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Quantifying universities' direct and indirect carbon emissions – the case of Delft University of Technology

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Abstract

Purpose – The purpose of this paper is to present a comprehensive analysis of the carbon footprint of the Delft University of Technology (TU Delft), including direct and indirect emissions from utilities, logistics and purchases, as well as a discussion about the commonly used method. Emissions are presented in three scopes (scope 1 reports direct process emissions, scope 2 reports emissions from purchased energy and scope 3 reports indirect emissions from the value chain) to identify carbon emission hotspots within the university's operations.

Design/methodology/approach – The carbon footprint was calculated using physical and monetary activity data, applying a process and economic input-output analysis.

Findings – TU Delft's total carbon footprint in 2018 is calculated at 106 ktCO_2eq. About 80% are indirect (scope 3) emissions, which is in line with other studies. Emissions from Real estate and construction, Natural gas, Equipment, ICT and Facility services accounted for about 64% of the total footprint, whereas Electricity, Water and waste-related carbon emissions were negligible. These findings highlight the need to reduce universities' supply chain emissions.

Originality/value – A better understanding of carbon footprint hotspots can facilitate strategies to reduce emissions and finally achieve carbon neutrality. In contrast to other work, it is argued that using economic input-output models to calculate universities' carbon footprints is a questionable practice, as they can provide only an initial estimation. Therefore, the development of better-suited methods is called for.

Keywords University carbon footprint, Scope 3 emissions, Procurement emissions, Carbon neutrality, GHG accounting

Paper type Research paper

1. Introduction

Reducing anthropogenic greenhouse gas (GHG) emissions to net-zero is the key strategy to limiting global warming to 1.5°C in the next century (IPCC, 2018; Kennelly *et al.*, 2019;

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UNFCCC, 2015). To this end, the EU aims to be climate neutral by 2050, meaning emitting net zero GHGs (European Commission, 2019; Government of The Netherlands, 2019). While climate change was long considered an issue governments and international organizations had to tackle, all kinds of organizations are now taking up the responsibility to implement climate actions and policies themselves (UNEP, 2015). Universities, in particular, carry climate responsibility for educating future society, fostering innovation and demonstrating sustainable transitions themselves (Botero *et al.*, 2017; Jain *et al.*, 2017). For example, more than 1,000 universities and colleges worldwide officially committed to the UN's "Race to Zero" with the goal of net-zero carbon emissions by 2050 (UNEP, 2021). This goal requires universities to be supported by all entities; faculties, corporate offices, administration, staff and students (Button, 2009).

Before engaging in carbon dioxide emission reduction strategies, organizations must assess their current carbon emissions to consider options, impacts and costs (Riddell *et al.*, 2009). Carbon footprinting – assessing the carbon dioxide emissions of an organization and its supply chain – is gaining popularity as tools and standards are being developed to streamline the calculation process. The most popular standard that accounts for both direct and indirect GHG emissions is the GHG Protocol, which divides emissions into three scopes (1–3). Scope 1 accounts for direct emissions, such as combustion and process emissions; scope 2 accounts for those from the purchase of energy; and scope 3 accounts for all indirect upstream and downstream emissions embodied in the value chain (World Business Council for Sustainable Development and World Resources Institute, 2004). Gaining insight into an organization's complete carbon footprint is vital to identify emission sources and thus starting points for impactful reduction strategies.

Research into the carbon footprints of universities has revealed a diverse picture. Many higher education institutions (HEIs) voluntarily publish their carbon footprints (Udas *et al.*, 2018). However, comparing them is difficult because of a lacking standard for HEIs and the variety of calculation methodologies, boundaries, functional units, inventories and published emission factors (Valls-Val and Bovea, 2021; Helmers *et al.*, 2021). Especially scope 3 emissions are often only partially accounted for. Nevertheless, results show that scope 3 emissions, if comprehensively included, are higher than scopes 1 and 2. Therefore, investigating scope 3 emissions of universities is essential, as it unlocks an often unconsidered reduction potential. Hence, a standardized scope 3 approach considering all emission sources is important and called for (Robinson *et al.*, 2015). Robinson *et al.* (2018) suggest a carbon footprinting standard for HEI, proposing two footprints. One comprehensive scope 1–3 footprint for internal carbon management use and one scope 1–2 carbon footprint for external reporting. However, this impedes the publication of full-scale carbon footprints, which are often stated to be lacking.

