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Identification of Significant Impact of Silicon Foundry Sands Mining on LCIA

Jozef Mitterpach [1,*], Emília Hroncová [2,*], Juraj Ladomerský [2] and Karol Balco [3]

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1 Department of Environmental Engineering, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, T.G. Masaryka 24, Zvolen 960 53, Slovakia
2 Department of Environmental Management, Faculty of Natural Sciences, Matej Bel University, Tajovského 40, Banská Bystrica 974 01, Slovakia; juraj.ladomersky@umb.sk
3 ZLH Plus a.s., Zlievarenská 533, Hronec 976 45, Slovakia; balco@zlhhronec.sk
* Correspondence: xmitterpach@tuzvo.sk (J.M.); emilia.hroncova@gmail.com (E.H.); Tel.: +421-455-206-417; Fax: +421-455-206-279

Abstract: This paper presents a case study based on a LCA (Life Cycle Assessment) research program of the silicon foundry sand (SFS) due to the large quantity of produced waste foundry sand (WFS). The foundry waste is a high priority sector within the growing European foundry industry. It is necessary to understand the full life cycle of the foundry waste in order to correctly identify magnitude and types of impacts it has on the environment. System boundary includes the processes: mining, modification, packing, storage and transport to foundry. Inventory analysis data were analyzed and finally converted to the functional unit, which has been defined as one ton of SFS. The resulting environmental impact of SFS production in endpoint is: consumption of natural resources 70.9%, ecosystem quality 18.2% and human health 10.9%. The following portions, with respective percentages, have the greatest overall effect on these results: diesel fuel consumption 32.4% and natural gas consumption 28.7%, electricity usage 17.2%, transport 12.2%, devastation caused by the SFS 5.35% and oil (engine, gear and hydraulic) consumption 4.14%. The highest contributor to the diesel fuel consumption is the SFS exploitation. The overall effect of desiccation was 35.8% and was caused by high consumption of resources and electricity.

Keywords: life cycle assessment; sand; mining; foundry; environmental engineering

1. Introduction

This paper is based on a LCA research program of the silicon foundry sand (SFS) production in central Europe (Poland). It also relies on important EU documentation [1]. Europe 2020 strategy sets out a strategy that aims to boost growth and jobs by maintaining and supporting a strong, diversified and competitive industrial base in Europe offering well-paid jobs while becoming more resource efficient [2]. In regards to this concept, the important aspect according to the COM (2011) 21 is that natural resources underpin the functioning of the European and global economy and our quality of life [3]. These resources include raw materials such as fuels, minerals and metals and also food, soil, water, air, biomass and ecosystems. Continuing in the current patterns of resource use is not an option.

Therefore, this work deals with identification of important factors that influence the quality and the amount of natural resources used in mining and exploitation of foundry sand. New solutions are being found to eliminate negative impacts on the environment arising from raw materials (resources) extraction and material handling and transport to the point of their next utilization and finally to the waste generation.

There is increasing environmental pressure from European consumption and production [4,5] and Roadmap to a Resource Efficient Europe [6] initiatives that talk about key condition of sustainable consumption implementation. The Resource-efficient Europe—Flagship initiative is part of the Europe 2020 Strategy and it is a flagship initiative for a resource-efficient Europe.

Regarding the fuel consumption aspects and overall energy demands in sand production, the arrangements respect the commitment where the agreed cut of 20% from 1990 levels by 2020, together with a 20% renewables target, was a crucial step for the EU's sustainable development and a clear signal to the rest of the world that the EU was ready to take the action required. The EU will meet its Kyoto Protocol target. It has a strong track record in climate action [7] and it exerts an effort to its fulfillment.

There are several possibilities on how to obtain compliance with all of these requirements, one being gathering of information through life cycle assessment (LCA) analysis according [1,8]. Method of Life Cycle Assessment is one of the techniques used for environmental care management, completing the Environmental Impact Assessment (EIA), Hazard Identification, Risk Assessment, Technology Assessment, Control audits of waste management, Design for the Environment and Product Stewardship Management System Standards (SETAC) [9].

Life cycle assessment is a powerful "system analysis" tool, used to study environmental aspects and potential impacts of a product or service system throughout its life cycle (from raw material extraction through materials' processing, manufacture, distribution, use, repair and maintenance, disposal or recycling, up to transportation). It is effective and can be used in various ways to determine environmental impact of a product or service system [10–14]. A few large mining companies have used it for a project and process selection [15]. Some published studies have also compared the environmental impacts of various production methods [16–18]. Other studies investigate the EMS implementation in the mining sector [19,20].

There are research works which main objective is to obtain sands for different industry sectors [21]. Here the author applied the evaluation method for CML fine sand used as addition to concrete composition. The selection of evaluation method is a key part to meet the study objectives. The results from these studies vary considerably. In general, we can say that the studies deal mostly with calculation of GHG emissions.

