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Cradle to Gate Life Cycle Assessment of Continuous Production for Solar Collector Selective Surface

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Abstract

In this study, a cradle-to-gate life cycle assessment (LCA) has been evaluated for the selective surface of solar collector which is commonly used in the production of renewable energy. The plant construction and production stages are investigated along with the use of technology and the recycling of raw materials in this assessment. The new production process is continuous and differs from the conventional batch systems in the respect. Product eco profile is obtained based on data from a live prototype plant in Istanbul, Turkey and its environmental impact is analyzed.

Keywords: LCA, Solar Collector, Selective Surface, Continuous System.

Güneş Kollektörü Seçici Yüzeyi Sürekli Üretimi için Beşikten Kapıya Yaşam Döngüsü Değerlendirmesi

Özet

Bu çalışmada, yenilenebilir enerji üretiminde yaygın bir şekilde kullanılan güneş kollektörünün seçiçi yüzeyi için beşikten kapıya yaşam döngüsü değerlendirmesi (YDD) yapılmıştır. Bu değerlendirmede, teknolojinin kullanımı ve hammaddelerin geri dönüşümünün araştırılmasının yanında, fabrikanın yapımı ve üretim basamakları araştırılmıştır. Bu çalışmada kullanılan yeni üretim prosesi süreklidir ve eski kesikli sistemlerden farklıdır. İstanbul, Türekiye'de üretimi olan ürünün ekoprofili kurulmuş bir prototip fabrikadan direk alınan data ile elde edilmiş ve çevreye olan etkisi analiz edilmiştir.

Anahtar Kelimeler: YDD, güneş kollektörü, seçici yüzey, sürekli sistem.

Introduction

Before innovative energy systems are introduced into the market, a thorough investigation of technical, ecological and economic aspects is necessary [1]. A life cycle assessment (LCA) can give the required ecological information. Since the interest on greener systems increases, to produce products with lower environmental impact became a priority.

The ecological investigation should take into account the full life cycle of that system. The energy need and the different environmental aspects of the various production steps showed that the energy balance is positive for thermal solar systems and that energy payback times on the order of several years only can be expected [2-5].

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Life cycle of products mostly consist of stages like raw material extraction, transportation, manufacturing, waste management, etc. The environmental impact of such stages of a product is obtained through LCA [6]. LCA presents a holistic environmental perspective, this result in LCA being a central concept for both environmental management in the industry and environmental policy making in public government. With this holistic perspective of LCA, all stages from material extraction to waste management/ recycling are described including the whole industrial system [7].

Most of the LCA studies of solar energy systems focus on the collector and the life stage [1,2,5]. On the other hand, in this study, the first comprehensive cradle to gate LCA of a solar selective surface produced from a new successful continuous system is detailed.

LCA Methodology

The LCA methodology developed during the 1960s is intended for analytical studies to promote reduction of a product's environmental impact, for example, or to identify environmentally critical phases during the life cycle of a product [8]. The LCA method has been widely used in many various studies of production, energy, including heating, ventilation, air conditioning systems, and etc. [3,9]. LCA is a very helpful tool in this regard. It provides a material and energy balance over the entire life of a material, product or service. It also helps determine its interaction with its environment and assessing its impact on the environment.

In a LCA it is very important to dictate the goals, objectives and investigation boundaries of the framework. The inventory analysis highly affects the results of the assessment. For example, if energy consumption is considered, this may differ from country to country [3]. There are following four interactive steps necessary for a complete life cycle study [9,10].

• *Planning*: The goals and the objectives along with the system boundaries have to be defined first whenever a life cycle assessment study is started.

• *Inventory analysis*: The quantitative input/output account of all matter that crosses the boundary defined in the goals and objectives phase.

• *Impact assessment*: This phase focuses on how the product affects the environment using both qualitative and quantitative approach to analyze the material use, energy demand, air pollution, waste, and effluent output streams.

• *Improvement analysis*: Enhancement on the system to reduce environmental burdens are investigated that may even result in product design changes, process changes, or change in waste management.

