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Improvement Proposals for the Machining Production Process in the Environmentally Responsible Manufacturing Perspective

Güzide Karakuş[1], Feridun Karakuş[2], Ozan Koçak[3]

ABSTRACT
In today's world, where we are experiencing the fourth industrial revolution, technological change and transformation cause significant changes in human life. Information, technology, and industrialization are the most critical issues for a sustainable life and are also crucial for an efficient supply chain. However, global environmental problems and new epidemic diseases cause significant damage to life quality.
Although the individual impact on environmental pollution is known, it cannot be compared with industrial impact. Commercial activities cause high levels of environmental damage. Unfortunately, the environmental aspect of sustainability does not receive the necessary attention, and practices do not go beyond legal frameworks. Businesses are reluctant to engage in environmentally friendly activities due to the belief that they will not increase profitability. However, the destruction caused by industrialization to the environment can no longer be left to the initiative of the companies.
Businesses should evaluate their manufacturing processes by considering environmental impacts and reorganize within the framework of cleaner production methodology. This study aims to develop suggestions for improving the machining production process, one of the most used manufacturing methods worldwide, from an environmentally friendly perspective. The authors' expertise was used in the study with the experimental research technique based on observation, expert interviews, and document review. In consequence of the study, suggestions for reducing emissions, swarf waste, wastewater, waste oil, and energy consumption to minimize the environmental damage of the machining production process were presented.

Keywords: Environmentally responsible manufacturing, green production, cleaner production, environmental friendly perspective, machining production.

1. Introduction

Since the last 200 years, the production and consumption patterns of people have seriously affected the ecological balance in the world. The industrial revolution that started in England has continued by developing in western countries, thus industrial production has spread in every region of the world, and significant pollution has spread to the environment. Unlimited use of resources, production and consumption waste have destroyed the atmosphere, seas, rivers, and living spaces globally. With the rapid depletion of natural resources, the change in the balance of natural life and the increasingly dangerous new health problems caused by environmental pollution, the perspective on environmental problems have become more and more important (Kotan, 2009).

[1]Assistant Professor at Necmettin Erbakan University, department of Aviation Management.
[2]Graduated from the Mechanical Engineering Department at Selcuk University.
[3]Graduated from Dokuz Eylül University with a bachelor's degree. Currently studying for a master's degree in Sustainable Development at Ca' Foscari University of Venice in Italy.

Environmentally responsible manufacturing is an issue that did not attract much attention until the 1970s and its importance was accepted later (Curkovic & Sroufe, 2016). In the 1990s, a significant increase was observed in both academic and business world in the efforts to develop strategies for "environmentally friendly" and "green approach" issues. The introduction of the ISO 14000 certification system in 1996 was the beginning of the transition towards a period in which environmentally friendly practices will develop and environmental protection activities will not be an optional business practice but a competitive necessity for survival (Handfield, Walton, Seegers & Melnyk, 1997). In these years, aiming to establish a strong theoretical basis for environmentally responsible manufacturing, the concepts of green supply chain management, corporate social sustainability, environmental sustainability, social sustainability, transparency, and integrated reporting have begun to develop. This evolution of terminology has led to a significant increase in academic studies on environmentally friendly production. This increase in academic studies has made a significant contribution to creating resources for practitioners and developing good practice examples (Curkovic & Sroufe, 2016).

Although concepts such as cleaner production, environmentally friendly production, green production, and sustainable production are used in the literature in order to reduce environmental impacts in production, the concept of "Environmentally Responsible Manufacturing" is preferred in this study. Environmentally responsible manufacturing is an environmentally friendly and proactive approach that aims to minimize the environmental effects caused by production and to use resources efficiently by preventing waste generation at its source (Atak & Fidan, 2014). The basic principles of environmentally responsible manufacturing can be listed as follows: taking a preventive approach rather than a corrective approach in pollution control, reducing wastes with lower use of raw materials and energy, improving technological processes to reduce the use of natural resources, and developing new processes (Yücel & Ekmekçiler, 2008). However, it is not enough to consider efficient and environmentally responsible manufacturing only as a matter of technology. In this context, people, skills, experience, motivation, systems, organization (Kjaerheim, 2005) and, of course, management are important elements.

