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RESEARCH PAPER

An Assessment of Carbon Footprint in MDF Manufacturing: A Case Study of Wood Based Panel Production in Turkey

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Abstract: Nowadays, carbon footprint (CF) became an important topic closely related to the ecological production of goods and services. Energy use and subsequent emissions of greenhouse gases (GHGs) in all human facilities affect the world's climate in the form of global warming in recent decades. The dominant greenhouse gas arising from human activities is carbon dioxide (CO_2). Carbon footprint is CO_2 and other GHGs that are released per unit product for a specific period. The main purpose of this study is the determination of most important critic processes about that contribute to the cf problem during medium-density fiberboard (MDF) production with Pareto analysis method. MDF is a kind of composite panel product which is typically containing of cellulosic fibers with the combination of synthetic resins and additives becoming under heat and pressure. For this purpose, a wood-based panel company is selected to examine cf for its each process. As a conclusion this study makes an important contribution to the panel based industry to see the emission problems with the help of Pareto analysis and help to perform an environmental oriented production for the future. Moreover, two scenarios are built up to decrease of total carbon footprint in the selected plant. So, the analysis results are supported with two scenarios. Also, this study shall provide a general view and perception for the importance of the carbon footprint in the wood panel based industrial sector.

Keywords: Carbon footprint, Medium-density fiberboard (MDF), Pareto analysis, scenarios.

MDF Üretimindeki Karbon Ayak İzinin Değerlendirilmesi: Türkiye'de Odun Bazlı Levha Üretimi Üzerine Bir Örnek Çalışma

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Öz: Günümüzde karbon ayak izi, mal ve hizmetlerin ekolojik olarak üretimiyle yakından ilgili bir konu haline gelmiştir. Son yıllarda tüm insanların faaliyetlerinde enerji kullanımı ve kullanımdan gelen sera gazı emisyonları küresel ısınma şeklinde dünya iklimini etkilemektedir. İnsan faaliyetleri sonucunda ortaya çıkan en baskın sera gazı karbondioksittir. Karbon ayak izi, belirli bir süre için birim ürün başına salınan CO_2 ve diğer sera gazlarıdır. Bu çalışmanın temel amacı, orta yoğunluklu lif levha (MDF) üretimi sırasında karbon ayak izi problemine katkı sağlayan en önemli kritik süreçlerin Pareto analiz yöntemi ile belirlenmesidir. MDF, ısı ve sıcaklık altında tipik olarak sentetik reçineler ve katkı maddeleri kombinasyonu ile selülozik lifler içerir. Bu amaçla, karbon ayak izini her bir süreç için incelemek üzere bir odun bazlı levha endüstrisi seçilir. Sonuç olarak bu çalışma, panel bazlı endüstrideki emisyon sorunlarını Pareto analizi yardımıyla görmeye ve geleceğe yönelik çevre odaklı bir üretim yapışmasına önemli katkı sağlamaktadır. Ayrıca seçilen tesiste toplam karbon ayak izini azaltmak için iki senaryo oluşturulmuştur. Dolayısıyla analiz sonuçları iki senaryo ile desteklenmektedir. Dahası bu çalışma, karbon ayak izinin odun panel bazlı endüstriyel sektördeki önemi hakkında genel bir bakış açısı ve algı sağlayacaktır.

Anahtar kelimeler: Karbon ayak izi, Orta yoğunluklu liflevha (MDF), Paretö analiz, senaryolar.

INTRODUCTION

Turkish wood-based panel industry is one of the most important industries for the country. Turkey is among the worlds' largest board producers in the world following China and Germany (Yıldırım, Candan and Korkut, 2014). Because of the high capacity of industry, energy supply and consumption become a significant topic for the industry.