Data required for assessing the mining impact on the quality of ecosystem come often in variety of formats, or are simply missing, which complicates precise identification of mining impact categories of the common (that intersect) effects of foundry sand mining on the quality of ecosystem.

According to Durucan *et al.* (2006), only very little is being done to improve data quality, and essential mining process details which affect the ultimate environmental impacts are rarely taken into account [22].

Further work is needed to develop a more simplified framework of indicators for small-scale mining and for small-to-medium enterprises since they, together with large organisations, play a significant role in the sector's efforts to achieve sustainability [23].

Impact category selection is based on the EU strategies and more recent indicator requirements listed in [11–13,24]. For example, the Europe 2020 strategy or the Roadmap to Resource Efficient Europe have much shorter delivery timeframes. This emphasizes the need for more flexible approaches to indicator requirements using already available datasets, those coming on stream from processes like GMES, and data modeling techniques such as those offered by environmental accounting. Impact category selection for the SFS production is also based on e.g., [25] and other research papers mentioned in this work.

The main objective of this work is a life cycle assessment study of the impact of the SFS production (mining of raw material/silicon sand) on the environment in Poland (central Europe). Selected company belongs to the major sand producers in the European Union. Sand is used in foundry industry, inputting as SFS and outputting as waste foundry sand (WFS). The important fact remains, that the consumption of sand is the consumption of non-renewable resources. Further presumption exists about the demandingness during the extraction phase of raw materials required for the consumption of other exhaustible resources (petroleum, oils, *etc.*). After a rigorous analysis of all processes associated with foundry sand mining in its initial phases of life cycle, or so called "cradle" phase, the consumption of non-renewable resources was identified as having important impact on the environmental impact assessment.

In our study, we have tried to develop a model and evaluate the data using Eco-indicator 99, given the nature of the premises and its operation. Our work gives an overview of the SFS life cycle phases from the mining of raw materials to their transport to next utilization in the foundry industry. The unit processes associated with such mining, modification, packing, storage and export and transport to next utilization are included. Transport of the sand by Silo trucks was also monitored. Data processing of this part of life cycle forms a valuable base for other studies where system boundaries are set up as "cradle-to-grave" and for comparative analyses or software database applications for further assessments. Continuous efforts are being made to adjust the operation of the SFS center for the sand processing to make it consistent with the latest EU guidelines concerning pivotal areas. It is important not only to reduce the negative impact of SFS on environment but also to capture the innovative trend towards more economical green technologies. Implementation of EU priorities through LCA analysis presents an inception of possible changes in environmental, social and economic impacts.

2. Materials and Methods

The analysis was elaborated using the LCA methodology. The International Organisation for Standardisation (ISO) provides guidelines for conducting a Life Cycle Assessment within the series ISO 14040 and 14044 [8,26]. The intended application of LCA results is considered during the defining of the goal and scope, but the application itself stands outside the scope of the International Standard ISO 14040:2006 [26].

Transdisciplinary integration framework for life cycle sustainability analysis describes in publication [27]. There are many LCA methodologies used in the research community such as Process-LCA, EIO-LCA, Hybrid LCA, *etc.* described by authors [28–30].

Data were evaluated using the SimaPro software [31], which allows to work with the current database applications. Used Eco-indicator 99 method is one of the most widely used impact assessment methods in LCA and it allows to express an environmental load of a product in a single score. The most critical and controversial step in the methodology is weighting. In the Eco-indicator 99 method, normalization and weighting are performed at the level of damage category (endpoint level in ISO terminology). There are three main damage categories, Human Health, Ecosystem Quality and Resources consumption, and the results from selected group indicate that the damage to human health and damage to ecosystem quality are about equally important while damage to resources consumption is considered to be about half as important. The damage function presents the relation between the impact and the damage to human health or to the ecosystem quality. This method was developed based on the contribution of several Swiss Experts and the National Institute of Public Health and the Environment [31].

The production program of the company is focused on the exploitation, mining and processing of silica sands. The main scope is the production of molding sands for the foundry industry and glass sands with an annual production of approximately 1,000,000 t of sand.

Some supplemented data of the inventory analysis, which were identified as important, provided the identification of the results for the defined system (for each unit process and for the defined functional unit of the modeled system product) within the frame of selected system boundaries.

2.1. Definition of the Goal and Scope in the SFS Production

The main aim of this LCA analysis is the evaluation of the SFS impact on the environment. Further, the study also deals with the identification of the pivotal elements of the suggestions leading to the permanent maintenance and economical green technologies in the mining step of the SFS life cycle. Data were collected by the systematic acquisition directly from the technology consumption and production, from the documentation and from the chief technologist as well. Qualifications and quantifications of the inputs and outputs are listed in Figure 1 and Table 1.