LCA of the Selective Surface Production with Continuous System

The continuous system is a newly developed technology that is used for the production of high efficiency selective surface using thin Cu plate by applying various processes. The production of the solar collector with the produced selective surface and life span of the selective surface are not taken into account. Therefore, cradle to gate LCA was carried out on the selective surface of 250000 m^2 area, which is a one year production. In Figure 1, the production phases of the system can be seen.

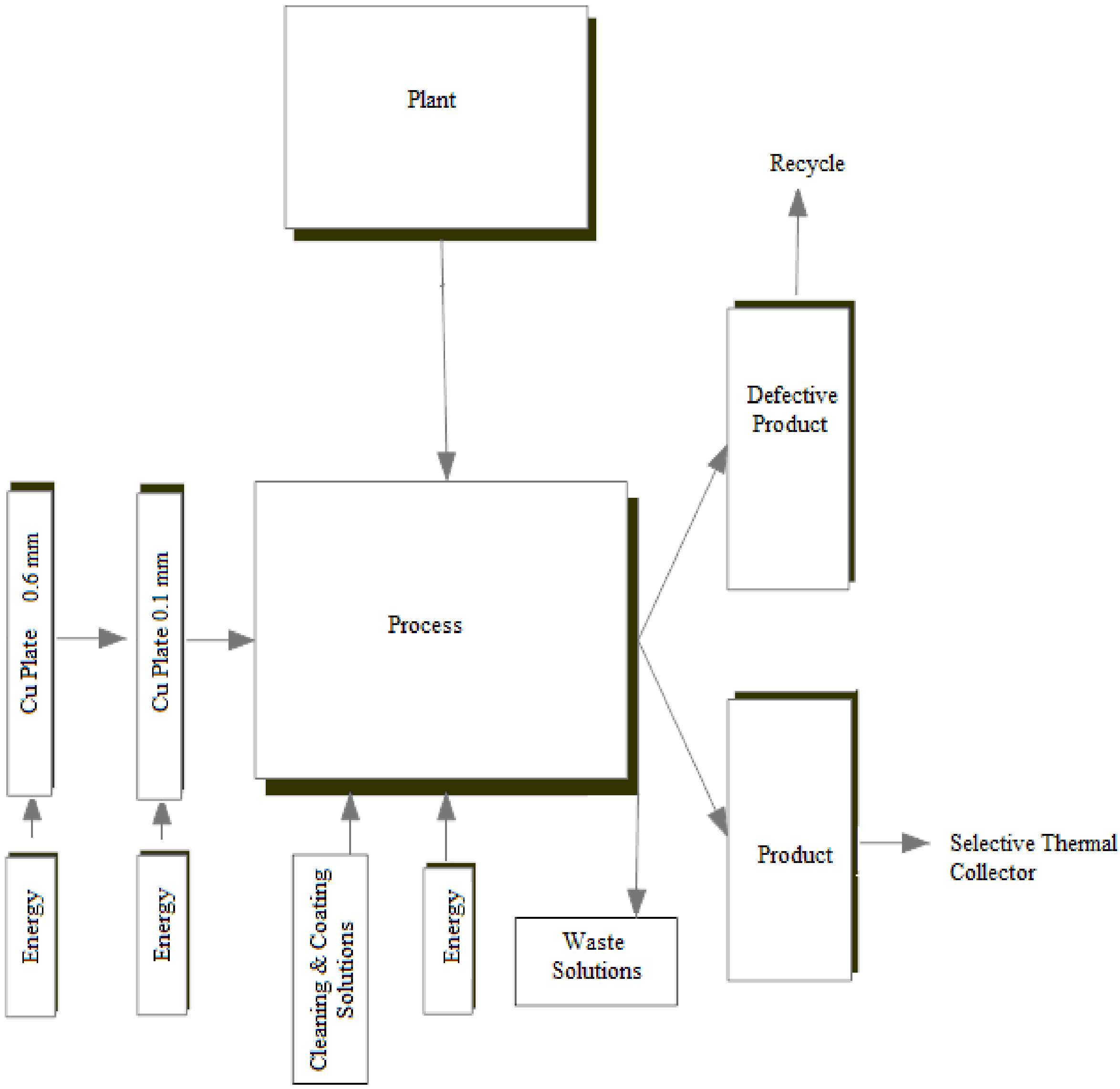

Figure 1. Schematic representation of the selective surface production

In the presented study, SimaPro7.3 software program was used for the calculations [11]. The production stages seen in Figure 1 were entered in the software's environment along with all the data collected from the production plant and the data which were not available on sight were directly taken from the library of SimaPro7.3 [12].

