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Comparative Assessment of Carbon Footprints of Selected Organizations: The Application of the Enhanced Bilan Carbone Model

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Abstract: Making organizations aware of their carbon footprint (CF) and proposing measures to reduce it are important segments of climate change mitigation. As a part of this process, an enhanced Bilan Carbone model with incorporated country-specific greenhouse gas (GHG) emission factors was applied for CF calculations of three organizations (Agency, Faculty, and Institute). The model, fully in line with international CF calculation standards, can be applied to calculate the CF of any organization on the global level. The paper provides a comparative assessment of CFs of considered organizations and preconditions for a reliable comparison. The calculated CFs values for 2017 were 513.4 t CO_2 e for the Agency, 4254.7 t CO_2 e for the Faculty, and 477.0 t CO_2 e for the Institute. Comparing specific CF, the Faculty had the highest value per employee (9.4 t CO_2 e/employee) and the lowest value per heated area (131 kg CO_2 e/m^2), followed by the Institute (5.4 t CO_2 e/employee and 222 kg CO_2 e/m^2) and the Agency (4.5 t CO_2 e/employee and 294 kg CO_2 e/m^2). Using the enhanced Bilan Carbone model, adapted to national conditions, could lead to the harmonization of the organizations' CF calculation and enable the identification of significant emission sources. This will facilitate the definition of GHG reduction targets and the identification of mitigation measures for achieving the targets, as presented in the example of the Institute.

Keywords: carbon footprint; climate change mitigation; emission factor; greenhouse gas; Bilan Carbone model

1. Introduction

The increase in greenhouse gas (GHG) concentration in the atmosphere is a significant cause of climate change. In 2018, the GHG concentration reached its highest level, with an average global CO_2 concentration of 407.8 parts per million (ppm), a CH_4 concentration of 1869 parts per billion (ppb), and N_2O of 331.1 ppb. These values represent an increase of 147%, 259%, and 123%, respectively, compared to the pre-industrial levels [1]. The global mean temperature in 2019 was 1.1 °C above the average temperature for the period 1850–1900 and was the second warmest year recorded after 2016. In addition, floods, long droughts, and strong hurricanes occur more frequently. The Fifth IPCC Report [2] claims with a level of certainty of more than 95% that humans have been influencing the climate and rising global temperatures since 1950 by anthropogenic GHG emissions. The report also notes that climate change is an ongoing process which requires appropriate climate change mitigation measures to be taken.

The world is in a critical phase of transition towards more sustainable development, and the measures taken in the next decade will determine the way forward [3]. It is now clear that if the development of human society is based only on the economic growth and not on the protection of climate, environment, and society, this can have adverse consequences, such as climate change, loss of freshwater resources, loss of biodiversity, and growing inequality. In short, world development would not be sustainable [4]. The concept of sustainable development, first mentioned in the World Conservation Strategy [5] and in the so-called Brundtland Report [6], aroused interest from ecologists first, and later from other environmentally conscious people from different social groups. Three common objectives were set for achieving sustainable development [4]: (i) Minimizing the consumption of resources, (ii) maximizing the value of products/services, and (iii) minimizing the impact on the environment and nature. The third objective includes reducing emissions to air and water, reducing the waste generation and the amount of waste to be disposed of, increasing the use of renewable energy sources, etc. This objective can be achieved by applying low-emission technologies and appropriate changes in attitudes.

The world's one hundred largest companies have been responsible for 71% of global industrial GHG emissions since 1998, according to the report published as part of the Carbon Disclosure Project [7]. In order to meet international climate protection obligations, organizations have been integrating carbon management systems into their production chains and have started paying attention to the calculation of carbon performance and reporting on it [8]. The climatic effect of an organization, a product, or a service is measured by their carbon footprint (CF), which quantifies all direct and indirect GHG emissions [9]. Voluntary corporate climate change disclosures in regular reports, which are not required by law, contributed to the development of the organizations' CF. Dawkins at al. [10] determine the extent to which environmental performance and media visibility in companies interact to voluntary climate change disclosure. The calculation of CF has been recognized as a significant step in efforts to reduce GHG emissions [11].

Today, CF is a widely used environmental indicator. A key to the management of GHG emissions of organizations is the understanding of their impact on climate. The challenges of providing relevant and reliable information on CFs of small and medium-sized businesses are addressed by Berners-Lee et al. [12].

In their paper, Navarro et al. [13] show that it is possible to estimate the CF of products accurately enough by collecting corporate data considering six methodological issues. These issues, identified and discussed in the paper using the example of the wine sector, are: Fugitive emissions, credits from waste recycling, use of equivalent factors, reference flow definition, accumulation, and allocation of corporate values to minor products. By setting emission standards per unit of product, organizations are motivated to improve their emission efficiency and reduce CF of their product below regulated threshold; this is elaborated in the paper written by Chen and Chen [14].

The CF of urban environments has been recognized as a valuable source of information for making decisions on the sustainability of urban development. In this context, Lombardi et al. [15] divide CF into two main categories, direct and life cycle-based. There are a few internationally agreed methods to estimate CF at the city level [16,17]. Roibas et al. [18] analyzed the CF of the Spanish community of Galicia. They calculated all direct and indirect GHG emissions related to the production and consumption in Galicia according to the territorial Life Cycle Assessment (LCA) method. The main contribution to the CF of Galician residents was made by accommodation and food consumption, while the biggest contribution of tourists was made by transport.

CF calculators are widely available online. However, most calculators estimate emissions only at the household or personal levels based on a limited set of data, such as energy consumption and transportation. There are significant differences between these calculators, and there is no standard model or practice [19–22]. Different methods and models deliver significantly different results by using the same input [23]. Despite these inconsistencies, CF calculators play an important role in raising public awareness, promoting appropriate changes in attitudes, and consequently mitigating climate change.

There are two internationally accepted methods for calculating the CF of organizations: GHG protocol and ISO standard. The old ISO 14064-1 standard [24] and the GHG Protocol Corporate [25,26] define three scopes, while new ISO 14064-1 standard [27] defines six categories of GHG emission for organizations. Organizations use a bottom-up, a top-down, and a hybrid approach to calculate CF. The bottom-up approach is based on the LCA method to quantify the impact of organization activities on its GHG inventory. This method was used by Radonjič and Tompa [28]. They focus their research on the importance of indirect Scope 3 emissions in the calculation of the CF of telecommunications companies. The top-down approach is based on an Input–Output Analysis (IOA) or a consumption-based method [11]. The paper highlights the multiple uses of generalized multi-regional input and output models to calculate the CF. The hybrid approach combines LCA and IOA to take advantage of both approaches, as stated in the study by Berners-Lee et al. [12]. The authors of the study seek to develop a hybrid tool for practical application in small and medium-sized businesses.

