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Introduction

On September 21-22, 2015, 6th International Scientific Conference "Quality of Life 2015. Human and Ecosystems Well-being" was held in Wrocław.

The conference was a part of the cycle of the conferences on the topic of quality of life that have been organized by the Department of Statistics (Wrocław University of Economics) since 1999. The aim of the cycle is to participate in the still rising all over the word wave of scientific studies on quality of life: ethical background and definitions of quality of life, investigating (how to measure it), presenting the results of differences of quality of life over time and space, its interdependences with natural environment, mathematical methods useful for the methodology of measuring quality of life and finally – possible methods of improving it. The conferences are meant to integrate the Polish scientific community doing research on these topics as well as to make contacts with foreign scientists.

This year our honorary guest was Professor Filomena Maggino, past President of International Society for Quality-of-Life Studies (ISQOLS), who presented a plenary lecture.

We hosted about 30 participants, among them scientists from Spain, Romania, Italy and Japan. We had 24 lectures on such a variety of topics as carbon footprint and mathematical properties of some estimators. The common background of all of them was to better comprehend, measure and possibly to improve the quality of humans' life.

The present volume contains the extended versions of some selected lectures presented during the conference. We wish to thank all of the participants of the conference for co-creating very inspiring character of this meeting, stimulating productive discussions and resulting in some potentially fruitful cooperation over new research problems. We wish also to thank the authors for their prolonged cooperation in preparing this volume, the reviewers for their hard work and for many valuable, although anonymous, suggestions that helped some of us to improve their works.

Finally, we wish to thank the members of the Editorial Office of Wrocław University of Economics for their hard work while preparing the edition of this volume, continuous kindness and helpfulness exceeding their duties of the job.

Katarzyna Ostasiewicz

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Quality of Life. Human and Ecosystem Well-being
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CARBON FOOTPRINT INDICATOR AND THE QUALITY OF ENERGETIC LIFE

ŚLAD WĘGLOWY A ENERGETYCZNA JAKOŚĆ ŻYCIA

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Summary: The paper presents methodology of Carbon Footprint indicator in the context of sustainable development. Introduction to Carbon Footprint calculation is supplemented by an empirical analysis of this indicator. Case study concerns the Faculty of Chemistry at the University of Warsaw. The analysis of this public building follows the general guidelines of ISO standard and takes into account direct and indirect CO_2 emissions. The final outcome of this study is a short-list of undertakings which are necessary to improve the efficient use of energy in the faculty. Conclusions tend to evaluate Carbon Footprint and the strengths and weaknesses of this indicator are briefly discussed.

Keywords: Carbon Footprint, sustainable development, energy efficiency.

Streszczenie: Artykuł przedstawia metodykę wskaźnika śladu węglowego (Carbon Footprint) w kontekście rozwoju trwałego i zrównoważonego. Wprowadzenie do rachunku śladu węglowego zostało poprzedzone przypomnieniem wskaźników proponowanych do oceny rozwoju trwałego i zrównoważonego, ze szczególnym uwzględnieniem wskaźników syntetycznych ze śladem ekologicznym (Ecological Footprint) na czele. Omówienie metodyki śladu węglowego zostało uzupełnione empiryczną analizą tego wskaźnika. Studium przypadku dotyczy Wydziału Chemii Uniwersytetu Warszawskiego. Analiza tego budynku bierze pod uwagę wytyczne standardu ISO i uwzględnia bezpośrednie oraz pośrednie emisje dwutlenku węgla. Wynikiem badania jest skrócona lista zalecanych przedsięwzięć, których realizacja poprawiłaby efektywność użytkowania energii w tym budynku. Podsumowanie skupia się na ocenie silnych i słabych stron omawianego miernika. Sformułowane rekomendacje podkreślają ograniczenia wskaźnika, ale wskazują uzasadnione i korzystne sposoby jego wykorzystywania w praktyce.

Słowa kluczowe: ślad węglowy, rozwój trwały i zrównoważony, efektywność energetyczna.

1. Introduction

The concept of sustainable development has resulted from political, ideological and cultural changes which took place at the turn of the 1960's and 70's. The origin and development of the sustainable development concept may be viewed as an attempt to find a compromise between the desire to continue socio-economic development and the necessity to consider limits to growth seriously. In the course of evolution, the sustainable development concept transformed from a political slogan to the strategy for real action. At present, sustainable development is becoming an indispensable element of various strategic developmental programs on the global, national, regional and also on the local scale. Conceptual aspects of sustainable development can be found in the policy framework of transnational organizations such as the UN and the European Union and in the national policy packages of the most developed countries.

Sustainable development is based on the ideas propagated by the Report of the UN Committee on the Environment and Development from 1987, more commonly known as "The Brundtland Report". In addition, the concept has been developed in some other basic program documents such as "Agenda 21" published by the United Nations in 1992. The following definition of sustainable development is acceptable in broad terms: "A nation is achieving sustainable development if it is undergoing a pattern of development that improves the total quality of life of every citizen, both now and into the future, while ensuring its rate of resources use does not exceed the regenerative and waste assimilative capacities of the natural environment" [Lawn 2006].