In the plant, selective surface can be produced with a speed of 1 $m \cdot min^{-1}$. The general flowchart of the continuous process presenting the main inputs is given in Figure 2. In this study, 4400 hours of active production time has been assumed per year containing 224000 kg Cu and 2225 kg Ni coatings. On the other hand, 80% of the produced surface is assumed to have emission and absorption specifications defined in related standards. The 44800 kg Cu in the remaining defective product is assumed to be recycled without any loss, however Ni coating (445 kg) is sent to waste. Thus, the functional unit (FU) was chosen to be 200000 m^2 per year.

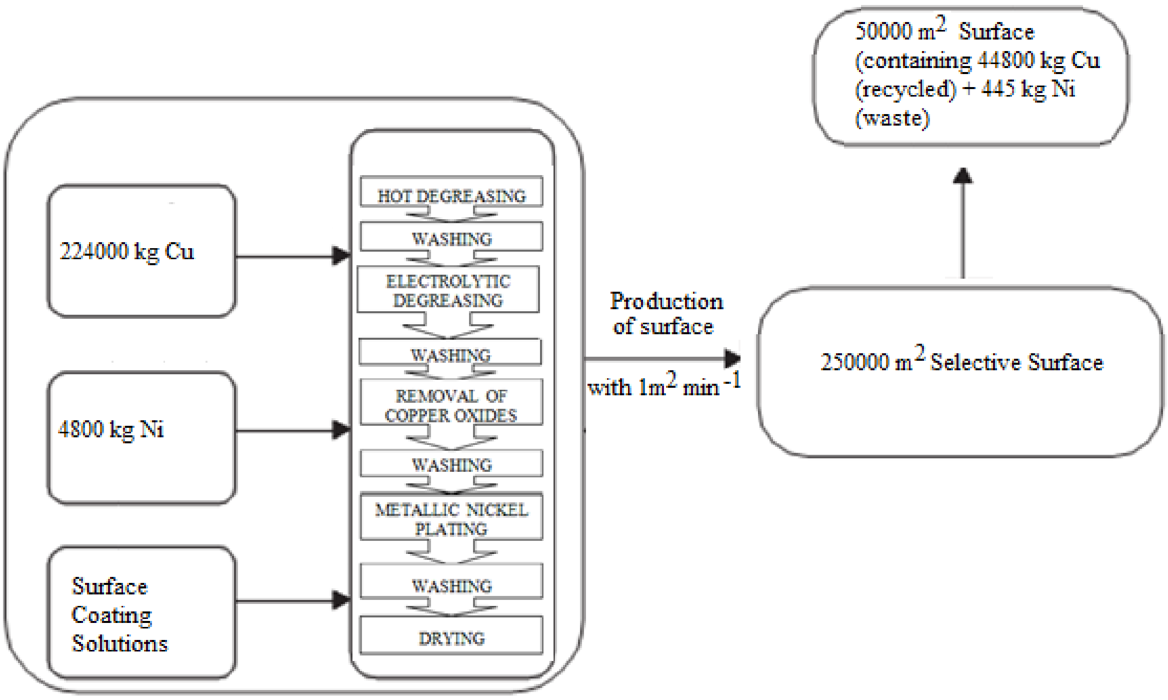

Figure 2. General flow chart showing the main inputs for the production of the selective surface (FU=200000m^2)

