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Sena AHMETOĞLU and Ayşegül TANIK

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Research Article

Carbon Footprint Calculation of Different Building Typologies under Construction and Operation Stages

Sena Ahmetoğlu , Ayşegül Tanık* 

ITU, Faculty of Civil Engineering, Environmental Engineering Department, Istanbul, TR

* Corresponding author: A. Tanık

* E-mail: tanika@itu.edu.tr

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Abstract

Construction sector in Turkey has been accelerating over time, highly contributing to the release of emissions to the atmosphere that causes climate change and global warming. In line with the calculation of carbon footprint (CF), the direct and indirect sources of emissions arising from two different building typologies in Turkey, a hospital and a complex building covering shopping mall, offices and residences were determined representing the construction stage, and another hospital and a shopping mall were selected as examples of operation stage to cover the entire sector. The scope was determined according to classifications specified in ISO 14064 Greenhouse Gas Calculation and Verification Management System. The calculations were done by multiplying the emission factors obtained from international sources with the actual consumption values gathered from a Contractor Company established in Turkey. As studies on national emission factors have not yet been completed, internationally accepted and recognized values were used. In the light of determined emission sources and scopes, the CF of the hospitals and complex building projects for at least 2 years were calculated and the changes were evaluated. The findings obtained within the scope of the projects built and/or operated representing different building typologies in the construction sector indicated that electricity consumption had the largest share regarding the CF calculations. In addition, worldwide examples on mitigation applications were referred and underlined in the study.

Keywords: Carbon Footprint, Construction Sector in Turkey, Climate Change, GHG Emissions.

Introduction

Electricity, transportation, industrial activities and energy consumption resulting from the use of fossil fuels, the unconscious resource consumption caused by industrialization, the inability to dispose the wastes properly, deforestation that disrupts the natural equilibrium of human beings, and the change in land-use impose an effect on the earth's balance. Today, this effect is known as climate change and global warming. The release of carbon dioxide (CO₂), nitrogen (N) and methane (CH₄) compounds to the atmosphere as a result of anthropogenic activities is regarded as the main cause of climate change and global warming. Carbon footprint (CF), which expresses the emissions of the activities carried out, should be controlled to leave the existing resources to the next generations. CF is the measure of environmental damage caused by human activities and it is determined by expressing the total amount of greenhouse gas (GHG) emissions in terms of CO₂ equivalent expressed as CO₂e (Pachauri et al., 2014). Calculation of CF involves the calculation of direct or indirect emissions of fossil fuels, which emit GHG that lead to the greenhouse effect known as the most important outcome responsible of global warming, and with the consumption of energy based on the activities of the individuals/institutions, the resulting CO₂ emerge into the atmosphere (Arslan and Akyürek, 2011; Mersin et al., 2019-2020; Ülker et al., 2020; Yue et al., 2020;).

It is globally observed that there is an increasing deviation in targeted carbon emission reduction levels (50% in 2025 and 80% reduction in 2050 compared to 1990) in line with the Paris Agreement, where the limiting global warming to 1.5-2°C was aimed (Green Construction Board (GCB), 2015). On the road map published by the GCB, it was stated that the reduction of GHG emissions in 2009 was 17% compared to 1990, while it was only 11% in 2012 (GCB, 2015; Bayırhan et al., 2019; Tokuşlu, 2021). In addition to its economic share, the construction industry has a significant impact on total GHG emissions with energy consumption and use of resources from the supply chain. In the synthesis report prepared for Intergovernmental Panel for Climate Change (IPCC), it was revealed that the construction sector was responsible for 18% of direct and indirect GHG emissions worldwide in 2010 (Pachauri et al., 2014). Significant environmental impacts during the construction and operation stages of buildings arise through resource consumption, waste generation and GHG emissions. While most of the policies and regulations focus on reducing direct emissions from buildings, recent research has drawn attention to indirect or life cycle (LC) GHG emissions from the construction industry (Akan et al., 2017). A new research on LC GHG emissions has put forth that LC energy consumption of the buildings (10-97% of all LC carbon emissions) depended on the energy consumed during construction, the service life of the building, energy requirements, location and material usage (Chastas et al.,

2016). Based on the data of 2012, Wen and Zhang (2020) tried to analyse the current situation of inter-sector carbon emission transfer, and identify the key sectors and the critical paths from multiple perspectives in China. Their results showed that electricity, petroleum and metal smelting were the largest carbon outflow sectors that emit carbon, whereas construction and other services were the most obvious carbon inflow sectors leading to indirect carbon emissions through their demand for other sectors.

The construction sector in Turkey has become the most popular sector in the recent years as a result of the growth momentum of the country's economy that accelerated the need for housing and infrastructure (Ahmetoğlu and Tanik, 2020). It is aimed to calculate the CF caused by the construction and operation stages of two different building typologies in this study. A hospital (Hospital A) and a complex multi-purpose building covering shopping mall, offices and residences (Complex Building A) representing the construction stage, and another hospital (Hospital B) and a shopping mall (Complex Building B) were taken as examples reflecting the operation stage. Thus, it was a key issue to reveal the effect and scope of the sector's main emission source, as well as the overall effect of buildings on GHG emissions. The calculation method and emission factors were explained in the CF calculations of the buildings during the construction and operation phases by using the actual data obtained from a Contractor Company located in Turkey. The raw data, detailed explanations on the complex structures obtained from the company, and the name of the buildings were not included in the study due to confidentiality reasons.

Some selected studies on CF calculations in construction sector

Ochoa et al. (2005) have calculated CF of a two-storey wooden framed residence project with an area of 186 m² to better understand the environmental impacts of the building. They used Economic Life Cycle Assessment (EIO-LCA) tool developed by Carnegie Mellon University-Green Design Initiative by taking into account all the required materials and equipment for the construction. Based on the calculations, such a construction facility consumed 550 MJ energy, 43 ton CO₂e emitted as GHG emission, 200 kg NO₂, 300 kg CO and released 100 kg particulate matter (PM) during the construction phase. By using the same EIO-LCA method, Guggemos and Horvath (2006) realized a hybrid calculation of a four-storey office building with an area of 8,760 m² again related to the construction phase. It was stated that this project consumed almost 4,180 GJ energy while it released 291-ton CO₂e, 2.466 kg NO₂, 1.997 kg CO and 321 kg PM. Both of these studies indicated a wide difference of CO₂ emission per storey; 21,5 ton CO₂ for the 2-storey wooden building and 72,75 ton CO₂ for the 4-storey office building during construction. These values put forth the reality that materials used, surface areas considered, and number of flats made this difference in the emissions. However,

more importantly was the high-energy consumption values in both cases.