Only very few universities present a carbon footprint also accounting for scope 3 emissions from university expenditures, for example, Yale University (Thurston and Eckelman, 2011), UC Berkeley (Doyle, 2012), De Montfort University (Ozawa-Meida *et al.*, 2013), Norwegian University of Technology and Science (Larsen *et al.*, 2013), Technical University of Madrid (School of Forestry Engineering) (Alvarez *et al.*, 2014) and University of Castilla-La Mancha (Gómez *et al.*, 2016). Emissions from expenditures account for a significant share in all studies, emphasizing the importance of including them in the carbon footprint of HEIs. However, here again, comparing those carbon footprints is difficult because of the variety of boundaries, methods used and unpublished emission factors.

This study investigates and quantifies the direct and indirect carbon emissions of the Delft University of Technology (TU Delft) in 2018, including emissions from procurement and related emission factors. The aim is to present the complete carbon footprint of the university to define starting points for reducing emissions, as the university aims to achieve CO_2 neutrality by 2030 (TU Delft, 2018b). Furthermore, the authors reflect critically on current calculation methods based on this study's analysis.

To that end, a process and extended input-output life cycle analysis (EIOA–LCA) was applied for the consumption-based carbon footprint calculations. Whenever possible, physical activity data were used. This was the case for scopes 1 and 2 emissions and business flights and commuting, for example. When physical activity data were not available, monetary activity data were used. For procurement and catering emissions, data based on economic input-output (EIO) and hybrid multi-region (HMR) methods were applied (Defra, 2014; Vringer *et al.*, 2010).

This study contributes to the literature on carbon footprinting by expanding the scope of analysis to include previously often neglected activities, such as procurement. This expansion has three implications. First, it could facilitate the comparison of the future carbon footprints of organizations. Second, it enables the identification of emission blind spots in organizational processes. Third, it calls again for developing HEI-specific carbon footprint guidelines.

2. The case of Delft University of Technology

2.1 The people and their campus

In 2018, TU Delft had 24,703 students and 5,421 full-time equivalent (FTE) employees. The number of students is expected to grow significantly in the years to come (28,000 students expected in 2026 [1]).

The university campus is connected to the Dutch city of Delft and covers an area of about 161 hectares. It has 73 buildings with a gross internal area of 612,000 m^2. The university has eight faculties: Aerospace Engineering; Applied Sciences; Architecture and the Built Environment; Civil Engineering and Geosciences; Electrical Engineering, Mathematics and Computer Science; Industrial Design Engineering; Mechanical, Maritime and Materials Engineering; and Technology, Policy and Management.

The technical state of a significant share of buildings is reasonable or moderate, with an aging process that has started locally or is already affecting constructions and installations. This can be linked to the construction years of the university's buildings, many dating to the 1960s and 1970s. The challenge for the coming years is, thus, the need to renovate the campus (Blom and van den Dobbelsteen, 2019).

TU Delft operates its own heating and electricity grids. The combined heat and power plant (CHP) supplies almost all the heat demand on campus, using natural gas-fired reciprocating engines (a small proportion comes from installed gas boilers). The university plans to drill a geothermal source to provide the campus with heat in 2022. Besides the share produced by the CHP, all electricity is bought from renewable sources (wind farms) in The Netherlands. Today, the installed capacity of solar photovoltaic (PV) panels on campus is about 1 MW (TU Delft, 2018a). The university's main characteristics in numbers are shown in Table 1. The university's consumption of electricity, natural gas, water, waste generation and travel data (business flights and commuting) is included in Table 2.