Besides, wood supply has a big problem for the industry from past through today (Mahapatra and Mitchell, 1997; Ok, 2005, Ilter and Ok, 2007; Daşdemir, 2018). The industry runs out of substantial amounts of energy in the forms of natural gas, biomass, and diesel fuel. So, greenhouse gas (GHG) emissions are released in atmosphere. Thus, increasing energy efficiency and developing pollution reduction methods in this sector will be important for decreasing GHG emissions in coming decades. The most important agreement of concerning global warming and climate change is known as Kyoto Protocol and six greenhouse gases are defined as CO, CO_2, CH_4, N_2O, PFCs (per fluorocarbons), and HFCs (hydro fluorocarbons) which cause strongly global warming and it has been thought those gases are released by human activities. (IPCC, 2006 ; IPCC, 2007 ; WBCSD/WRI, 2007 ; ECCM, 2008). The dominant GHG is carbon dioxide that partly derives from diesel fuel burning (Post, 2006; ETAP, 2007; Steinfeld and Wassenaar, 2007; Da Schio and Fagerlund, 2013).

Carbon footprint concept was originated from the terminology of ecological footprint which was proposed by Wackernagel and Rees in 1996 (Wackernagel and Rees, 1996; Wackernagel et al., 1999; Ercin and Hoekstra, 2012). Carbon footprint is the total amount of CO_2 and other GHGs that occur over the full life cycle of a process or facility and it has been described units of tones or kg equivalent (Brenton et al., 2008; Matthewset al., 2008; IEA, 2012; Radua et al., 2013). Some researchers explain it as a measure of amounts of CO_2 emitted from the combustion of fossil fuels (Patel, 2006; Post, 2006; Carbon Trust, 2007; Grubb & Ellis, 2007; Wiedmann and Minx, 2007). The footprint is divided into two groups as primary (direct) and secondary (indirect) (Energetics, 2007; Goodier, 2010; Atabey, 2013; Uribe et al., 2019

Moroşanu et al. (2001) studied on identifying and evaluating of defects on oak veneer for four regions. The researchers were used the Pareto analysis method for developing the quality of the studied products. Pareto analysis was also used in order to determine the important carbon footprint problem(s) each of process in this research. Lippke et al. (2012) investigated different uses of wood to see their efficiency by means of carbon and energy impacts to displace fossil energy. The researchers found out when waste wood was consumed as a biofuel instead of fossil fuels and so the emissions were decreased. In this study, it is aimed to calculate CO_2 emissions for each process in a MDF industry in a plant scale of the largest producer in Marmara region, in Turkey. The plant named as XYZ plant afterwards in this study. This study was prepared by the data of XYZ company which belong to the year of 2015. The amount of annual production of MDF is 389561 m^3/year in 2015. The study is also aimed to make some suggestions to decrease the emissions fort the future. So, two scenarios were produced and suggested. Carbon footprint values are calculated as statistically with Tier 1 method (IPCC, 2007) during the MDF production, and Pareto analysis is applied for determine the footprint' problem.

MATERIALS AND METHODS

Medium-density fiberboard: XYZ is a plant operating in forest products industry and it produces particle board, medium density fiberboard (MDF), and parquet as products and it is also one of the largest plant due to its capacity in this field in Marmara region. Work flow in concerning with MDF manufacturing is shown in Figure 1. The MDF production follow the processes such as chipping, screening, evaporation, refiner, gluing, drying, laying, pressing, sizing, climatization, and sand- papering. MDF is described as a wood based panel product manufactured from raw fibers of wood, wood chips, and small amount of other materials such as glues, binders, and additives.

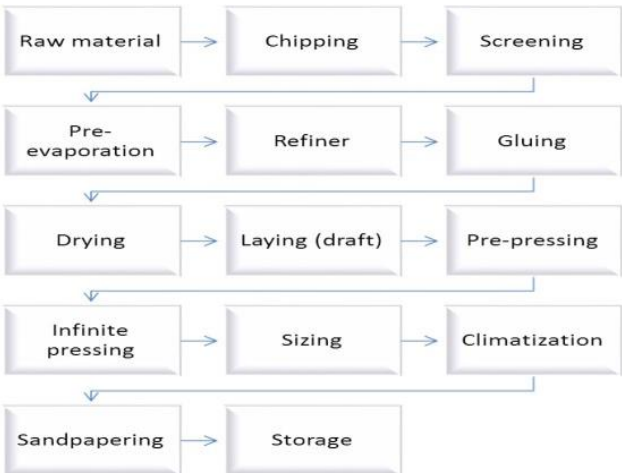

Figure 1. Flow chart for medium-density fiberboard panel production in XYZ plant (Erdil, 2018).

