

THE ROLE OF MANUFACTURING TECHNIQUES IN ENTERPRISES PRODUCING HEATING DEVICES IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Received: 16 November 2012

Accepted: 12 February 2013

ABSTRACT

Manufacturing techniques are concerned with quality, cost, productivity and sustainability. With today's environmental awareness and the pressure of the sustainability requirements, existing manufacturing techniques of heating devices are evolving into the redesign manufacturing unit processes to increase overall sustainability. Also, these techniques need a measurement method to assess processes-related sustainability performance indicators.

The purpose of this paper is to stress the role of manufacturing techniques: welding, cleaning and painting in the manufacture of heating appliances (solid fuel fired boilers used renewable energy sources) in terms of incorporating into the field the concept of sustainable development. It then focuses on the environmental, technical, economical and social impact of sustainable technologies and argues for the need to ensure that the concept is being applied to the manufacture of heating devices.

In this paper, author tries to propose a unified, standard scientific factory-level methodology to evaluate the influence of manufacturing techniques on the sustainability of enterprises producing heating devices. The proposed methodology in the terms of the case study is a comprehensive answer to the question of to what extent the improvements in those techniques influence the sustainable development of the enterprises. An industrial case study demonstrates that the proposed improvements can effectively influence the sustainability of enterprise. The results of this assessment can be applied to broad industry sectors, and can lead to the accepted measures and practices.

KEYWORDS

manufacturing techniques, sustainable development, welding, cleaning and painting processes, heating devices, environmental impact, life cycle assessment (LCA).

Introduction

As a result of discussions from European regulations related to environment and health, sustainable techniques and technologies has become a strategic move as industries begin to seek novel ways to make an efficient use of resources, ensure compliance with regulations related to environment and health, and enhance the quality of their manufactur-

ing processes. The idea of introducing sustainability in manufacturing processes planning and scheduling, where cost, quality and lead time, and energy are needed for the unit manufacturing processes performances assessment towards sustainability, which was proposed by Mani and Lyons [1]. In the pursuit of sustainable development in manufacturing processes (called also sustainable manufacturing), this paper aims to emphasize the importance of welding, clean-

ing and painting techniques on the need to meet the legal regulations and requirements of different manufacturing installation/equipments used to produce heating boilers. It has been noted that in production process of heating appliances, manufacturing techniques have the potential for significantly improved environmental and social performance relative to other technologies. So, these techniques give considerable attention to the sustainable development of manufacturing enterprises.

The other aim of this paper is to show a case study towards implementing the sustainable development in enterprises. Hence, the scope of the paper is being limited to a case study – based on the discussion of the role of the welding, cleaning and painting techniques in terms of the sustainable development of an enterprise.

The production of boilers can contribute to the development goals of the three-pillar model and can be assessed in terms of an exact impact on the sustainable development of enterprises. Welding, cleaning and painting techniques are the main causes of the consumption of the resources, materials and toxic waste generated by the surface preparation methods of metals and application method, which, in turn, are the side effects of the production process. Possibilities of change of the production processes of heating devices appear in the improvement of manufacturing techniques and technologies to optimize production and to accommodate the new needs of sustainability. On the other hand, requirements of changes of the existing technology are determined by governments that promulgate the environmental interests to reduce emissions and toxic waste being generated by the surface treatment.

These aspects underline the need to assess both the technical, environmental, economical and social impacts of these manufacturing processes to ensure that welding, cleaning and painting technology deployment remains aligned with overall sustainable development goals. The STPI white papers also stressed the “need for accessible and affordable measurement systems and analytical tools for assessing (...) and across the production process” [2] in the context of the sustainable development.

