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CONFERENCE PAPER

Life cycle assessment of an office: Carbon footprint of an office staff

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ABSTRACT

Environmental problems have become today's most emphasized issues due to the unconscious use of natural resources and the ongoing increase in consumption resulted in an increased level of environmental pollution. Offices, where most of the daily time is being consumed in today's modern world, generate the important amount of daily wastes and increase the environmental burden. In this respect, it is important to investigate and to reveal their environmental impacts. In this study, the Organizational Life Cycle Assessment (O-LCA) of an office has been conducted in order to investigate the environmental impacts caused by a typical office and to reveal carbon footprint of an office staff. The water and energy consumption (electricity and natural gas), transportation, and business travel data were obtained based on the real consumptions of the organization, while data required for the calculation of the waste amount (paper, cardboard, plastic etc.) were provided from literature. Afterwards, data obtained for office have been run into SimaPro Analyst 8.0.2 software in order to calculate carbon footprint and to analyze the environmental impacts. As a result of the calculations made, the carbon footprint of the office has been found as 10^5 kg CO_2-eq $year^{-1}$ and the carbon footprint of an office staff has been determined as 5263.16 kg CO_2- eq $year^{-1}$, accordingly. The obtained results have indicated that the highest share in terms of carbon dioxide emission is caused by electricity consumption, followed by transportation, business travel, office consumables, electronic devices, natural gas consumption, office wastes, water consumption, and electronic wastes, respectively.

Keywords: Carbon footprint, environment, life cycle assessment (LCA), office waste

1. INTRODUCTION

The ongoing increase in consumption and the increasing environmental problems (such as global warming) associated with population growth in the world are one of the most important discussed issues today. The actions which have been taken until today and what needs to be done further in order to solve these problems are also among the important issues on the agenda [1].

Buildings are one of the largest consumers of energy in any country with intense industry, and office buildings have a significant participation. As the transformation of the global economy towards the service industries intensifies, so too do investments in offices and other commercial buildings. Studying the energy and environmental effects of office buildings throughout their life cycle, therefore, is important [2].

According to a study carried out in the United Kingdom, waste generated from commercial sector represents 12% of all waste in the UK. The amount of waste which commercial offices occupied by large companies in the financial sector generally produce is around 500 kg per employee for each year and it comprises of 60% paper and cardboard. It also refers to a study carried in 2000, which has been found that almost 70% of all waste was disposed of to landfills [3].

The wastes and the emissions which offices generate are just the one part of the issue. The other part is the interaction with the environment during the life cycles of the products and services [1]. One of the best ways to make this interaction clear is the Life Cycle Assessment (LCA) approach, which provides a numerical output that identifies potential environmental impacts by examining the

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environmental aspects of production, use, end-of-life evaluation, recycling and disposal stages of products and services throughout the entire life cycle [1], [4].

In response to the increase of offices' importance in terms of environmental burden, the environmental impacts of different types of office buildings have been investigated via LCA approach in some previous studies. In the LCA study of a 4-story commercial office building located in Southern Finland with 4,400 m^2 gross floor area and roughly 200 staff, the emissions related with the materials, construction, use, maintenance, and end-of-life phases have been investigated. It has been found that the use phase of the office has the highest share as 50-90% in all emissions (for CO_2, SO_2 NO_x, and PM_{10}) among the other phases. Use phase's contribution in the total CO_2 emission of the office has been found as 83%. When the use phase investigated in detail, it has been revealed that the highest impact with a range between 30-45% is caused by electricity consumption and heating process. On the other hand, it has been found that the use phase dominates the materials, construction, maintenance and end-of-life phases for a 5-story commercial office building located in Midwest U.S. with 4,400 m^2 area, in terms of all emissions except PM_{10} (particulate matter smaller than 10 μm). It has been found that the use phase has an important share which is not less than 46% among other phases in terms of all emission categories, and lighting and electricity consumption have been dominated in use phase [2]. In another study carried on in Thailand, it has been found that the life cycle distribution of environmental impacts is concentrated in the operational stage of the typical commercial office building. It has been stated that the operational phase was accounted for approximately 52% of the total global warming potential, about 66% of the total acidification potential, and about 71% of the total photo-oxidant formation potential, respectively. The results indicated that the main contribution to the impact categories during the operation phase was caused from emissions related to fossil fuel combustion, particularly for electricity production [5]. In reference [6], authors performed an economic input-output LCA and compared it to primary energy and CO_2 emissions of 10 office buildings with 40 years of service life in Japan. The study reported that the energy use and CO_2 emissions caused by the electrical energy utilization in the use phase of the office building contributed most of the environmental impacts in all 10 cases with an average percentage of 80%. The significance of the use phase in terms of environmental impacts has been further revealed in another LCA study of an 8-story office building located in Athens, Greece. Investigating the environmental impacts of raw material extraction, components manufacture, components transportation, construction of the office building, use, and demolition/waste management stages of the office building, it has been found that the use phase contributes by 91.94% to the total of the environmental score. Global warming potential is the environmental impact that corresponds to the highest portion as 78.35 % in the use phase. The environmental impact of the use phase was regarded to the energy consumption used for heating, cooling, and lighting of the building, which is attributed with fossil fuel use in energy production processes [7].