Basically, the concept says that economy, society, and environment are three indispensable pillars of sustainable development. Moreover, three major spheres of our life should be integrated in one policy-making context and, in particular, in decision-making process supporting three following strategies:

- economic development increasing the "real" welfare and quality of life,
- improving environmental quality and rational use of natural resources,
- ensuring social equity (also with regard to future generations) and building democratic institutions.

It implies that the global community but also each nation should safeguard the survival of the biosphere and all its evolving processes while recognizing and analyzing complicated interrelationships between economic development and social problems, and their natural environment. Thus, sustainable development needs quantitative assessment and permanent monitoring. However, this is not easy because sustainable development itself is a multidimensional and multifactor phenomenon. The following typology of sustainability indicators takes into account the way indicators can be calculated and the fact who is their potential user [Śleszyński 2000]:

1. Structural indicators – a set of selected individual indicators addressing simultaneously economy, environment, and society; they can refer to industrial sec-

tors, or regions, or administrative levels, or environmental media, or natural resources selected for a more careful investigation.

2. Synthetic indicators – sometimes called single-number because like a barometer they pretend to synthesize in one number economic, environmental, and social aspects; some of them comment more precisely environmental impact, and some other are focused on economic welfare or social well-being.

3. Indicators for local communities – a set of indicators selected originally for a defined local level; they are specific for the local level of monitoring and, therefore, allow for local parties participation, and take into account local aspirations and particular local priorities.

Some of the synthetic indicators are measured in monetary values and some others are measured in physical units [Śleszyński 2013]. Synthetic indicators in monetary terms are quite well founded in the economic neoclassical theory: Index of Sustainable Economic Welfare, Genuine Progress Indicator, Genuine Savings. Non-monetary synthetic indicators are the answer to the crucial question of environmental resilience and capacity which are important aspects of sustainability adopted from the definition of sustainable development. The most popular indicators represented in physical units are: Total Material Requirement, Human Appropriation of Net Primary Production, and manifold footprint indicators.

Ecological Footprint (we will continue using the abbreviated form of EF) being something like "footprint" trace left in the environment by a human being's foot is such a synthetic indicator. Physical amount – in the case of EF it is the amount of land surface – is used for the assessment of natural resources management. EF has been defined by the creators of this concept, Wackernagel and Rees, as "the total area of biologically productive soil surface (including the sea) necessary to compromise consumption needs of a given population and to assimilate waste generated by this population" [Rees, Wackernagel 1994; Wackernagel 1994; Borgström Hansson, Wackernagel 1999]. Every economic activity has an impact on the global ecosystem because it uses the resources and services taken away from the natural environment. EF can be estimated through the recalculation of basic economic activities motivated by compromising human needs into ecological functions expressed in terms of the biologically active area and confronted with actually available natural area.

Publication of EF concept initiated worldwide research on similar sustainability indicators. All footprint indicators can be regarded as a specific environmental pressure indicator. As a matter of fact, footprinting is now a standard method to measure anthropogenic pressure damaging sustainability of the environment.

In particular, a family of footprint-indicators includes also Carbon Footprint which measures our contribution to the greenhouse effect. Carbon Footprint is defined as the total amount of greenhouse gases produced to directly and indirectly support certain human activities, usually expressed in equivalent tons of CO_2 (carbon dioxide). In other words, Carbon Footprint is the sum of all emissions of CO_2 which were induced by somebody's activities in a given time frame. Usually, Carbon Footprint is calculated for the time period of a year.

Energy efficiency is important for the economy and saves the environment. No doubts that it is one of our national policy priorities. Energy efficiency is also mentioned in many UN and EU documents on strategic adaptation to the climate change. Publications identify industries that emit the most and suggest adaptive activities contributing to the reduction of GHG emissions thanks to more economic use of energy. Controlling GHG emissions in big cities, and first of all controlling emissions from public buildings, belongs right now to the most advisable and required EU strategies. In addition, improving energy efficiency is still the cheapest option among tools available in Poland that can be applied to work for reducing GHG emissions.

In this paper, Carbon Footprint was applied to the assessment of energy efficiency of one public building: Faculty of Chemistry at the University of Warsaw. This pre-war building, which is the present seat of Chemistry, was carefully analyzed and collected data allowed for the calculation of Carbon Footprint. In addition, Carbon Footprint results for Faculty of Chemistry were compared to Carbon Footprint indicators for some other public buildings in Warsaw and abroad. The results of this study helped to reveal the current energy losses in the Faculty and also to list actions that could improve the efficient use of energy.