The selective coating process is realized on a 0.1 mm thick Cu sheet which is assumed to be obtained from 0.6 mm thick Cu sheet defined in SimaPro7.3 data base [12]. The data in the library represent a cradle to gate scenario for the production of 0.6 mm thick Cu sheet as used by end consumers including the end of life recycling of the material. The data set includes the burden and credit associated with the recycling of copper scrap (obtained by pyrometallurgy, as well as semi-fabrication clean scrap) during copper production, manufacturing and End-of-Life. For this, the current European average recycling rate is estimated to be 95%. The production process of 0.6 mm Cu sheet in principle is based on similar technology worldwide. The process route encompasses the following steps: mining and processing (concentrate production), hydrometallurgy (leaching, solvent extraction, electro winning) and pyrometallurgy (smelting, converting, fire refining, electrolytic refining). Copper cathodes are produced from both, the hydro- and the pyrometallurgical route. The semi-fabrication process for copper sheet includes the process steps melting and alloying, casting and rolling.

Additionally, input and output accounts for electricity consumption, metallic Ni, Na_2CO_3, Na_2SO_4, H_2SO_4, and also these concerning the plant and the facility are directly taken from the database libraries purchased with the software [12]. Since the technology presented in this study directly consumes the electric energy from the grid, the process letting the customers directly use the electricity from the grid was selected. Also, the library advises about the data set can be used for all LCA studies since the process includes the shares of national electricity production of UCTE member countries (in 2000) at the busba [12].

The module for 99.5% metallic Ni included the following technology: a mining done underground, followed by beneficiation through flotation with considerable amount of agents and lime addition. Overburden and tailings are disposed on the mining site and partly re-filled. Sulphur dioxide in the off-gas is recovered producing sulphuric acid. For electricity mix of 60% locally produced hydropower and 40% electricity at grid was chosen.

For the oil removal and cleaning processes Na_2CO_3, $NaS0_4$ and H_2SO_4 are being consumed as the main chemicals. Thus, the inventories of these chemicals again were taken directly from SimaPro7.3 database [12]. The data for Na_2CO_3 were obtained from the known modified Solvay process which delivers co-products of ammonium chloride and sodium carbonate. $NaS0_4$ inventory has been prepared from a mixture of three possible production ways: natural resources by evaporation and further treatment; by product out of chemical industry; main product from Mannheim process (NaCl and H_2SO_4). At last, H_2SO_4 inventory included the obtention of SO_2-containing gas (by means of oxidation of the sulphur containing raw materials: elemental sulphur, pyrites, other sulphide ores or spent acids) followed by the conversion of SO_2 to SO_3 and the absorption of SO_3 into solution (sulfuric acid in water) to yield sulphuric acid [12].

In addition, the plant equipments like pumps, electrolytic coating bath, water heater, stove, and etc. and two floored reinforced concrete building were also undertaken into considerations in order to achieve a full life cycle of the new developed technology. Since, with this enhanced assessment their contribution in the environmental impact could be calculated. For this, their life times were assumed to be 20 years. Since in this study, the LCA of one year of production is considered only 5% of their burdens were included into the inventory. For this, the corresponding data sets were selected from the SimaPro7.3 library [12].

Discussion

In order to do an enhanced cradle to gate LCA of the selective surface production with continuous system, three different methods were used. These methods are; Cumulative Energy Demand (CED); Greenhouse Gas Protocol; the Eco-indicator 99.

The cumulative energy demand of the system was calculated as $7.85x10^6$ MJ for 200000 m^2 net selective surface production per year using Cumulative Energy Demand (CED) method included in SimaPro7.3 software [13]. This energy demand is equivalent to 39.25 $MJ{\cdot}m^{-2}$. On the other hand, Turkish State Meteorological Service reports an average of 3.6 kW solar energy fall daily on a 1 m^2 selective surface [14]. A good solar collector transfers 80% of the incoming solar irradiance to water as heat. Then the amount that is transferred to the collector can be simply calculated as follows:

$$3.6*0.80*3600=10.368 \text{ MJ}{\cdot}m^{-2} \qquad (1)$$

According to this calculation the payback time of the corresponding selective surface will be 39.25/10.368= 3.8 days. However, in the literature it has been reported that only 1% to 4% of the thermal solar energy systems cumulative energy demand is used by the selective surfaces [2,5]. To be able to calculate the real energy payback time, it is also very important to obtain the primary energy demand during life time which is defined the energy quantities consumed by final users. Thus, the net energy feasibility and saving cannot be stated in this paper.