Gomes et al. (2007) developed a CO₂ emission matrix in Lisbon, Portugal to determine the GHG emissions of the buildings within the Oerias Municipality. In this calculation, electricity consumed in the buildings, amount of solid and liquid wastes generated, and consumption of liquid and gas fuels were considered. This study formed an example of a large-scale (residential area) community GHG calculation rather than individual buildings.

In order to analyse CO₂ emissions arising from the active 25 sectors in India, Parikh et al. (2009) developed an Input-Output (IO) table and a Social Accounting Matrix (SAM). Resulting consumptions were divided into six categories including special ultimate consumption costs, national ultimate consumption costs, gross fixed capital formation, change in stocks, export in goods and services, and import of goods and services. It has been revealed that the total emissions of the Indian economy in 2003-2004 were 1217 Mtons CO₂ and 57% of this amount was due to the use of coal and lignite. The emission per capita was calculated as approximately 1.14 tons. The largest direct emission source was the electricity sector, followed by manufacturing sector and highway transportation. The final demands of the construction and manufacturing sectors were equal to outputs from almost all energy sectors, taking into account both direct and indirect emissions.

Jeong et al. (2012) aimed to measure CO₂ emissions from the main construction materials used in construction sector in Korea in the buildings of different sizes. Calculation was made for the buildings consisting of 6 apartment types. The areas were 29.9m² (A type), 46.2m² (B type), 59.6m² (C type), 84.9m² (D type), 102.5m² (E type) and 149.5m² (F type). It has been determined that CO₂ emission in the buildings was approximately 569.5 kg CO₂/m². The CO₂ emission of 84.9 m² D type, which is the typical apartment type in Korea, has been calculated as 45.1 tons of CO₂.

Wong et al. (2013) conducted a prototype architecture of virtual prototyping technology and made a carbon emission estimation for construction projects. Integrated 4D models of the 34-storey office and residential complex construction project in Hong Kong were drawn; estimated GHG emissions including all construction activities were calculated from the images obtained. The 3D project drawn in Revit program during the studies was made in 4D with the Autodesk NavisWorks program; equipment and tools to be used for the construction of the project were determined; GHG emissions were then calculated, taking into account the approximate values of operating times and resource consumption. As a result of the calculation, it was determined that the tower crane, excavator and generator were the three main contributors to CO₂ emissions with the distribution share of 39%, 26% and 15%, respectively in this project.

Hu and Liu (2016) focused on the construction industry in New South Wales, Victoria, Queensland, Western

Australia, South Australia, Tasmania, Northern Territory and the Australian Capital Territory in Australia in the period of 1990-2012. This study emphasized on the carbon efficiency, which was defined as the ratio between gross value added and CO₂ emissions. In the first step, the Daily Average Divisia Index (DADI) was used to analyse the impressive factors of technological innovation and regional regulation. In the second step, correlation analysis was conducted to develop explanatory indicators of change in carbon yield. As a result, it has been demonstrated that the improvement in carbon efficiency was possible with a decrease in energy density rather than machinery and equipment.

Solis-Guzmán et al. (2018) presented an open-source online tool for the estimation of the CF of residential buildings by non-specialized users as a product from the OERCO₂ Erasmus+ project. The ten most common building typologies built in the last decade in Spain were analysed by using the OERCO₂ tool, and the order of magnitude of the results was analysed by comparing them with the ranges determined in similar other studies. Accordingly, the tool was proved reliable as the results fell within the acceptable value ranges. Moreover, the major simplification of the interface allowed non-specialized users to evaluate the sustainability of buildings.

Zhang et al. (2019) aimed to determine the CO₂ emissions from the construction sector due to structural decomposition analysis and by means of a dynamic hybrid input-output (IO) model in China. A series of energy-economy hybrid IO tables were created using energy balance tables and IO tables published by the National Statistics Bureau of different years (2007, 2010, and 2012). In the second step, the outputs resulting from the technological developments and final increase in demand of various sectors were revealed by structural decomposition analysis. Initially, sectoral effects of energy consumption and technological advances were examined. As a result, it has been determined that there has been an increase in production demand, technical services and scientific researches in parallel to technological changes, and it has been stated that it caused an increase in emissions originating from tertiary industry, especially from electricity energy consumption. The Chinese government followed strict policies to increase energy conservation and to reduce emissions from energy production as Zhang et al. (2019) underlined. For example, the Chinese State Council has issued two policies that prohibit increasing production capacity in the steel and cement industry.

Another recent work from Malaysia aimed to contribute to pre-assessments of CO₂ levels at an early stage of LC studies for sustainable decisions and safe green social developments. 3D parametric models of selected case studies were developed in a virtual environment using building information modelling (BIM) (Gardezi and Shafiq, 2019). Moreover, Li et al. (2020) employed an environmental input-output (EIO) model to calculate the sectoral embodied energy, CO₂ emissions and water (ECW) from 2002 to 2015, and adopted indicators to

explore sectoral ECW nexus characteristics of China in 17 different sectors including construction industry. Calculations carried out in line with the goal of calculating and reducing GHG emissions from the construction and operation phases of the construction sector are summarized in Table 1 including the project details and calculation method(s). It is clearly seen that especially the recent studies focused on developing and using various models to achieve the targets in complex multi-storey, multi-purpose buildings.