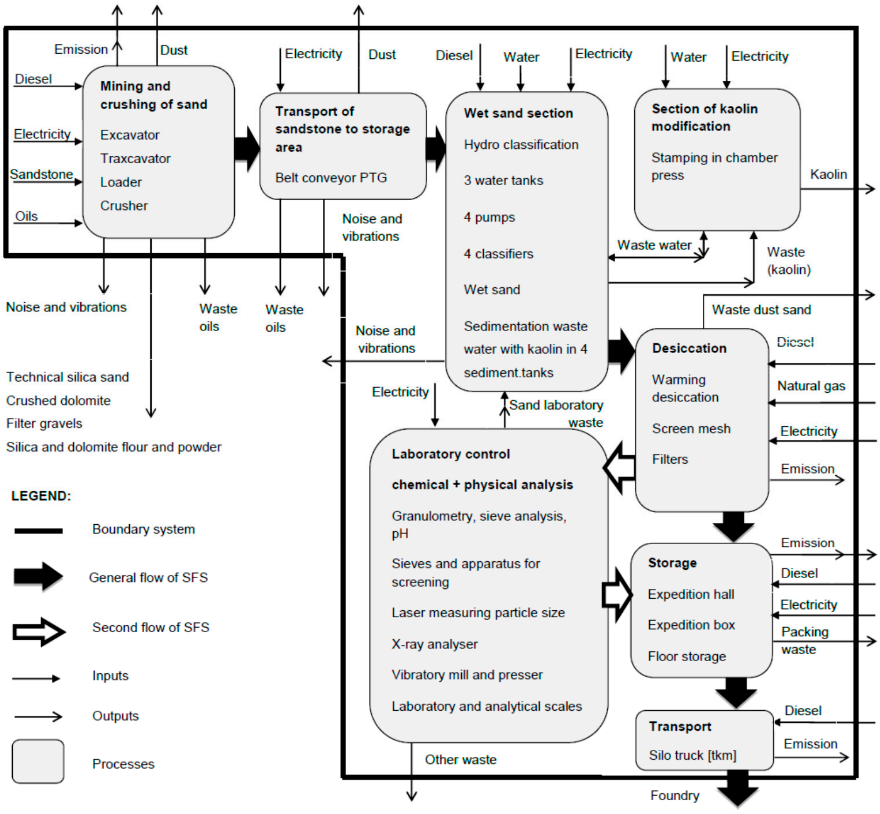

Figure 1. LCA Scheme of the SFS production.

Table 1. Inputs and outputs of the SFS processes.

Inputs	Process	Unit	Qnt.
Sand rock	Mining	t/t	**1.03**
Water	Hydro classification	m^3/t	**0.01**
Gas	Desiccation	m^3/t	**11.0**
Oil	Mechanisms	kg/t	**1.11**
Electricity	Mining	kWh/t	3.60
	Kaolin process	kWh/t	1.20
	Hydro classification	kWh/t	3.30
	Desiccation	kWh/t	4.20
	Wastewater treatment	kWh/t	2.10
	Illumination	kWh/t	0.60
	Sum	**kWh/t**	**15.0**
Diesel	Mining	kg/t	6.9
	Kaolin process	kg/t	2.1
	Desiccation	kg/t	1.06
	Mechanisms	kg/t	0.53
	Sum	**kg/t**	**10.59**
Output Kaolin	Kaolin process	t/t	**0.03**

2.2. System Boundaries of the SFS Production

The boundaries for the SFS system were defined from the cradle to the transport for the next utilization. System boundaries represent a set of criteria specifying which unit processes are part of the SFS product system. Processes in the SFS production with the defined system boundaries include following unit processes: mining, transport to modification, hydro classification, desiccation, kaolin section, laboratory control (physical and chemical), packing, storage and expedition. Due to the fact that the SFS production is located in central Europe, the SFS transport is provided by the road transport using Silo trucks. Silo truck represents the truck transport to the foundry, where the SFS is used in subsidiary processes of the foundry industry. Producing high quality SFS for BATNEEC steel cast iron and cast iron provides its sales to a few hundred km, for example to Slovakia. Additional supplementary processes, which are outside of the selected system boundaries, involve kaolin production for porcellanite and sanitary products; production of ceramic tiles; production of filter sands; and technical sand, quartz silica powder and dolomite powder. System boundaries, unit processes, inputs and outputs are depicted in Figure 1.

2.3. Inputs and Outputs of the SFS Production

The general reference flow implies from Figure 1. Noise, vibrations, production of filter gravel, technical sand, silica and dolomite powders, wastes arisen during the production, and laboratory waste are not taken into account because of their slight significance.

The constituent inputs and outputs of the SFS production are presented in Table 1 and depicted in Figure 1.