In their article, Larsen et al. [29] apply an environmental extended input–output model to calculate the CF of the Norwegian University of Technology and Science. The results show that the average CF per student was 4.6 tons of carbon dioxide equivalent (CO_2 e). A similar analysis was conducted for the Curico University campus at the University of Talca in Chile [30], and the average GHG emissions per student were 1.0 tons of CO_2 e.

The CF calculation for the University of Indonesia recognized electricity consumption as the main emission category [31]. On the other hand, the calculation of the CF of the university campus in Chile suggested that the transportation of college students and employees to and from the campus is the main source of emissions [32]. The application of different CF calculation approaches, together with a different set of input activity data and emission factors, gave the results that were not comparable. The possibility of establishing a universal approach to the calculation of CF of different organizations, with an emphasis on universities, was analyzed by Robinson et al. [33].

Establishing a harmonized model for the CF calculation was the main task of the LIFE Clim'Foot project [34], implemented in five EU countries—France, Hungary, Greece, Italy, and Croatia. The project aimed to develop and implement five national models for the CF calculation of organizations, by adapting the comprehensive French Bilan Carbone® model (BC model) to the national conditions of the aforementioned countries. For the needs of the model, national databases of emission factors have been developed; the databases include more than 150 country-specific emission factors for each country. The aim of the project was also to spread the developed approach for calculating the CF of an organization and standard emission factor databases across all EU countries, and even globally.

In their previous paper, Jurić et al. [35] emphasize the need for establishing a harmonized approach to the calculation of the CF of organizations. This paper presents the BC model enhancement and the application of the enhanced model for the CF calculation of three considered organizations (Agency, Faculty, and Institute). The paper focuses on the comparative assessment of considered organizations' CFs. The preconditions for a reliable comparison are the same: (1) CF calculation method, (2) a set of input data and emission factors, (3) socio-economic and climatic conditions, (4) the type and size of organizations. The paper proves the hypothesis that it is possible to identify the key emission sources and define priority measures for GHG emissions reduction, after CF calculation. The paper also points out the need for applying a uniform approach to the CF calculation at the global level. As a possible solution, the implementation of the BC model, adapted to national conditions, is proposed.

2. Materials and Methods

The CF calculation process is based on the LCA approach. This includes the calculation of direct and indirect GHG emissions (CO_2, CH_4, N_2O, NF_3, SF_6, HFCs, and PFCs) and removals from all business-related activities, on-site and off-site. In addition to the activities for which the organization is directly responsible, it is important to include all other input and output activities related to the organization. The CF is expressed as a CO_2 e emission, using the Global Warming Potential (GWP) for each greenhouse gas.

2.1. The Method Used for Calculating CF

The analyzed organizations calculated GHG emissions, based on the internationally accepted methods for calculating CF—ISO standard and the GHG Protocol.

The international ISO 14064-1 standard [24] and the GHG Protocol for organizations [25,26] define three scopes of GHG emission calculation: Direct GHG emissions and removals, generated on-site from fuel combustion, production process, company vehicles, and fugitive sources—Scope 1; Indirect GHG emissions from purchased energy, which occur off-site and are related to the purchased electricity, heating, and cooling—Scope 2; and Other indirect GHG emissions, which occur off-site and include activities related to the upstream and downstream flows of people and materials important to the business of an organization—Scope 3.

According to new ISO 14064-1 [27], GHG emissions and removals are divided into six categories: Direct GHG emissions and removals—Category 1; Indirect GHG emissions from purchased energy—Category 2; Indirect GHG emissions from transportation—Category 3; Indirect GHG emissions from products used by the organization—Category 4; Indirect GHG emissions associated with the use of products from the organization—Category 5; and Indirect GHG emissions from other sources—Category 6.

Classification of GHG emissions into the corresponding six categories is made following the Annex F of the new ISO 14064-1 standard [27], while the GHG emission distribution in the three scopes are determined in the old ISO 14064-1 standard [24] and ISO/TR 14069 technical report [36]. Figure 1 provides an overview of on-site and off-site activities and the corresponding three scopes and six categories.

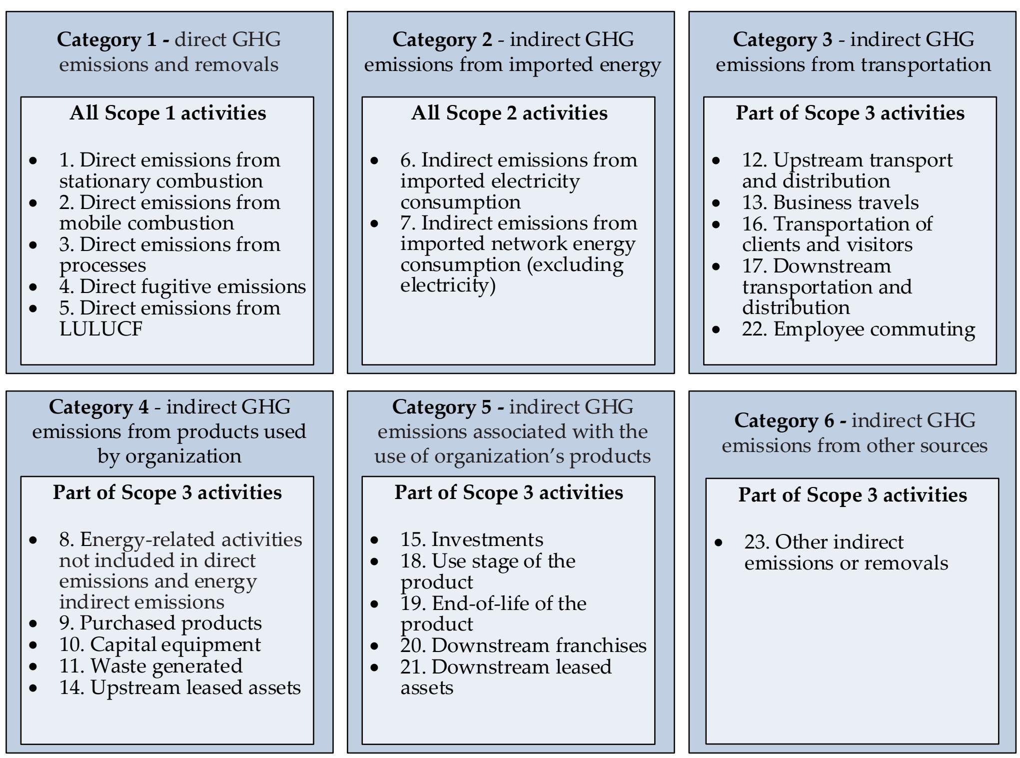


Figure 1. Classification of greenhouse gas (GHG) emissions into the corresponding scopes and categories [24,27,36]. (LULUCF-land use, land-use change and forestry)

2.2. Enhanced Bilan Carbone® model

The French BC model was developed by ADEME [37], following international standards. The model contains more than 2000 GHG emission factors, which mainly reflect French conditions. The model also provides extraction of the CF results, according to the ISO standards [24,36] and GHG protocol for organizations [26]. In the model, emissions are adequately divided into three scopes.