2. Carbon Footprint

The concept of Carbon Footprint (we will continue using the abbreviated form of CF) was established in 2005 during the debate on the monitoring of GHG emissions. It is used for the analysis of GHG emissions from the perspective of the consumer and the producer. CF was promoted mostly by private initiatives, NGOs and corporations, and much less by the scientific community. This has led to a large variety of definitions and methods of calculation. For the first time it was used in the press in 2000. Five years later, the British company British Petroleum launched a major campaign to promote this indicator. The first mention in the scientific literature on the subject appeared in a letter to the journal "Nature" in 2007 [Hammond 2007].

Carbon dioxide is a greenhouse gas causing global warming. Other greenhouse gases which might be emitted as a result of one's activities are e.g. methane and ozone. These greenhouse gases are normally also taken into account for CF [Aryen, Ertug 2012]. They are converted into the amount of CO_2 that would cause the same effects on global warming (this conversion is possible because of the coefficient called CO_2 equivalent). CF can measure the volume of all greenhouse gases emissions or just the volume of CO_2 emissions only. In the next step all assessed emissions are added to form final CF.

CF can be calculated and presented in many variants. CF can calculate emissions per unit of production or consumption, per one product, per single service or process, or per capita. Few people express their carbon footprint in kg carbon rather than kg carbon dioxide. However, one kg of carbon dioxide can always be converted in kg carbon by multiplying with a factor 0.27 (e.g. 1000 kg CO_2 equals 270 kg carbon).

The best way is to calculate the carbon dioxide emissions based on the fuel consumption. In most cases, calculation of CF employs emission coefficients. Most analyses of CF are based on the global data on average emission per unit of product. In Poland, in order to standardize the method of estimating the reduction or avoidance of greenhouse gas emissions, the reference carbon dioxide emission rate for electricity production has been developed. The emission rate according to the National Centre for Emissions Balancing and Management is: 0.812 Mg CO_2 / MWh [KOBiZE 2011]. What simplifies the CF method is that the specificity of calculation makes the place and the course of emissions irrelevant. The key variable considered by CF is the amount of gases emitted into the atmosphere.

The scope of the analysis can be defined in three different ways. The first option is to take into account only direct emissions that are created at the source belonging to a particular entity (furnaces, boilers, cars, etc.). The second approach allows calculations to be carried out on the basis of data on emissions accompanying energy used by the entity (this is the case of electricity use). The third option includes also other indirect emissions that are the result of the activities of the entity but the emitters responsible for them do not belong directly to the entity (e.g. external incineration of waste).

The most complete assessment of CF assessment should incorporate Life Cycle Analysis. "The Publicity Available Specification 2050" [Sinden 2009] – publication created by the British institution of standardization was one of the first such works and was published in 2008 and updated in three years. It regulated the method for calculating CF of the product by taking into account the entire life cycle of the product.

Other widely used methods are described in the "Protocol gases greenhouse" set up by the World Resources Institute and with the World Business Council for Sustainable Development [2016]. International Organization for Standardization also established its own ISO standard, namely: ISO/TS 14067:2013 [ISO, 2013].

The methods used for CF calculation can be divided into three groups according to the sources of information and their elaboration:

1. Bottom-up is the first way based fully on the life cycle, This approach is designed to calculate the emissions associated with the product "from the cradle to the grave". Thus, it is mainly used for the analysis of individual items, such as computers, newspapers or cars. The results obtained by this method of calculation are the most precise and accurate.

2. The top-down approach is generally used to determine CF for sectors, regions, cities and countries. The predominant method is Environmentally Extended Input-Output Analysis, which brings together all of the environmental elements introduced into the system and final products. It shows the interdependence and connections between sectors. It also includes data on imports, exports and final con-

sumption information in the site. Due to the large scope of the analysis it is fraught with considerable risk of error and is much less accurate than bottom-up.

3. In the hybrid approach, data on the most basic emissions are collected using the method of life cycle, while intermediate values are obtained using an input-output matrix.

Thus, the potential role of CF assessment is crucial. First of all, each new estimate assessing CF contributes to the monitoring of climate change. CF methodology provides data for a guidance application for local, regional or national climate policy. CF based upon Life Cycle Analysis but also a direct evaluation of CF can suggest where and how the improvement of energy efficiency would be possible or required. To sum up, footprinting carbon emissions is a very powerful tool to understand the impact of personal behavior as well as the impact of socio-economic system on global warming.

The main influence on CF magnitude includes population, economic output, and energy and carbon intensity of the economy. These factors are the main targets of individuals, businesses and politicians determined to decrease GHG emission. Scientists suggest the most effective way to decrease CF by either decreasing the amount of energy needed for production or decreasing the dependence on carbon emitting fuels.

3. Faculty of Chemistry at the University of Warsaw

The object selected for the case study was the building of the Faculty of Chemistry, which is located on Pasteur Street in Warsaw and belongs to the University of Warsaw[1]. On June 23 1939, the finished building was put into operation. The building was made using traditional technology. External walls are made of clay and ceramic bricks, floors are made of reinforced concrete, flat roof is ventilated. Basic technical data on the main building of the Faculty of Chemistry are: building area 4481.60 m^2, usable area of 17700.90 m^2, volume 63658 m^3, the height of 13.05 m, 3 floors above ground and one underground floor.