Currently, a Life Cycle Assessment Methodology is an assessment tool of business activity, assuming the depletion of natural resources and the impact of pollutants as criteria for evaluation of the business activity [3, 4]. The methodology ensures the comparable results by consideration the environmental problems in industrial plants, but according to Finnveden an assessment evaluates the significant environment impact of throughout the product’s life

cycle, including human health, and resources [5]. Another approach proposed by Hui et al. [6] limiting their model to the environmental hazards in manufacturing. The network analytic method with a numeric fuzzy weighting factor was employed to determine and analyze the potential of each impact category created by different kinds of waste in manufacturing processes [7].

In Jawahir’s work [8] there have been attempts taken to evaluate the degree of sustainability of the given manufacturing process, namely machining whereas the Office of Science and Technology Policy report has highlighted the need for the accessible measurement tools for assessing and managing the sustainability across the production process supporting the advanced manufacturing. But none of these known methods did consider an influence of the technological factors on sustainable development on enterprises.

The meaning of sustainable development in manufacture

Since the Brundtland Commission popularized the term of sustainable development in 1987, the concept has increased extensively and it features more and more as a core element in policy documents of the governments. It follows the Brundtland definition that development is sustainable if it “meets the needs of the present without compromising the ability of future generations to meet their own needs”. A growing environmental damage caused by the increase in production could be reduced by the sorts of technological changes. But the growth is possibly through the powers of appropriate techniques and technology, which allows finding new sources or providing alternatives if a particular resource appear to be running out.

In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and the future potential to meet human needs and aspirations” [9]. Sustainable development in manufacturing techniques requires “improvements in material, resource, and energy efficiency, adequate reductions in exposure to toxic substances, significant opportunities for stable, rewarding, and meaningful employment with adequate purchasing power (...)” [10, 11]. The use of manufacturing techniques and technologies which require less energy, water as well as wastes would lead to decrease in burden of environment. The report of Our Common Future UNCED calls also for “recog-

nition of the concept by business” [12] and solutions to urgent environmental and societal problem [13]. This need to incorporate the concept of sustainable development into the enterprise level, combined with several dimensions to sustainable development, resulted in the principle of so-called triple bottom line¹ [14, 15]. This concept is based on the description of three factors: the financial result (profit) combined with social responsibility (people) and concern for the ecological dimensions of activity (planets) that should form the basis for measuring and evaluating the functions of enterprises; economic, environmental and social in sustainable development. According to these concept actions taken by industrial facilities through the use of sustainability drivers (environmental, economic and social) create advanced products, production technologies and new market places [16]. Furthermore, in the sustainable development context, technological aspect is viewed as one of the four dimensions of sustainability concentrating on the design of devices, technologies and systems to produce more social goods with less environmental harm. It means designing technology by reducing material consumption, energy intensity of production, prevention of pollution at each stage of manufacturing processes over the rational use of natural resources. Techniques and technology can be successful in the closed-loop system if at least three dimensions appear (environmental, economic and social) as well as “if its aims are directed toward the system as a whole rather than at some apparently accessible part” [17].

Requirements of the sustainable development in manufacturing processes are focused on the utilization of available resources and the generation of new resources, decision-making aspects such as supply chain, quality initiatives, environmental costing, and manufacturing techniques assessment.

Review on sustainability of welding, cleaning and painting techniques

With initiated R&D programmes launched in European Union (EU) are covering objectives with environmental requirements.

The importance of production techniques (Best Available Techniques) was underlined by U.S. Environmental Protection Agency (EPA) in the Sec. 5 of Environmental Protection Agency Acts, 1992 and 2003, as the “most effective and advanced stage in the development of an activity and its methods of

operation, which indicate the practical sustainability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent or eliminate or, where that is not practicable, generally to reduce an emission and its impact on the environment as a whole” [18]. EPA gives regard to the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and humans, and the use of low-waste technology, while Cleaner Production – greater overall efficiency through improved production techniques and technologies, including modifying manufacturing process, upgrading equipments or substituting different materials. This new dimension called sustainability was remarked and added to manufacturing industries. Pekkarinen states that the driving force behind the sustainability in manufacturing demands are among all quality, productivity and working environment [19].

