Management and Production Engineering Review
Volume 6 • Number 3 • September 2015 • pp. 47–54
DOI: 10.1515/mper-2015-0025

LIFE CYCLE ANALYSIS OF TISSUE PAPER MANUFACTURING FROM VIRGIN PULP OR RECYCLED WASTE PAPER

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Received: 22 April 2015
Accepted: 7 July 2015

Abstract
The aim of this work is to compare the environmental impacts of two production processes of tissue paper using virgin pulp (virgin fiber) or waste paper pulp (recycled fiber). This comparison is based on the materials and energy used as well as emissions and waste resulting from the production of tissue paper. Life cycle assessment (LCA), ReCiPe method, was chosen as the analysis tool. The results of the research proved that electricity has the most considerable participation in the overall environmental impacts in both production processes, followed by either virgin pulp or heat. Consequently, these two production processes are the greatest contributors to the following midpoint environmental impact categories: human toxicity, climate change, human health and ecosystems, and fossil depletion. The analysis based on endpoint impact categories proved that the production process based on waste paper is more environmentally friendly than the one based on virgin pulp in all impact categories: human health, ecosystems, resources. This is largely because of its lower material and energy requirements in the entire life cycle. Due to the fact that the tissue paper is the final use of fiber, using recycled waste paper is strongly recommended. The obtained research results are a valuable source of management information for the decision makers at both company and national levels required to improve the environmental performance of tissue paper production.

Keywords
life cycle assessment (LCA), tissue paper, recycled waste paper, virgin pulp.

Introduction

Poland produces approximately 425 000 of tissue paper annually accounting for 13% of total paper and board production. That makes Poland the 15th largest tissue paper manufacturer in the world and 6th largest in the European Union, just after Italy, Germany, France, UK and Spain [1]. The production of tissue paper covers toilet paper, kitchen towels, tablecloths, napkins and wipes, but toilet paper dominates the market. There are nearly 300 000 of toilet paper produce in Poland yearly, 2/3 of which is domestically consumed [2].

Fibrous material mix is used for the production of tissue paper in Poland, estimated at 60/40 of recycled waste paper to market virgin pulp [1]. This production of tissue paper, both of virgin pulp (virgin fiber) and waste paper pulp (recycled fiber) is associated with significant environmental impacts resulting from the consumption of raw materials and energy, as well as emissions to air, water and soil. Considering that the processes of producing paper from both types of masses are analogous to one another, it is believed that their burdens on the environment are almost the same [3]. However, the use of waste paper as the main raw material does

not require an additional investment of time, energy and money, and it may also bring economic and environmental benefits. Almost each type of used paper can be put into production again, multiplying the potential profits of entrepreneurs [4]. The production of recycled waste paper reduces the use of forest timber, helping to conserve natural resources.

This paper is divided into two main sections. The first section outlines the environmental system analysis method employed in the research, Life cycle assessment (LCA). The second section presents and discusses the results of LCA for the production processes of tissue paper using virgin paper or waste paper pulp. Only after thorough assessment of the ecological balance of both manufacturing processes, taking into account input factors (energy, materials, water) and output factors (air emissions, sludge, waste), it is possible to answer the question of which of these processes is more environmentally friendly.

The life cycle assessment (LCA) framework is the most commonly used technique of life cycle management (LCM) for evaluating the environmental performance of products and services. Recently, the European Commission has issued the recommendations on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations (2013/179/UE). The methods are based on LCA methodology and, thus, cover multi criteria environmental evaluation of goods and services. It is assumed that LCA methods become a part of obligatory regulations in the area of environmental protection, energy efficiency, green tenders, competitiveness and other actions contributing to the development of green economy [2]. Consequently, the application of LCA methodology in the Pulp and Paper Industry may help to improve the environmental performance of this sector and its products and, therefore, is worldwide applied [5–8].

Methodology

The study is fully in respect to international standards ISO 14040 and 14044 and consists of four phases: goal and scope definition, inventory of all inputs and outputs related to the production processes (LCI, life cycle inventory), assessment of the potential impacts associated with these inputs and outputs (LCIA, life cycle impact assessment) and interpretation of the impact assessment results (see Fig. 1).

