the high amount of thermal energy used to produce bricks making up 60 % of the total GWP. The raw material stage shows a negative value due to the usage of wood products such as timber, paper and wooden pallets and the saw dust comes in as raw material input that represents harvested biomass with a negative value for GWP due to the intake of CO_2 [20]. No detailed information about the fuel type during cradle-to-gate and no interpretation of the results have been found in brick EPDs in Denmark. GWP of AAC is mostly higher than FCB due to the cement production process. GWP value of only one AAC factory is lower than the values of the FCB factories. It is due to pulverized fuel ash (PFA) that is used to substitute part of the cement reducing the carbon emission in this AAC factory (Table 1). It is indicated that raw material acquisition is the dominant stage within almost all the environmental impacts. 80 % of GWP results from the process of raw material acquisition (A1) and 16.30 % of GWP results from the process of manufacturing stage (A3) [22]. In AAC EPD (Germany), it is highlighted that the environmental performance of AAC production is primarily determined using binding agents. The lime and cement production have a significant role on the environmental results [25].

The value of ozone depletion potential (ODP) for FCB and AAC is low. In FCB EPD (Norway), it is indicated that 96% of the ODP are generated due to the demand for thermal during the life cycle of bricks [20]. In AAC EPD (Germany), it is stated that both the binding agents and aluminum have a relevant influence on the ODP [25].

Considering EPDs of the two materials, it is observed that acidification potential (AP) values are between 0.6 and 3.4 kg SO_2 eq. for FCB; between 0.2 and 1.2 kg SO_2 eq. for AAC (Table 1). Nitrogen oxides (NO_x) released as a result of the use of coal during firing leads to acidification in brick manufacturing. On the other hand, the use of natural gas during the manufacturing of AAC and the low value of sulfur gas in the content of natural gas fuel reduce the rate of sulfur released into the atmosphere. However, a large amount of NO_x increases the AP of the AAC, as a result of the combustion of natural gas. In FCB EPD (Norway), it is indicated that 55% of the AP is produced by thermal energy utilization. The raw material (21 %) and production stage (17 %) contribute to the AP. 64 % of the AP is due to the usage of manganese oxide in raw material process [20]. In AAC EPD (England), it is highlighted AP is predominantly driven by the production of NO_x and SO_x (Sulphur oxides) from the combustion of fossil fuels [24].

Eutrophication potential (EP) during the manufacturing of building materials depends on the NO_x caused by the combustion of fossil fuels. Considering EPDs of the two materials, it is observed that EP values are between 0.07 and 0.12 $(PO_4)^3$ eq. for FCB; 0.01 and 0.22 $(PO_4)^3$ eq. for AAC (Table 1). The burning of coal or natural gas in brick manufacturing causes eutrophication. The reason why these values are high in AAC is the intensive consumption of natural gas in autoclaving. Because with the use of natural gas, a high amount of NO_x is released into the environment.

Photochemical ozone creation potential (POCP) (48 %) is mainly driven by the manufacturing stage of FCB and thermal energy utilization causes 35 % to the POCP of bricks [19]. Abiotic depletion potential (ADP) for fossil resources values are between 2370 and 3393 MJ for FCB; 1200 and 2609 MJ for AAC (Table 1). Fossil fuel is consumed in the artificial drying and firing process in the manufacturing of FCB, while fossil fuel is consumed in autoclaving in the manufacturing of AAC. In AAC EPD (Germany), it is stated that energy requirements only have a significant influence during manufacturing in the fossil abiotic depletion of resources impact category [25].

Water consumption is high for the EPDs of the two FCBs because mixing water is 8% of the product content (Table 1). Water is needed for the hydraulic reaction undergone by the binding agents and used as process and mixing for AAC manufacturing.

Nonhazardous waste values for AAC manufacturers are higher than FCB manufacturers except one AAC manufacturer (Table 1). In AAC EPD (Germany), nonhazardous waste represents the largest percentage during manufacturing and is incurred as a result of the extraction and processing of sand [23]. As per brick EPD (Norway), the largest amount of waste includes non- hazardous waste (96 %) and 76 % of the total amount of non- hazardous waste is sand. Hazardous waste represents 3.5 %, and radioactive waste represents 0.5 % during the life cycle of bricks [20].

3.2. Results of the Case Studies

Considering local data and case studies in Turkey, it is observed that the energy consumption during the raw material acquisition of AAC is more than that of FCB (Table 2). One of the reasons is due to the energy consumption during the extraction and transportation of the main raw materials such as cement, lime, and quartzite. Another important reason is the operation of the jaw crusher used during the conversion of quartzite to quartzite sand at all times of the day. In Turkey, high energy consumption and the use of coal as an energy source increase the environmental impacts in the cement production process.