While revealing the most of the environmental impacts of offices are caused from the use phase, these studies have not investigated the use phase with an organizational approach exhaustively. In this respect, the Organizational Life Cycle Assessment (O – LCA) of an office located in Turkey has been conducted by means of this study. The LCA method was applied referring to ISO/TS 14072 standard which provides recommendations and requirements specifically for O-LCA to ensure a more effective application of ISO 14040 and ISO 14044 to organizations [8].

2. MATERIALS AND METHOD

2.1. Life Cycle Assessment Goal and Scope Definition

The goal of this study was to investigate the environmental impacts caused by a typical office and to reveal the carbon footprint of an office staff. In this study, Organizational Life Cycle Assessment of a 3-roomed, 160 m^2 typical office operating in a service sector with 19 staff located in a 6-story commercial office building in Nilüfer, Bursa was performed. The total carbon dioxide emission of the office has been calculated and the carbon footprint of an office staff has been determined. In addition, environmental impacts were investigated.

The system boundary of the study was determined as cradle-to-grave, which includes the energy consumption and emissions of the use phase of the office for a given reference period, and the end-of-life phase (i.e., waste disposal and recycling) of products used by the organization throughout the reference period. In other words, solely the use phase of the office for a given reference period has been investigated in cradle-to-grave boundary. The construction and demolition phases of the office have not been included in the study. Besides, the reference period of the study has been defined as one year, 2016.

2.2. Life Cycle Inventory

In order to create inventory analysis, the activities and materials have been categorized as follows:

2.2.1. Water and energy consumptions

In this category, monthly bills for 2016 served as a source for calculating the amount of water and energy consumption (for electricity and natural gas) of the office.

2.2.2. Transportation

Transportation data include the distance covered by each staff to come to the office in the reference period. In order to calculate emissions caused from transportation, the distances were determined

separately for shuttle service, individual car, and public transportation (subway).

2.2.3. Business travel

This activity includes travels made for purposes such as scheduled and unplanned visits of the customers on-site, project meetings, fairs, symposiums, conferences and so on. In this category, the intercity and overseas distances passed on for business travel in the reference period, 2016, were taken as a basis, and emissions have been calculated for car (taxi), train (intercity), airplane (separately for domestic and international flights), coach (intercity), and ferryboat, individually.

2.2.4. Office consumables

During the calculation of the emissions related to office consumables, the type and yearly consumption amount of consumables for a typical office have been determined from the literature [3]. Major ones were selected as whitepaper, cardboard, newspaper and magazine, glass, aluminum cans, and plastic cups. Since some types of the consumables are not possible to evaluate accurately, sections named other paper and other plastic were determined additionally.

2.2.5. Office wastes

In order to determine the carbon dioxide emission in office wastes category, the waste amount generated from office consumables in a year and recycling rates for each type have been obtained from literature [3], [9], [10].

2.2.6. Electronic devices

Electronic devices refer to desktop computer, portable computer, computer adaptor, cabled mouse, black and white printer, and colored printer. The total amount has been determined by taking as a basis the number and weight of each of these electronic devices within the organization. The operation and production phases were investigated separately for desktop and portable computers with taken into consideration the operation hours and working days in the reference period.

2.2.7. Electronic waste

To evaluate the emissions associated with this category, the amount of electronic waste was obtained from the organization's real consumptions, while the service life for each equipment was estimated based on the organization's experience. Besides, an assumption referred to the organization's attitude was made for recycling rates in terms of electronic devices. Service life has been assumed as 5 years for desktop computer, portable computer and computer adapter, 1 year for cabled mouse, 10 years for black and white printer and, 8 years for colored printer. On the other hand, it has been assumed that all the computers and printers are dispatched to be recycled, while computer adaptors and cabled mouses are disposed of to landfills after completing their service life.

2.2.8. Wastewater

Wastewater amount has been calculated by using the organization's real consumption data. All the wastewater goes to a treatment plant located in the industrial zone and there is no reuse of wastewater within the organization. Regrettably, the characterization of the wastewater could not be assessed and there is no information about its treatment process.