In Figure 3, absolute total energy demand percentages (with 1% cutoff) can be seen. The process to obtain 0.1 mm thick Cu sheet has 60% energy demand which is the highest energy demand among the other processes. However, the coating processes in the continuous system

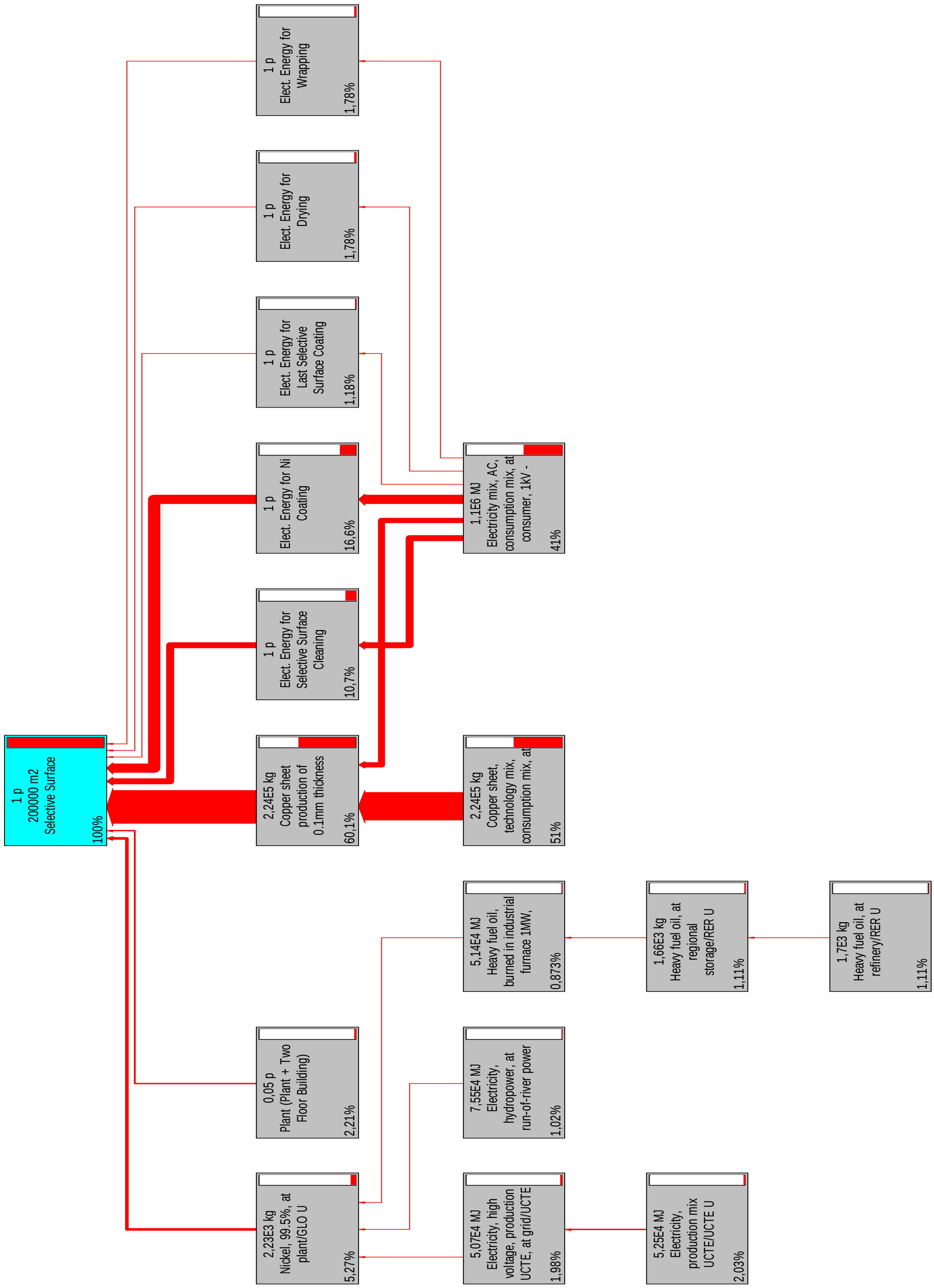

Figure 3. Cradle to gate absolute total energy demand percentages (with cutoff 1%)

uses only 32% of the total energy consumed as seen in Figure 3. The energy demand of the plant and the building were calculated as 2.2%.