Celal Bayar University Journal of Science
Volume 16, Issue 2, 2020, p 109-117
Doi: 10.18466/cbayarfbe.610833

For the FCB, only clay is transported to the manufacturing plant. For AAC, quartzite stone is extracted from a very close distance to the manufacturing plant, but cement, lime and aluminum powder are taken from further distances. (Table 2). These distances increase energy consumption and GWP value between the two factories.

Hard coal is transported by trucks of 25 tons from 244 km distance to the production factory. Approximately 850 L of diesel fuel is consumed during transport (Table 2). During the production of AAC, electrical energy and intensive natural gas during autoclaving are consumed. Raw bricks are fired at 850 - 1000 °C for 10 - 12 hours in the Hoffman brick kiln. Therefore, Hoffman kilns operate continuously day and night and intensive energy is consumed at the manufacturing stage.

According to the data obtained from the manufacturers in the brick factory through the mutual interview, 1158 MJ of energy is consumed to produce 1 m^3 of FCB. Autoclaving of AAC takes place at 190 ° C for twelve hours and 448 MJ of energy is consumed to produce 1 m^3 of AAC as per the data obtained from the manufacturers in the AAC factory through the mutual interview.

According to the data obtained from the factories, 0.61 pcs/m^3 and 21.35 kg/m^3 wooden pallets are consumed for 1 m^3 of FCB, 0.92 pcs / m^3 and 32.40 kg/m^3 wooden pallets are consumed for 1 m^3 AAC.

4. Conclusion

In this study, the cradle -to- gate environmental impacts of two commonly used walling materials were evaluated based on the data obtained by the EPDs and two factories in Turkey. Although the environmental values of FCB and AAC are different between the local data and EPDs, the comparison results are parallel to each other. Considering the case studies and evaluations, the following results and recommendations are obtained:

- The fact that the raw material source of building materials is local and close to the material production plant is important in terms of reducing environmental impacts such as energy consumption and emission of greenhouse gases causing global warming. Clay, the raw material of FCB, can be easily found and obtained from local sources. On the other hand, AAC requires separate production processes in order to obtain some raw materials such as quartzite, cement and lime. During the processes, a high amount of toxic gas is released to the environment and natural resources are consumed. Therefore, the raw material acquisition is dominant stage in terms of environmental impacts for AAC.
- Energy efficiency is very important for sustainability during the production of building materials. In the results of the study, it is seen that fossil energy resources have a crucial share in the environmental impacts. Therefore, consumption of renewable energy instead of fossil energy will reduce the environmental impacts of building materials in the life cycle process. The manufacturing of the FCB is the stage in which the most energy is consumed during "cradle-to-gate" process. In particular, the combustion of coal consumed during the firing process results in a high amount of CO_2, SO_x and NO_x gas emissions into the air and causes environmental impacts as global warming, acidification and eutrophication. Improving supervision of the firing process, adding carbonaceous wastes that contain some combustible material to the clay mixture, periodic maintenance of the kiln can provide to reduce energy consumption.
- On the other hand, a large amount of natural gas is consumed during the production of AAC, especially autoclaving. A small amount of CO_2 gas emitted as a result of combustion of natural gas reduces greenhouse gases that cause global warming. However, NO_x is released into the atmosphere at a high rate and increases the acidification rate of soil and water. Using different materials to replace cement can reduce energy consumption and consequently environmental impacts.
- When the physical properties of the two materials are examined, it is seen that the thermal conductivity coefficient of the brick is higher than that of AAC. This will increase energy consumptions and environmental impacts during the building use stage. Therefore, thermal conductivity coefficient can be reduced by experimental studies to be performed in the production process of FCB.
- EPDs can be useful in comparing the environmental impacts of building materials and in the development of inventory data for building materials, especially for developing countries. In this context, environmental awareness of building materials manufacturers and encouragement of innovation are required. Some of AAC manufacturers have EPD certificates in Turkey. However, to date no initiative has been made to get EPD certificate by the local brick manufacturers yet. The development of laws and regulations to ensure the declaration and monitoring of environmental data are required for taking part in international markets and for a livable world.
- The scope of this study is limited for the "cradle-to-gate" process of FCB and AAC. However, the entire life cycle is important to correctly interpret the environmental impacts of a material. The scope of the study should be expanded by considering the

environmental impacts of entire life cycle of these materials including the construction stage, use process and end-of-life with future researches.