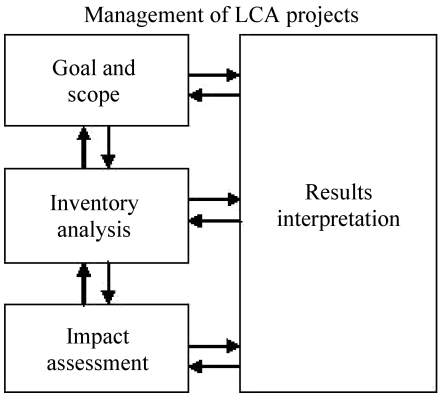


Fig. 1. Model of life cycle assessment (LCA) [9].

Goal and scope of the analysis

The main aim of this research is to determine the environmental impacts that arise from manufacturing of tissue paper using virgin pulp or waste paper pulp. In doing so, the research bring several outcomes. First and foremost, this enables the comparison of the above two production processes, based upon the same methodology (LCA) and life cycle impact assessment method (LCIA, ReCiPe method). As a consequence, it proves that LCA is a valuable alternative for the modeling of current and future tissue paper production process that can be incorporated into the calculation of eco-efficiency, the implementation of eco-management and audit scheme (EMAS) and eco-labeling.

The scope of the study directly stems from the goal and thus covers two alternative tissue paper production processes. Description of the production processes refers to the report of "The Best Available Techniques (BAT), Guidelines for the Pulp and Paper Industry" [3].

Functional unit

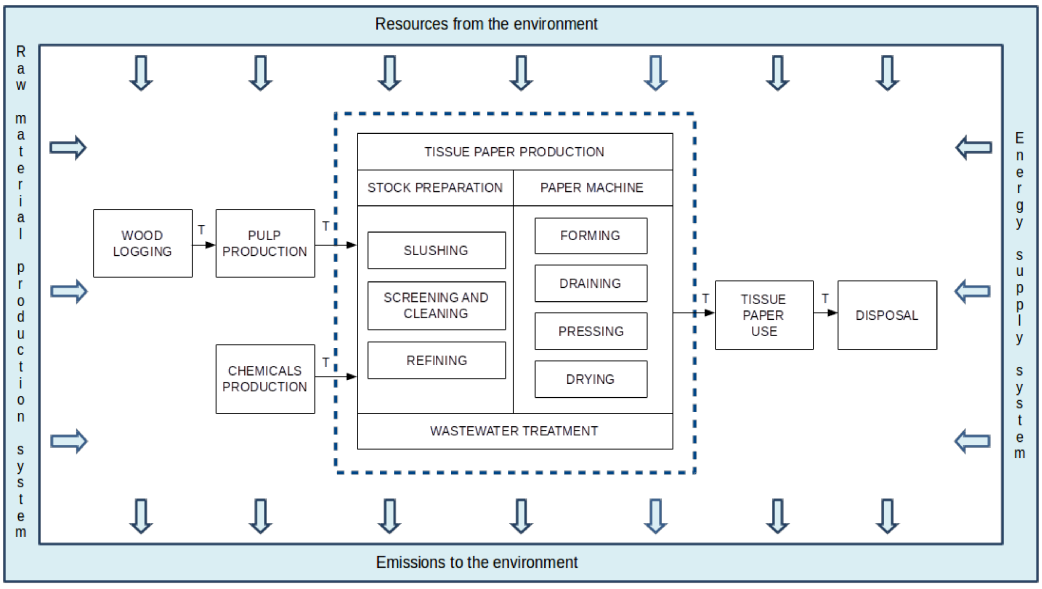
The functional unit is a key element of LCA and provides a reference to which the inputs and outputs can be related [10]. In this LCA study, the functional unit of the system is defined as 1 ton of produced tissue paper. A special attention was paid to the functional equivalency of the products since only then their life cycles (production processes) can be compared [11].