A summary of the data and the sources they are compiled from is shown in Table 1.

Table 1. Summary of data and their source

Data	Data Source	Recycling Rate Source
Electricity Consumption	Direct Measurement	-
Water Consumption	Direct Measurement	-
Natural Gas Consumption	Direct Measurement	-
Transportation (Shuttle Service, Subway, Car)	Direct Measurement	-
Business Travel (Taxi, Train, Airplane, Coach, Ferryboat)	Direct Measurement	-
Office Consumables (Whitepaper, cardboard, plastic cups, etc.)	[3]	-
Office Waste	[3]	[9, 10]
Electronic Devices	Direct Measurement	-
Electronic Waste (Desktop computer, portable computer, etc.)	Direct Measurement	Assumption referred to organization's attitude
Wastewater	Direct Measurement	-

2.3. Life Cycle Impact Assessment

The data obtained for office have been run into SimaPro Analyst 8.0.2 software and total carbon footprint of the office has been determined. In addition to global warming potential (which reveals the carbon footprint), several environmental impacts comprising;

- Abiotic depletion (Decrease in the natural availability of abiotic natural resources, including minerals [11].)
- Abiotic depletion (fossil fuels) (Decrease in the natural availability of abiotic natural resources, including fossil energy resources [11].)
- Ozone layer depletion (Depletion in the ozone layer that leads larger fraction of UV-B radiation to reach to earth surface, and may cause harmful effects on human health, animal health, terrestrial and aquatic ecosystems, and biochemical cycles [11].)
- Human toxicity (Effects of toxic substances on the human environment [11].)
- Freshwater aquatic ecotoxicity (Impact of the emissions of toxic substances to air, water, and soil on freshwater ecosystems [11].)
- Marine aquatic ecotoxicity (Impact of toxic substances to marine ecosystems [11].)
- Terrestrial ecotoxicity (Impact of toxic substances to terrestrial ecosystems [11].)
- Photochemical oxidation (The formation of reactive substances (mostly ozone) which are hazardous to human health and ecosystems [11].)
- Acidification (Impacts of acidifying substances on soil, groundwater, surface water, organisms, ecosystems, and materials (buildings) [11].) and,
- Eutrophication (Impacts of excessive levels of macro-nutrients in the environment related with emissions of nutrients to air, water, and soil [11].)

have been investigated. EcoInvent, the most comprehensive database available, and the CML-IA BaseLine 3.0 method have been used in terms of calculation of carbon dioxide equivalent emissions (global warming potential) and other environmental impacts throughout the study.

3. RESULTS & DISCUSSION

As a result of the analysis, the carbon footprint of the office was found to be 10^5 kg CO_2 –eq $year^{-1}$, and it is determined that an office staff's carbon footprint is 5263.16 kg CO_2-eq $year^{-1}$. The environmental impacts of the office have been revealed, and the contribution of each parameter was investigated.

In Fig 1, which is obtained from SimaPro Software, the characterization of the environmental impacts have been revealed. If the global warming potential (GWP) column in Figure 1 was examined in detail, it could be seen that 66% of the carbon footprint which an office staff generates in a year was caused from electricity consumption, 15% from transportation, 10.3% from business travel, 4.74% from office consumables and, 2.88% from electronic devices. The total rest of the share, 1.08%, which is too small hence it is not possible to visualize in the graph, is caused by natural gas consumption, office waste, water consumption, and electronic waste, respectively. The characterization of the wastewater plays a major role when assessing its impacts in an environmental point of view and it would also affect the selection of its treatment process. Since the software could calculate the exact emissions caused from wastewater only depending on its characterization, and wastewater's characterization could not be evaluated in this study, no environmental impact in terms of global warming potential caused from wastewater has occurred.

Fig 2 illustrates the network obtained from SimaPro Software in terms of global warming potential of the office which has been demonstrated that the highest carbon dioxide emission is caused from electricity consumption as $6.61 \bullet 10^4$ kg CO_2 – eq $year^{-1}$.

As the second highest share in carbon dioxide emission is caused from transportation, investigation of transportation type hereby gains importance. In Fig 3, the percentages of transportation types have been illustrated. It could be seen that the highest effect is caused from passenger car and subway, after shuttle service.