Data are converted to the functional unit 1 ton (1 t) of the SFS, which allows the use of LCA for further analysis and simultaneously it is appropriate for the quantification of the obtained data and for the overall application of the study.

2.3.1. Mining and Exploitation of Sandstone

The basic starting material for the SFS production is 1.03 t of a sandstone. Sandstone is obtained by uncovering soil layer surface with the excavator (diesel 1.3 kg/t, oil 0.176 kg/t). Subsequent disruption of a sandstone rock in a checkboard manner is done by the traxcavator TD-40G (diesel 3.2 kg/t, oil 0.276 kg/t). Disrupted sandstone is loaded by the loader (diesel 2.4 kg/t, oil 0.276 kg/t), which is subsequently emptied into the crusher (electricity 1.58 kWh/t, oil 0.069 kg/t). After mining, the crushed sandstone is transported by the belt conveyor to the process of hydro classification. Belt conveyor is also used for the transport of SFS between the unit processes of modification. Considered inputs in this step are the total consumption of the belt conveyors (length 4.5 km, electricity 2.02 kWh/t, oil 0.069 kg/t). Data for emissions, which are produced by frequently used equipment and mechanisms, are not available. Therefore, for example, the total consumption for the mining, forklift (storage) and Silo truck was used for the calculation of the emission (Table 2) in this case, using the emission factors for heavy lorries with diesel engines over 3.5 t [32,33].

Table 2. Examples of chosen mechanisms and emissions of the production of 1 ton of SFS with consumption of diesel (mining 6.9 kg, forklift 0.53 kg, silo truck 5.36 kg).

Consumption/Production	Unit	Mining	Forklift	Silo Truck
Cd	µg/t	0.07	0.01	0.05
Cu	µg/t	11.7	0.9	9.1
Cr	µg/t	0.3	0	0.3
Ni	µg/t	0.48	0.04	0.38
Se	µg/t	0.07	0.01	0.05
Zn	µg/t	6.9	0.5	5.4
CO_2	g/t	21,652.2	1663.1	16,819.7
CH_4	g/t	1100.4	99.8	1009.2
CO	g/t	135.9	11.1	105.6
NOx	g/t	242.2	18.6	188.1
VOC	g/t	33.1	2.5	25.7
PM	g/t	7.6	0.6	5.9
PAH	g/t	1.7	0.1	1.3

2.3.2. Hydro Classification

Material extracted from the mining step is emptied from the belt conveyor to a storage area, from which it is loaded by the loader (diesel 2.1 kg/t, oil 0.276 kg/t) to the process of hydro classification. A suspension of sand and water represents the raw input material into the hydro classification process. During this process, the extracted sandstone grains are separated from the layers of kaolin, which encloses the sandstone. Water is pumped from the mining valleys, where it was accumulated after the sandstone extraction from the ground and rain water, water which seeped through the kaolin tank and also from the water from the kaolin cleaning itself.

The pump (electricity 3.3 kWh/t), which is under pressure, ensures a steady supply of the suspension to the storeyed hydro classifier, which consists of 4 hydro classifiers. The effect of gravity energy removes kaolin. Grains separated from the kaolin sandstone, with the size of 0.4–0.5 mm, are used in the foundry processing. To obtain products for other industrial fields, e.g., glass sands, spiral separators are used. Overflow from the process of hydro classification occurs in the form of the finest fractions containing clays, water with the content of kaolin and separated sand fraction. Sand assorted into the fractions is collected in storage boxes, which serve for pre-drying. The total water consumption in the process of hydro classification is 0.01 m^3/t.

2.3.3. Kaolin Processes and Waste Water Management

Water, which contains the finest fractions and clays, is transported by a pipeline, with the help of pumps, to the three settling tanks, where the water and kaolin are cleaned from the residual contaminants. The depth of the settling tanks is approximately 5–7 m with a slight scope for a faster process of sedimentation. Water is purified and returned to the process of hydro classification by the pump (electricity 2.1 kWh/t), with the output of 500 m^3/h. In the neighborhood of the settling tanks, collecting lakes are located. They collect the water, which seeped from the factory ground and collected water is then used in the process of sedimentation, where it needs to be purified and pumped into the process of hydro classification. Kaolin is rolled up from the settling tanks by the loader (diesel 2.1 kg/t, oil 0.276 kg/t, implicated in the process of Hydro classification) and further it is conveyed to the filter press. After the separation of the sand fraction and subsequent sedimentation without chemical additions, kaolin is molded in chamber press (electricity 1.2 kWh/t). Finally, compact kaolin is stored in a dry place to prevent re-wetting and it is sold to the tiles and ceramic manufacturers. The overall production of the kaolin is calculated to 0.03 t/t of the SFS.