As expressed before, the inventory for Ni was taken from the library of the program. The data set designed in the library did not considered any recycling of Ni metal. Thus, all the Ni used in the selective surface was taken from the ore resulting with energy demand of 5.27%, which was higher than the expectations, since in the production of the selective surface Ni has only 1% of place.

In Figure 4, greenhouse gas emmisions percentages (with 4% cut off) can be seen calculated using The Greenhouse Gas Protocol method [15]. Even though the plant equipments and building had small contribution to total energy demand with 2.2%, their contribution to the greenhouse gas emissions is 20.6% as can be seen in Figure 3. This variation is due to important amounts of CO2 emissions in productions of the concrete, iron, steel, cement, brick, and polypropylene bath, in which these processes are included to the LCA as parts in plant equipment and building. In contrary, the effect of Cu sheet production decreases to 23%. This is due to the fact that there are great amounts of greenhouse gas emissions realized from production of Ni from ore, production of cement, steel, iron, concrete, brick, and polypropylene and consumption of conventional energy kinds like natural gas and heavy fuel oil.

Greenhouse gas emissions can be expressed either in physical units (such as grams, tones, etc.) or in terms of CO2 equivalent (grams CO2 equivalent, tones CO2 equivalent, etc.). Thus, CO2 equivalent term became an important representation of a products ecoprofile and it found its place on the products label. The cradle to gate greenhouse gas amount was obtained as 64200 kgCO_2 and with this value CO_2 equivalent of the selective surface production could be calculated as follows:

$$64200 \text{ kg } CO_2/200000 \text{ m}^2 = 0{,}321 \text{ kg/m}^2 \quad (2)$$

At last, to simulate the environmental impact of the continuous system used in the selective surface production the Eco-indicator 99 (H) V2.08 / Europe EI 99 H/A was used, where (H) represents hierarchist version and A refers to the average weighting set and H refers to the weighting set belonging to the hierarchist perspective [16]. In the hierarchist perspective the chosen time perspective is long-term, substances are included if there is consensus regarding their effect. In this method the weighting factors for Ecosystem quality is 40%, resources demolition is 20%, and human health is 40%.In addition, in the hierarchist perspective damages are assumed to be avoidable by good management.

As it can be seen in Figure 5, cradle to gate environmental impact percentages are shown with a cut of 4%. As expected, 0.1 mm thick Cu sheet production and Ni production have the highest environmental impacts with 42.4% and 37.4%, respectively. The environmental impacts of the coating processes were under 10% and impact of the plant was as low as 2.2%.