The French BC model, version 7.4, offers the ability to calculate GHG emissions/removals from all activities relevant to the organization operations. Activities defined by internationally recognized methods for calculating the CF of organizations [24,26,36] are included, but the distribution of GHG emissions is logically classified into ten source types: Energy sources, Non-energy sources, Inputs, Packaging, Freight transport, People transport, Direct waste, Capital goods, Use of products, and End of life. The BC model also offers the ability to extract results according to the GHG Protocol [26] and ISO/TR 14069 [36]. The GWPs published in the Fifth IPCC report [2], for a time horizon of 100 years, were used in the model.

The enhanced BC model is based on the French BC model (version 7.4), with incorporated improvements in two segments. The first improvement is related to the expansion of the emission factor database with 172 country-specific emission factors. The second improvement is the fact that the enhanced model enables the appropriate extraction of results divided into six categories (Figure 1), according to the new ISO 14064-1 standard [27]. The enhanced BC model is presented in Figure 2.

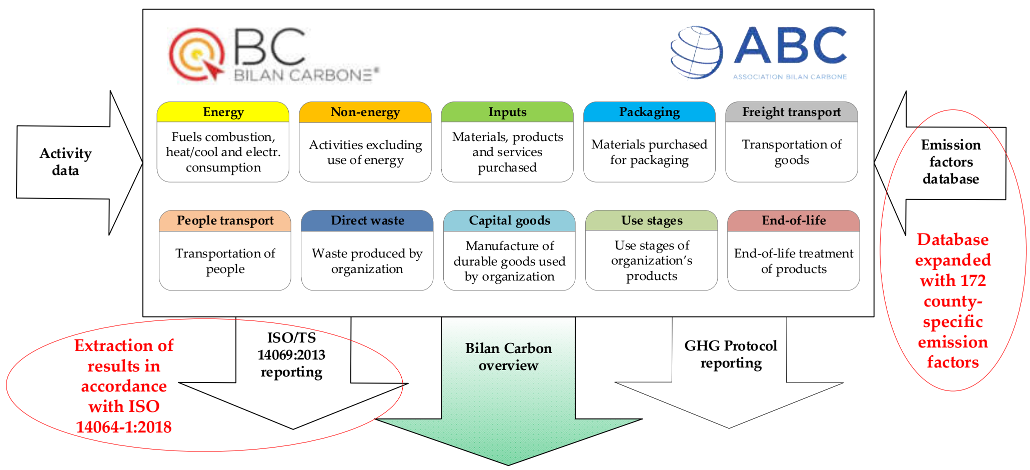


Figure 2. Enhanced Bilan Carbone (BC) model for calculating the carbon footprints (CFs) of organizations [35].

The national emission factor database has been incorporated into the enhanced BC model. The database consists of emission factors of fossil and organic fuel consumption, electricity and heat consumption, transport of people and goods, land-use change, agriculture, waste, purchase of goods, and refrigerants. The technical description, data quality, data sources, methodology, and emission factor uncertainty analysis are presented in the document LIFE Clim'Foot project [38].

2.3. Uncertainty Estimation

Uncertainty estimates are an important element of the CF calculation. In this paper, the Tier 1 method from the IPCC Good Practice Guidance [39] is used for this purpose. The estimated uncertainty of the calculated GHG emission from each emission source represents a combination of uncertainties of activity data and corresponding emission factors, using an equation:

$$U_{ES,i} = \sqrt[2]{U_{AD,i}^2 + U_{EF,i}^2} \tag{1}$$

where $U_{ES,i}$ is the uncertainty of GHG emission for emission source *i* (%), $U_{AD,i}$ is the uncertainty of the activity data for emission source *i* (%), and $U_{EF,i}$ is the uncertainty of the emission factor for emission source *i* (%).

The uncertainty of the organization CF calculation, expressed as a percentage, was estimated by the following equation:

$$U_{TOT} = \frac{\sqrt[2]{(U_{ES,1} \cdot X_{ES,1})^2 + (U_{ES,2} \cdot X_{ES,2})^2 + \cdots + (U_{ES,n} \cdot X_{ES,n})^2}}{X_{ES,1} + X_{ES,2} + \cdots + X_{ES,n}} \quad (2)$$

where U_{TOT} is the total uncertainty of the organization CF (%), $U_{ES,i}$ is the uncertainty of GHG emission for emission source *i* (%), and $X_{ES,i}$ is the share of the emission source *i* in the organization CF (%).

2.4. CF Calculation Process

First, organizational boundaries were defined using the principles of operational control. Then, the operational boundaries were set to identify direct and indirect emissions/removals associated with the organization operation. This was followed by the collection of activity data and the selection of emission factors. Finally, GHG emissions were calculated, while CO_2 removals were not recognized.

The enhanced BC model was applied to calculate the CF of the Croatian Agency for the Environment and Nature (Agency), the Faculty of Mechanical Engineering and Naval Architecture of University of Zagreb (Faculty) and the Energy Institute Hrvoje Požar (Institute), for 2017. These organizations, located in Zagreb, provide administrative, educational, and research services.

The Agency is responsible for collecting and compiling data on the environment and nature, for ensuring and monitoring the implementation of sustainable development policies and other professional activities related to environmental protection and nature conservation in Croatia. The Faculty is one of Croatia's leading institutions in education, science, and expertise in the fields of mechanical engineering, naval architecture, and aeronautical engineering. The Institute provides local, regional, and state administrations, private entrepreneurs, scientific, educational, and professional institutions in Croatia, in the region and globally, with services related to the development of long-term sustainable energy strategies, with an emphasis on energy efficiency and renewable energy sources.

When calculating GHG emissions, all relevant activities in the following ten categories were considered: Energy sources, Non-energy sources, Inputs, Packaging, Freight transport, People transport, Direct waste, Capital goods, Use of products and End of life; these categories and relevant activities were also considered in the article by Jurić et al [35].