System boundaries and unit processes

The system boundaries determine which unit processes ought to be included in the LCA study [12]. Generally, LCA is a "cradle-to-grave" approach and covers the whole product life cycle from the raw material extraction through the manufacturing and use

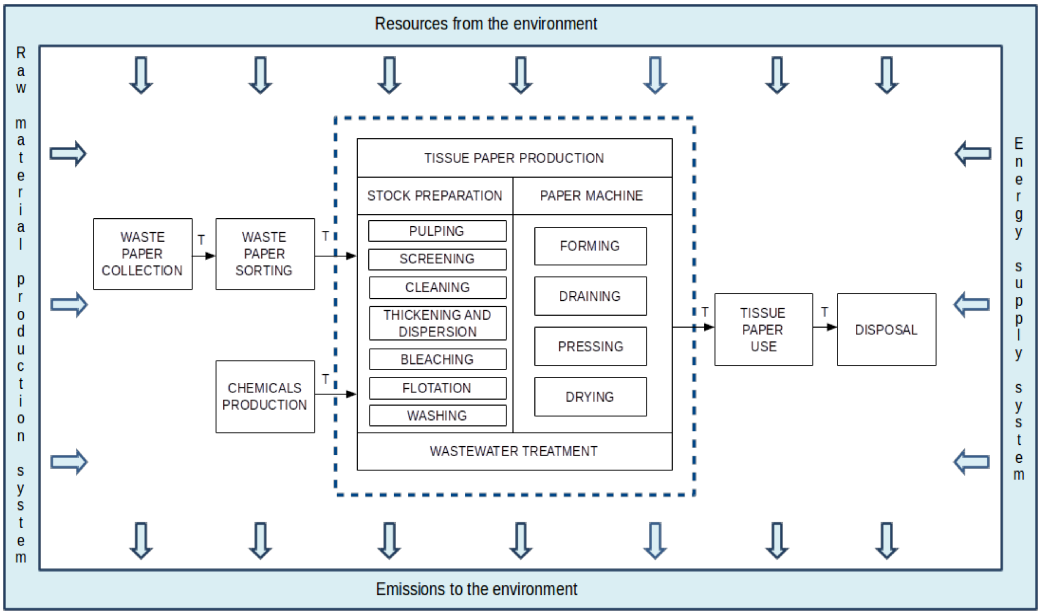
stage to disposal. However, it can be equally applied to the selected stages of a product's or process's life cycle [13, 14].

The life cycle of tissue paper manufactured from virgin pulp includes the following processes: the wood logging, the pulp and chemicals making processes, the tissue paper production, and, finally, the use and disposal of tissue paper. In the presented study, the system boundaries have been restricted from the point that the main raw material has been delivered to the mills manufacturing papers to the point where the final products are made. The process flows of tissue paper manufactured from virgin pulp and the system boundaries that cover the tissue paper production are illustrated in Fig. 2. The tissue paper production has two basic units: the stock preparation and the paper making process in the paper machine. The stock preparation consists of the following stages: fiber slushing, the removal of impurities, fiber refining. Finally, the pulp is fed to a paper machine where it is formed and most its properties are determined.



where T means transportation

Fig. 2. Process flows of tissue paper production from virgin pulp.



where T means transportation

Fig. 3. Process flows of tissue paper production from recycled waste paper.

Regarding the tissue paper manufactured from the recycled waste paper, the complete life cycle covers the following processes: the collection and pre-treatment of waste paper, the tissue paper production and the treatment of waste from the production processes, the use of tissue paper and, finally, its disposal. Due to the fact that a numerous of former studies proved that all the above enumerated unit processes, despite the production phase, have minor environmental impacts on the life cycle of tissue paper, they were excluded from the analysis [10, 15, 16]. Figure 3 presents the process flows of tissue paper production from recycled waste paper and the system boundaries that cover the tissue paper production. The main stages of the recycled waste paper preparation cover: waste paper storage, repulping of the dry recovered waste paper, mechanical removal of impurities (screening, cleaning) and bleaching. Finally, the pulp is pumped to the storage chests that serve as a buffer between the stock preparation and paper machine [3].