The scope of the analysis included data on internal emissions produced within the building (heat) as well as data on external emissions accompanying production energy used by the building and external emissions emerging outside as a result of the Faculty's waste disposal. This allowed to determine what air emissions were linked to the operation of the Faculty of Chemistry of Warsaw University.

RWE, who is the supplier of electricity, buys electricity on the power exchange and then sells and delivers it to the consumer. That means that the energy used by the building came from many sources and pointing out one producer and place of

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[1] More advanced presentation of CF methodology can be found in [Frączek 2014], and more detailed description of the Faculty of Chemistry and developed case study is available in the paper accepted for publication [Frączek, Śleszyński 2015].

emission was impossible. Regarding waste, it was produced on the territory of the Faculty of Chemistry and then disposed somewhere else.

Data included in the analysis are the following:

1. Total consumption of electricity.
2. Total consumption of natural gas.
3. Waste, divided in two groups: municipal solid waste and laboratory waste.

In this particular assessment of carbon emissions, trips of the employees of the Faculty as well as students' were not taken into consideration. The same decision applied to commuting to and from the workplace for both groups. It was caused by the difficulty in gathering data mandatory for a reliable and detailed calculation.

The Municipal Cleaning Company (MPO) received municipal solid waste produced by the building while REMONDIS and EKO Harpoon were responsible for the treatment of hazardous chemical wastes in a way that minimized their negative impact on the environment while maximizing retrieval of raw materials. Organic liquid waste with and without halogens (liquid organic, water-organic liquid and liquid halogen) were recycled and were useful for re-solvent recovery. Other wastes were subjected to thermal liquidation.

Table 1. Technical data concerning energy use in the Faculty of Chemistry

Data used in analysis		Value
Total electricity consumtion		2860 MWh
Total gas consumption		292915 m³
Number of students		650 people
Number of employees		294 people
Municipal waste produced		ca. 705.6m³
Mixed municipal waste		ca. 540 m³
Paper		ca. 66 m³
Plastic		ca. 66 m³
Glass		ca. 33.6 m³
Waste derived from laboratory		3963 kg
including:	Liquid organic compounds	170 kg
	Liquid organic with chlor compounds	30 kg
	Organic liquid compounds	935 kg
	Inorganic liquid compounds with chlor	1085.5 kg
	Liquid halogen compounds	497 kg
	Liquid heavy metal salts	30 kg
	Solid (both organic and inorganic)	1215.5 kg

Source: author's own elaboration based on information from the Administration of the Faculty of Chemistry.

4. Calculation of Carbon Footprint

There are three basic variants of the CF calculation as far as emission connected to electricity is concerned. The first one takes into account emission coefficient given by the National Center for Balancing and Management of Emissions (KOBiZE) that equals 812 kg CO^2/MWh. It can be only applied to carbon dioxide emission. This variant is used in most of the CF estimations. The second way of calculations involves using data presented by the distributor, in this case it would be RWE. The third and the last method, which can be used in calculations, is based on the document "Energy Policy of Poland until 2030" (2009:26). This document was passed by the Council of Ministers in 2009. The coefficient of emission given by the document is the highest and equals 950 CO_2/MWh.

Electricity as a source of CO_2 emission presented in all three variants:

- I variant: 2860 MWh × 812 kg CO_2/MWh = 2322320 kg CO_2 = 2322.32 Mg CO_2.
- II variant: 2860 MWh × 731.533 kg CO_2/MWh = 2092184.38 kg CO_2 = 2092.18 Mg CO_2.
- III variant: 2860 MWh × 950 kg CO_2/MWh = 2717000 kg CO_2 = 2717.00 Mg CO_2.

The third solution seemed to be the most appropriate because it was based on the principles described in ISO 14001, which is the norm that standardizes environmental management in institutions and is commonly used in environmental declarations. The third estimate was also applied to further analysis of CF in this paper.

As far as thermal energy is concerned, the data should be based on the amount of natural gas bought in 2013 by the Administration of the building. The next step was to calculate the emission with the use of calorific value specific to this fuel.

Thermal energy as a source of CO_2 emission:

- 292915 m^3 × 0.0344 GJ/m^3 = 10076,28 GJ; and next
  10076.28 GJ × 55.82 kg CO_2/GJ = 562457.95 kg CO_2 = 562.46 Mg CO_2.

Emissions that were the outcome of the waste treatment, which was connected with Chemistry Faculty activity, was calculated in a similar way. The quantity of different type of waste was converted into energy outcome with the use of specific coefficients. The next and final step was to calculate emission which would be inevitable in the incineration process. This method was not perfect because not every compound emitted in the process was taken into account. This omissions were due to the fact that there were no reliable data describing the amount of compounds other than CO_2 (e.g. ammonium).