Cleaner production is a time-consuming process as it involves organizational and technological changes. Leadership and organization of management is an essential requirement for successful pollution prevention projects. Nevertheless, the fact that enterprises turn pollution prevention into a part of organizational culture and daily life (Fresner, 1998) should be determined as a more proactive approach in order to solve the problem at its source. In this direction, the subject of environmentally responsible manufacturing (Curkovic & Sroufe, 2016), which is still developing in the academy, should continue to be worked on to include industrial applications. Manufacturing methods and requirements for the production of environmentally friendly products and services should be determined on a sectoral basis, these requirements should be transformed into legal regulations, and sanctions should be implemented by auditing their applications.

In this study, it is aimed to determine the environmental effects of the machining process, which is one of the most widely used production methods in the world, from an environmentally friendly production perspective. Studies carried out within the scope of environmentally friendly production in social sciences are generally aimed at developing

concepts, understanding, and developing strategies for developing and understanding environmental practices (see also Handfield et al. (1997), Fresner (1998), Gungor & Gupta (1999), Curkovic (2003), Glavič & Lukman (2007), Severo, de Guimarães, Dorion & Nodari (2015), Curkovic & Sroufe (2016)). Within the scope of engineering sciences, process-based technical improvement studies have been implemented for environmental applications. In the machining process, efforts have been focused on reducing energy, water, oil consumption and waste (see also. Hur, Lee, & Kim (2002), Liou, Slattery, Kinsella, Newkirk, Chou & Landers (2007), Diaz, Helu, Jayanathan, Chen, Horvath & Dornfeld (2010), Faludi, Bayley, Bhogal & Iribarne (2015), Nagamatsu, Sasahara, Mitsutake & Hamamoto (2020)). However, no study has been found that defines all inputs and wastes on the machining process and also develops a proposal in this context from an environmentally friendly perspective. Since machine tools are used extensively and are also used in the production of many other products, it is a subject that needs to be studied. Research questions within the scope of this study are following:

- *What are the inputs and outputs of the machining process within the framework of environmentally responsible manufacturing understanding?*
- *What preventive measures can be taken on the machining process to be made more environmentally friendly?*

As a result of the study, suggestions were developed to reduce resource consumption and waste generation in the machining process by preserving the efficiency and cost criteria with mechanical engineering, industrial engineering, and environmental engineering expertise. After the introduction, the concept of environmentally responsible manufacturing and the sections related to the machining process are included. Afterwards, the machining process is depicted with an environmentally friendly perspective. Finally, suggestions for improvement are presented in the conclusion section.

2. Environmentally Responsible Manufacturing

Environmentally responsible manufacturing (ERM) is the implementation of a preventive and integrated environmental protection strategy applied to minimize the environmental impact of products and services produced in production processes (Fresner, 1998, Kotan, 2009). ERM is a proactive management approach that encompasses an enterprise's efforts to integrate environmental practices into decision-making processes (Curkovic & Sroufe, 2016). The main actors of ERM are the enterprises that control the production processes, and these enterprises are strongly affected by their customers (private, public or other companies) and policies (laws, regulations, taxes) (Fresner, 1998).

The concept of environmentally responsible manufacturing is a set of actions that allow an enterprise to qualify itself as an efficient user of raw materials and energy in a production process, aiming to increase productivity and therefore competitiveness, and improve organizational performance (Severo et al., 2015). The main focus of environmentally responsible manufacturing is to raise awareness for the prevention of pollution, to find the source of wastes and emissions, to reduce emissions, to provide a holistic perspective on production, economy and environment in order to increase

resource efficiency with efficient material use and reduced energy consumption (Kjaerheim, 2005, Fresner, 1998). Gungor & Gupta (1999), who introduced the concept of environmentally conscious production and recycling, defined the activities that can be carried out in this context as environment conscious manufacturing (ECM), life cycle analysis or assessment (LCA), design for the environment (DFE), and recovery of materials and products (Gungor & Gupta, 1999). According to the interdisciplinary approach of environmentally responsible manufacturing, there are a range of options available to reduce negative environmental impacts, including:

- Reduction in material and energy use,
- Training of employees, better logistics, improvement in data availability and interdepartmental communication,
- Substitution of raw and auxiliary materials with less harmful or more efficient and recyclable ones,
- Product modifications to eliminate production steps with large environmental impact,
- Process improvements to minimize waste and emissions,
- Internal recycling,
- Inclusion of waste in external recycling networks (Fresner, 1998).