Inventory analysis

Life cycle inventory (LCI) covers the collection and quantification of inputs and outputs for a given product or process system throughout its life cycle [17]. Consequently, data collection is carried out in order to draw up a comprehensive balance of the energy, materials and chemicals taken from the environment that enter the system and that leave the system as emissions to the environment [18, 19]. A summary inventory of environmental flows of the system of tissue paper production covers: virgin pulp or waste paper pulp, water, electricity, heat, resin, starch and dyes (as inputs), and air emissions, water emissions and solid waste (as outputs) (see Fig. 4). All the data refer to the defined functional unit that is 1 ton of tissue paper. The primary source of data was the report on "The Best Available Techniques (BAT). Guidelines for the Pulp and Paper Industry" since the majority of Polish paper mills producing tissue paper fulfill the environmental requirements of BAT [3, 4].

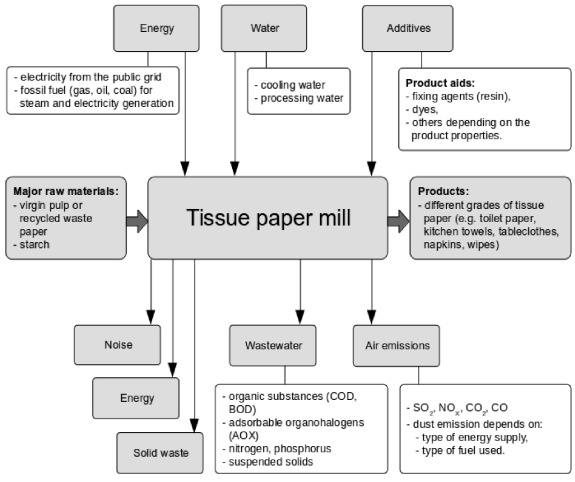


Fig. 4. The general scheme of inventory analysis of tissue paper mill.

Results and discussion

The LCA analysis of the two systems of tissue paper manufacturing was done using the software of SimaPro8 and the ReCiPe method. This LCIA method comprises harmonized category indicators at two levels: eighteen midpoint indicators (including climate change, terrestrial acidification, fresh water eutrophication, photochemical oxidant formation, particulate matter formation, fossil depletion) and three endpoint indicators (Resources, Ecosystems, Human Health) [20]. The indicator scores are a measure of the environmental load of a product or process.

In this study, the inventory (LCI) results of the product systems are presented as the process trees (see Figs. 5 and 6). The thickness of the line represents the total environmental load of the each process according to the ReCiPe Endpoint score.

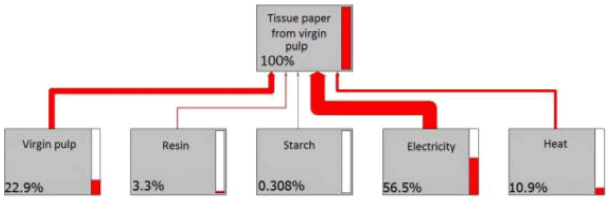


Fig. 5. The process tree for the tissue paper production from virgin pulp.

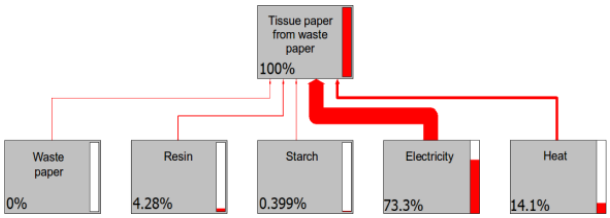


Fig. 6. The process tree for the tissue paper production from recycled waste paper.

In the case of the tissue paper made of virgin pulp, electricity has the most considerable participation in the overall environmental impacts, followed by virgin pulp. In total they cover nearly 80% of all the negative impacts on the environment that occur during the process of tissue paper production. The usage of electricity generates as much as 56.5% of the impact on the environment, which results from