Data and Methodology Used

In this study, scope classification was made according to the ISO 14064 GHG Calculation and Validation Management System. Scope-1 covered the activities that create direct CF. In this context, the fossil fuels used by the projects for heating or energy needs, and the emissions from the fuels of the vehicles were taken into consideration. Within Scope-2, the CF of the emissions caused by the electrical energy consumed in the construction projects has been calculated. Scope-3 is an indirect CF and included emissions from projects that were not directly emission-driven projects. Within this context, emissions from non-owned or uncontrolled sources such as production, transportation, leased assets, outsourced services and disposal of the wastes generated during the construction or operation stages of the buildings were included in the calculation. Globally accepted IPCC, GHG Protocol and ISO 14064 emission factors published in Europe and the United States (USA) have been used. By multiplying the emission factors used and the actual data obtained, CF of a hospital and a complex structure consisting of a shopping mall, office and residence (Complex Building) were calculated. The changes in CO₂ emissions of the projects under construction and operation were examined and the contributions to the CF of the resources were determined by prioritizing the emission sources. Schematic diagram of the methodology used is given in Figure 1. Details on the calculation method and the emission factors were given in detail in Ahmetoglu (2019) and Ahmetoglu and Tanik (2020).

Data on emission sources were obtained from the consumption values appearing in the invoices provided by the Contractor Company established in Turkey. Natural gas data were provided in m³ from the invoices of the national gas distribution companies (IGDAS), electricity data was obtained in kWh from the invoices of electricity distribution companies (BEDAS, TEDAS). Water consumption amounts were invoiced and expressed in m³ by the water administration of the city where the project was located. The fuel consumption amounts were obtained from the values in the invoices in litres and from the receipts of the fuels received. Waste amounts were compiled from the waybills expressed by the municipality or by the responsible firm that collected the wastes. Since the disposal method of the wastes was effective on the emission factor, the disposal methods of the wastes have been confirmed from the company where the data was obtained. Gas filling information originating from air conditioners has been accessed

through the maintenance forms delivered by the firm that maintained the heating and cooling systems. Consumption data of generator fuels in litres were obtained from the plugs of the engine used together with the generator's working hours. Data sources according to each scope used in monitoring gas emissions are given in Table 2.

In order to ensure a sustainable carbon management, it is important that companies and organizations inform their stakeholders about data collection, calculation, reporting and transparency of their activities. The Intergovernmental Panel on Climate Change (IPCC) (Url-2), Greenhouse Gas (GHG) Protocol (Url-3), United

Nations Framework Convention on climate Change (UNFCCC) (Url-4), ISO 14064 standard on Greenhouse Gases (Url-5) were used as guidelines for this purpose. The emission factors used within the framework of this study were the National GHG Conversion Factors for Company Reporting by the United Kingdom (UK) Ministries and the IPCC (International Panel on Climate Change) taken from the Guidance documents prepared for 2006 National GHG Inventory (Url-6). In addition to these resources, ISO 14064 standard also approved by the authorities in Turkey, derived by the Department of Environment, Food and Rural Affairs (DEFRA) of the UK government by conducting a long-term study was selected as the data of this study.

Table 1. Examples of worldwide CF calculation methods in the construction industry

Country	Project Detail	Calculation Method	Reference
Pennsylvania, USA	Two-storey wooden framed residence project with an area of 186 m ²	Economic Life Cycle Assessment (EIO-LCA) tool developed by Carnegie Mellon University Green Design Initiative	Ochoa et al. (2005)
California, USA	Four-storey office building with an area of 8,760 m ²	LCA and EIO-LCA	Guggemos and Horvath (2006)
Lisbon, Portugal	Buildings located in Oerias Municipality	CO ₂ emission matrix	Gomes et al. (2007)
India	CO ₂ emissions from 25 sectors including construction sector	IO chart and Social Accounting Matrix (SAM)	Parikh et al. (2009)
Korea	Building with 6 different areas	The ratio of building area (m ²) of the newly built apartments to the building and the product of CO ₂ emissions (tonnes CO ₂ /m ²) released in the unit area	Jeong et al. (2012)
Hong Kong, China	34-storey office residence complex building project	Revit and Autodesk NavisWorks program	Wong et al. (2013)
Australia	Australian construction sites	Carbon efficiency, Daily Average Divisia Index and correlation analysis	Hu and Liu (2016)
Spain	Determination of CF of residential buildings according to their dwelling type, built-up surface, above-ground and underground floors, and the constructive solutions adopted for the foundations, structure and roof	OERCO ₂ tool	Solis-Guzmán et al. (2018)
China	Determination of CO ₂ emissions caused by energy consumption of the construction industry	A dynamic hybrid IO model with structural decomposition analysis	Zhang et al. (2019)
Malaysia	Seven typical conventional Malaysian houses with a single and double-story height	Integrating statistical multiple regression and 3D virtual modelling (BIM) in a LCA to propose a CO ₂ prediction tool for operational phase	Gardezi and Shafiq (2019)
China	Determination of direct energy consumption, CO ₂ emissions, water use 17 main sectors (i.e. agriculture, power, food, construction) in China	IO tables and ECW data	Li et al. (2020)

The limits (scope) determined for the CF calculations of the two building typologies in the construction and operation stages were generally the same. Although the diesel consumption of the vehicles, construction equipment and forklifts used was included in both the operation and construction processes, large differences have been observed in their contribution to GHG emissions. The data item, which differed in the scope of the two processes, belonged to the number of vehicles

entering the car park. It was aimed to calculate the indirect GHG emissions of the service provided by visiting the building under operation, regardless of whether it was a hospital or a complex building with a shopping mall.

Introducing the buildings under construction

Hospital A was a project realized in Bursa Province of Turkey with public-private sector cooperation model and

was built on a total area of 830,813 m². This ancient city, ranked as the 4th crowded city of the country, is a highly industrialized region with a current population of approximately 3 million (Url-7). The project was an integrated health campus project with a total capacity of 1,355 beds and owned different specialised hospitals including general hospital, cardiovascular disease hospital, oncology hospital, maternity and child, general and psychiatric hospital. This project was a candidate of Leadership in Energy and Environmental Design (LEED) certificate, which examines structures from energy, water consumption, waste generation, ventilation, natural lighting, and use of environmentally friendly materials organized by the USA Green Building Council (USGBC).

The scope of this study included all rough construction works, mechanical and electrical works, covering the activities carried out in 2017 and 2018. While the number of people working on the project was 1200 in 2017, this number reached approximately to 4000 in 2018. On the other hand, Complex Building A located in Istanbul included a shopping mall with a leasable area of 56,000 m², an office with a leasable area of 38,000 m² and more than 200 residences in 1 + 1, 2 + 1, 3 + 1 types with a total area of about 300,000 m². Istanbul, the most crowded province of Turkey as well as of Europe, has a current population of approximately 16 million (Url-8).