Environmental responsibility is now seen not only as a legal or moral obligation but also as a tool that empowers business commercially. Providing goods and services that minimize the impact on the environment helps to expand the market and increase sales, thereby growing financial turnover (Curkovic & Sroufe, 2016). Environmentally responsible manufacturing will provide benefits such as increasing the competitiveness of the enterprise, improving the organization, turning into a learning organization, providing resources for new R&D and investment projects with savings from energy costs, and contributing to sustainability. In addition, the expected benefits from environmentally responsible manufacturing practices are following:

- Improved material usage (eco-efficiency),
- Decrease in energy consumption and greenhouse gas production,
- Less emissions to air, water, and soil,
- Less toxic substance use in production and products,
- Less waste generation,
- Increase in capacity utilization (Kjaerheim, 2005).

The emphasis and research on environmentally responsible manufacturing has increased significantly in recent years, and research topics are focused on managerial practices, business processes and technology. Environmentally responsible manufacturing systems include proactive measures such as life cycle analysis, environmental design, design for disassembly, total quality and environmental management, remanufacturing, ISO 14000 certification and green supply chains (Sarkis, 1999). However, the environmental impact is not limited to the technical processes of the enterprise. More and more manufacturers operate in supply chains where different businesses are connected by exchanging materials, services, and information (Bullinger, Von Steinaecker & Weller,

1999). If enterprises intend to develop environmentally responsible manufacturing practices for purchasing and materials management, they have to incorporate suppliers into their environmentally friendly practices (Walton, Handfield & Melnyk, 1998). Integration of new technologies into green supply chains will make an important contribution in this regard. In line with Industry 4.0, it is predicted that developments in information and communication technologies will create important opportunities for environmentally responsible manufacturing. While production processes and equipment needs are recorded with smart production systems, the material flow will be supported with smart logistics, and suppliers using renewable energy will be defined and preferred. (Stock & Seliger, 2016). The environmentally responsible supply chain is illustrated in Figure 1.

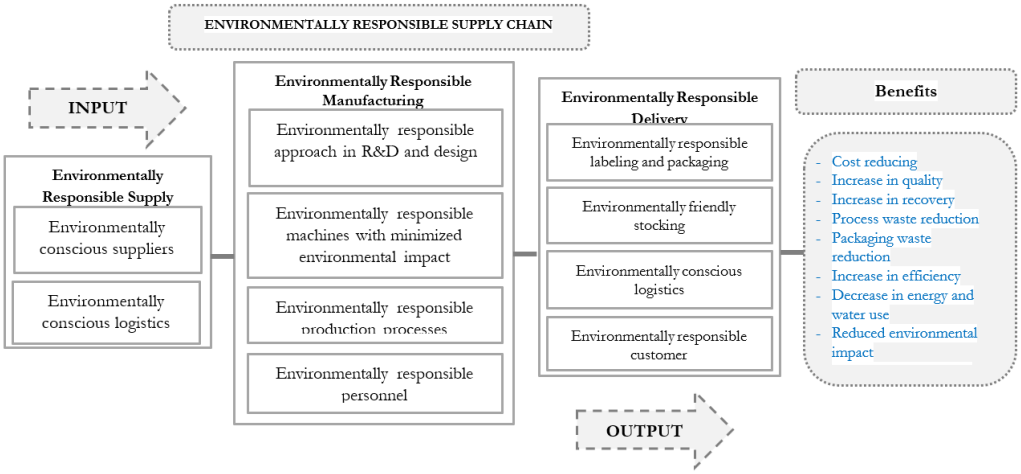

Figure 1. Requirements and benefits of the environmentally responsible supply chain

While environmentally responsible manufacturing is an important issue where every small step will benefit, the holistic benefits to be created by large-scale participation are indisputable. As can be seen in Figure 1, environmentally responsible products should be implemented by all units of the enterprise, which should also be evaluated in terms of materials, equipment, and machinery, and will bring significant benefits to the entire supply chain.