the energy consumption characteristic of paper industry and negative consequences arising from the processes of electricity production. The generation of electricity in Poland is almost entirely based on the solid fossil fuels – hard coal and brown coal, and therefore, it is highly burdensome for the environment, causing the production of mostly considerable emission of gas pollution and constant side combustion products. Significant amounts of energy absorbed in order to maintain the motion of engines in machines and devices used in the tissue paper production process, influence degradation and pollution of the natural environment. In particular, the Through-Air Drying process (TAD) is highly energy consuming, since during that process it is necessary to warm the huge amounts of air. Furthermore, making frequent changes of grade and color of tissue paper in the paper machine slightly decrease the efficiency of raw materials' usage, energy included. Degradation of the natural environment in the tissue paper production process also results from the usage of virgin pulp whose production involves such significant environmental aspects as: raw materials' usage, including wood, the usage of chemicals and energy, emissions to the air, emission of pollution into the wastewater and the creation of the solid waste. Considering the environmental impact of individual input factors, it is evident that the electricity dominates some impact categories, for instance human toxicity, freshwater eutrophication, freshwater and marine ecotoxicity, while virgin pulp dominates others, mostly urban and agricultural land occupation, terrestrial ecotoxicity (see Fig. 7).

Corresponding the data inventory, four inputs were identified that have the greatest environmental load during the tissue paper production from waste paper. These are electricity, heat, resin and starch (see Fig. 6). They constitute 92.08% of environmental impacts of all materials and substances used during the manufacturing process of the tissue paper from waste paper. Out of these four inputs, electricity consumption accounts for 73.3% and thus has the largest contribution in the environmental impacts. Similar trend occurs when the contribution of energy in the individual impact categories is considered (see Fig. 8). Consequently, in all categories, despite ozone depletion, the electricity has the largest share. In the case of the following impact categories: human toxicity, freshwater eutrophication, freshwater and marine ecotoxicity, urban land occupation and natural land transformation, the share of electricity exceeds 90%.

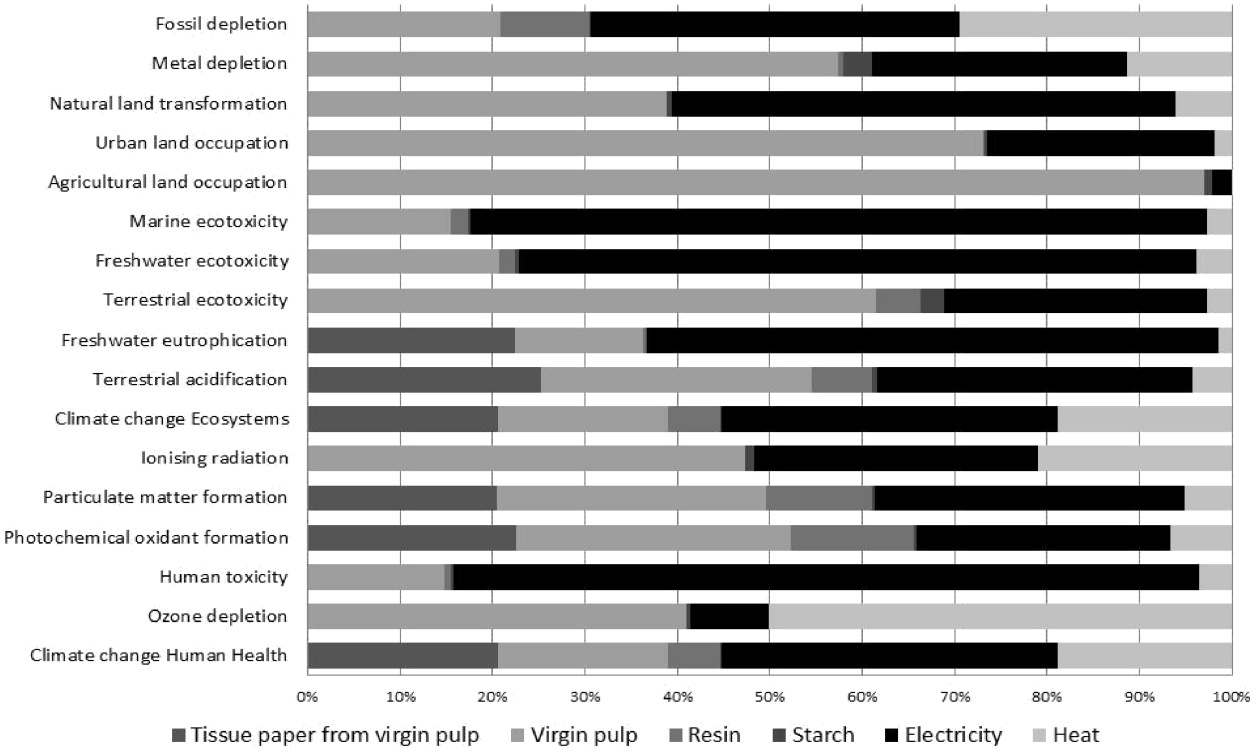


Fig. 7. Characterization of the tissue paper production from virgin pulp.