Energy sources included electricity and heat consumption of all organizations, and natural gas consumption in the case of the Faculty. Country-specific GHG emission factors were used for the consumption of electricity, heat, and natural gas. Activity data were taken from monthly electricity, heat, and gas bills for three buildings of the Faculty and one of the Institute. On the other hand, for the Agency, which is housed in a large building, along with other organizations, there were only bills for the total electricity and heat consumption of the whole building. Therefore, the share of consumption of the Agency was calculated based on its share in the total building area.

Non-energy sources were associated with refrigerant leakage from the building cooling systems. The GHG emission factors proposed in the original BC model were used, and the refrigerant leakage was estimated for the Agency and Institute.

Inputs encompassed the input flows of materials and services, more precisely of the supply of paper, plastic, consumables, office equipment, food, and water, and the services of external providers (cleaning, insurances, external translation, catering, etc.). The CF calculation was mainly based on the BC emission factors, except for the paper for which the national emission factor was used. Some activity data were collected from accounting departments (bills for office equipment, consumables, water consumption, and services). The mass of paper and plastic was calculated, based on the number of packages and the mass of the package units. The number of meals for a particular type was determined in an interview with a chef of the restaurant.

Packaging consisted of GHG emissions from envelopes and cardboard boxes, but those emissions were estimated in the Inputs category, along with other paper.

Freight transport was estimated only for the Institute. It refers to the upstream transport of paper from the supplier location in Portugal to the Institute building and the downstream transport of studies/reports by diesel cars of the company. The national GHG emission factor was applied for the diesel consumption of official cars, while the emission factor for the paper transport by heavy-duty vehicles was taken from the original BC model.

People transport covered business travels, commuting of employees, and travels of visitors by various means of transportation. A bottom-up approach was used to calculate business trips, based on the collected data for each travel. The necessary data for commuting was obtained through a survey, which included questions about the home-office distance, vehicle category, and in the case of a car, the type of car (e.g., diesel or gasoline), fuel consumption, and occupancy (car sharing). The number of visitors was estimated based on the number of visitors registered at the entrance ports, while the share of different means of transportation and the distance travelled by visitors were determined using special questionnaires. National emission factors were used for diesel and gasoline consumption and travel by train. The emission factors from the BC model were used for the calculation of GHG emissions from other sources.

Direct waste included non-hazardous and hazardous waste. The identified non-hazardous waste covered mixed municipal waste, organic waste, paper, plastic, and wastewater, while the hazardous waste encompassed batteries, toners, electronic equipment, light bulbs, and light pipes. Activity data were gathered from persons who were responsible for waste collection in the organizations. Plastic and paper were recycled, while other types of waste were collected by authorized waste management companies. GHG emissions were calculated using only typical emission factors from the BC model, which also includes emissions related to transport to landfills or waste recycling/recovery sites.

Capital goods covered GHG emissions from the construction or manufacture of durable goods. The capital goods category consisted of buildings, IT equipment, furniture, and vehicles. Activity data were the floor area of buildings, the mass of furniture and vehicles, and the number and price of IT devices. To calculate emissions, activity data were multiplied by typical emission factors from the BC model and divided by the depreciation period.

Use of products was not an appropriate emission category for the three analyzed organizations because when using the final products of organizations, there were no GHG emissions.

End of life was associated with emissions that occur at the end of product service life—paper and plastics (studies/reports). In the same way, as in the calculation of GHG emissions for direct waste, emissions were calculated based on the estimated mass of paper and plastic and typical emission factors from the BC model.

3. Results and Discussions

3.1. Results of CF Calculation

The CF calculation results for the three organizations are shown in Table 1 and Figure 3. People transport, Energy sources, Capital goods, and Inputs accounted for more than 97% of their respective CF in 2017.

Table 1. CFs of three organizations by the BC emission categories in 2017.

BC emission categories	Agency		Faculty		Institute	
	t CO_2 e	%	t CO_2 e	%	t CO_2 e	%
Energy sources	101.7	19.7	2102.0	49.4	145.2	30.4
Non-energy sources	2.3	0.4	0.0	0.0	7.2	1.5
Packaging	0.0	0.0	0.0	0.0	0.0	0.0
Inputs	88.2	17.1	539.3	12.7	45.1	9.5
Freight transport	0.0	0.0	0.0	0.0	4.0	0.8
People transport	256.5	49.7	1040.8	24.5	213.3	44.7
Direct waste	1.0	0.2	32.3	0.8	1.1	0.2
Use of products	0.0	0.0	0.0	0.0	0.0	0.0
End of life	1.1	0.21	0.6	0.02	0.1	0.01
Capital goods	65.8	12.7	539.6	12.7	60.9	12.8
Total CF	**516.4**	**100.0**	**4254.7**	**100.0**	**477.0**	**100.0**

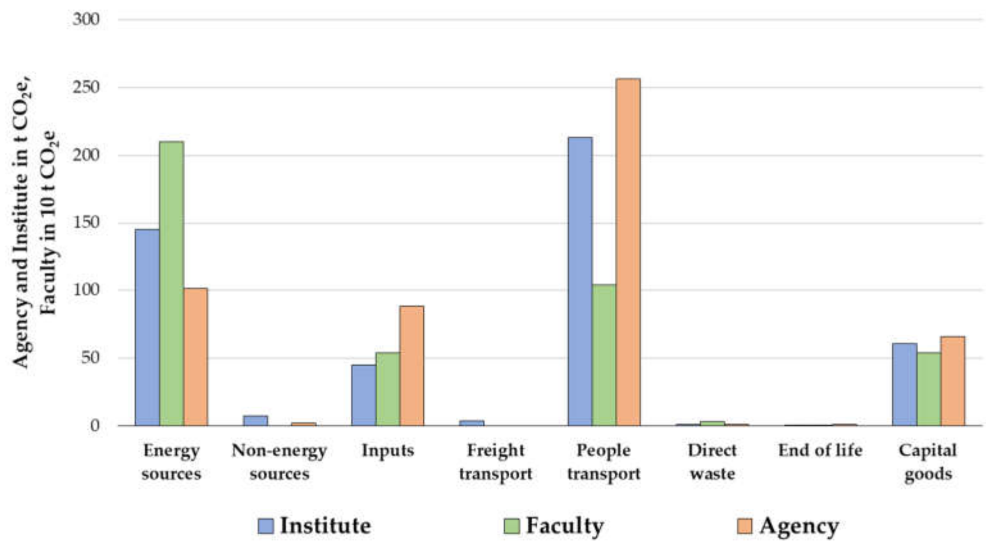


Figure 3. Significance of BC emission categories for the overall CF of organizations.