Since environmentally responsible manufacturing is an interdisciplinary subject, it has found application in both engineering and social sciences in the literature. Handfield et al. (1998) conducted a case study, one of the qualitative research methods, to describe environmentally friendly supply chain practices in five businesses in the furniture industry. As a result of the study, he made the following suggestions: Businesses should proactively manage their supply chain environmental initiatives and target higher criteria instead of acting only to meet the legislation. Business and cross-functional processes, including product design, suppliers' processes, supplier assessment systems, and logistics, should be considered from an environmentally responsible manufacturing perspective.

There are also studies conducted within the scope of the relationship of environmental practices with other systems and sustainability. Fresner (1998) conducted a research to examine the impact of a corporate environmental management system on continuous improvement. As a result of the research, he stated that cleaner production and ISO 14001 support each other in terms of reducing negative environmental impacts in enterprises. It was concluded that with the environmental management systems put forward on the basis of cleaner production projects, awareness and motivation were achieved throughout the enterprise, systematic tools were developed to reduce environmental impact, and costs due to inefficient material and energy use were reduced. Severo et al. (2015) conducted a study to examine the relationship between cleaner production, environmental sustainability and organizational performance. They concluded that cleaner production practices affect environmental sustainability as well as corporate performance, moreover, cleaner production methodologies contribute to increasing production capacity and flexibility, also improving health and safety issues.

Gungo & Gupta (1999) defined the concept of Environmentally Conscious Manufacturing and Product Recovery with a literature review and developed recommendations for the system. They have defined ECMPRO as the development of methods for the production of products from conceptual design to end-of-life disposal, and the reduction of waste through product recovery, recycling and remanufacturing. They stated that the concept is in its infancy and needs to be developed. The concept has been developed over the years and studies have been implemented for its benefits. Kjaerheim (2005) suggested that the promotion of the environmentally responsible manufacturing approach should create job opportunities, eradicate poverty, protect public health and improve safety. Environmentally responsible manufacturing should be integrated into all business development activities to increase sustainability and quality of life.

Studies on environmental production have also been carried out in the field of industrial engineering. Subai, Baptiste & Niel (2006) conducted a new model development study on adding the environmental dimension within the frame of energy consumption and waste generation parameters to mathematical models built in the quality-cost-time framework in the surface cleaning process (the motion scheduling problem of the working robot). It is concluded that including environmental parameters in the model does not cause any loss in efficiency.

All the studies reflect the benefits of environmental activities. Environmental activities for businesses can be seen as a cost, loss of workforce and giving up investment in production in the short term. However, it should be known that environmentally responsible manufacturing will provide significant advantages to the business in the long term. More importantly, it is no longer an option for people to raise awareness and develop behavior that they do not contribute to global environmental damage.

3. Machining Process

Machining is the general name of the process of removing and removing swarfs from the material in order to bring a raw material to the desired shape and size and is a subtractive manufacturing method. With machining, it is possible to manufacture wood, plastic, ceramic and composite, etc. materials in addition to metal parts (Tezel, Topal &

Kovan, 2018). Machining is one of the most widely used production methods in the manufacturing industry (Munoz & Sheng, 1995, Çomak, Koca, Özlü, Özşahin, Öztürk, Tunç, Uysal, Budak & Özgüven, 2013). As with other industrial processes, the aim is to produce the required quality in the fastest and most economical way. Thanks to the high spindle speeds and precision machines that have continued to increase in recent years, significant increases in production capacities have been made possible (Çomak et al., 2013).