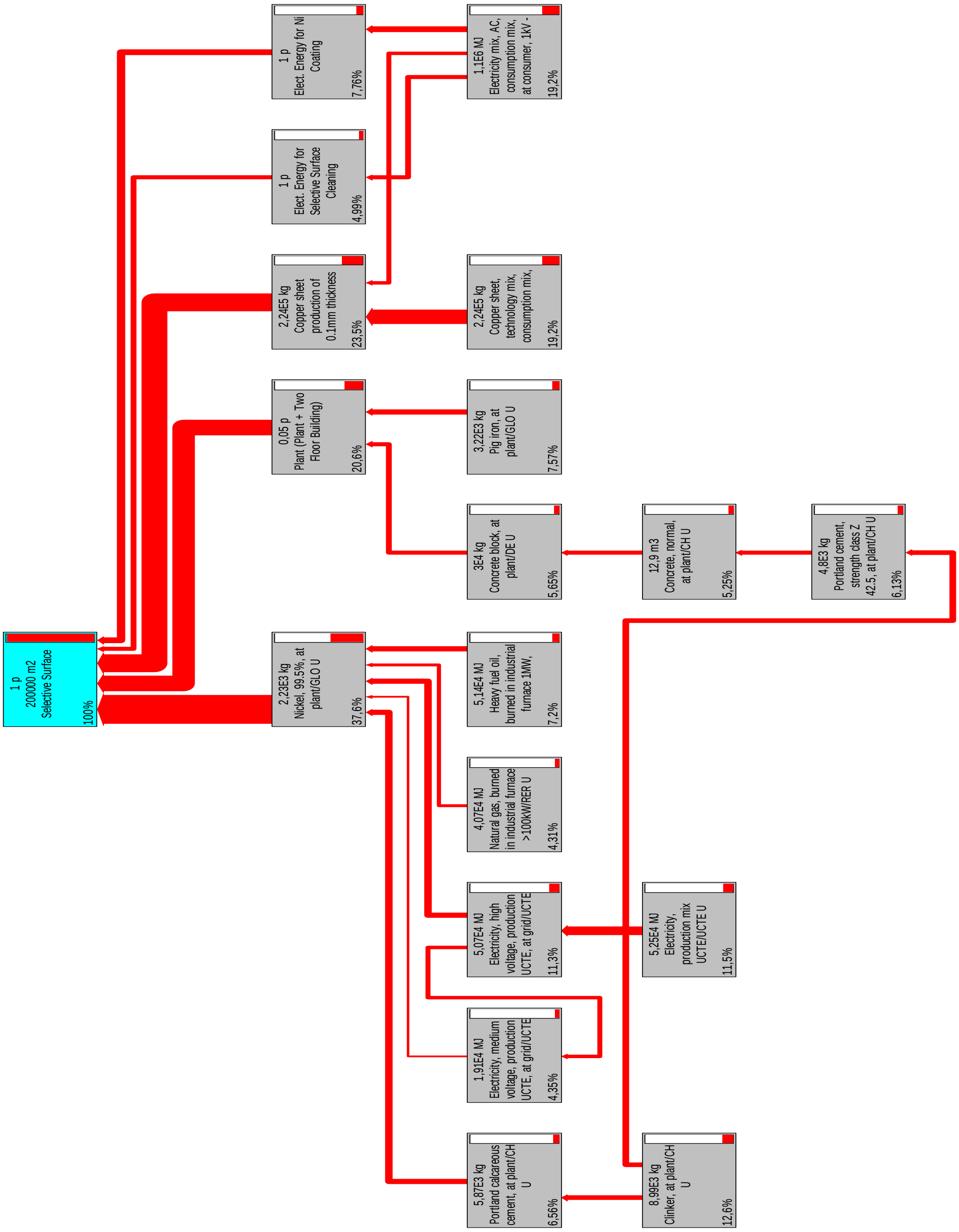

Figure 4. Cradle to gate green gas emmisions percentages (with 4% cut off)