In these processes, energy is consumed in the forms of natural gas, biomass, and diesel fuel. Considering all the contributing factors, carbon footprints values are calculated using the Tier 1 method according to IPCC 2006 Guidelines (IPCC, 2006). To produce 389561 m^3 of the medium-density fiberboard in 2015, it was used 10275 tons of wood chips, 10972 tons of emery powder, 8995 tons of edge trimming, and 7964 tons of fiber (dry) in boiler. On the other hand, the plant used 43277505 m^3 (460472653kWh) natural gas energy, 141971971 kWh biomass energy, and 29365 liters (315673,7 kWh) of diesel fuel for annual production in 2015. The study is carried out in the XYZ plant considering the improvements of all of the energy flow processes comprises of following steps:

1-Design a study plan

2-Calculate of carbon footprint for each process.

3-Practising of the Pareto analysis steps

4-Drawing the Pareto diagram

5-Designate major emission problem(s) according to 80/20 law by the help of Pareto diagram.

6-Make suggestions for the major emission problem(s).

Energy balance: In this plant, natural gas, biomass are consuming as the main (directly) inputs for obtaining energy. While natural gas, and biomass are consuming in MDF production process, diesel fuel is used by transportation equipment (volvo, escalator, and forklift) which are using in the field. Those inputs are primary and direct energy sources for MDF production in process.

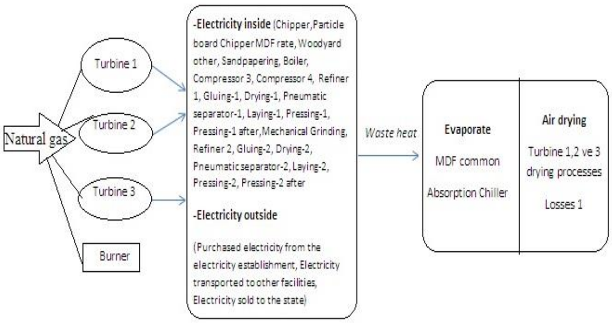

Figure 2. Energy balance flow chart 1 in medium density fiberboard (Erdil, 2018).

Natural gas is consuming in Turbine 1, 2, 3 and burner. As a result of the use of natural gas, electricity energy is producing and waste heat releases. The waste heat is recovered in evaporation, and air-drying units as energy sources as seen in Fig.2. Those sources are called as indirectly energy sources. Even though the company produces its own electricity in the plant, in some cases the factory buys electricity from the electricity suppliers.

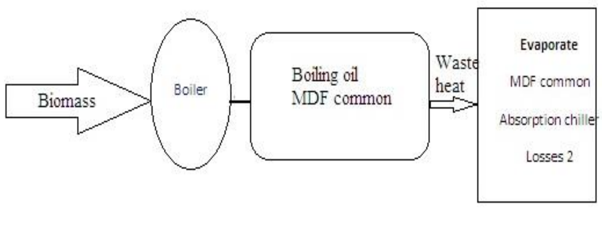

Figure 3. Energy balance flow chart 2 in medium density fiberboard (Erdil, 2018).

According to Fig. 3, biomass sources vary from wood dust, wood chips, bark, emery powder, etc. It is generally composed of process wastes. As a result of the process, waste heat is also released. The waste heat is recovered in evaporate as energy sources. Those sources are called as indirectly energy sources (Erdil, 2018).