There was also one facilitating assumption in the analysis presented below. The Faculty of Chemistry separated plastic waste (66 m^3) according to its type, so mechanical and chemical recycling of plastic would be possible. On further stages containers were cleaned, granulated and used in such industries as: energy, cement and lime industry, and packaging industry. Therefore the emissions created during this step were part of another institution's carbon footprint and were not considered in this work [Terebuła-Fertak 2014]. As for glass waste (33,6 m^3), smelting glass cullet needed very high temperature (not less than 1500°C). Such a temperature was the reason why emissions associated with this process did not belong to six compounds listed in the Kyoto protocol. What was more, emissions combined with furnace operation were part of another institution's carbon footprint. That is why plastic and glass waste was not taken into account in this analysis.

Waste as a source of CO_2 emission:

- Mixed: 540 m^3 × 42.2 kg/m^3 = 22788 kg = 22.788 Mg; next 22.788 Mg × 3 GJ/Mg = 68.364 GJ; and finally 68.364 GJ ×98 kg CO^2/GJ = 6699.672 kg CO_2 = 6.699672 Mg CO_2 ~ 6.70 Mg CO_2.
- Paper: 66 m^3 × 15.2 kg/m^3 = 1003.2 kg = 1.0032 Mg; next 1.0032 Mg × 11 GJ/Mg = 11.0352 GJ; and finally 11.0352 GJ × 140.14 kg CO_2/GJ = 1546.472928 kg CO_2 = 1.546472928 Mg CO_2 ~ 1.54 Mg CO_2.
- Hazardous waste [Matlak 2014]: 3963 kg = 3.963 Mg × 18 GJ/Mg = 71.334 GJ; finally 71.334 GJ × 140.14 kg CO_2/GJ = 9996.74676 kg CO_2 = 9.99674676 Mg CO_2 ~ 10 Mg CO_2.

Finally, it was possible to add together CO_2 emissions stemming from all three origins: electricity consumption, natural gas used in the heating system and waste incineration. The total emission of CO_2 for the year 2013 was: 3297.70 Mg CO_2. Therefore, CF per one student was 5.07 Mg CO_2, and CF per one person in the building (students plus employees) 3.49 Mg CO_2. Analogous calculations were also made for two years prior to 2013: 2011 and 2012. Thanks to the expanded field of analysis the results of incidental CF calculation can be better analyzed in the next section.

5. Analysis of results

The analysis of the input data show that the most significant emissions connected with the Faculty of Chemistry resulted from electricity intake (82.39%) and the consumption of natural gas (1706%). They stand for 99.45% of the whole emission. Gas consumption can be divided into three different purposes: water heating (circa 11%), laboratory work (circa 4%), and heating inside the building (circa 85%).

The sources of CO_2 emissions created a clear structure dominated by the energy consumed by the Faculty of Chemistry in the form of electricity. This is shown in Figure 1.

The analysis of the collected data showed that the most significant emissions connected with the Faculty of Chemistry resulted from electricity intake (82.39%) and the consumption of natural gas (17.06%). They stand for 99.45% of the whole emissions. Gas consumption can be divided into three different purposes: water heating (circa 11%), laboratory work (circa 4%), and heating inside the building (circa 85%).

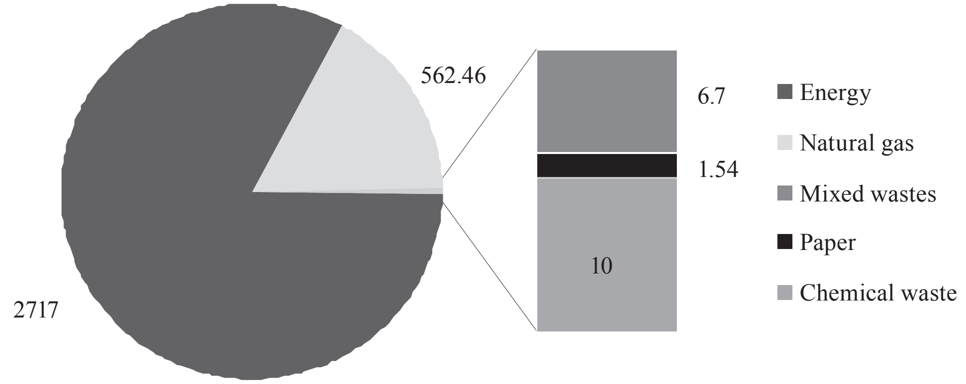

Figure 1. The structure of CO_2 emissions [Mg CO_2] for the Faculty of Chemistry for the year 2013

Source: authors' own elaboration based on information from the Administration of the Faculty of Chemistry.

It is clear that the electricity had the biggest share in carbon footprint. This is due the fact that energetic mix in Poland consists mainly from hard coal. Knowing that, it is easy to draw in advance a simplest conclusion that minimizing energy consumption is the most effective way to decrease CF of the Faculty.