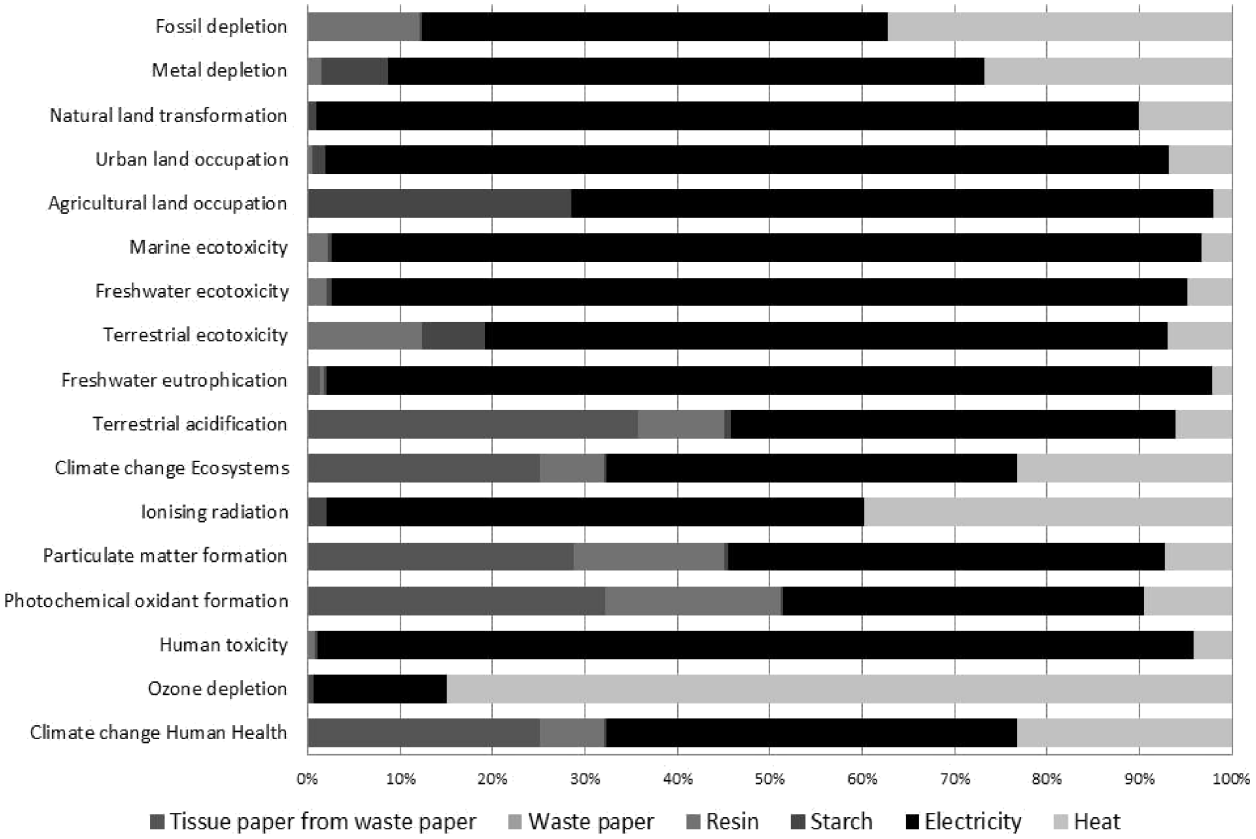


Fig. 8. Characterization of the tissue paper production from recycled waste paper.