The main goal of machining is to provide the geometric and dimensional measurements and quality of the workpiece surface to be produced within the desired limits (Dedeakayoğulları & Kaçal, 2020). Machining, especially with CNC technology, offers significant advantages in the production of products with high precision, high speed, high flexibility, effective process planning technique and desired structural properties (Hur et al., 2002) and the repeatability of the production. Although it is possible to obtain screw threads, precise holes, very smooth edges and surfaces by machining, the scrap materials produced during manufacturing and the length of production time are disadvantageous aspects of the method in terms of production management (Tezel et al., 2018).

With the developing and changing technology, a need for transformation in traditional production methods has emerged, and instead of subtractive manufacturing methods, additive-additive manufacturing methods that provide three-dimensional (3D) material production or hybrid manufacturing methods that integrate two methods have started to be investigated (see also Liou et al., 2007; Faludi et al., 2015; Tezel et al., 2018; Nagamatsu et al., 2020). Although it is thought that these studies will contribute to environmentally responsible manufacturing at the point of waste reduction, hybrid manufacturing methods have not been included in this study since they are new and need to be developed.

Faludi et al. (2015) conducted a study to compare the environmental effects of two-layer manufacturing machine and traditional CNC milling machine by life cycle analysis. Within the scope of the study, the environmental impacts of the product including transportation, energy use, waste material, cutting fluid and disposal were examined. As a result of the study, it was stated that it cannot be said that the environmental impact of additive manufacturing is superior to CNC processing, it depends on the use of each machine. They stated that by increasing the operating time of the machine, in other words, saving the energy consumption during idle mode, idle-mode energy consumption will be reduced, and thus negative environmental effects of the machine will be depreciated. Considering the results of the study, 3D printers use more electricity and coolant, while material waste is higher in machining.

Diaz et al. (2010) conducted a study to analyze the lifetime energy consumption of a machine tool, including the effect of manufacturing environment, transport, coolant, lighting, and automation. As a result of the study, while developing suggestions for energy reduction in machine tool design, they emphasized the importance of the facility used in the production of the product in reducing energy consumption.

4. Methodology

In the study, a multi-case study including observation and interview technique, which is one of the qualitative research methods, was used in the data collection stage. The

obtained information was combined with the experiences of the researchers and the inputs of the machining process along with the environmental waste types caused by these inputs are illustrated from an environmentally responsible perspective. In the conclusion section, in line with the knowledge gained from the application and the experiences of the authors (with an interdisciplinary approach and environmental, industrial and mechanical engineering approaches), suggestions have been made to prevent the formation of these wastes or to reduce them at the source.

Evaluating data collected from multiple locations in case studies helps support the generalizability of the results (Handfield et al., 1997). In this context, interviews were made with the production managers of 5 machining enterprises, and it was observed that the process was carried out in a similar way, as well as similar wastes were generated. Along with the obtained information, suggestions were made by combining the theoretical and practical knowledge of the author's 16-year experience in machining, machine repair maintenance and machine production in a preventive approach. It is thought that the study will create a unique basis for academicians and R&D personnel who will work on the subject.

5. Findings of the Study, Conclusion and Recommendations

First of all, the inputs of the machining process and the waste types generated by these inputs are illustrated with an environmentally friendly production perspective in this section. In the last section, suggestions are made to prevent these wastes or to reduce them at the source.

5.1 Findings of the Study

Various studies have been carried out in the international literature on the environmental effects of machining within the scope of different parameters. The subject is worth investigating due to its importance. Because even small improvements in production can have a significant impact on greenhouse gas emissions and other environmental impacts (Faludi et al., 2015). In this study, the inputs and outputs of the machining process are illustrated with an environmentally friendly production perspective. Some of the inputs identified have never been described before in the literature. The types of wastes caused by these defined inputs at the end of the process are described.

5.2 Conclusion and Recommendations

As a result of globalization and industrial development, it has been known that any environmental degradation has negative effects on the entire ecosystem, and there are global concerns about pollution and the environment. This is a problem that can be solved by the local implementation of the regulations to be established by a global authority and by raising awareness and developing practices for all actors on environmental protection and reducing environmental impacts. The environmental degradation that has emerged over the years cannot be postponed or ignored any longer. Global studies should be started immediately, and all innovative ideas and R&D projects should be environmentally friendly or designed for the environment. It is a vital necessity to increase the number of

research studies aimed at reducing environmental negative effects and promoting environmentally responsible manufacturing in all sectors is vital.