In Poland, the current sustainability awareness in manufacturing unit processes, mainly welding, cleaning and painting is fairly low. The society is however much more concerned about the environmental aspects. These drive for a continuous development of the manufacturing processes and applications.

The environmental impact of the cleaning and painting technologies depends on the volatility of the compounds used. From the environmental perspective, cleaning and painting systems have produced hazardous waste and releases of toxic chemicals to air and solid media. From the economic viewpoint, energy enables the manufacturing operations add value to the intermediate products. The design features of many technologies or improvement of existing techniques reduce employee exposure to any hazards posed by the use of paints.

The associated environmental aspects of welding generating toxic fumes during the welding job can adversely have an impact on the environment/air quality and solid waste which can result in land abuse if not disposed properly. The hazards will depend on the type of welding, the materials (base metals, surface coatings, electrodes) to be welded, and the environmental conditions (outside or in a confined space). Use of local exhaust ventilation removes fumes and gases at the source. However, general ventilation is not as effective as local exhaust ventilation, but often it is helpful when used to supplement local ventilation.

Welding is primarily considered to be a “health and safety” problem, which is noted in the allocation of responsibility for sustainable development. Even

¹“Triple bottom line”, a concept for reporting business activities, introduced by John Ellington and described in his book titled: *Cannibals With Fork: The Triple Bottom Line of 21 Century Business*, New Society Publishers, Stony Creek, CT, 1998.

though we are fairly slow in implementing the environmental programmes in the welding industries, we have major challenges in developing the joining processes [19]. Then, the impact on the environment could be reduced greatly. For example, in the Junbeum's et al. paper [20], within forklift manufacturing unit processes, cutting, welding and painting had the highest impact on the values. In order to minimise the environmental impacts, a new paint was created with an increased solid content over the existing solvent paint used in the painting process.

In manufacturing of heating devices, the most common method for preparing the steel surfaces for painting is sandblasting, preceded by vapor degreasing to remove any oily film present [21]. Sandblasting leads to create the amount of hazardous dust, hence, abrasive-blast treatments (by shot blasting machine) would be seen as the best treatment. In this type of application, solvent (xylene or toluene are preferable solvents) wiping should be used only as a last resort. Solvent cleaning removes all visible oil, grease, soil, cutting compounds and other foreign matter from surfaces. Solvent degreasing has to be upgraded according to the provisions of the solvent emissions. Chemical treatments for non alloy quality steel², mentioned in the Engineering Handbook [22], are to be used only when abrasive equipment is not available. Finally, painting technology should be used.

Shot blast media can be recycled, generate less waste than sand blasting, and it is cheaper than the compared one.

Wet painting is a traditional method applied: water based or solvent – based paints to a surface.

Metal painting generates quantities of liquid waste and harmful vapors thereby influences the human health and the natural environment by air and groundwater pollution. If solvent-based paints must be used, airless spray guns or air-operated spray pump application technologies should be treated as a high transfer efficiency. It allows to save the paint material (30–50% compared to the air spray, and both application technologies produce a higher film build than air spray) [23].

Because of the hazards to the community associated with the chemicals during the paint application, the best way to reduce vapors and volatile organic compound emissions (acetone, toluene, xylene) is the use of an installation (paint spraying and drying booth with its own air supply and exhaust fans and with its own heating system) which meets the requirements of the industry regulations and environmental regulations, in particular: due to fire safety,

worker safety, quality of products, less use of painting materials, lower emissions of volatile substances into the air. On the other hand, to cut a significant cost of the pollution control investment, the use of powder or high-solids paints is being recommended instead of solvent-borne options which would improve also the efficiency of the pollution control systems. In this aspect the investment decisions play a crucial role in the heating industry.