Author's Contributions

Saniye Karaman Öztaş: Drafted and wrote the manuscript.

Sinan İriş: Supervised the writing progress, provided technical support and helped in arrangement of manuscript.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1]. Ding, G.K.C. LCA of Sustainable Building Materials: An Overview, 3, 38-62, Woodhead Publishing Limited, 2014; pp 38- 62.

[2]. EN ISO 14040, 2006. Environmental management – Life Cycle Assessment, principles and framework.

[3]. EN 15804, EN15804+A1:2014. 2014). Sustainability of construction works. Environmental Product Declarations. Core rules for the product category of building materials.

[4]. ISO 14025, 2011. ISO 14025:2011-10 Environmental labels and declarations. Type III environmental declarations, principles and procedures.

[5]. Bribian, I, Z, Capilla, A, V, Uson, A, A. 2011. LCA of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco- efficiency improvement potential. *Building and Environment*; 46: 1133- 1140.

[6]. Franzoni, E. 2011. Materials selection for green buildings: which tools for engineers and architects. *Procedia Engineering*; 21: 883- 890.

[7]. Calkins, M. Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials, John Wiley & Sons, Inc., Hoboken, New Jersey, 2009.

[8]. Berge, B. The Ecology of Building Materials, 2nd edition, Architectural Press: Elsevier, Oxford, 2009

[9]. Murmu, A, L, Patel, A. 2018. Towards sustainable brick production: An overview. *Construction and Building Materials*; 165: 112- 125.

[10]. Kömürlü, R, Önel, H. 2007. Usage of aerated concrete construction elements in houses. *Megaron*; 2 (3): 145-158.

[11]. Nadoushani, Z.S.M, Akbarnezhad, A. 2017. Multi-criteria selection of facade systems based on sustainability criteria. Building and Environment, 121: 67-78.

[12]. Sangeeth, A., Perera, R., Perera, N. 2019. "Cradle to gate" assessment of material related embodied carbon: a design stage stratagem for sustainable housing, 5th International Conference on Countermeasures to Urban Heat Islands (IC2UHI).

[13]. Shukla, R. 2014. Burnt clay bricks versus AAC blocks: a comparative analysis, international journal of Engineering and Research Technology, 3,11, 575-580.

[14]. Esin, T. 2007. A study regarding the environmental impact analysis of the building materials production process (in Turkey). *Building and Environment*; 42 (11): 3860- 3871.

[15]. TS EN 771-1+A1, 2015. Specification for masonry units - Part 1: Clay masonry units.

[16]. Kumar, S, Maithel, S. Introduction to Brick Kilns and Specific Energy Consumption Protocol for Brick Kilns, Greentech Knowledge Solutions Pvt. Ltd, New Delhi, India. https://breathelife2030.org/wp-content/uploads/2016/09/12.pdf. (accessed at 10.05.2019).

[17]. TS EN 12602, 2016. Prefabricated reinforced components of autoclaved aerated concrete.

[18]. EPD, generic brick, UK, https://www.mbhplc.co.uk/wp-content/uploads/brick-epd.pdf (accessed at 20.05.2019).

[19]. EPD, gray brick, Denmark, http://www.epddanmark.dk/site/images/gallery/md-17002-en/MD-17002-EN_rev1.pdf (accessed at 20.05.2019).

[20]. EPD, extruded brick, Norway, https://www.wienerberger.co.uk/download-centre.html, (accessed at 20.05.2019).

[21]. EPD, yellow brick, Denmark, http://www.epddanmark.dk/site/images/gallery/md-18015-EN/MD-18015-EN.pdf, (accessed at 20.05.2019).

[22]. EPD, AAC, Turkey http://www.akg-gazbeton.com/SF/591/AKG-EPD-2018-2023.pdf (accessed at 20.05.2019).

[23]. EPD, AAC, Germany, https://www.environdec.com/Detail/?Epd=10333 (accessed at 20.05.2019).

[24]. EPD, AAC, England, https://epd-online.com/PublishedEpd/Detail/9480 (accessed at 20.05.2019).

[25]. EPD, AAC, Germany, https://epd-online.com/PublishedEpd/Detail/10266 (accessed at 20.05.2019).

[26]. **26.** IPCC: Guidelines for National Greenhouse Gas Inventories., United Nations Intergovernmental Panel on Climate Change, 2006. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html (accessed at 15.07.2019).