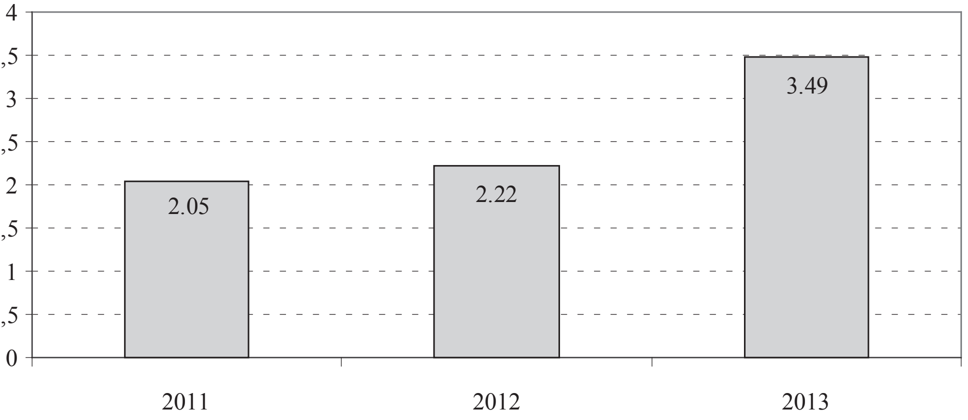

Figure 2. Carbon Footprint (Mg CO2) per capita of the Faculty of Chemistry

Source: authors' own elaboration based on [Frączek, Śleszyński 2015].

During three years: 2011, 2012 and 2013, the energy use presented an upwards trend. In 2012 CF based only on power was 8% higher than the year before, while in 2013 it was 57% higher. This strong trend can be an outcome of constant demand for purchasing new equipment for laboratories and their cooling appliances.