Calculation of Carbon Footprint (CF): Carbon footprints (CF) were calculated for each process according to the inputs' emission factors and then Tier 1 method was applied (IPCC, 2006; IPCC, 2007). Due to the simplicity in application and suitability to the data available, Tier-1 method was used in this study. Process based data related to energy and fuel consumption consumed for emission calculations through the equation given below (Pekin, 2006; Atabey, 2013; Turanlı, 2015). Before carbon footprint calculation, it must be known fuel consumption and emission factor. Emission factor can be researched in literature (Defra, 2010; Lelyveld and Woods, 2010; Cefic, 2010).

Emission is calculated according to the equation 1 is given in below and CF is calculated according to equation 2 (IPCC, 2006; Erdil, 2017; Erdil et al., 2017; Keskin et al., 2017; Erdil, 2018).

$$\text{Emission} = \text{Energy consumption} \times \text{Emission factor} \times \text{Oxidation factor} \quad (1)$$

(Oxidation factor is taken as 1)

$$\text{CF} = \text{Emissions (kg } CO_2\text{e)} / \text{Amounts of annual production (m}^3\text{)} \quad (2)$$

Pareto Analysis: Vilfredo Pareto was an Italian economist who lived in 19th century and evaluated economic problems by applying mathematics and developed a method which was maintained as his name and it was assisted to define and classify the problems according to the significance of the percentage values. It is a way of assisting causes of problems to derive an effective solution. This method uses due to 80/20 law in general. As a result of this method diagrams are obtained which is useful tool in defining the important problems. Pareto diagrams assist to build a relationship in between the problems and the reasons (Gitlow et al., 2005; Erdil, 2017; Erdil, 2018).

Pareto diagrams are the graphical tool used in Pareto analysis (Cravener et al.,1993; Leavengood and Reeb, 2002). Pareto analysis is a method which is used to distinguish causes from less significant ones. Pareto analysis follows the procedures in below (Akın, 1996; Akın and Oztürk, 2005; Erdil, 2017; Erdil et al., 2017; Erdil et al., 2017; Erdil, 2018):

1. Problems should be determined and then classified.

2. Data are classified according to the problem. Total values which are in different categories and their percentages are determined.

3. A bar chart was drawn. In this bar graph, while the y-axis establishes the totals and percentages, the x-axis presents the classified groups.

4. Pareto diagrams are carried out to notice the biggest problem from beginning of the upper right-hand corner of the first bar.

Building up scenarios for decreasing of carbon footprint: After calculation and exhibition of carbon and energy footprints' of the MDF plant, there were built up two different scenarios for decreasing carbon footprint. According to scenario 1, biomass usage was suggested instead of natural gas in turbines (1, 2 and 3) as a fuel. On the other hand, according to scenario 2, solar panel establishment seems to help to decrease carbon footprint instead of usage an electricity.

RESULTS AND DISCUSSION

In this study, CF values were calculated for each process by means of primary and secondary energy sources. Furthermore, Pareto analysis was applied to define carbon footprint' problem in the plant. Moreover, two scenarios are built up to decrease of total carbon footprint in the plant.

Carbon footprints: The distribution of carbon footprints determined for the processes used in the plant as primary and secondary sources are presented in Figure 4. As can be seen, CF of Turbine 3 the highest value at 88,08 kg-CO_2e/m^3MDF of all other processes as primary in Figure 4-a. CF of MDF common (it's a general classification for the plant) which has the highest value at 44,91 kg-CO_2 e/m^3MDF of all other processes as secondary sources in Figure 4-b.