The machining process has an indispensable position since it is one of the most widely used manufacturing methods worldwide for the production of other products. Some authors even think that the negative environmental impacts can be negligible when we consider the positive aspects and the length of the machine's service life (machines over 50 years old are still in use in various productions). Diaz et al. (2010), states that used machine tools are constantly changing hands by reselling and thus the service life of the machine cannot be determined, the operating time of each machine owner cannot be determined, and this situation creates an important difference in the environmental impact per piece processed. Considering the importance of the process, making improvements to reduce environmental impacts is an important requirement.

The inputs and outputs of the process in the machining process are defined with the environmentally responsible perspective illustrated in Figure 2. Recommendations to reduce resource consumption and waste generation on machines or processes are as follows:

- **Development of inserts that will provide cutting without the need for cooling water:** Although ceramic cutting inserts have been developed to be used in lathes in this direction, their application areas are limited because their impact resistance is insufficient, and their formability is weak.

Efforts are being made to develop new solutions in line with the aim of not using cooling water. One of them is the vortex tube technique. This technique requires high flow rate compressed air supplied by compressors. However, the result does not meet the expectations, since the compressor itself is low energy-efficient equipment.

- **Development of friction or bearing systems that do not need slide lubricating oils:** The oil used in friction and bearing systems as well as waste oils will be reduced.
- **Reduction of hydraulic systems in power units:** Reducing hydraulic systems will reduce the use of hydraulic oil and waste.
- **Reducing the number of mechanisms:** It is important to use direct linear motors instead of the motor, screw and nut mechanisms used to convert the rotary motion to linear motion. Thus, by using a single mechanism instead of two mechanisms, the need for lubrication and the amount of waste will be reduced. Although the linear motor technology cannot meet the expectations in terms of size and efficiency yet, it has the potential to be an important solution point in environmentally responsible manufacturing with the research and development studies to be carried out. The reduction of mechanisms will also be an important factor in reducing the wastes that will arise in repair and maintenance activities.
- **Reduction of filter media and chip deflectors:** Although filter materials and chip deflectors are used to treat, separate, and reduce environmental impacts of waste generated in the process, they are also an important waste on their own. These types of equipment were used as consumables and sufficient data regarding their recycling and disposal could not be reached. The end-of-life filters and chip deflectors are seen as garbage and create

significant contaminated waste. In this direction, magnetic systems that do not require filtration materials and cyclone mechanisms should be developed to separate micron-level particles from the cutting and cooling water with the help of centripetal forces.