The above review is generally attempting to describe the environmental aspects of manufacturing techniques and lets appear how to implement various technologies in order to improve sustainability level. It means that the literature of sustainability of manufacturing unit processes is missing a standard, structured assessment methodology that enables to assess the current state of techniques and technologies and defines the impact on sustainability. Moreover, the current use of ad-hoc methods does not consider the technological factors of sustainable development of the manufacturing enterprise. Additionally, they are used, not only for evaluating the environmental impact on the manufacturing processes, but also for selecting processes when the environmental impact is one of the factors to be considered. According to the concept of sustainability, all three factors (environmental, economical and social) must be integrated in the manufacturing domain.

This paper presents a measurement method to fill this required gap.

Methodology for analyze and assessment of manufacturing techniques

For this research, welding, cleaning and painting techniques have been studied for one of the leading heating boilers manufacturers in Poland with a very high manufacturing potential. The enterprise run in the Lublin Region has developed a lot of new products not only pellets, wood fired boilers but also biomass. The analysis and assessment were framed in terms of technological changes in manufacturing techniques for the enterprises. It has been viewed as goals that should be achieved for the manufacturing processes to contribute to the sustainable development of the enterprise.

The potential improvement actions of welding, cleaning and painting techniques will facilitate to achieve a pathway towards environmental, social and economic development. The choice of the best option

²In accordance with EN 10020, P235GH, P265GH, P295GH and P355GH are non alloy (carbon) quality steels to operate at an elevated temperature. All of other grade are alloy special steel.

(installation) was assessed by taking into account the economic and technical viability of upgrading existing installations as well as environmental regulations.

Interpretation of components for sustainable development

The importance of welding, cleaning and painting techniques with respect to sustainability can be assessed in terms of the sustainable development perspectives. The investigation was done in the form of case study.

Based on the literature concerning the sustainable development issues, there were four perspectives of sustainable development and their components distinguished. While three perspectives are typical for the assessment of the manufacturing techniques, the author has proposed one more perspective (technical) stimulating the sustainable development in the manufacturing enterprises to complement and detail the components.

Classified components according to the four perspectives (and their indicators): technical (I_{TECH}), economical (I_{ECO}), environmental (I_{ENV}) and social (I_{SOC}) are shown in the Table 1.

Each perspective has been given a value of indicator expressed by a 5-point scale. It has allowed to

compare the cleaning and painting in the context of perspectives of the sustainable development.

By this means, the development of the perspectives of the enterprise sustainable development as well as the principles underlying sustainability assessment as well as rating can be traced and understood.

Calculating

The paper shows the unit manufacturing processes that affect the production process of heating boilers as shown in the Fig. 1. Identification of the unit manufacturing processes helps the enterprise to take the remedial action by prioritizing the most occurring and influential ones through production. Measures were identified for manufacturing processes like: cutting, welding, cleaning and painting. Bending and final assembly processes were not evaluated due to low air pollution emissions and little or no harm to human health.

To assess the impact of manufacturing techniques on the sustainable development of enterprises in terms of environmental, technical, economical and society the scoring method was used by a 5-point scale, defining (in points) the impact as: 1 – slight, 2 – small, 3 – medium, 4 – large, 5 – very big.

Table 1
 Classified components of sustainable development of enterprise

| Technical perspective | Economical perspective | Environmental perspective | Social perspective |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> ✓ Size and capacity of the facility ✓ Quality production ✓ The state of technical infrastructure (degree of devices' wear) ✓ Reliability of devices ✓ Technical innovation | <ul style="list-style-type: none"> ✓ Installing the capital-intensive machinery ✓ Forces to maximize their use (capital investment) ✓ Time implementation of new solutions ✓ Repair cost and maintenance ✓ Cost of purifying and waste disposal ✓ Required permits for production and wastes | <ul style="list-style-type: none"> ✓ Energy intensity ✓ Use of toxic materials ✓ VOC, dust emissions ✓ Noise/Odour/Radiation ✓ Solid/liquid wastes ✓ Transport | <ul style="list-style-type: none"> ✓ Health & Safety at work, especially in the workplace hazardous to the health or life of man ✓ Knowledge and skills, competences of employees (employees training) ✓ Job performance and attitudes of employees ✓ Ergonomics ✓ Improvement of enterprise's image by participating at community programmes |