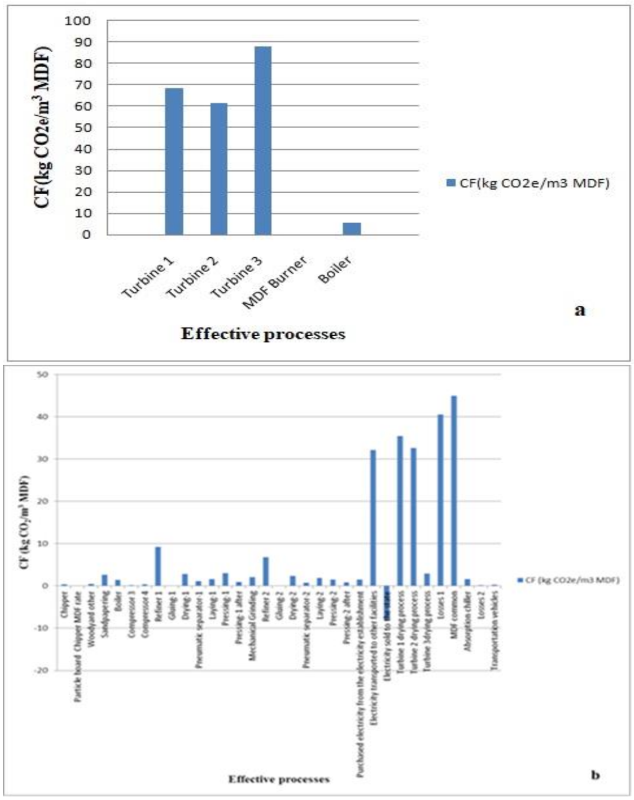

Figure 4. Carbon footprint (CF) for each effective process (a-Primary and their' CF b-Secondary and their' CF).

Application of Pareto analysis: In this study, CF values were calculated for each process by means of primary and secondary energy sources with Tier 1 method. After then, Pareto analysis procedures are applied for drawn Pareto diagram. Pareto chart was drawn to define the problems which were revealed by the help of 80/20 law. For this aim, firstly, calculated CF values of every process' sources were enumerated as presented in Table 1.

Table 1. CF data according to effective processes in MDF production.

Serial number	Effective processes	CF (kg CO_{2e}/m^3 MDF)
1	Turbine 1	68.47
2	Turbine 2	61.69
3	Turbine 3	88.08
4	MDF Burner	0.43
5	Boiler (consumed)	5.47
6	Chipper	0.35
7	PB Chipping MDF rate	0.05
8	Woodyard other	0.45
9	Sandpapering	2.59
10	Boiler (produced)	1.43
11	Compressor 3	0.2
12	Compressor 4	0.34
13	Refiner 1	9.21
14	Glueing-1	0.05
15	Drying-1	2.79
16	Pneumatic separator-1	1.13
17	Laying-1	1.62
18	Pressing-1	3.01
19	Pressing-1 after	0.96
20	Mechanical Grinding	2.03
21	Refiner 2	6.8
22	Glueing-2	0.03
23	Drying-2	2.38
24	Pneumatic separator-2	0.78
25	Laying-2	1.89
26	Pressing-2	1.45
27	Pressing-2 after	0.87
28	Purchased electricity from the electricity establishment	1.52
29	Electricity transported to other facilities	32.08
30	Turbine 1 drying process	35.45
31	Turbine 2 drying process	32.55
32	Turbine 3 drying process	2.93
33	Losses 1	40.54
34	MDF common	44.91
35	Absorption chiller	1.59
36	Losses 2	0.15
37	Transportation vehicles	0.22

Then enumerated values were ranked from high to low and the total amount of CF was found as shown in Table 2. Besides seen in Table 2, percentage and cumulative percentage were calculated for every sources' of values were took place.

Pareto chart was drawn with 3 axes. While y axes in the left side shows CF values, y axes in the right side shows cumulative percent and x axes defines the sources in Fig.4.

Table 2. CF data in ranked from high to low, calculated percent and cumulative percent of CF in medium-density fiberboard production.