It is ranked as the 13th most crowded city of the world (Url-9). The scope of this study included all activities (all rough construction and fine construction works, mechanical and electrical works, including the superstructure and infrastructure works) carried out in 2015, 2016 and 2017, respectively.

Within the scope of the project, the contractor firm has outsourced the fine works. For this reason, material consumption of the subcontractor company could not be included in the calculations since data could not be provided. Resource consumption such as electricity, fuel and water in the fine works performed were reflected in the calculations. While the number of people working on the project in 2015 was around 2000, this number reached to 5000 in 2016, and to 6500 in 2017. At the beginning of 2018, the construction phase of the project was completed and the building was commissioned. During the calculation of CF, consumption values and data together with other information regarding the items that were differentiated according to their scope were obtained from the company (Ahmetoğlu, 2019). Actual values transmitted monthly with the relevant document, and invoice data were multiplied by the emission factors shared and the results were obtained. The items included in the calculation limits and their scope are shown in Table 3.

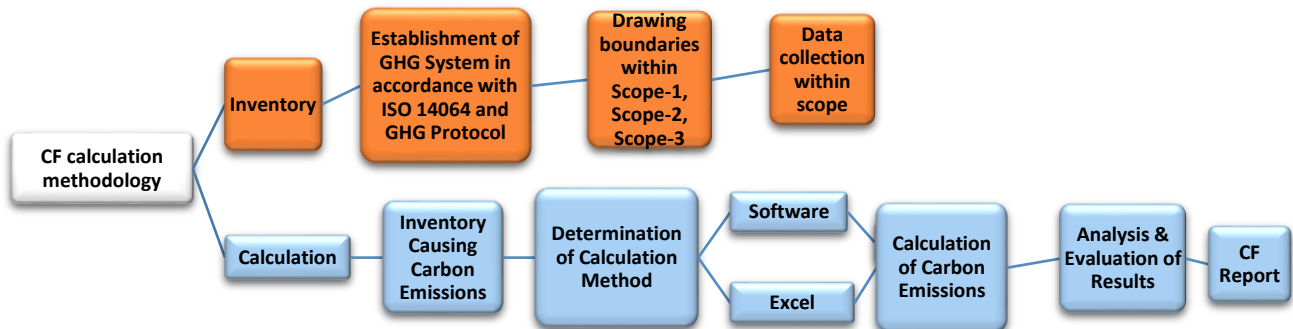


Fig. 1. CF calculation methodology used

Table 2. Data resources used in each scope

Scope 1	Scope 2	Scope 3
Natural gas, fuels etc. consumed for the production of heat and steam during all kinds of activities carried out in projects in operation and construction process.	Electricity used in projects in operation and construction process	Number of vehicles entering the car parks of the enterprises
Fuels of generators used in power outage in projects in operation and construction process		Wastes from projects in operation and construction process
Diesel used by vehicles, construction equipment and forklifts used in the own activities of projects in operation and construction process		Personnel transportation activities (service, etc.)
Fire extinguishers used in projects in operation and construction process		CO ₂ emissions from 25 sectors including construction sector
Gas consumption from air conditioners used in projects in operation and construction process		Staff travel
		Water consumption in projects during operation and construction

Introducing the buildings under operation

Hospital B was a project with a 500-bed capacity built on a total area of 142,000 m² located in Yozgat Province of Turkey. The city is located in Central Anatolia with a population of around 0.5 million (Url-7). The construction work started in 2015 and was completed in 2 years. The hospital started accepting patients at the beginning of 2017. The project has been a Gold Class project in the LEED certification system, where structures are examined in terms of energy, water consumption, waste generation, ventilation, natural lighting, and use of environmentally friendly materials organized by USGBC. The scope of this study included all the activities realized in 2017 and 2018. The hospital reached to an annual capacity of approximately 550,000 patients upon commissioning.

The shopping mall (Complex Building B), which was an exemplary project selected for CF calculations during the operation phase, was opened in 2008 in Istanbul. It owned a leasable area of approximately 45,000 m² and an average of 13 million visitors annually. There are dining halls and open-air terraces with a seating capacity of 2,500 people, and an ice rink of 540 m². With all these features, the project was deemed worthy of awards such

as Europe's Best Outlet and Best Outlet of the Year from platforms in Europe. The scope of this study included all the activities carried out between 10:00 and 22:00 in 2016, 2017 and 2018. Unlike the hospital project under operation, natural gas consumption was not separated as leasable area and common area in this project. The reason for this was that, in line with the contract made with tenants, natural gas consumption expenses were covered by the relevant company.

Results

CFs caused by the emission sources of different building typologies either under construction or operation phases have been given in proportion to the total annual emissions to prevent phrasing of the actual emission amounts as was a requirement of the contractor company in line with their management policy.

CF calculation of the projects under construction

Calculation of the CF for the hospital project was done for the two respective years through utilizing the data obtained. The distribution of the GHG emissions are given in Figure 2 (a) and (b) for years 2017 and 2018, respectively.

Table 3 Hospital and complex building construction project items and their related scope during construction and operation phases

Scope-1	Scope-2	Scope-3
Generator fuel consumption	Electricity consumption	Wastes
Work equipment fuel consumption		Business Trips
Fire extinguisher filling / changed information		Staff Transportation
Refrigerant filling information of cooling units		Visitor cars
Natural gas consumption		Water consumption
Personnel / rental cars		