Source: Own based on empirical research

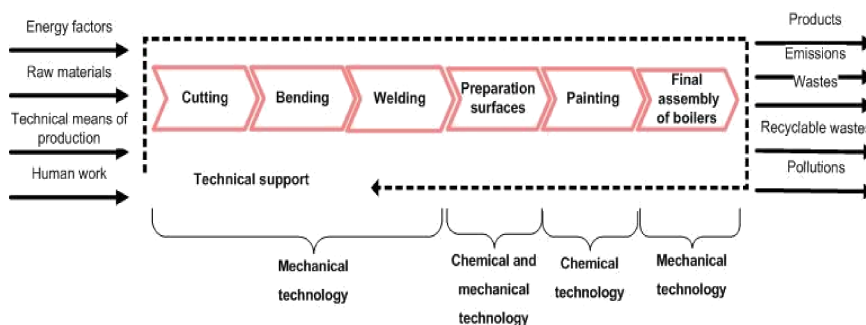


Fig. 1. Manufacturing processes for central heating boilers. Source: Own based on empirical research.

The indicator of influence I_{av} was calculated for two groups of manufacturing techniques: before and after their improvement as an arithmetic means from the sum of the partial results called the indicator of partial influence (I_{ij}) for processes (cutting, welding, bending, cleaning, painting and final assembly). Percent values of the indicator of the influence was defined as a calculation of the final impact index taking into account the economical, technological, social and environmental aspects divided by maximum possible to achieve scoring. The difference in scoring between two groups of the manufacturing techniques: before and after their improvement multiplied by 100 gives the percent value of the indicator's influence.

In the analysis of the manufacturing techniques, the cleaning and painting process had the greatest impact on the sustainable development of the enterprise. As a result, there was an improvement of 24% compared to the state of prior improvements. Somewhat less streamlining of (23%) was observed in the painting process. In regards to cutting and welding process it was a streamlining of 11% and 12% respectively (as shown in Fig. 2).

The analysis of the enterprise's manufacturing processes (base scenario) showed that the influence of manufacturing techniques on its sustainability is not strong and it is needed to find various ways of

improving its manufacturing processes in order to prove the influence of these streamlines on the sustainable development of the enterprises. An in-depth study and a thorough investigation should be made before making decisions regarding the improvement of manufacturing processes and equipment selection for an application. Based on these findings, solutions were proposed in manufacturing processes relaying on making the improvement in processes or replacing the older model machines by more advanced ones (Table 2).

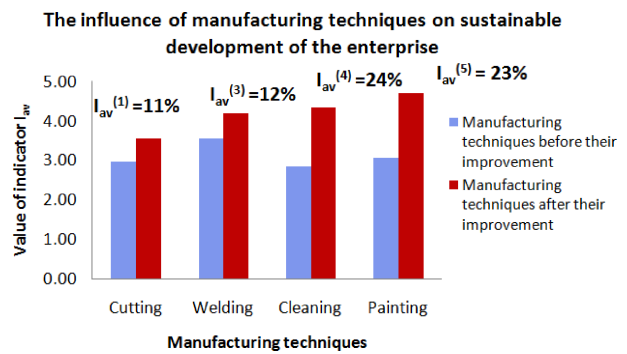


Fig. 2. Percent values of the influence indicator I_{av} of manufacturing techniques on sustainable development of the enterprise before and after their improvement. Source: Own based on empirical research.