Serial number	Effective processes	CF (kg CO_2 e/m^3 MDF)	Percent (%)	Cumulative percent (%
3	Turbine 3	88.08	19.29506	19.30
1	Turbine 1	68.47	14.99923	34.29
2	Turbine 2	61.69	13.51399	47.81
34	MDF common	44.91	9.838113	57.65
33	Losses 1	40.54	8.880808	66.53
30	Turbine 1 drying process	35.45	7.765778	74.29
31	Turbine 2 drying process	32.55	7.130496	81.42
29	Electricity transported to other facilities	32.08	7,027536	88.45
13	Refiner 1	9.21	2.017569	90.47
21	Refiner 2	6.8	1.489627	91.96
5	Boiler (consumed)	5.47	1.198274	93.16
18	Pressing-1	3.01	0.659379	93.82
32	Turbine 3 drying process	2.93	0.641854	94.46
15	Drying-1	2.79	0.611185	95.07
9	Sandpapering	2.59	0.567373	95.64
23	Drying-2	2.38	0.52137	96.16
20	Mechanical Grinding	2.03	0.444698	96.60
25	Laying-2	1.89	0.414029	97.02
17	Laying-1	1.62	0.354882	97.37
35	Absorption chiller	1.59	0.34831	97.72
28	Purchased electricity from the electricity establishment	1.52	0.332976	98.05
26	Pressing-2	1.45	0.317641	98.37
10	Boiler (produced)	1.43	0.31326	98.68
16	Pneumatic separator-1	1.13	0.247541	98.93
19	Pressing-1 after	0.96	0.2103	99.14
27	Pressing-2 after	0,87	0.190585	99.33
24	Pneumatic separator-2	0.78	0.170869	99.50
8	Woodyard other	0.45	0.098578	99.60
4	MDF Burner	0.43	0.094197	99.70
6	Chipping	0.35	0.076672	99.77
12	Compressor 4	0.34	0.074481	99.85
37	Transportation vehicles	0.22	0.048194	99.89
11	Compressor 3	0.2	0.043813	99.94
36	Losses 2	0.15	0.032859	99.97
7	PB Chipping MDF rate	0.05	0.010953	99.98
14	Glueing-1	0.05	0.010953	99.99
22	Glueing-2	0.03	0.006572	100.00
TOTAL		456.49		

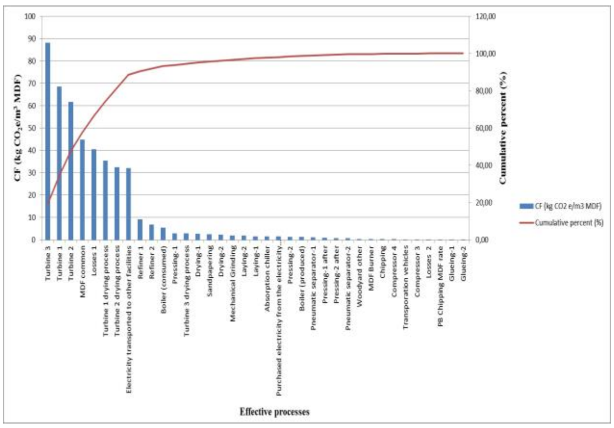

Figure 4. Application of Pareto analysis according to relationships between effective processes and carbon footprint values.

Evaluation of scenarios to decrease of CF: As seen in Table 3, plant's total carbon footprint was calculated as 24.04 kg-CO_2e/m^3-MDFtaking into consideration of all the processes for production according to scenario 1. The plant's total carbon footprint, taking into account of all the processes for production was calculated as 158.34 kgCO_2e/m^3-MDF according to scenario 2.

Table 3. Carbon footprints according to scenarios.

INPUT/ OUTPUT	Effective processes	CF(kg CO_2e/m^3 MDF)	
		Scenario 1	**Scenario 2**
Primary	Turbine 1	5.55	-
	Turbine 2	5.002	-
	Turbine 3	7.14	-
	MDF Burner	0.43	-
	Boiler	5.47	-
Primary Total		**23.82**	-
Secondary	Chipper	-	0
	Particle board Chipper MDF rate	-	0
	Woodyard other	-	0
	Sandpapering	-	0
	Boiler	-	0
	Compressor 3	-	0
	Compressor 4	-	0
	Refiner 1	-	0
	Gluing-1	-	0
	Drying-1	-	0
	Pneumatic separator-1	-	0
	Laying-1	-	0
	Pressing-1	-	0
	Pressing-1 after	-	0
	Mechanical Grinding	-	0
	Refiner 2	-	0
	Gluing-2	-	0
	Drying-2	-	0
	Pneumatic separator-2	-	0
	Laying-2	-	0
	Pressing-2	-	0
	Pressing-2 after	-	0
	Purchased electricity from the electricity establishment	-	0
	Electricity transported to other facilities	-	0
	Electricity sold to the state	-	0
	Turbine 1 drying process	-	35.45
	Turbine 2 drying process	-	32.55
	Turbine 3drying process	-	2.93
	Losses 1	-	40.54
	MDF common	-	44.91
	Absorption chiller	-	1.59
	Losses 2	-	0.15
Secondary Total		-	**158.12**
Primary and Secondary	Transportation vehicles	**0.22**	**0.22**
Total		**24.04**	**158.34**