2.2 Sustainability strategy

The university stated its aim to become a climate-neutral and circular campus by 2030 in its strategic framework for 2018–2024: "Develop and execute a sustainability plan for a CO_2

neutral and circular campus in 2030." (TU Delft, 2018b, p. 45). The university has recently taken several strategic decisions concerning the sustainability of its operations following this framework. Moreover, in 2019, TU Delft defined its position on Climate Action, which is one of the UN's Sustainable Development Goals: "TU Delft will harness its innovative powers to support the world-wide transition to non-fossil energy, and adaptation of the living environment to the consequences of global warming." (TU Delft, 2019b) To do so, the university will use its "intellectual and innovative power for safeguarding the world population against the risks of climate change, by developing technologies and methods . . ." (TU Delft, 2019b).

The Executive Board took another step by officially supporting the "Climate Letter" in 2019, as did all other Dutch universities (TU Delft, 2019a; VSNU, 2019). In the letter, scientists called on universities to reduce their carbon emissions by adopting and implementing ambitious climate agendas. Goals and measures should include reducing energy consumption, cutting back on flights, promoting sustainable modes of commuting, disinvesting in the fossil fuel industry, supporting environment-friendly food options and reviewing educational offers concerning energy efficiency (Klimaatbrief Universiteiten, 2019).

In 2021, the vision, ambition and action plan called "Sustainable TU Delft" was delivered to the Executive Board, comprising a comprehensive analysis of the current status, a lookout to the future and steps to be taken to reach the sustainability ambitions of the university (van den Dobbelsteen and van Gameren, 2021). The report includes education, research, valorization and funding, community and operations. For climate neutrality, key performance indicators for the campus buildings include reducing the university's overall energy consumption by 50%, 50% on-campus generation of electricity and nearly 100% self-generation of heat on campus by 2030. Furthermore, ambitious targets for new buildings and renovations address circularity, heat and electricity consumption, electricity generation and carbon emissions in the building chain (Hänsch, 2020; Hänsch *et al.*, 2020).

3. Methods

3.1 Carbon accounting methods used

The emission scopes and sources were calculated according to the GHG Protocol of the World Business Council for Sustainable Development and World Resources Institute (2004). The choice of calculation method was influenced by data availability. When available, primary data in the form of physical activity and process data were used. This was the case for scopes 1 and 2 and for waste, business flights, water and commuting data (scope 3). To calculate procurement and catering emissions, we used a top-down spend-based method that considered the economic value of services and goods purchased by the university. These methods will be further explained in the remainder of this section.

Calculations for all emission sources followed the same pattern. First, activity or consumption data were collected. The data are presented in, for example, kWh used, km

Table 1. Main characteristics of Delft University of Technology in numbers

TU Delft 2018		
Campus area	ha	161
Gross internal area	m^2	612,000
Number of students		24,703
Number of staff	FTE	5,421
Spending	Euro	294,886,326

Table 2. Description of input data and emission factors of emission sources (physical activity data)

Scope	Emission source	Input data and assumptions	Emissions factors	Activity and unit [× 1,000]
Scope 1	Natural gas	Obtained from the university's Energy team and the TU Delft's Energy monitor website (TU Delft, 2018a). Data were divided into TU Delft's consumption and energy supply to third parties on campus	Well-to-wheel emission factors are used, including energy production and related processes until the energy carrier gets to the point of use and the energy use itself. Emission factors from Milieu Centraal *et al.* (2018), yearly published and updated for the Netherlands	9,271 m^3
Scope 2	Electricity	Obtained from the university's Energy team and the TU Delft's Energy monitor website (TU Delft, 2018a). Data were divided into TU Delft's own consumption and the supply of energy to third parties on campus	Well-to-wheel emission factors from Milieu Centraal *et al.* (2018). The emission factor for electricity purchased from a wind farm is LCA-based. The same applies to the generation of electricity by PV panels	53,644 kWh purchased
Scope 3	Business flights	Obtained from the university's travel agency	Emission factors comprise energy production and use and differ according to the flight distance: Regional flights (< 700 km), European flights (700–2,500 km) and Intercontinental flights (> 2,500 km). Moreover, a detour factor is included, considering that flights usually have to make detours before landing or because of weather conditions. Also, a radiative forcing factor of 2 is included, accounting for the climate effects of non-CO_2 GHGs at high altitudes. Emission factors from Milieu Centraal *et al.* (2018) and Otten *et al.* (2015)	33,333 passengerkm
Scope 3	Commuting by staff and students	According to an internal survey, 44% of TU Delft employees cycle to campus, 32% arrive by car, 17% take public transport and 5% use carpools, e-bikes, motorbikes, scooters or walk (van de Klugt *et al.*, 2018). In all, 40% of employees live in Delft. Those employees and those living up to 6 km from the campus are assumed to cycle or walk to	The given shares of transportation modes and the corresponding emission factors were applied to the traveled kilometers. Based on the Dutch average, emission factors for fossil-fuel cars include the share of different car types (petrol, diesel, LPG, electric and hybrids). Emission factors are well-to-wheel for all transportation modes and are taken from Milieu Centraal *et al.* (2018) and Stichting Stimular (2018)	Fossil fuel car: 16,946 vehiclekm Carpool: 830 passengerkm Motorcycle: 415 km Scooter: 415 km Train: 5,810 passengerkm Other public transport: 1,245 passengerkm