Table 2
 State of techniques for the base scenario and improvements scenario).

| Manufacturing techniques | Existing techniques (base scenario) | Proposed solutions (improvement scenario) |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cutting | Steel sheets for boilers are cut in plasma (Jantar 2HD type by Eckert) by using a computer control system which accurately reproduces the shapes designed in CAD/CAM system. This technique enables cutting arbitrary, complex elements which do not require further finishing. | Laser cutting machine, workplaces to laser and plasma cutting will be equipped with a separation ventilation system (filtering system). |
| Welding | Welding of the boilers body with semi – automatic welding MIG/MAG in the shield of CO ₂ . SpG3S-wire electrode with a diameter of ϕ 1.2 mm Due to the high versatility of the process, MIG/MAG welding allows performing a variety of structures with different metals and alloys in the workshop and assembly conditions, in all positions. The burner is cooled with ethylene glycol. Welding stations are equipped with jigs and fixtures, lifts point. | Push – Pull welding ventilation system. Stationary and central suction and filtering systems with cartridge filter units reducing welding fumes and gases. |
| Cleaning | The whole process of applying color is preceded by thorough cleaning of the painted element: sanding, sometimes degreasing. | The abrasive blast processing with a closed abrasive circuit. For blasting the surface prior to welding it was intended to apply a dust-free, shot blasting machines suspending with shot closed circuit. |
| Wet painting | The paint coating on the base of solvent with the spraying hydrodynamic and air – operated method. Preparing the surface allows for permanent corrosion protection of the details. | Wet painting in spray booth. The use of paint spraying and drying cabin with air recirculation loop; with application technique of hydrodynamic spraying |

Source: Own based empirical research.

The indicators of influence I_{av} for cleaning amount to $I_{av} = 4.19$ and for painting process $I_{av} = 4.33$, what compared with those activity areas for manufacturing processes before their improvement ($I_{av} = 2.72$, $I_{av} = 3.03$) have obtained a higher impact. For welding the value of indicator I_{av} stands at 3.91 after its improvement versus 3.32 before improvements have been implemented.

Partial parameters such as environmental, technical, economic and social ones have also improved (Fig. 3 versus Fig. 4). For cleaning process the highest mean value of indicator (I_{ENV}) stands at 0.51 versus 0.23 before improvement of the processes, while I_{SOC} amounts to 0.58 vs. 0.44.

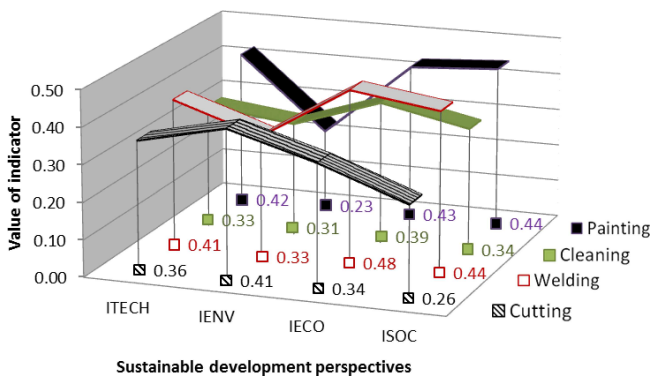


Fig. 3. Mean values of sustainable development perspectives for manufacturing techniques before their improvement. Source: Own based on empirical research.

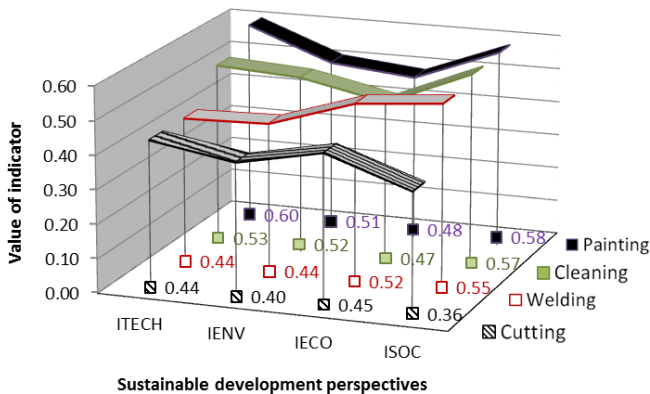


Fig. 4. Mean values of sustainable development perspectives for manufacturing techniques after their improvement. Source: Own based on empirical research.