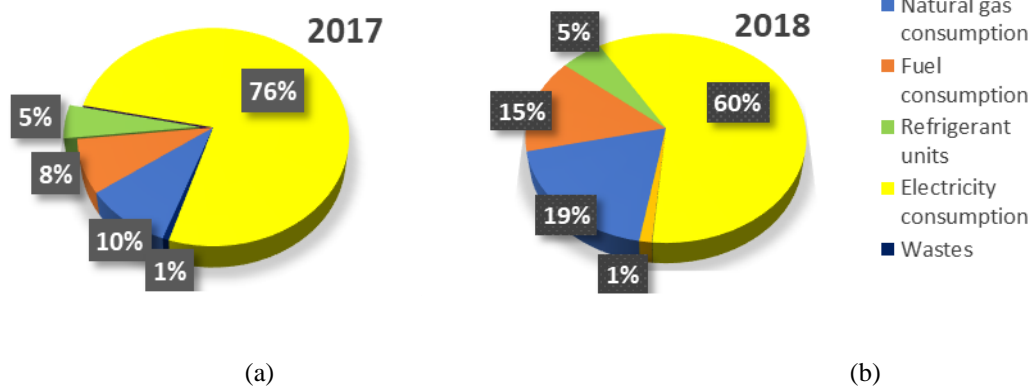


Fig. 2. Distribution of GHG emissions of the hospital project under construction in (a) 2017, (b) 2018

The major emission source in 2017 was electricity consumption followed by natural gas and fuel consumptions. The total amount of diesel used for generators and work machines in fuel consumption was included in the calculation.

The CFs have designated that GHG emissions in ton CO_{2e} increased in the second year of construction (2018) compared to the previous year of 2017. The below referred phrases can be derived from the analysis of the results attained for year 2018 compared to the previous year of construction;

- Emissions from electricity consumption increased by 45%.
- Emissions from natural gas consumption increased by 250%.
- Emissions from fuel consumption increased by 231%.
- Emissions from refrigeration systems gas filling increased by 94%.
- Emissions from wastes decreased by 90%.

On the other hand, for the complex building project, the similar distribution profiles are shown for years 2015, 2016 and 2017 in Figure 3 (a), (b) and (c), respectively.

Figure 3(a) shows that almost the entire CF calculated in line with the real data obtained from the Company for the complex building project in 2015 was due to electricity consumption. In 2015, when the project's mobilization and rough construction activities were in question, the sources that were more effective in GHG emissions compared to other items were the fuel consumption of passenger vehicles used in connection with the project, and fuel consumption from generators and work machines, respectively.

According to the CF comparison made by taking into

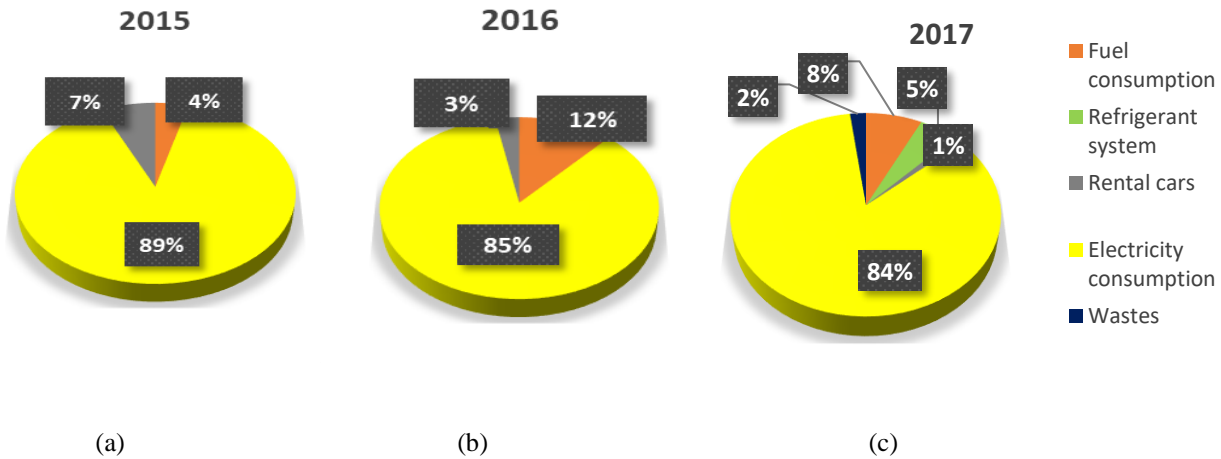


Fig. 3. Distribution of GHG emissions of the complex building project under construction in (a) 2015, (b) 2016, (c) 2017.

Since the largest share in the CF calculation was due to electricity consumption, the effect of this situation has emerged as an increase of the total CF in 2016 by about 127%. In 2017, the Contractor Company has provided more data for the calculations regarding the impact of project management and the development of the data recording system during the construction phase. It is seen in Figure 3(c) that unlike the previous 2 years, emissions from air conditioning gases and wastes had a significant share in the total GHG emissions in 2017. Total GHG emissions of the project increased by 98% in 2017 compared to 2016. This was because of

- 95% increase in emissions from electricity consumption,
- 35% increase in emissions from fuel consumption of the construction machinery,
- Emissions from air conditioning gas refills,
- Emissions from waste, primarily construction wastes.

Emissions from generator fuel consumption decreased by 23% and from rental vehicle fuel consumption by 14%. There was a significant increase in total GHG emissions since the largest share in the CF was due to electricity consumption and the reductions seen could not compensate the other emission increases.

CF calculation of the projects under operation

In the hospital project (Hospital B) under operation, the calculations were done for 2017 and 2018; however, the

consideration the increasing GHG emission in ton CO₂e of the complex building project in 2016 (Figure 3(b)), the following results were achieved;

- The emission share of the generator fuel decreased due to the increase in other items although the fuel consumption from the generator was the same as in 2015.
- Emissions from electricity consumption increased by 118%.
- Emissions from fuel consuming construction equipment increased with the start of construction activities.

information about the following data sources could not be provided in the hospital.

- Information regarding the refrigerant used by the cooling system.
- Water consumption.

Unlike the construction phase, the natural gas consumption of leasable areas such as food, pharmacy and cafe serving in the hospital was separated from the main activities and included in the responsibilities of these enterprises. Figure 4(a) and (b) presents the CF calculations of the hospital project for 2017 and 2018, respectively.

According to the 2017 outputs, the largest CF contribution in the operating process as well as in the construction of the hospital was due to electricity consumption. Within the scope of this project, it has been observed that more than half of the GHG emissions were released because of the electricity consumed. In the calculation of GHG emissions of the hospital project in 2018, it was determined that patient acceptance area had the second largest share of natural gas consumption in common areas, including the areas where the treatment was carried out. This item was followed by natural gas consumption in the leasable area. The total value of the common areas had a rate of approximately 38%. The CF share of waste was about 2%.