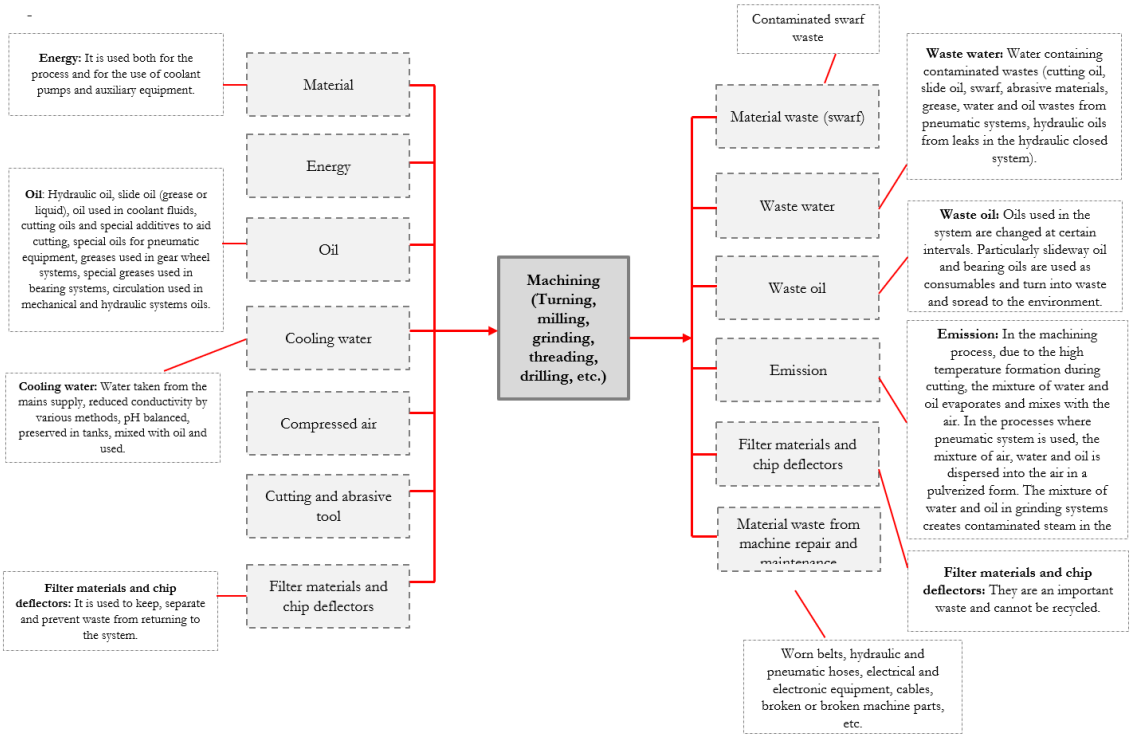

Figure 2. Machining process from an environmentally responsible manufacturing perspective

Developing systems to reduce emissions: In the machining process, the mixture of water and oil evaporates and combines with the air by the formation of high temperature during cutting. In systems using pneumatic system, the mixture of air, water and oil is dispersed into the air in a pulverized form. In grinding systems, a mixture of water and oil creates contaminated steam in the working environment.

Enterprises install chimney ventilation, filtration, and chimney systems in their production areas to prevent the specified emissions from mixing with air. However, these systems do not constitute a solution in terms of occupational health and safety since they do not prevent the emission in the production environment. Moreover, the amount to be cleaned increases as the emission generated in the process spreads throughout the production area. Chimney systems of large areas require high investment, and the materials and equipment used in these systems also generate significant environmental waste. For these reasons, it is necessary to minimize the emission at its source with smaller equipment and stronger vacuum systems. These systems have started to be used in welding and casting processes that are not included in grinding, milling, turning or even machining, but they are less known. The development and dissemination of these systems will have a significant effect in terms of emission reduction.

- **The transition from general-purpose machine tool production to production and use of machine tools specially designed for the product:** Machine tool manufacturers make and produce machine tool designs that can meet more than one operation at the same time in line with different demands from customers. For this reason, many mechanisms are available on the counter and offered to the customer. However, many customers do not use many of these general features and these mechanisms remain idle. These mechanisms create both a significant cost (waste of resources) and negative environmental impacts. The simpler design and production of the machine tools for the product will both contribute to the efficient use of resources and reduce the negative effects on the environment (For example, when considering general-purpose production in a turning lathe, 30 kW motor is used. The 30 kW motor in the machine tool is an important cost factor for both the manufacturer and the user, and it can also cause excessive electrical energy use in the production process).
- **Development of integrated manufacturing technologies to reduce the amount of contaminated swarf waste:** Today, the forging technique is used to reduce the amount of swarf waste. However, the method, which is difficult to apply, is not common. The development of the forging technique and its integration into the machining process will provide environmental advantages.

Similarly, studies on the integration of 3D printers using metal in vertical machining center machine tools have been started. Although it cannot be said with certainty that improvements in energy consumption and time saving by using integrated systems, it is certain that it will provide a solution in reducing the amount of contaminated swarf waste. The swarf waste generated in reduced production is incomparably higher than additive manufacturing. The most important disadvantages of integrated systems are contour and surface quality problems caused by 3D printers. Elimination of these problems will make a significant contribution to reducing environmental impacts caused by machining in the long term.

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