2.3.4. Desiccation

Separated sand fractions are transported by the belt conveyors to the fluidized bed dryers. Desiccation output is 60 t of sand in 24 h and the captured waste sand is returned to the production. Desiccation takes place in three modern bed dryers of Finnish manufacture, which are based on the drying of moist air by the supply of natural gas while the dust is captured by the dry filters, which are regulated by the pressure differentiation. Filters are cleaned automatically during the operation by the pulses of compressed air. The dried materials are stored in silos or containers for transport. The loader (diesel 1.1 kg/t, oil 0.161 kg/t) is responsible for the manipulation with the dried sand as well. The gas consumption in this process represents 11.0 m^3/t and the total electricity consumption for this unit process is 4.2 kWh/t. Output emission production for the process of desiccation is characterized in Table 3.

Table 3. Output emission production from the desiccation process.

Emission	Unit	SO_2	NO_2	CO	PM
D1 E max	kg/h	0.015	0.096	-	1.092
D2 E max	kg/h	0.014	0.09	-	5.236
D3 E max	kg/h	1.026	0.9	-	19.847
Total	kg/h	1.041	1.01	0.09	26.175

2.3.5. Laboratory Control

This section involves the chemical and physical analysis of the sand quality before the expedition. The chemical analysis using X-ray method is performed in the main laboratory. A sample is ground in a vibration mill, after it is pressed by a vibration press it continues to the melting apparatus, where the purity of a sample is defined. The physical laboratory provides the sieve analysis and measures the level of sand humidity, pH and weight of a sample. The basic features of SFS are characterized by the chemical composition of: SiO_2 99.35%, Fe_2O_3 0.05%, carbonates 0.08%, mean grain size D500.39 mm, main fraction 0.40/0.315/0.20; binder 0.11%; homogeneity index 90%; sintering point 155 °C; humidity max. 5.5%; permeability 490 m^2. The electricity consumption for the heating, illumination and running of technical equipment (0.3 kWh/t) is included in the total illumination (0.6 kWh/t). Other inputs and outputs have not been included.

2.3.6. Expedition and Transport

Three basic types of expeditions are used in the center for SFS production. The first one involves the storage in the shipping boxes using cranes, which load the sand into wagons or trucks with a tilting system. The second type involves the expedition in packaging materials and the sand is packed and transported in returnable Big Bag containers (1.0 to 1.3 tons) or in paper bags (25 kg) on EUR pallets, which are secured by stretch follies (another waste). The sand manipulation is provided by the forklift (diesel 0.53 kg/t, oil 0.026 kg/t). In the study, the last type of expedition was analyzed. This type of expedition involves Silo trucks, vehicles with special silo trailers. With the help of compressed air, the SFS are blown into the trailers (Silo truck, 28 t). The Silo truck is able to pump the sand into reservoirs directly to the usage place in the foundry. The model SFS transport distance is 100 tkm, in this case 100 tkm = 1 $t_{MATERIALS}$ x 100 $km_{DISTANCE}$.

3. Results and Discussion

3.1. Results of the Assessment of the SFS Production

Inputs and outputs (Figure 1, Table 1) are included into the particular negative effects within the frame of selected endpoints (sources, ecosystem quality and human health). Total electricity consumption (Figure 2) of 15 kWh/t represents the ratios of electricity consumption in particular SFS processes. Diesel consumption (Figure 3) represents the ratios of diesel consumption in the SFS processes. Other important consumptions are natural gas 11.0 m^3/t, oil 1.11 kg/t, water 0.01 m^3/t and sand 1.03 kg/t (Table 1).

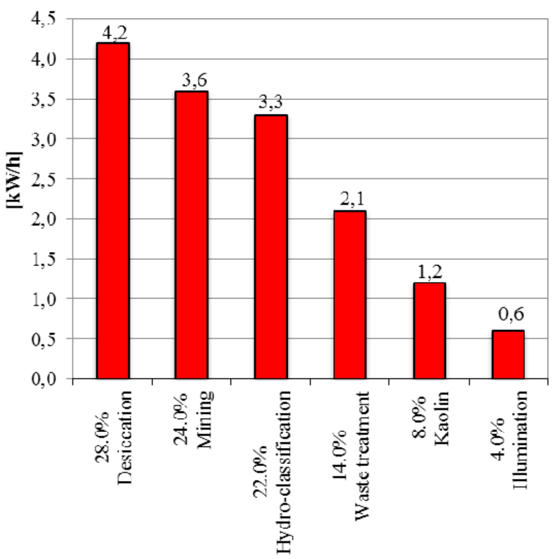

Figure 2. Electricity consumption during SFS production.