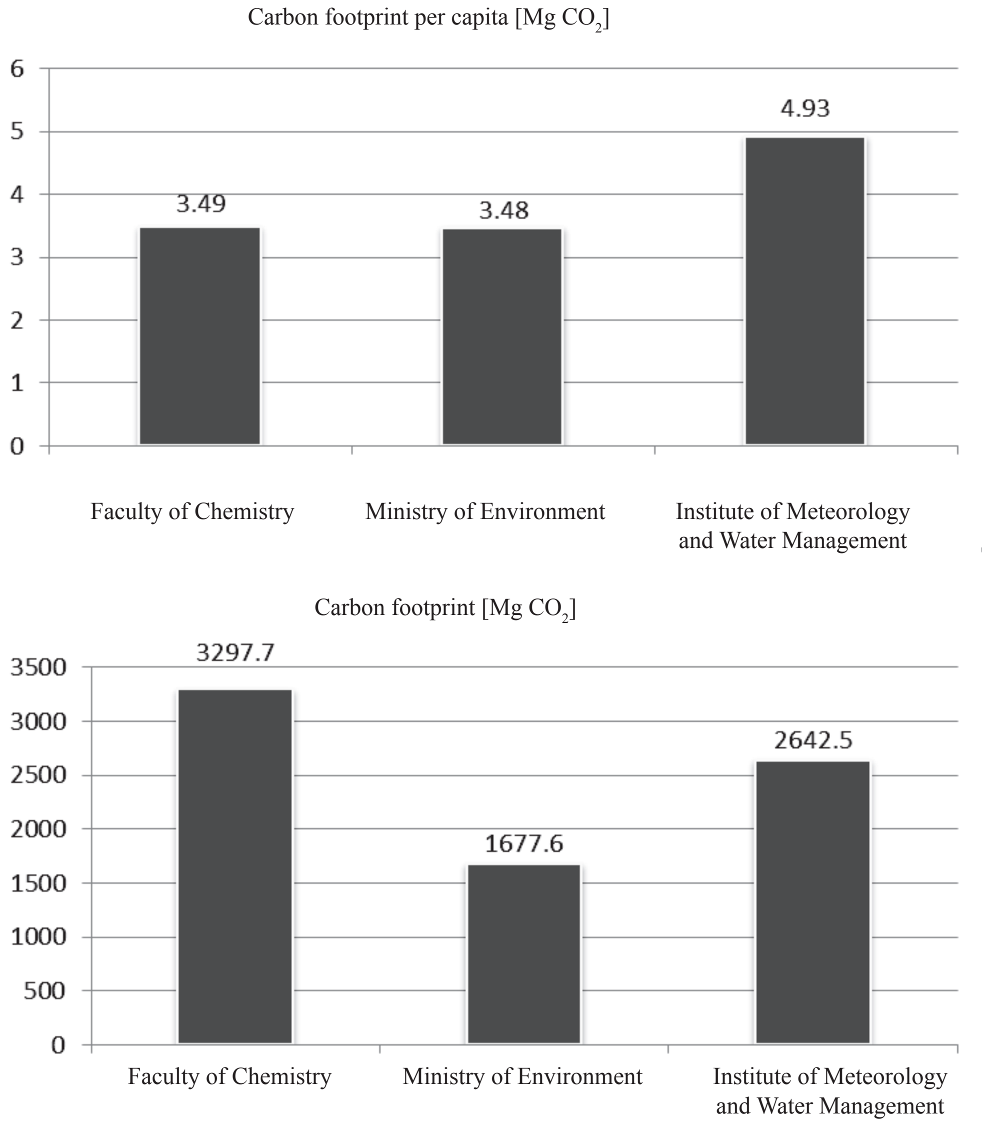

Figure 3. CF and CF per capita for three public buildings in Warsaw

Source: author's own elaboration based on "Environmental Declarations" [Institute of Meteorology and Water Management 2013; Ministry of Environment 2014].

The isolated results of CF calculation presented above were not sufficient to estimate the magnitude of actual environmental impact of the examined building.

Therefore, CF estimates for the Faculty building had to be compared with some other existing thematic studies focused on public buildings and estimating their CF.

In particular, the Faculty of Chemistry, the Ministry of the Environment, and the Institute of Meteorology and Water Management National Research Institute were compared to some extend. The first two institutions are located in buildings which were built during the interwar-period (the 1930s) while the last one occupies a building built between 1955-64. There are significant differences in capacities of the buildings (Chemical Faculty – 63658 m^3; Ministry of Environment – 102000 m^3; IMGW-PIB – 61175 m^3). It is also important that 55 residential apartments situated in the Ministry of the Environment will not be taken into account in the analysis.

The buildings compared in this paper are used for different professional, scientific and technical purposes. For instance, the Faculty of Chemistry carries out research with the use of specialized equipment, while the Ministry undertakes activities which are strictly administrative. Institute of Meteorology and Water Management National Research Institute conduct both scientific and administrative work.

While comparing buildings it was crucial to distinguish their demand for usable, primary, and final energy. The definition states that usable energy is directly used, while final energy is delivered to the building. Any losses caused by installations' efficiency were taken into consideration in the second type of energy. Primary energy also included losses caused by energy production and type of energy carrier. Data available for the Chemistry Faculty and the Ministry of Environment showed a difference between final energy demand for both institutions. This was caused by the type of activities held in both institutions.

The figures (Figure 3) show interdependencies between the form of activity undertaken by the institution and the amount of emissions of CO_2. However, the assessment of CF per capita for all three buildings was quite similar. It may be surprising, but CF per person estimated for the Faculty was similar to values calculated for the Ministry. It can be caused by the differences in amount of people staying on the premises of those institutions (Ministry – 482 employees, Chemistry Faculty – 994 employees and students, IMGW – 536 employees).

Next section compares the Faculty of Chemistry and the Faculty of Environmental Sciences at the University of Science and Technology (NTNU) in Trondheim, Norway. Nevertheless, some major differences in assessment methods used should be pointed out. The NTNU is situated in Trondheim, where most of the townspeople are students. There are slightly more than 20 000 students and 5 500 employees on 7 different faculties. In 2005 an environmental program based on ISO 14001 was implemented.

The main goal of the program was to introduce improvements in four sectors: energy, transport, waste management and supplies. The follow-up of this action was conducting very detailed research and gathering precise data. It has been also proposed to implement permanent monitoring with the use of environmental indicators. One of them was CF estimated with the use of "input-output" model.

The scope of this assessment was very wide, due to the fact that over 200 different categories of services, goods and investments were taken into account. However, electric power and building heating still made up almost 93% of emissions which were assessed as most significant.

The comparison of two similar type institutions from Poland and Norway had its clear limits. First of all, there are factors such as geographical location that can contribute to differences in these two organizations. Warsaw is situated in the region of temperate warm climate, while Trondheim is situated in the area of sub-Atlantic moderate zone. This difference is the reason why the day in Warsaw (52°14' N) is longer (it is caused by the increase of latitude). For instance, on 19 November 2014 the day lasted 8 h. 34 min. in Warsaw, while in Trondheim (63° 417' N) it was 6 h. 20 min. long. This led to different energy uptake for lightning, which increased the amount of emissions in Trondheim.

Comparison between carbon footprint produced by departments within UW and NTNU carrying out the same activities [Mg CO_2]

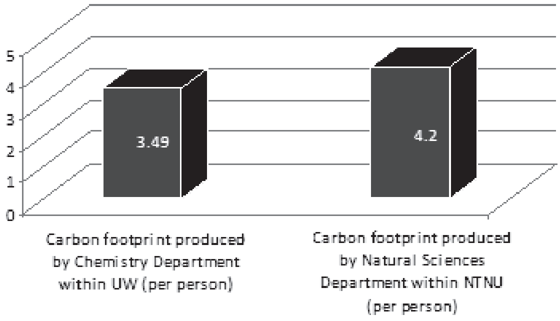

Figure 4. CF per capita for the Faculty of Chemistry in Warsaw and the Faculty of Environmental Sciences in Trondheim

Source: author's own elaboration based on [Larsen, Pettersen 2013, p. 46].