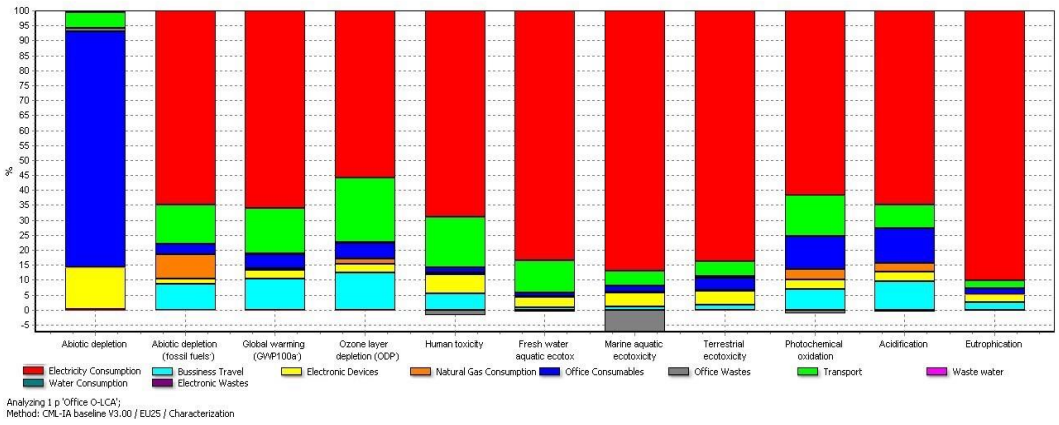

Fig 1. Characterization graph of the environmental impacts of the office

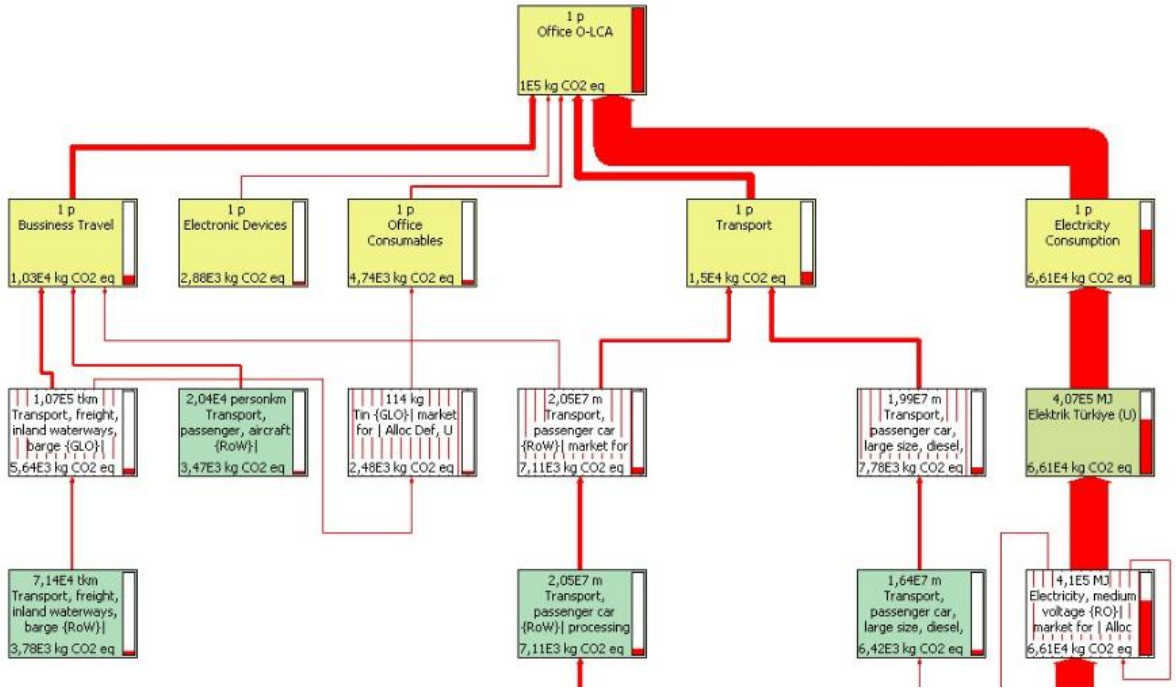

Fig 2. Global warming potential network

This result is related to the office's location which does not make it attractive for the staff to prefer subway to come to the office.