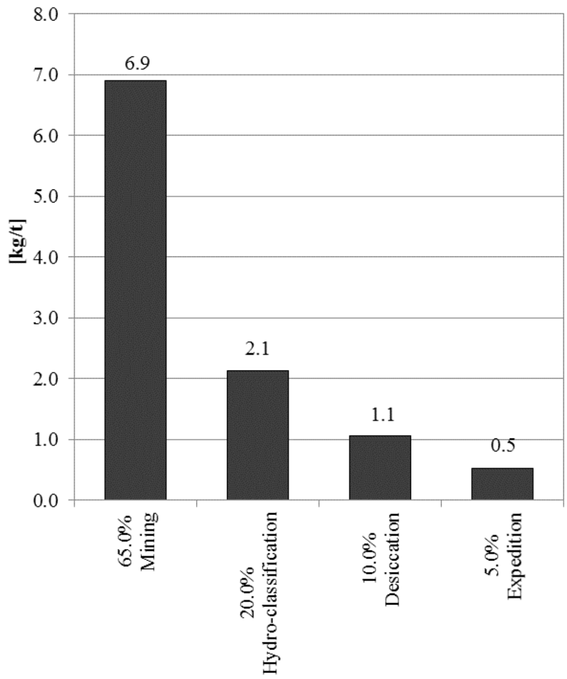

Figure 3. Diesel consumption during SFS production.

The results of LCA study of the SFS production (with system boundaries from cradle—to caudal gate—to the transport) are calculated to the percentage ratios in the particular groups of impacts. The adjustment of the databases, included in the software, allows the elaboration of the study and evaluation of the SFS life cycle in the selected and further selectable LCA scope. Whole system remains multivariable and it could be simulated further.

The greatest overall effect on these results has the consumption of diesel 32.4% and natural gas 28.7%, the consumption of electricity 17.2%, transport 12.2%, devastation by the SFS 5.35% and the consumption of oils 4.14% (Table 4, Total). The highest contribution (65%, 6.9 kg/t) to the diesel consumption is connected with the processes of the SFS exploitation. The percentage impact of the SFS production on the environment received from the LCA study in the endpoint is: natural sources consumption 70.9%, ecosystem quality 18.2% and human health 10.9% (Table 4, Share).

Table 4. Results of the assessment of the SFS production in endpoints, Eco-indicator 99.

Endpoint	Resources	Ecosystem Quality	Human Health	Total Impact
Unit	%	%	%	%
SFS devastation	0	5.35	0.00	5.35
Diesel	29.80	0.54	2.06	32.40
Natural gas	27.40	0.26	1.01	28.70
Oil	3.57	0.16	0.40	4.14
Silo truck	0.81	10.90	0.49	12.20
Electricity	9.26	0.96	6.94	17.20
Share	70.90	18.20	10.90	100.00

Concerning unit processes included in mining, the consumption of non-renewable resources was identified to have an important impact. Table 4 show that the largest contribution to the non-renewable resources consumption, in the center for the sand processing, has diesel at first place (29.8%), natural gas at second place (27.4%) and third place is occupied by electricity (9.26%).

After the mold is uncovered by the excavator, sandstone rock is disrupted by traxcavator TD-40G in a checkboard manner. The material is loaded by the loader to the crusher, from which it is transported by a belt conveyor to other processes. This system is the most profitable in terms of the working distances and the efficiency of mining. Mining processes are interesting with regard to the potential greater amount of the emission produced by the combustion processes of the motors (Table 2) and by the dustiness of the mechanisms. The emissions, arisen from the dustiness, need to be measured *in situ*.

In the mining model, it is important to sensibly adjust the functions such as the amount of consumed electricity in time, the mode of electricity production, the amount of oil waste produced into the soil and water, emissions of dust particles (an assumption of fugitive dust), *etc.* The system could be modeled either as an ensemble or in parts. The redistribution of the consumption and production effects in particular processes in the mining model is presented in Table 5.

Table 5. Overview of the resources consumption and production of the emission in the mining model.

Mining	Unit	Diesel	Oil	Electricity	Emission	Total
Loader	%	23.0	3.2	0.0	2.6	28.9
Excavator	%	12.3	3.0	0.0	2.5	17.8
Crusher	%	0	0.9	4.9	0.0	5.8
Traxcavator	%	33.4	3.6	0.0	3.0	40.0
Belt conveyor	%	0	0.9	6.5	0.0	7.4
Share	%	68.8	11.7	11.4	8.0	99.9

The impact of the SFS devastation, discussed in Figure 4, is not taken into consideration in this point.

The electricity is another important category with 17.2% of the total impact. The overall electricity consumption in the SFS production is 15 kWh/t. The electricity consumption for particular processes is depicted in Figure 2. For the evaluation of the impact in endpoints, the Electricity LV Ecoinvent database was used. The database contains information about the transformation of the middle voltage to the low voltage electricity and about the distribution of the low voltage, the loss of electricity and the emissions released into the atmosphere. The impacts were calculated separately for each type of electricity production and the results of electricity production are expressed as an average of four years. Small differences can occur due to rounding. Transport and transformation losses (13.4%) as well as material and construction requirements for transmission and distribution are included (described in System model Energy Carriers) [31]. Equipment management, automatization and optimization could contribute to the reduction of the impact and to the achievement of energy savings. Other alternative arrangements are discussed in papers by [34,35].