The dominant emission categories for the considered organizations were People transport and Energy sources. People transport participated with 49.7% in the CF of the Agency, 44.7% in the CF of the Institute, and 23.3% in that of the Faculty. On the other hand, Energy sources was the main emission category for the Faculty (47.0%), and the second most important emission category for the Institute (30.4%) and the Agency (19.7%).

Table 2 shows carbon footprints of the three organizations, divided into 23 emission sources and defined according to ISO 14064-1 [24,27] and ISO/TR 14069 [36]. The results are-summarized for three scopes [24] and six categories [27]. The contribution of scopes and categories to the total CF of organizations are also shown in Figure 4.

Table 2. CFs of three organizations in 2017, divided into 23 emission sources, 6 categories, and 3 scopes.

Emission Sources/Categories/Scopes	Agency t CO_2 e	Faculty t CO_2 e	Institute t CO_2 e
1. Direct emissions from stationary combustion sources	0.0	17.2	0.0
2. Direct emissions from mobile combustion sources	13.5	4.4	29.2
3. Direct emissions from processes	0.0	0.0	0.0
4. Direct fugitive emissions	2.3	0.0	7.2
5. Direct emissions from land use, land-use change and forestry (LULUCF)	0.0	0.0	0.0
Scope 1 = Category 1 (sources: 1–5)	15.8	21.5	36.4
6. Indirect emissions from electricity consumption	58.6	461.2	80.6

7. Indirect emissions from network energy consumption (excluding electricity)	34.2	1435.4	51.9
Scope 2 = Category 2 (sources: 6–7)	92.8	1896.6	132.5
8. Emissions due to energy not covered by sources from 1 to 7	11.5	189.1	18.3
9. Purchased goods	88.2	539.3	45.1
10. Capital goods	65.8	539.6	60.9
11. Waste generated	1.0	32.3	1.1
12. Upstream transport and distribution	0.0	0.0	3.7
13. Business travels	63.4	318.9	60.9
14. Upstream leased assets	0.0	0.0	0.0
15. Investments	0.0	0.0	0.0
16. Transportation of clients and visitors	17.4	409.0	35.9
17. Downstream transportation of goods and distribution	0.0	0.0	0.0
18. Use of sold products	0.0	0.0	0.0
19. End-of-life of sold products	1.1	0.6	0.1
20. Downstream franchises	0.0	0.0	0.0
21. Downstream leased assets	0.0	0.0	0.0
22. Employee commuting	159.6	307.7	67.3
23. Other indirect emissions	0.0	0.0	0.0
Scope 3 = Categories 3+4+5+6 (sources: 8–23)	407.8	2336.6	308.0
Category 3 (sources: 12, 13, 16, 17 and 22)	240.4	1035.7	182.5
Category 4 (sources: 8, 9, 10, 11 and 14)	166.4	1300.3	125.4
Category 5 (sources: 15, 18, 19, 20 and 21)	1.1	0.6	0.1
Category 6 (source: 23)	0.0	0.0	0.0
Organization's *CF*	**516.4**	**4254.7**	**477.0**

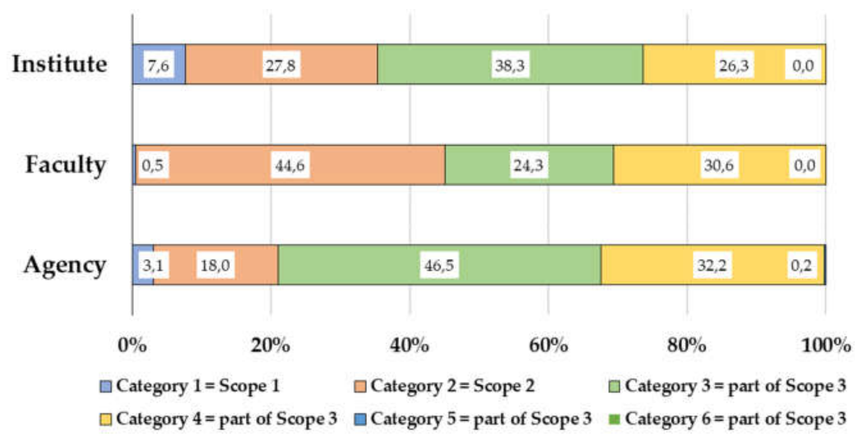


Figure 4. Contribution of scopes and categories to the total CF of organizations.

Under the new ISO 14064-1 [27], Indirect GHG emissions from purchased energy was the most important emission category for the Faculty (44.6%), while Indirect GHG emissions from transportation was the most significant category for the Agency (46.5%) and the Institute (38.3%). According to the old standard, ISO 14064-1 [24], Scope 3 emissions were dominant in all observed organizations (79.0% for the Agency, 54.9% for the Faculty, and 64.6% for the Institute).

Detailed CF calculation results, obtained using the enhanced BC model, are presented in Supplementary material (Tables S1–S3).

3.2. Uncertainty of the CF calculations

The results of CF calculations and CF uncertainties for the Agency, the Faculty, and the Institute, obtained using Equations (1) and (2), are shown in Figure 5.

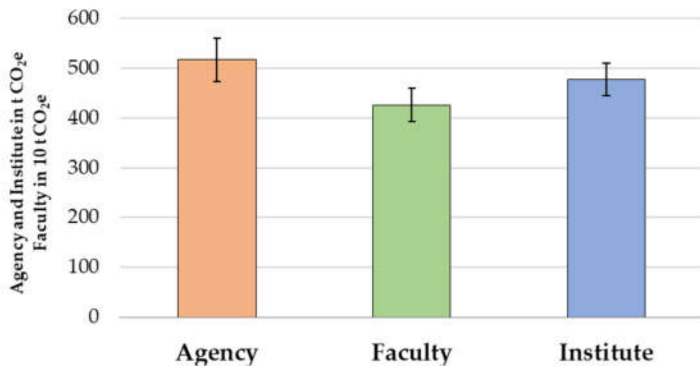


Figure 5. The CFs of three organizations (bars) and uncertainties of calculation (black error bars). Error bars refer to the total uncertainty of CF calculation based on Equations (1) and (2) and Tables S7–S9 in Supplementary material.

The estimated value of the Institute CF for 2017 was 477.0 t CO_2 e, but the CF could be between 444.9 t CO_2 e and 509.1 t CO_2 e, based on the uncertainty analysis. The CF of the Faculty was 4254.7 ± 331.9 t CO_2 e, while that of the Agency was 513.4 ± 42.9 t CO_2 e. The uncertainty of the CF calculation was at ± 6.7% for the Institute, ± 8.4% for the Faculty, and ± 7.8% for the Agency. The detailed analyses of uncertainties of the CF calculation are presented in Supplementary material (Tables S7–S9).