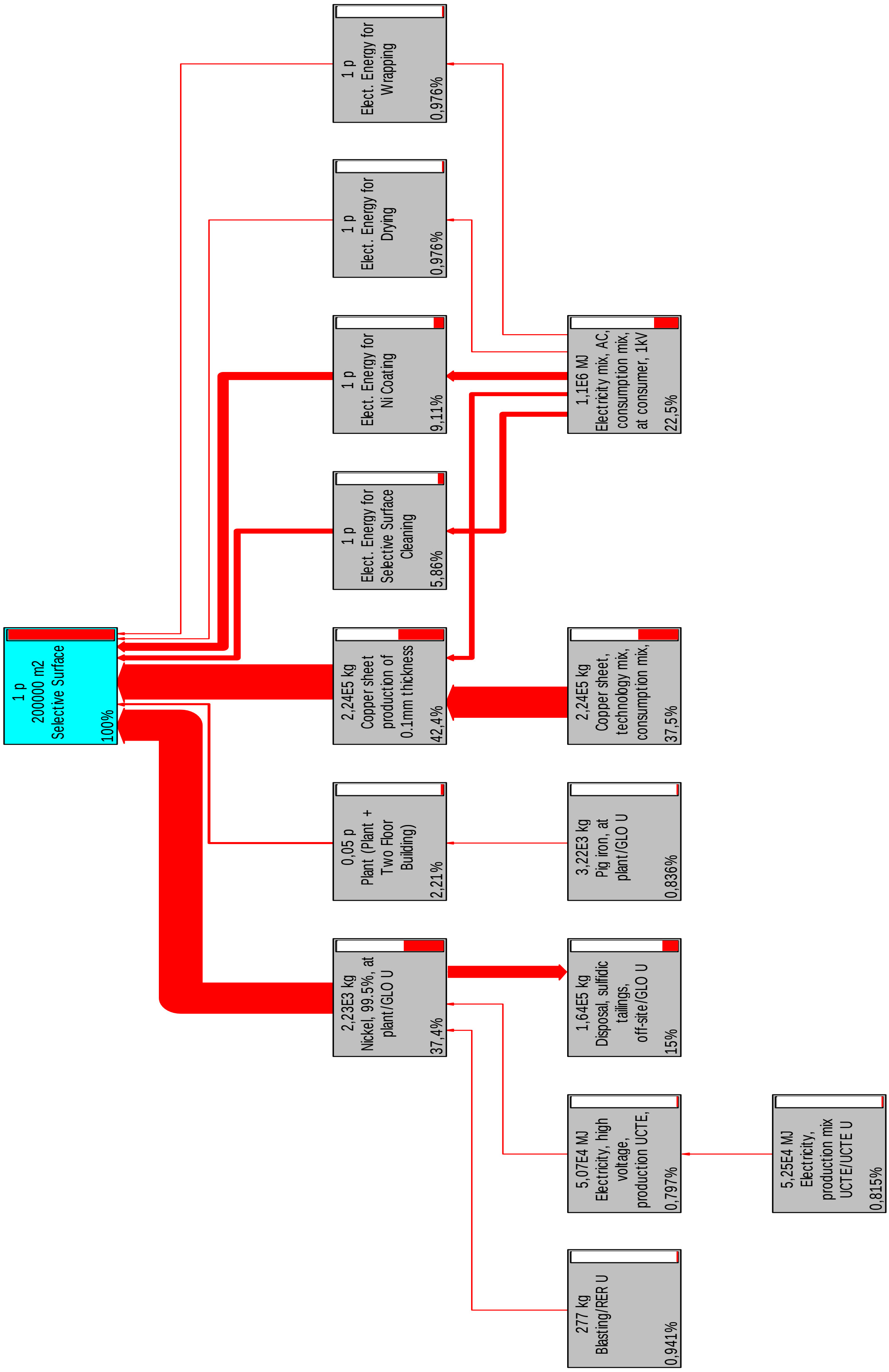

Figure 5. Cradle to gate environmental impact percentages (with 0.8% cut off)

Conclusion

The study presents the results of a cradle to gate LCA performed for the production of a selective surface using a new continuous process. The researched showed that only taking into account of the selective surface, energy payback time was calculated as 3-4 days.

The important point resulted from this study is that the production of the selective surface in the plant along with the process steps had a smaller environmental impact and greenhouse gas emissions compared to the mining processes of Cu and Ni. The recycling of Cu was proposed as 95% in the database taken from the European standard but this amount is believed to be 98-99% in Turkey, since the manual labor is cheap. Thus recycling of the materials have very important effect in obtaining the environmental burdens.

Also, the plant under consideration was taken as a small plant. Thus, a real big plant that can produce more amounts of selective surface would decrease the environmental impact per area. In addition, with a bigger plant consuming energy from natural gas instead of the local grid would also decrease the energy demand, greenhouse gas emissions, and environmental impact to more desired values for the heating and cleaning processes per area.

In addition, producing energy from the thermal collectors specifically using the selective surface produced with continuous system would have much lower energy demands, greenhouse gas emissions, and environmental impact compared to producing same amount of energy using conventional resources.

At last, a comparison of conventional solar collectors LCA with the presented continuous system in this paper should be done using cradle to grave approach as a future work.

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