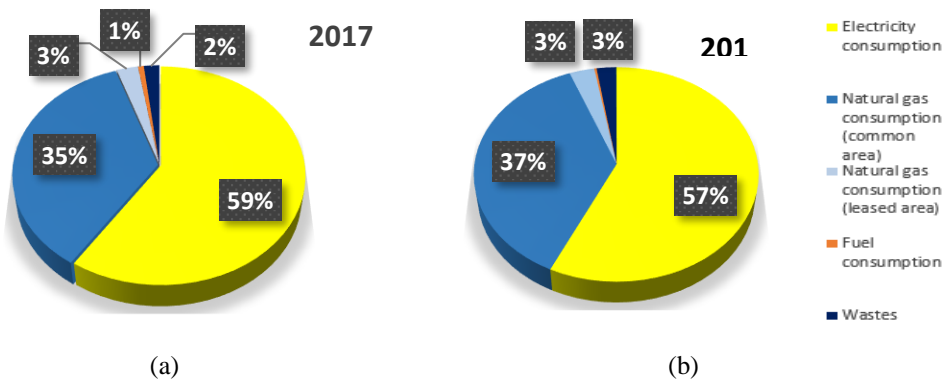


Fig. 4. Distribution of GHG emissions of the hospital project under operation in (a) 2017, (b) 2018

The high CF share of the wastes can be explained by the excessive amount of medical waste in the entire content of the wastes.

Total GHG emissions of the project in 2018 increased by approximately 750 tons of CO₂e compared to 2017. The change between the two operation years is given below in terms of data sources.

- Emissions from electricity consumption increased by 0.06%,

- Emissions originating from natural gas consumption common area increased by 9%,
- Emissions from natural gas consumption, leasable area, increase by 24 %,
- Emissions from fuel consumption decreased by 59%,
- Waste emissions increased by 36%.

CF was determined for the shopping mall (Complex Building B) project for 3 consecutive operation years. The results are given in Figure 5 (a); (b) and (c) for years 2016, 2017 and 2018, respectively.

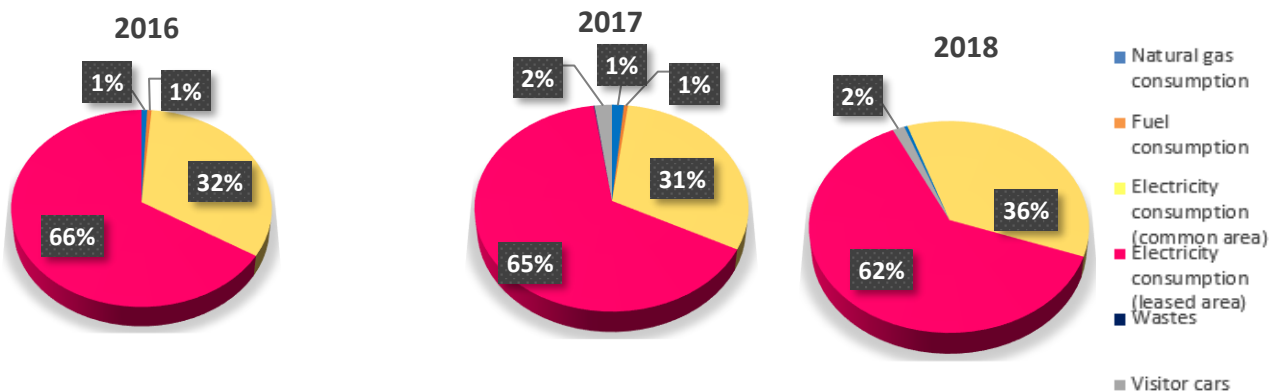


Fig. 5. Distribution of GHG emissions of complex building project under operation in (a) 2016, (b) 2017, and (c) 2018

In the Complex Building B project, CF has been calculated under three main headings; the item with the biggest share in the emissions was electricity consumption in 2016, as was the case in the projects in the construction stage and the hospital project under operation. In this project, electricity consumption contributed to total GHG emissions by more than 98%. It is observed that the leasable area (leasable in electricity consumption) was differentiated according to the common areas that included the areas belonging to stores and dining areas, had more share (Figure 5(a)). In 2018, the total GHG emissions decreased by approximately 950 tons of CO₂e compared to 2017. The change between these two years is given below;

- Emissions from natural gas consumption decreased by 77%,
- Emissions from fuel consumption decreased by 46%,

- Emissions from electricity consumption resulted in 1% reduction.

Discussion of results

The findings obtained within the scope of the projects built or operated for different purposes representing different building typologies of the construction sector is that the electricity consumption has the biggest share regarding the CF calculations. Environmentally conscious companies around the world are working on solutions that will provide efficiency in electricity and resource use, and are taking various measures in order to reduce GHG emissions released to the atmosphere due to their activities.

Figure 6 shows the CF data for 15 buildings under Scope-1 and Scope-2 for CO₂e given in the Sustainability Report of 2017 shared by America-based Bechtel Company, which is accepted as the best contracting firm in the world (Url-10). With the calculations made by including Scope-1 and Scope-2 for office buildings and their CFs, Bechtel shared its total revenue intensity in tons of CO₂e/billion USD. Bechtel aimed to decrease CO₂ emissions with the increase in their incomes. Figure 6 reveals the positive trend fulfilling this purpose over the years.

In Bechtel's Sustainability Report, it is mentioned that the reduction of GHG emissions was achieved through changes in the lighting system and systematic improvements applied to the heating and cooling elements. As an example, it was referred that 6200 \$ (US Dollars) was saved annually by replacing the bulbs with LED (Light Emitting Diode) bulbs in the UK Head Quarters building of Bechtel (Url-10).