Taking into account all known data and existing differences, it should be stressed that footprint indicator for the Faculty of Chemistry was characterized by somewhat high CF and quite low CF per capita when compared to two other public buildings located in Warsaw. Footprint indicator for the Faculty of Chemistry was characterized by a relatively high CF per capita when compared to its bigger, better equipped and "colder" Norwegian partner for comparison. However, the CF assessment was not enough to formulate solutions to the energy efficiency problem. Action improving the present situation required the identification of inefficiency sources inside the building.

In order to clarify the results of Carbon Footprint assessment an additional tool was used. The thermographic examination with the application of advanced measuring equipment and specialized software took place in the Faculty of Chemistry. The thermography-based method is the contact-free measurement of surface temperatures. Only those inspections enabled a detailed analysis of thermal insulation in the building. Thermal image showed energy losses, especially due to transmission through windows and coupling between external walls and ceiling. These are typical leak points in most poorly insulated buildings. The combined results of CF and of thermo visual examination showed that the Faculty was very ineffective in thermal energy management.

Increase in energy efficiency in the Faculty building would require modernization of the whole building. These are some practical solutions presented below:

1. Replacing currently functioning fragmented system of ventilation with centralized system and optimization translated in adjusting the frequency of rotation to existing demand.
2. Lighting automation, especially in the corridors, toilets, social premises and the basement.
3. Decrease in the number of luminaries and use of energy-saving bulbs.

Increase in heat utilization efficiency in the Faculty of Chemistry could be achieved through solutions presented and explained below:

1. The biggest energy loss (45-60%) was caused by external walls and roof heat leaks. It is reasonable therefore to conduct thermal modernization of the whole building.
2. Modern solution would be creating a “green roof” on the building. That means the placement of containment, introducing soil and suitable species of plants.

6. Conclusions

The results presented in this study confirm the usefulness of the footprint method for monitoring energy and environmental efficiency of public buildings. This method can be used both to design and control building renovation projects, as well as to optimize and improve power consumption. As stated in the Declaration of the Ministry of the Environment [Ministry of Environment 2014, p. 12] the goal is to reach very high energy efficiency (of up to 78%), as part of the modernization of the building. It is advised to implement similar projects in all university buildings.

CF analysis showed that the Department of Chemistry in 2013 (with a score of 3 297.7 Mg CO_2eq, which stands for the 3.49 Mg CO_2eq per person) is characterized by a relatively high and increasing CF compared with other public buildings in Warsaw and abroad. Nevertheless, the data base is very short and not perfect which requires a future vision as well as critical analysis of the present state.

The characteristics of the Department of Chemistry, where the basic teaching and research facilities are chemical laboratories, are the dominant energy-consuming installations are powered by electricity. Almost 50% of energy is consumed by distributed systems of ventilation. Therefore, it would be advisable to optimize individual fan systems, and then introduce a central ventilation system. The most important changes would be in the area of energy consumption and electric power working hours as well as implementing a method of operating a building for teaching and research purposes.

In a country where the dominant energy carriers are coal and lignite, an extremely important factor in reducing greenhouse gas emissions is the reduction of the energy consumption among energy consumers by increasing energy efficiency and reducing waste heat and electricity. This underlines the need to integrate programs to increase energy efficiency, especially in public buildings.

Carbon Footprint (CF) is an ideal tool to help raise awareness, measure emissions, reduce costs and engage staff in carbon management program. An individual's, nation's, or organization's CF can be measured by undertaking a GHG emissions assessment or other calculative activities denoted as carbon accounting. Once the size of CF is known, a strategy can be devised to reduce it, e.g. by technological development, better process and product management, changed Green Public or Private Procurement, carbon capture, consumption strategies, carbon offsetting and others.

Several free online CF calculators exist, including a few supported by publicly available peer-reviewed data and calculations including the University of California, Berkeley's CoolClimate Network research consortium and CarbonStory [2015]. These websites ask their visitors to answer more or less detailed questions about their diet, transportation choices, home size, shopping and recreational activities, usage of electricity, heating, and heavy appliances such as dryers and refrigerators, and so on. The website then estimates visitors' CF based on their answers to these questions. A systematic literature review was conducted to objectively determine the best way to calculate individual/household CFs.

Concluding, it should be stressed that the use of CF as an indicator of sustainable development should be associated with an extensive listing of its obvious limitations. The indicator's characteristics implies that it comprises only one selected problem and aspect of human impact on the natural environment. Moreover, it does not provide sufficient information on economic or social aspects of development of a given population. Therefore, CF being a specific and synthetic indicator, should be regarded as a complementary measure and for policy purposes it should always be used together with other tools and indicators.

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