The uncertainty of CF calculations is smaller when emissions are estimated using more accurate activity data and emission factors. However, this is often not feasible for every individual source category due to limited resources.

3.3. Key Sources Analysis

It is useful to identify key emission sources that give a major contribution to the CFs of the considered organizations; therefore, the most significant emission sources are presented below. They have been defined in the same way as the key source categories of the national GHG inventory [39]. The key sources are those that, when added together in descending order, make up over 95% of the total CF of an organization.

In the analysis of the Agency, 12 key emission sources were identified. The most significant contribution came from employees commuting by car (28.5%), followed by electricity from the grid (12.4%), services (10.2%), IT capital equipment (8.5%), business travel by plane (7.4%), heat from district heating (7.3%), meals (6.5%), office building (4.0%), business travel by private car (3.7%) and office car (3.1%), visitor travels by car (2.3%), and employees commuting by bus (2.1%). The remaining 20 emission sources contributed less than 5% to the total CF of the Agency.

The same analysis carried out for the CF of the Faculty identified 10 key emission sources. The most important source was the heat from district heating (37.1%), then IT capital equipment (12.3%), electricity from the grid (11.3%), meals (7.6%), employees commuting by car (6.8%), visitor travels by car (6.7%), consumable office equipment (4.9%), business travels by plane (4.5%), business travels by private car (2.7%), and visitor travels by bus (1.9%), while the remaining 21 emission sources participated with less than 5% in the total CF of the Faculty.

The analysis of key emission sources of the Institute identified 13 significant emission sources. The largest contribution to CF in 2017 came from electricity from the grid (18.5%), followed by that from business travels by plane (15.3%), employees commuting by car (13.9%), heat from district heating (12.0%), business travels by office car (7.2%), IT capital equipment (5.9%), meals (5.8%), office building (5.3%), visitor travels by plane (4.0%) and car (3.5%), services (2.0%), leakage of refrigerant (1.5%), and office vehicles (1.5%). In the case of the Institute, 19 smaller emission sources were outside the group of key emission sources.

The applied method estimates the impact of different emission sources on the total CF in the selected year. It led to the identification of key emission sources, while further GHG emission calculations should be focused on improving the accuracy of calculations for these key sources. The complete results of the key emission source category analysis of the considered organizations are presented in Supplementary material (Tables S4–S6).

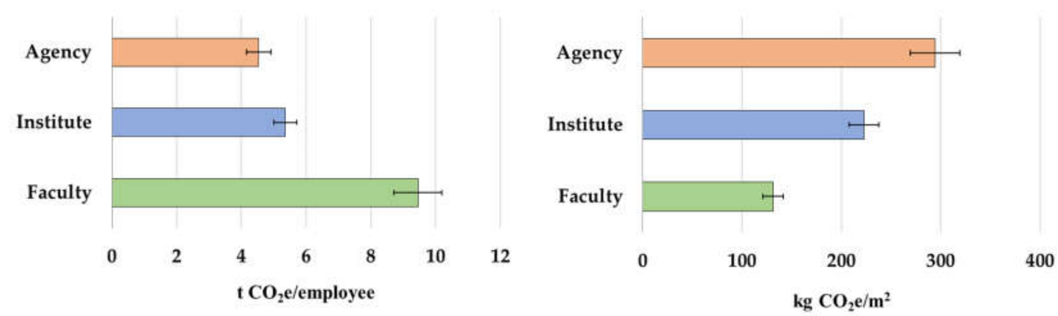
3.4. Comparison of the CF Results

Comparing different CFs requires great caution. For a valid comparison, the same CF calculation method should be used; this requirement is met in our case. An enhanced BC model, consistent with the method defined in the relevant ISO standards and the GHG protocol, was used for all organizations analyzed here. Socio-economic and climatic conditions at the location of the organizations should be equal. These preconditions were fulfilled because all three organizations are in the same city (socio-economic conditions), and CF calculations were prepared for the same year, 2017 (climatic conditions).

In addition, organizations should be of the same type. This requirement, however, was not met. The activities of the Agency and the Institute are very similar because they provide mainly research and consultancy services. Unlike the Agency, the Institute has an additional educational component, and significant GHG emissions are associated with visitors (including seminar/training participants). On the other hand, the primary task of the Faculty is to educate students (2358 students in 2017). Consequently, the estimated emissions of visitors for the Agency were only 3.4%, for the Institute 7.5%, while for the Faculty these emissions were 9.6% of the total CF value of the organization.

A further precondition for a valid comparison is the use of the same set of input data and emission factors. This precondition is not fully satisfied. For example, the Institute calculated GHG emissions of the paper transport from the place of production to the Institute and the transport of final products (studies/reports) from the Institute to the location of their customers. On the other hand, the Agency and the Faculty did not collect the necessary data for the estimation of these GHG emissions.

The number of employees greatly affects the overall CF of the organization. To neutralize this effect, it is necessary to compare specific CFs per employee. In 2017, the Institute had 89 employees in an office building (heated area: 2144 m^2), the Agency had 114 employees (heated area: 1755 m^2), and the Faculty 450 employees (heated area: 32,368 m^2). Figure 6 shows the CFs of the observed organizations per employee and heated area.



(**a**) (**b**)

Figure 6. The three organizations compared by their CF per employee (**a**) and per heated area (**b**). Error bars refer to the total uncertainty of CF calculation based on Equations (1) and (2) and Tables S7–S9 in Supplementary material.

The Faculty exhibited the highest value of specific CF per employee (9.4 t CO_2 e/employee), followed by the Institute (5.4 t CO_2 e/employee) and the Agency (4.5 t CO_2 e/employee). A comparison of the specific CF per heated area gives the opposite ranking: 294 kg CO_2 e/m^2 for the Agency, 222 kg CO_2e/m^2 for the Institute, and 131 kg CO_2 e/m^2 for the Faculty. For illustration, a more detailed comparison is given in Table 3.

Table 3. Comparison of specific CFs of the three organizations with the results from the literature.