It has been determined that electricity consumption is the most important emission source for the complex building (Complex building A) that also included a shopping mall. The average distribution for the Complex Building B project in the operational phase for 3 years was 98%. The high emission contribution once again proved the necessity of reducing electricity consumption in shopping malls, which are the pioneers of the service sector, and emphasized that efficiency measures have become mandatory. In line with these requirements, Unibail-Rademco-Westfield Company, which is the most important operator of Europe, has been shared as an example in this study. Unibail-Rademco-Westfield is a company that was founded in 1968 and operates 93 shopping malls in 13 countries in Europe, especially in France, with 1.2 billion visitors annually. It is the biggest company of Europe in the name of business. Unibail-Rodemco-Westfield reported that it has achieved 13% reduction in energy consumption and a further decrease of 17% in carbon density with new applications and improvements between 2012 and 2015 (Url-11). Improvements continued in 2016 as well. While ensuring this efficiency, the actions listed below have been taken.

- Electricity use from renewable sources was accelerated; all shopping malls have managed to use green electricity since 2016 in Spain.
- A 4% reduction in energy consumption was achieved through continuous improvements in energy efficiency from 2015 to 2016.
- The energy producers' efforts to improve their energy mixes and CO₂ emission factors from 2015 to 2016 constituted 20% of this decrease.

The decrease achieved as shown in Figure 7 was realized due to the measures taken, and the improvements made was encouraging to combat with global warming and CF. The use of resources, primarily electricity, in accordance with the concept of sustainability, makes it possible to achieve the goal of reducing GHG emissions. An example of this fact is

the CO₂ reduction of Unibail-Rodemco-Westfield for 2014, 2015 and 2016, respectively (Figure 7). After the 2016 performance, a cumulative decrease in the CO₂ of 41% from 2012 to 2016 was observed.

With the calculations made in this study and as highlighted in the application examples referred, reducing the electricity consumption was determined as the main cause of the CF, and that obtaining the electricity requirement from renewable sources may provide a noticeable decrease in CO₂ emissions.

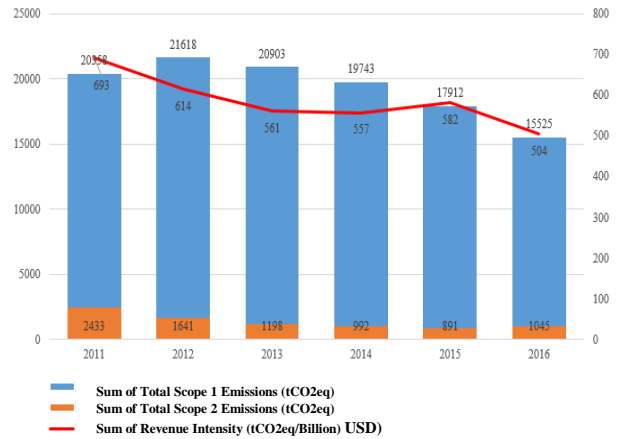


Fig. 6. Change of CF data of Bechtel Company, the world's best construction company, by years (Url-10).

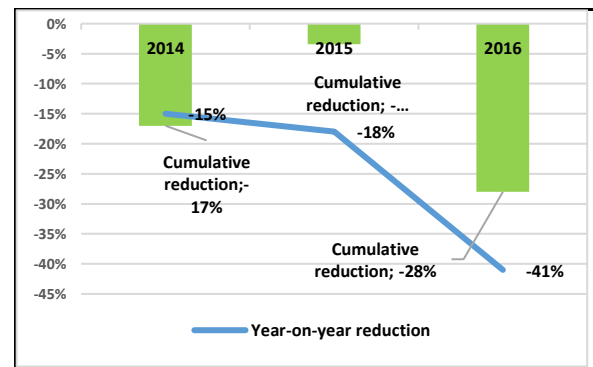


Fig. 7. CO₂ emissions after Unibail-Rodemco-Westfield's mitigation measures (Url-11)

Oktay et al. (2017) has published a book entitled as 'Sustainable World Right: Global Agenda and Turkey' in which the amount of investment made in renewable energy on a global scale was detailed. As mentioned in this book, global investments in renewable energy in 2016 were estimated to be 241.6 billion \$. These investments, made in 2016, decreased by 23% compared to 2015. The investment in renewable energy and fuels in the 7 years before 2016 was more than 200 billion \$ annually on the average. When hydro-power plant investments above 50 MW capacity were added, the total of global renewable energy investments reached approximately to 364.8 billion \$. Investments in renewable energy from 2012 to 2017 had almost doubled the investments allocated to coal and natural gas capacity. Most of the investments in the field of renewable energy were from solar energy. The most invested renewable energy source after solar energy was wind energy (Oktay et al. 2017). The trend

of global renewable energy consumption of the world within the past 50 years was tabulated in Figure 8(a), and of Turkey in Figure 8(b). Renewable energy consumption was measured in terawatt-hours (TWh) per year. Traditional biofuels referred to the consumption of fuelwood, forestry products, and animal and agricultural wastes (Url-12).

Recent international experiences towards reducing CF in buildings

Zhang and Wang (2016) conducted a study to provide a broad perspective on the CF of building construction in two alternative techniques, namely, the process-based and the input-output analytical methods. Their primary aim was to enhance the accuracy and detail the data on the embodied CO₂ in construction.

Three buildings of differing heights and applications were assessed in the case study. The results indicated that manufacturing materials accounted for 80–90% of

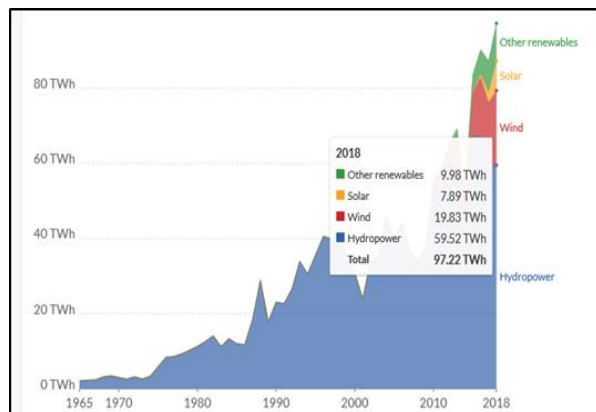
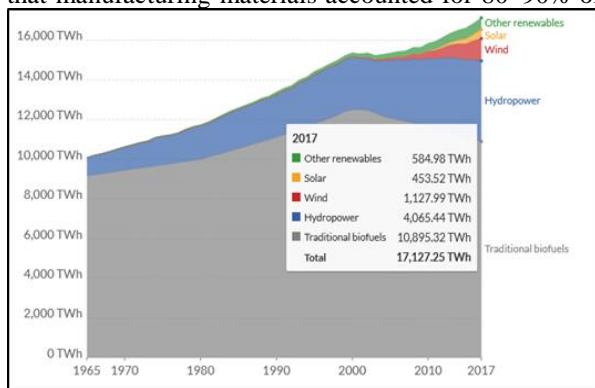