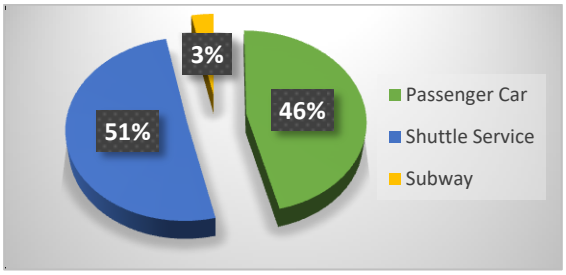

Fig 3. Percentages of transportation types in terms of GWP

Besides, business travel has a significant share, as 10.6%, in terms of global warming, and revealing the effects in a more detailed way, therefore, is important. The types of transportation used for business travel and their share have been illustrated in Fig 4. It has been found that the highest emission is generated from the ferryboat, followed by airplane (international flights), coach, airplane (domestic flights), train, and car, respectively. Although it has been found in the literature that the emission per person related with domestic flight is higher than international flight, and the emission caused from ferryboat is the smallest among both types of flights [12], such a result could be explained by the staff's attitude to prefer mostly ferryboat and coach in their domestic travels, and the numbers of travels abroad to be quite less compared to the domestic ones.

It is also important to investigate other environmental impacts besides the global warming potential. As it could be seen from Fig 1, electricity consumption dominates in terms of all environmental impacts except abiotic depletion. In the eutrophication category, it has been shown that the electricity consumption has an important proportion as 90%. On the other hand, it is clear that transportation has a significant share in each environmental impact category.

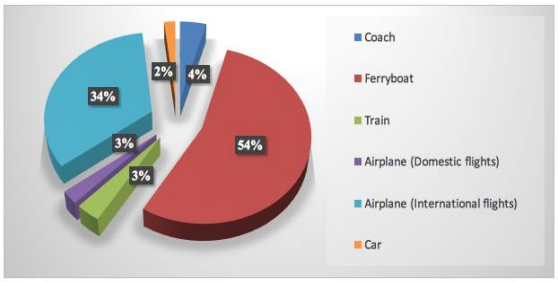

Fig 4. Percentages of transportation types in business travel in terms of GWP

Investigating all impact categories, it has been shown that the transportation has its biggest share in ozone layer depletion category as 23.5%. Besides, it has been demonstrated that office consumables have an important share as 78.7% in terms of abiotic depletion, while the second highest impact has been caused from electronic devices. The second and third highest impacts caused by office consumables have been found to be in acidification as 12% and in photochemical oxidation as 11%, respectively. It also could be seen that the recycling of some of the office wastes caused 7% improvement in terms of marine aquatic ecotoxicity, %2 in human toxicity and %1 in photochemical oxidation. In abiotic depletion (fossil fuels) category, natural gas consumption has a significant share as 8% after electricity consumption and transportation, respectively.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the carbon footprint of one office staff for 2016 has been determined as 5263.16 kg CO_2-eq $year^{-1}$. Given that a large portion of this release (66%)

is due to the electricity consumption, it is evident how important energy source use habits are. In this case, it is clear that taking actions such as changing the bulbs with more efficient ones, giving more importance to the use type of electronic devices (computers, printers, etc.), and air conditioners would affect the total carbon footprint. Besides, such a result also matches up with the studies previously mentioned in the introduction section which have been stated that the electricity consumption has the highest impact in the use phase of the office.

On the other hand, the obtained results indicated that transportation has a significant contribution as 15% in terms of global warming. Considering the highest share is caused from shuttle service and individual car, it could be seen clearly how effective results switching to public transportation would reveal. Additionally, the emission associated with business travel should not be ignored since it has an important role in the total carbon footprint of an office staff. Choosing the transportation type with low emission where possible could be a good solution to achieve notable reductions in terms of environmental burdens.

Besides, it should not be ignored that recycling and reduction in the usage amount of typical office consumables such as whitepaper, cardboard, and plastic cup are also one of the major factors which have a direct effect in terms of reducing the carbon dioxide emission and environmental burdens. The awareness of the office staff hereby takes an important role. In this case, the separation and collection processes of recyclable and reusable materials would have a significant effect in terms of waste amount reduction. The recycling rate of the consumables in the office itself should be increased, and, if possible, the materials which are appropriate to reuse must be selected. In addition, promoting campaigns in order to increase the awareness in terms of reuse and recycling could be a good solution to reduce the waste amount and hence the environmental load. Besides, if reasonable purchasing policies and waste management practices are implemented, the amount of emission caused from wastes could be fairly small in the overall footprint.

Considering the electricity consumption dominates all the environmental impacts except abiotic depletion, it can be said that energy source use habits and attitude take an important role in the use phase of the office. On the other hand, it is explicit that one of the most important issues in terms of reducing the environmental load caused from the office appears to be the office staff's awareness. Since offices generate a significant amount of daily wastes, working towards the environmental impacts which these wastes reveal should be one of the issues that need to be emphasized. Besides, all the actions associated with reducing the total carbon footprint of an office staff should be carefully investigated and implemented. It is indisputable that knowing the energy profiles and expected emissions of the life cycle of offices could be useful in the matter of making informed decisions about the environment for future.

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