The production of tissue paper from recycled waste paper requires large quantities of electricity for driving the machinery (approximately one third is consumed during thickening and dispersion) and wastewater treatment. At the same time, a considerable amount of steam is used for heating of water, pulp, air and chemicals to the demanded process temperature and for drying the paper. To meet the need for electricity and steam, the tissue paper mills either buy electricity from the public grid and generate heat internally or apply co-generated heat and power installations (CHP). The second solution is far more environmentally friendly, due to its high total yield, up to 80%.

Both the tissue paper production from virgin pulp and from recycled waste paper are the greatest contributors to the following midpoint environmental impact categories: human toxicity, climate change human health and ecosystems, and fossil depletion, which constitute 49.85%, 15.85% and 12.65%, and 12.35% on average, respectively (Table 1). The achieved results confirmed that paper mills are the source of considerable water emissions (COD, BOD), solid waste (discards, sewage sludge) and air emissions (CO_2, NO_X) associated with the production of energy by burning fossil fuels. In the case of the tissue paper made of virgin pulp, harvesting forest lands to procure the wood for pulping makes an additional environmental burden that contribute to the agricultural land occupation impact category (6.5%).

Table 1
Environmental impact assessment of tissue paper production in the midpoint impact categories.

Impact categories	Tissue paper from virgin pulp	Tissue paper from waste paper
Climate change Human Health	15.4%	16.3%
Human toxicity	47.4%	52.3%
Climate change Ecosystems	12.3%	13%
Agricultural land occupation	6.5%	0.3%
Fossil depletion	12.2%	12.5%
Others	6.2%	5.6%

Tissue paper manufacturing from virgin pulp is more environmentally intensive than from recycle waste paper in all endpoint impact categories: human health, ecosystems and resources (see Fig. 9).

As a result, the overall environmental impact of the production process of tissue paper from virgin pulp is larger by 0.4 Pt. Although there are plenty reasons for such dissimilarities, the major one seems to be use of raw materials (the wood pulp) and related to it deforestation, fossil fuel emissions that arise from the transportation and, finally, use of water, energy and chemicals during pulp making process.

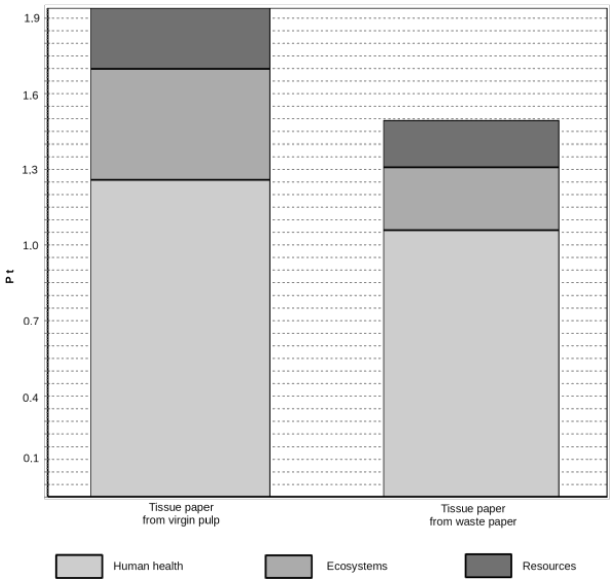


Fig. 9. Environmental impact assessment of tissue paper production in the endpoint impact categories.

Conclusions

Life cycle assessment (LCA) of tissue paper manufacturing proved that using recycled waste paper instead of virgin pulp is beneficial from the environmental point of view. Most importantly, it allows reducing the consumption of wood resources that otherwise will be lost forever, since tissue paper is the last stage of the fibers' use. To improve the environmental profile of both tissue paper production processes, it is recommended to implement co-generated heat and power installations (CHP).

The results presented in this publication were obtained as a result of studies carried out under the framework of the project "Perspektywy RSI Świętokrzyskie – IV etap", No WND – POKL.08.02.02 26 – 001/12 – European Social Fund, Human Capital Operational Programme, Priority VIII Regional human resources, Measure 8.2. Knowledge Transfer, Submeasure 8.2.2 Regional Innovation Strategies.

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