Organization	Result	Year	Method	Contribution of Scopes/Categories	References
Norwegian University of Science and Technology, Norway	4.6 t CO_2 e/student 16.7 t CO_2 e/empl.	2009	GHG Protocol	Energy: 19%, Travels: 16%, Buildings: 19%, Equipment: 19% Consumables: 11%, Services 5%, Other: 10%	[29]
School of Forestry Engineering, Technical University of Madrid, Spain	1.9 t CO_2 e/student	2010	GHG Protocol	Scope 1: 8%, Scope 2: 33%, Scope 3: 59%	[40]
Curico campus of the University of Talca, Chile	1.0 t CO_2 e/student	2012	GHG Protocol	Scope 1: 16%, Scope 2: 16%, Scope 3: 68%	[30]
Autonomous Metropolitan University, Cuajimalpa Campus, Mexico	1.1 t CO_2 e/person [1] 1.3 t CO_2 e/student 5.4 t CO_2 e/empl.	2016	GHG Protocol	Scope 1: 4%, Scope 2: 24%, Scope 3: 72%	[41]
Institute of Engineering at Universidad Nacional Autónoma, Mexico	1.5 t CO_2 e/person [1]	2010	GHG Protocol	Scope 1: 5%, Scope 2: 42%, Scope 3: 53%	[42]
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia	1.8 t CO_2 e/student 9.4 t CO_2 e/empl.	2017	ISO 14064-1	Scope 1: 1%, Scope 2: 44%, Scope 3: 55%	This paper
Croatian Agency for the Environment and Nature, Zagreb, Croatia	4.5 t CO_2 e/empl.	2017	ISO 14064-1	Scope 1: 3%, Scope 2: 18%, Scope 3: 79%	This paper
Energy Institute Hrvoje Požar, Zagreb, Croatia	5.4 t CO_2 e/empl.	2017	ISO 14064-1	Scope 1: 8%, Scope 2: 28%, Scope 3: 65%	This paper

Note: [1]—students and staff members.

Table 3 shows the specific CFs per employee, student, or person (students and staff members) for the selected organizations, following the GHG Protocol or ISO 14064-1 approaches. The observed approaches for the CF calculation are very similar, but slight differences may exist regarding the calculation of GHG emissions for capital goods. The GHG protocol does not consider the amortization period, but only emissions related to capital goods acquired/manufactured during the year of the CF calculation. On the other hand, ISO 14064-1 may use the amortization method and include all capital goods that were acquired or manufactured during the last few years equal to the amortization period (e.g., for vehicles: 4 years). Applying that method, the calculated GHG emissions from capital goods for the Agency, the Faculty, and the Institute were divided by the number of years of amortization, in accordance with financial accounting rules.

The highest GHG emissions per student were from the Norwegian University (4.6 t CO_2 e/student, [29]), and the lowest from the Chilean Campus (1.0 t CO_2 e/student, [30]). The Croatian Faculty with 1.8 t CO_2e/student was in the middle. Scope 3 GHG emissions were dominant for all organizations, with shares from 53% for the Mexican Institute [42] to 79% for the Croatian Agency. Bearing in mind that the type of chosen organization, the socio-economic and climatic conditions, the applied method, the set of input data, and the emission factors were not the same, the CF of the organization in the last inventory year should primarily be used for comparison with corresponding GHG emissions in previous years for the same organization.

Calculating and presenting organizational CF can help to highlight the most influential components of CF and serve as a benchmark for future development. The temporal comparison of CFs for the same organizations can help in measuring the effectiveness in decarbonization.

3.5. CF Reduction

Once a GHG inventory has been made, it is possible to better understand the relative contribution of key emission sources and identify appropriate measures to reduce GHG emissions from these sources.

All three analyzed organizations want to reduce their respective CFs and become carbon-neutral organizations in the future. However, only the Institute has quantified the target and developed an action plan to reduce its CF impact. The targeted CF reduction of the Institute is at least 20% by 2030 with respect to the level of CF in 2017. The long-term goal is for the Institute to become carbon-neutral by 2050.

The action plan for reducing the CF level of the Institute identified cost-effective measures in all three scopes. The expected reduction in GHG emissions for measures from Scope 1 is 5.2 t CO_2e in 2030; this reduction could be achieved through the eco-training of drivers and the adjustment of the size and model of official cars to the needs of the Institute. Although most of the energy-saving measures (Scope 2) have already been implemented, some relevant measures can still be taken: Reduction in the internal room temperature by 1 °C, installation of thermostatic valves on the radiators, installation of the photovoltaic (PV) system on the roof, replacement of the existing air-cooled compressor chiller, and energy efficiency improvement in the ventilation system. The application of the proposed measures of Scope 2 would reduce emissions by 20.0 t CO_2e in 2030. The measures proposed to reduce GHG emissions in Scope 3 are the establishment of a teleworking program, promotion of videoconferencing, promotion of public transport for business travels, inclusion of green criteria in public procurement, introduction of a paperless program, and installation of water pressure regulators. The measures have a total GHG emission reduction potential of 76.5 t CO_2e in 2030. The analyzed measures to reduce CF of the Institute are shown in Table 4.

Table 4. Analyzed GHG emission reduction potential of the Institute by 2030.

No.	Name of Measure	Description of Measure	Sub-Category	GHG Emission Reduction in 2030 (t CO_2e)	Description of the Target in 2030	Key Monitoring Indicator
1.	Eco-driving	Additional eco-driving training for new employees (training was conducted in the past)	Official cars	1.72	5% reduction in official car emissions	Number of trained drivers
2.	Adjusting of company fleet	Replace official cars with smaller (low power), hybrid and electric cars	Official cars	3.45	10% reduction in official car emissions	Vehicle fleet renewal monitoring
		Sub-total (Scope 1):		**5.17**		
3.	Maintaining the internal room temperature	Maintaining the internal temperature in the room during the heating season	Heat consumption	2.16	1 °C less room temperature, compared to the current temperature	Measurement and regulation of internal room temperature
4.	Installation of thermostatic valves on radiators	Installation of radiator thermostatic valves to save heat energy	Heat consumption	0.18	Thermal energy savings: 528 kWh/a	Number of installed thermostatic radiator valves
5.	Installation of the PV system	Installation of 46.4 kW (312 m^2) photovoltaics on	Electricity consumption	13.74	Electricity production: 44,291 kWh/a;	Measurement of electricity production