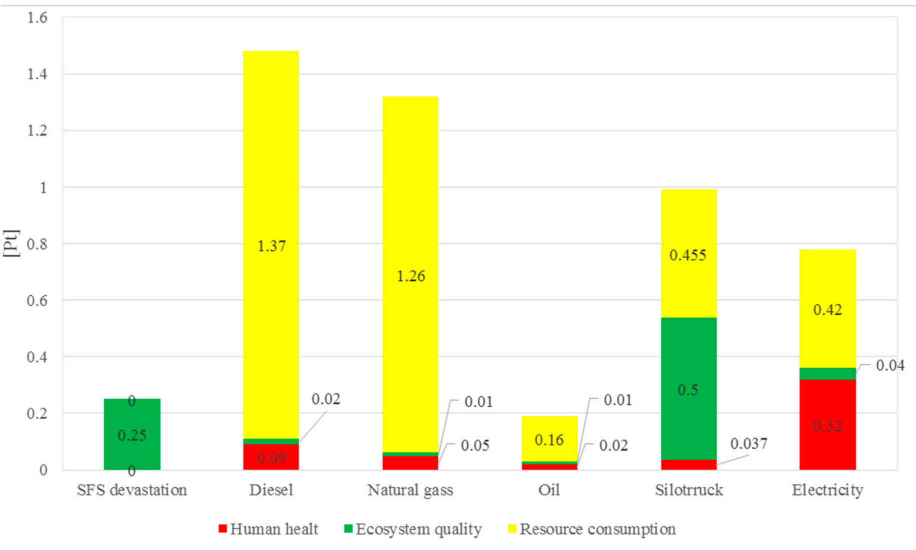

Figure 4. Results of the assessment of the SFS production in endpoints, Eco-indicator 99.

The low water consumption (0.01 m^3/t) is yet another important element identified and it represents a positive aspect in the sand mining process. Water comes from the sandstone mining center and kaolin processes. Hydro classification process works in a closed cycle, in which polluted kaolin water is purified in settling tanks and re-circulated into the production. The seepage water is accumulated in lakes located in the mining area from where it is reused in the production process. Regarding the impact on the environment, the hydro classification process represents the important positive impact of working in the closed cycle. This positive fact is not fully included in this paper. LCA study partially includes the effect of water consumption, diesel and oil consumption by the loader (diesel 2.1 kg/t, oil 0.276 kg/t) and electricity consumption 2.1 kWh/t. Hydroclassification together with all the water related processes is hence important for the sustainable disposal with the non-renewable resources.

The next evaluated unit process in the SFS production is the utilization of kaolin waste material in ceramic industry. Before such utilization kaolin was a waste. Precautions against the waste production allowed the formation of raw material from the waste material. This fact contributes to the decrease of waste production and economization (or more precisely wastage) of raw material resources. Other adjacent products e.g., filter sand, technical sand, quartz silica and dolomite powders, which were waste materials in the past, became the raw material for the next production. This fact was not included in the study. Concerning properties and amount, other waste coming from the SFS production, *i.e.*, common waste, waste from packaging, laboratory waste, *etc.*, is not interesting for this study. Only the negative effect of communal appliances, kaolin (1.2 kWh/t) and water waste treatment (2.1 kWh/t) electricity consumptions are included.

In relation to the aims of this work, the transport of SFS for its next usage is selected by Silo trucks. Emissions from the transport of 1 ton of SFS for 100 km are involved in the database program. The effects on the ecosystem quality, the resource consumption and production of large amounts of emissions in the transport by Silo trucks represent an important impact on the environment (12.2% for 100 tkm). The pump (0.1 tkm), which is installed on the trailer of the Silo truck, has the impact of 0.11%. All information about the operation, production, services, vehicle disposal as well as about the construction, services and disposal of motorways were included into the used Transport, lorry 28 t/CH S, database. The database was also complemented with the data from the Silo truck pump´s consumption. The transport by Silo truck enables the transport of the raw material directly from the particular utility processes. It means that on-site of the SFS utilization the energy needed for the manipulation is lost, there are no particulate pollutants and the storage area is decreased as well. On the other hand, the transport database has been modified by the negative effects on the ecosystem quality, similarly as in the case of the mining process. The reduction of the transport impacts could be proposed according to the works by [4,5,14,36–39]. The truck transport has a significant effect on the environment in terms of the transformation of the land by the network of roads, the amount of emissions emitted into the atmosphere or the consumption of non-renewable resources, *etc.*

3.2. Proposals and Recommendations

According to the determined impacts on the environment and consistent with the EU strategies and the research mentioned in this work, the concept of proposals and recommendations for the SFS production is elaborated in Table 6. The aim is to effectively manage the mining processes, e.g., modernization, fuel switching and changes in pre and post mining land use (see Table 6).