Gorener and Toker (2013) by using Pareto Analysis method; calculated the firm engaged in forest products industry which is specialized on medium-density fiber production. They purposed to define and classify failure modes and then make offers due to their importance degree by Pareto analysis. They also researched the occurrence of waste process by applying Pareto analysis. Bergman et al. (2014) investigated the carbon effects of wood products. This research determines how carbon emissions savings when wood products are consumed in constructing buildings in place of non-wood sources. Çetin et al (2014) are used pareto analysis method on the scope and extent of extra work caused by management and workers' issues in Turkish furniture industry. In our research, according to the Pareto diagram, it was clearly seen that Turbine 3, Turbine 1, Turbine 2, MDF common, Losses 1, and Turbine 1 drying processes are the first six effective processes constituting 74 % of the total problem sources (Fig. 4). While these six effective processes cause 74% of total problem, here is no problem of in remain which is composed of 26% of 37 effective processes.

Dodoo and Gustavson (2013) developed numbers of scenarios about the effect of wooden frame design on the life cycle of primary energy use in buildings. So, comparisons are made on the energy use and effects of carbon footprint for traditional and thermal insulated houses with those scenarios (usage of electric resistance heaters, heat pumps, cogeneration based heaters, and biomass based energy source heaters). Scenarios are created to decrease of carbon footprint values. Carbon footprint value is reduced 89 % by the use of biomass instead of natural gas energy according to scenario 1. According to scenario 2, solar panels are used instead of electricity energy so the carbon footprint value is reduced 1.41 % in this case. The objective of this research is to present and define factors that decrease of efficiency through issues of management, production processes, supervision of workers and aspects of the products themselves, therefore helping enterprises acquire necessary measures. These researches was based on occurring cause effect diagram and evaluate the Pareto diagram to see the reasons which cause the highest emission problem(s).

CONCLUSION

In this study, it was demonstrated that the total amount of 6 effective processes which take place in sequences of 37 effective processes in the process correspond to 74 % of total amount of the processes with Pareto diagram by the help of 80/20 law. So primarily some improvements can be proposed for these 6 processes which are called Turbine 3, Turbine 1, Turbine 2, MDF common, Losses 1, and Turbine 1 drying process. It can be suggested that these processes may use biomass energy instead of natural gas as an energy source. Additionally, other renewables such as sun panels can be used as an energy source. Some best available techniques (BAT) can also be recommended. These techniques are explained below (Federal Environment Agency, 2011; BAT, 2014; Erdil, 2017; Erdil, 2018):

-Staff must be trained to develop environmental awareness periodically.

-Environmental management system must be applied for control of procedures and carry out responsibilities by personnel.

-Equipments' maintenance should be supplied regularly.

It is clear that, CF value is exhibited a very serious decline according to scenario 1 as a result of calculations mentioned in above. However, it seems that the biomass waste is not enough for obtaining energy as suggested in scenario 1. In case of being preferred scenario 1, biomass waste should be purchased out to carry out of this scenario. Also, it needs to be investigated in terms of cost and availability. On the other hand, installation cost of solar panels must be questioned for replacing the place of consumption of the electricity energy according to scenario 2. Furthermore, if the biomass wastes can be achieved to convert with high added-value products and high calorific products in MDF industry, which provide largely sustainable resources from forests, it will be achieved an environmentally friendly production.

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