Similar situation occurs in the case of painting process, where a mean value of influence $I_{ENV} = 0.52$ for manufacturing techniques after their improvement is high compared with a mean value of influence $I_{ENV} = 0.31$ before their improvement. A little bit higher value than previous one has the indicator $I_{SOC} = 0.34$ vs. $I_{SOC} = 0.57$ after the introduction

of improvement in the painting process. From the economical perspective, an increase in the values of indicator I_{ECO} is not pertinent due to investment in installation. It can be summarized that the economical dimension does not necessarily disagree with sustainable manufacturing, because if enterprises plan to increase the production volume, then it does not save energy (and materials too), especially advanced techniques require to be powered by electricity. It highlights of how the enterprise social-environmental performance is strongly associated with financial and technological aspects of the enterprise.

It should be noted that enterprises produced heating devices boilers which are not able to reduce their impact in 100% on the environmental degradation. A positive phenomenon can be observed that due to the improvement of the existing cleaning and painting techniques the analyzed enterprise limits the impact of production processes on the environment well below current limits (i.e. welding, cleaning and painting process). The enterprise limits the amount of wastes and decreases the use of solvents needed to the production, improves the work conditions of its employees. In this way, the enterprise contributes to reducing the impact of industry on the surrounding natural environment.

Findings

Heating devices industry, especially manufacturing processes: welding, cleaning and painting are/have always been considered to be a source of the environmental problems. However, the industry is an important contributor to development. The need for achievement of the environmental improvements has been expressed by BAT and Cleaner Production as tools of the sustainable development in “green production” of boilers. The need for this approach is particularly essential in small and medium-sized enterprises whose cumulative impact on the environment and human health is often greater than that of large-scale incidents. The meaning of the new manufacturing techniques and technologies requires a continuous development and improvement of how the manufacturing processes are developed and assessed. This paper was done taking one of the manufacturing enterprise as a case study. The study was depicted and assessed in a medium-sized enterprise. Although this study is confined to a relatively narrow sample, arguably it is among those which are the most influential in achieving the sustainable development. It has been suggested in order to improve the processes and thereby minimize the waste generation. The right choice and use of welding, cleaning and painting

techniques in a way that ensures the maximum protection of the environment is one of the most important principles of the sustainable development. Under this policy, techniques aimed at reducing harmful effects on the environment, minimizing wastes and the emission of substances and gases into the air and soil has been recognized.

It was also observed there was an improvement of cleaning process of 24%. Somewhat less improvement was observed in the painting process of (23%). In regards to a cutting and welding process it was a streamlining of 11% and of 12% respectively. It shows a great importance of the influences on the sustainable development of the enterprise in cleaning and paint technique over the second ones. Results showed that improvement techniques and technologies presents potential for reducing environmental impacts and improve economic results in comparison to the base scenario for manufacturing techniques before their improvement. However, such applied options may not completely mitigate the environmental problems.

Results indicated that scenario for manufacturing techniques after their improvement in the considered plant is more suitable than the conventional ones (before their improvement).

In addition, it provided a substantial (economical and environmental) benefits of the improvement techniques, which are not equally available to all the heating devices businesses. The results of cost-benefit analysis have not been covered by this paper. Further, it allowed understanding of the real benefits of the enterprise flexibility in the Polish condition. In this context, improving environmental performance may require more financial outcomes to use new methods, technologies or alternatives not always leading to financial profits or return.

Speaking about cleaning and painting technology it will require changes not only in its technology but also in the way materials resources are supplied and the way there are used. If sustainable development is to be achieved, production process of heating boilers, has to be reoriented towards new patterns in order to reduce the environmental burden and bring better industrial productivity. The described application of the proposed solutions from the heating devices industry proves that sustainability is requiring improvement of manufacturing unit processes.

The presented assessment methodology that enables to assess the current state of manufacturing techniques is a value concept providing industrial companies the computation of sustainability performance. Therefore, it will facilitate a practical implication of this method.

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