Table 6. Proposal of the arrangements for the SFS production.

Unit Process SFS	Technologies	Identified Effects	Arrangements
Uncovering	Excavator	• noise and vibrations • decrease in resources, ozone layer, damage to ecosystems • emissions SO_x, NO_x, particulate pollutants • human health, mortality • species diversity • smog, heavy metals in atmosphere • concentration of CO, NO_x and C_xH_y in atmosphere near motorways • air pollution by dust • energy consumption • production of waste oils	• usage of unleaded fuels and easily degradable oils • application of car filters and catalytic converters • following the health and safety code • safety tools • optimization of the processes • new technologies • BAT usage • energy saving appliances • renewable resources
Mining	Traxcavator		
Loading	Loader		
Crushing	Crusher		
Storage	Illumination		
Transport to process	Loader Belt conveyor		
Hydro classification	Hydro classifier	• decrease in resources • emissions from manipulation • air pollution by dust • effect of oil and chemicals on water and soil—electricity consumption	• efficiency of exploitation, storage area • new appliances • wet process • usage of easily degradable oils • BAT usage • energy saving appliances • renewable resources
Kaolin	Chamber press		
Desiccation	Desiccation Screen mesh	• emissions SO_2, NO_2, particulate pollutants • air pollution by dust • solid waste • packaging material consumption • electricity consumption	• changes in technological solutions • optimization of the processes • BAT installation • filter installation—if installed, recovery • recycling of packaging material, returnable packaging, simple design • renewable resources
Packing	Forklift		
Storage	Expedition boxes		
Expedition	Crane		
Transport	Silo truck	• concentration of CO, NO_x, a C_xH_y in atmosphere near motorways • lead compounds in water and soil • environmental devastation due to road construction • leakage of oil and fuel into water and soil	• formation of bio corridors • usage of unleaded fuels • application of car filters and catalytic converters • vehicles inspection and service • different type of transport

The results of this work complement well and are comparable in details with the results of various analyses, see, e.g., [40], in the total amount of materials, fuel and energy used, as well as environmental impacts in the South African Sub-sector (Company B) and in the Australian Sub-sector (Company B). According to the authors, similar comparisons could obviously be made regarding any technology combination relative to any regional base line. It is obvious, that electricity consumption, as well as fuel and material consumption are the priority tools for sustainable consumption in given regions.

4. Conclusions

This study brings an overview of the environmental impacts caused by the production of one ton of silicon foundry sands and introduces the proposal of possible recommendations for their elimination. Three endpoints, consumption of resources, the quality of the ecosystem and human health, were followed by using the method Eco-indicator 99.

The most important impact from the sand mining is the consumption of resources (70.9% share of the three endpoints). In this case study, the highest consumption of resources (diesel, 29.8%) is caused by transport and service mechanisms, which are used in majority of production processes. The second most important factor of resource consumption is represented by the consumption of natural gas (27.4%) in the desiccation unit process. The electricity consumption is the third important impact factor of resource consumption. The electricity consumption significantly (9.26%) contributes to the negative impact in the silicon foundry sands production.

The second important impact from the sand mining is the ecosystem quality (18.2% share of the three end points). Two main factors are silo truck (10.9%) and silicon foundry sands (5.35).

The smallest important impact from the sand mining is the human health (10.9% share of the three end points). Electricity consumption is 6.94% of this impact.

The greatest total effect on these results has the consumption of diesel 32.4% and natural gas 28.7%, the consumption of electricity 17.2%, transport (at 100 km) 12.2%, devastation by the silicon foundry sand 5.35% and the consumption of oils 4.14%. The highest contribution (65%, 6.9 kg/t) to the diesel consumption is connected with the processes of the silicon foundry sand exploitation.

Another significant factor, which negatively affects the consumption of non-renewable resources, is transport. Emissions from the transport and the landscape modification are identified to have an important impact on ecosystem quality, human health and resources. The significance of the transport increases with the increasing transport distance. The silicon foundry sands production is localized in the middle part of EU, which in terms of minimization of the transport seems to be a suitable baseline situation.

This study, because of the analysis of such calculated, measured and adjusted data (values), become an important basis for the LCI or LCIA for foundries, waste foundry sands or for extraction of inorganic materials in the initial phase of their life cycle, "in the cradle". Further studies of full life cycle, the LCA comparative analysis and case studies can all be based on this work. The case study was based primarily on long-term specific measurements and documentation of manufacturing silicon foundry sand and the producer serves as a base to improve its environmental profile. For these reasons, in this paper, we dealt with the uncertainty.

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