Fig. 8. The trend of global renewable energy consumption of (a) the World, (b) Turkey Vaclav Smil (2017), Url-13

Lu and Lai (2020) conducted a study on GHG emissions in CO₂e based on operational energy use of existing commercial buildings; energy use data of two large countries, the USA and China, and two energy-intensive places, Hong Kong and Singapore. They concluded that the energy use of commercial buildings in the USA, which accounted for the majority of all the energy consumed in the commercial sector, was around 450 Mtons CO₂e in 2016. Again, in 2016, the energy use of commercial buildings in China approached to 384 Mtons CO₂e, which almost tripled this level compared to 2001 use (Lam, 2000; Jing 2017).

Nansai et al. (2020) calculated the CF of Japanese healthcare services, i.e. the domestic GHG emissions caused by health care expenditures using input-output analysis. They stated that in 2015, the total CF had increased to 72.0 Mtons CO₂e, a rise of over 15% in 4 years and medical care and pharmaceuticals were the main factors responsible for this increase. They recommended that the potential annual GHG mitigation achievable through avoidance of unused prescribed medicines resulting in waste was estimated as 1.24 Mtons CO₂e, comparable with the total CF of home medicines.

On the other hand, Ghajarkhosravi et al. (2020) conducted a study in which 120 multi-unit residential buildings (MURBs) has been benchmarked and

the entire embodied emissions. The main structure and the foundation work of the buildings were the sub-projects that contributed the most to embodied emissions (>60%). Chastas et al. (2018) analysed 95 case studies of residential buildings as an effort to identify the range of embodied emissions and the correlation between the share of embodied energy and carbon for different levels of building's energy efficiency. They identified that a range of embodied emissions were between 179.3 kgCO₂e/m²-1050 kgCO₂e/m² (50-year building lifespan) that reflected a share between 9% and 80% to the total life cycle impact. That same share followed similar trends with the respective embodied energy and ranged between 9% and 22% for conventional, between 32% and 38% for passive, and between 21% and 57% for low energy buildings, while the normalised results indicated a sensitivity for the share of operating emissions that related to the electricity mix.

analysed. The study entailed the following steps; performing energy benchmarking using statistical analysis, developing meaningful performance indicators, determining performance ranking, and examine different levels of percentile savings (energy and GHG emissions). The study underlined that the most appropriate indicators were energy consumption per m² (kWh/m²), energy consumption per number of occupants (kWh/capita), energy consumption per number of units (kWh/units), and energy consumption per number of floors (kWh/floor). The range of energy performance indicator for the chosen MURBs varied between 141–580 kWh/year-m². Although reducing the overall natural gas consumption (improving heating system and domestic hot water system) may not lead into much of cost savings (due to system upgrading), but it could have significant positive environmental impacts like reducing GHG emissions.

In this study, energy consumption was defined as the most important contributor to GHG emissions in operation and construction stages. This fact was also underlined and focused on by Lucon et al. (2014).

Concluding Remarks and Recommendations

The construction sector was examined in two consecutive stages in this study, from the supply of

materials to covering the entire construction and operation processes, and data on all sources of the sector causing CF were revealed. The calculations were made by multiplying the emission factors obtained from international sources with the actual consumption values gathered from a Contractor Company established in Turkey. As studies on national emission factors have not yet been completed in the country, internationally accepted and recognized values were used. In order to obtain information about the entire construction industry, CF calculations were made on two different building typologies representing the construction and operation stages. Regardless of the process, it would be useful to include all processes in the calculations to obtain more comprehensive results regarding the CF of each building project.

In this study, although it varied according to the project, 2 or 3 years of the projects were included as representative cross-sections in all processes. The information that the decrease in all consumption sources was caused by efficiency regulations and practices related to savings have been obtained from the Contractor Company.

Various measures have been implemented to reduce the CF in the world. Suggestions for minimizing the consumption of fossil fuels, particularly electricity consumption, and waste generation, are given below:

- Automation systems can be set up to identify and track activities with high-energy consumption in the enterprise so that the changes in energy distribution can be monitored instantaneously and measures can be taken with system or equipment improvements.
- Lighting systems can be replaced or supported by LED lighting with lower energy consumption, timers, photocells or proximity sensors. This can provide up to 70% reduction in GHG emissions.
- Recycling of recyclable waste can be realized more carefully in order to reduce GHG emissions.
- Emissions from the generator can be reduced by timely maintenance necessary to maintain the working efficiency of the generators.
- Preferring newer models in construction machines, performing regular maintenance and acting in accordance with the work plan may decrease fuel consumption.
- Energy efficiency certificate and recyclable features should be considered in material and equipment selection, and should be taken into consideration when making a choice.
- The use of composite materials such as wood with a low CF, straw bales and compacted soil can be increased.
- Alternative fuels with low GHG emissions can be preferred for personal/rental vehicles and road trips.
- Carpool can be shared with the plans to be made for personal/rental vehicles and road trips; thus, fuel consumption can be reduced.
- Engine maintenance and tire pressure control should be provided for personal/rental vehicles to operate at full efficiency.

With this study, it is aimed to shed light on more comprehensive studies to understand the different phases of the construction industry extending from material supply to commissioning, and from commissioning to operation, and on how these practices affect the GHG emissions and, in turn, the global warming and climate change.

Similar studies to be conducted on the calculation and/or estimation of GHG emissions arising from different sectors will hopefully raise the awareness of public on their significant contribution to the CF budget. Calculations done will aid to take actions towards reducing or minimizing the emissions, which in turn will have a positive effect on climate change and global warming which still tends to increase over time.

Conflict of interest statement

We declare that we have no conflict of interest.

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