		the roof of EIHP's building			electricity self-consumption: 41.771 kWh/a	and self-consumption
6.	Installation of the new chiller	Replacement of existing air-cooled compression chiller to achieve full energy efficiency of the cooling system	Electricity consumption	0.18	Electricity savings: 481 kWh/a	Measurement of electricity savings
7.	Energy efficiency improvement of the ventilation system	Better energy efficiency can be achieved by installing recuperators in chambers and frequency converters on fan motors	Heat consumption	3.10	Thermal energy savings: 8857 kWh/a; electricity savings: ,600 kWh/a	Measurement of electricity and heat savings
			Electricity consumption	0.61		
		Sub-total (Scope 2):		**19.99**		
8.	Teleworking program	Encourage work from home among the Institute's employees	Employee comm. by car	26.51	Average 2 working days from home per week	Number of working days from home
			Other commuting	0.41		
9.	Videoconferencing	Promotion of videoconferencing and virtual meetings	Business travels by plane	21.89	30% reduction in business and visitor travels	Number of videoconf. and virtual meetings
			Other business travels and visitor travels	11.57		
10.	Public transportation for business travels	Promotion of transport by train or bus, instead of car or plane	Business travels	15.12	10% reduction in emissions from business travels	Numbers of business travels by train and bus
11.	Green public procurement	Include green requirements in the tender documentation as part of the selection criteria	Upstream transport	0.74	20% reduction in emissions from paper transport	Reducing the distance for purchased papers
12.	Paperless program	Promoting the paperless program and practices to reduce paper use	Purchased goods	0.24	30% reduction in the number of pages of printed paper	Number of printed study pages
13.	Regulator of water pressure	Installation of water pressure regulators on taps	Water consumption	0.04	10% reduction in water consumption	Measuring water consumption
		Sub-total (Scope 3):		**76.51**		
		TOTAL (Scopes 1, 2 and 3):		**101.67**		

The application of the above measures would achieve a 21.3% GHG emission reduction (101.7 t CO_2 e) in 2030, compared to the emissions in 2017. For the Institute, this represents a greater reduction than the targeted minimum GHG emission decrease of 20%.

Measures to reduce GHG emissions from the 5 largest key sources have been selected as priority measures (Table 5).

Table 5. Analyzed contribution of the priority GHG emission reduction measures for the Institute by 2030.

No.	Key Source Categories	GHG Emissions in 2017 (t CO_2 e)	Priority Measures	GHG Emission Reduction in 2030 (t CO_2 e)
1.	Purchased electricity from grid	88.13	PV installation and energy efficiency improvement	14.54
2.	Business travels by plane	72.96	Videoconferencing	21.89
3.	Employee commuting by car	66.26	Teleworking program	26.51
4.	Purchased heat from district heating	57.11	Energy efficiency improvement	5.44
5.	Business travels by office car	34.47	Eco-driving and adjustment of company fleet	5.17
	Total	**230.81**	**All priority measures**	**73.55**

The largest key source of GHG emission was purchased electricity from the grid. Appropriate priority measures are PV installation and energy efficiency improvement of electricity consumption, with a GHG emission reduction potential of 14.5 t CO_2 e in 2030 (16.5%). Greater use of videoconferencing is an important way to reduce the second key emission source—business travel of employees by plane. The expected reduction in GHG emissions is 30% or 21.9 t CO_2 e in 2030. Additionally, this measure would facilitate work from home. If all employees worked from home two days a week in 2030, GHG emissions would be reduced by 26.5 t CO_2 e (40%) from employee commuting by car. Additional priority measures are energy efficiency improvement of heat consumption (5.4 t CO_2 e in 2030), eco-driving training, and adjustment of company fleet (5.2 t CO_2 e in 2030). The potential of the priority measures is 72.3% of the total GHG emission reduction potential of all analyzed measures (Table 4).

Unlike the Institute, the Agency and the Faculty have not yet prepared action plans. However, based on CF calculations, the biggest expected contribution to reducing GHG emissions of the Faculty should be the energy renovation of their buildings, which could significantly reduce its heating demand. On the other hand, the biggest contribution to reducing the emissions of the Agency is the commuting of employees.

It should be noted that a significant reduction in GHG emissions is likely to occur as early as 2020 in all three considered organizations, because of the COVID-19 pandemic. The expected reduction in GHG emissions could be mostly in employee travel, business travel, and visitor travel, due to teleworking and virtual meetings/webinars.

After reducing GHG emissions within organizations and in the related upstream and downstream activities, the organization may also invest in GHG offset projects to reduce emissions by sources or increase removals by sinks. These offset projects take place outside the organization and can be applied to achieve emission reduction targets when costs of internal measures are high or reduction opportunities are limited. In any case, the cost-effective GHG emission reduction measures related to the organization operations should be implemented first. After that, the organization can buy GHG offset credits and become carbon-neutral, which is a long-term goal of the Agency, the Faculty, and the Institute.

4. Conclusions

Calculations of CFs and corresponding uncertainties for the Agency, the Faculty, and the Institute were performed using the enhanced BC model. The model, based on the original French BC model, is extended with a country-specific emission factor database and gives a possibility for extracting the CF results in three scopes and six categories following the GHG protocol and ISO standards. The model can be applied for calculating the CF of any organization regardless of its geographical location.

The paper presents a comparative assessment of CFs for three analyzed organizations. The absolute values of CFs in 2017 were 513.4 t CO_2 e for the Agency, 4254.7 t CO_2 e for the Faculty, and 477.0 t CO_2 e for the Institute, with the estimated uncertainties of the CF calculation at ±7.8%, ±8.4%, and ±6.7%, respectively. Comparing the specific CF, the Agency had the smallest value of the CF per employee (4.5 t CO_2 e/employee), followed by the Institute with a slightly higher value (5.4 t CO_2e/employee), and the Faculty with the highest value (9.4 t CO_2 e/employee). On the other hand, the comparison of specific CFs by heated area showed the opposite ranking: The highest value for the Agency and the lowest for the Faculty. Although the CF calculation method and socio-economic and climatic conditions for the observed organizations were the same, it should be noted that the type of organization and the set of input data were only similar.

The CF calculation is only the first step in which it is possible to identify the key emission sources and define priority measures for GHG emissions reduction. Feasible and cost-effective measures were analyzed on the example of the Institute, and the expected reduction in CF in 2030 was estimated at more than 20%. A significantly larger emission reduction is needed by 2050 to achieve the long-term goal of all three analyzed organizations, carbon neutrality. In this way, the Agency, the Faculty, and the Institute could significantly contribute to national, EU, and global climate change mitigation goals.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/12/22/9618/s1, Table S1: The CF of Agency for 2017, using the enhanced BC; Table S2: The CF of Faculty for 2017, using the enhanced BC; Table S3: The CF of Institute for 2017, using the enhanced BC; Table S4: Key source analysis for Agency's CF in 2017—Level Assessment; Table S5: Key source analysis for Faculty's CF in 2017—Level Assessment; Table S6: Key source analysis for Institute's CF in 2017—Level Assessment; Table S7: The uncertainties of the CF calculation for Agency; Table S8: The uncertainties of the CF calculation for Faculty; Table S9: The uncertainties of the CF calculation for Institute.

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