(*continued*)

Table 2.

Scope	Emission source	Input data and assumptions	Emissions factors	Activity and unit [× 1,000]
		work. In 2018, the average distance to campus was 14.5 km in a beeline, corrected by a factor of 1.2 to account for route detours (Blom and van den Dobbelsteen, 2019). It is estimated that 2.3% of students arrive at the campus by car; the rest cycle or take a train. The average distance to campus for students was 16 km in a beeline, also corrected by a factor of 1.2. Blom and van den Dobbelsteen (2019) assume that employees travel to the campus 44 weeks per year, making ten trips a week; students travel to campus 42 weeks a year, making eight trips per week		Bike: 18,261 passengerkm Walk: 830 passengerkm
Scope 3	Energy supply to third parties on campus	See Natural gas and Electricity	See Natural gas and Electricity	Natural gas: 1,873 m^3 Electricity: 14,669 kWh
Scope 3	Waste	Obtained from the Facility Management Department. Furthermore, the waste handling company, which includes avoided CO_2 emission calculations in its annual reports for TU Delft, was approached. In all, 14 waste streams are collected at TU Delft[2]	Emission factors differ for each waste stream and its further processing: recycling, combustion or landfill. After considering and comparing the waste company's emission factors with those in the literature (Turner *et al.*, 2015), the authors decided to use the former, as they matched exactly the 14 waste streams [3] and their specific processing and, thus, increase calculation precision. Emission factors include emissions from logistics and transportation, sorting, processing and avoided production for recycling. For combustion, emission factors include emissions from logistics and transportation, processing and avoided energy/products	2,789 t
Scope 3	Water	Obtained from the Energy team and through the Energy monitor website	The energy input for the sewage plant and the distribution network are included in the emission factor from Pulselli *et al.* (2019)	167 m^3

traveled, kg generated or euros spent. Second, specific, matching emission factors were derived from the literature to convert the data into GHG emissions. Emission factors indicate the amount of GHG emitted per data unit, for example, per liter of fuel or kWh consumed. They are presented in kilograms of CO_2 equivalents (kgCO_2eq) per unit. Then, the activity or consumption data were multiplied by the relevant emission factors to obtain the total CO_2eq emitted per emission source, which add up to the total carbon footprint (Figure 1).

Emissions can be calculated in two ways. *Process analysis* maps all physical flows of a particular product throughout its life cycle. This enables the precise calculation of environmental impacts. However, obtaining the necessary data can be challenging and time-consuming, making the method expensive. In contrast to process analysis, *economic input-output (EIO) models* describe an economy by mapping trades between economic sectors. All deliveries between producer, trader and consumer are shown in a matrix. These matrices facilitate quickly calculating a product's or service's environmental impacts along the whole supply chain in one specific sector. EIO tables, generally at the country level, allow for a fast overview; however, they are subject to a high level of aggregation (Kennelly *et al.*, 2019; Thurston and Eckelman, 2011; Vringer *et al.*, 2010). Hybrid models have been developed to combine the advantages of both models while avoiding their disadvantages. In those models, a

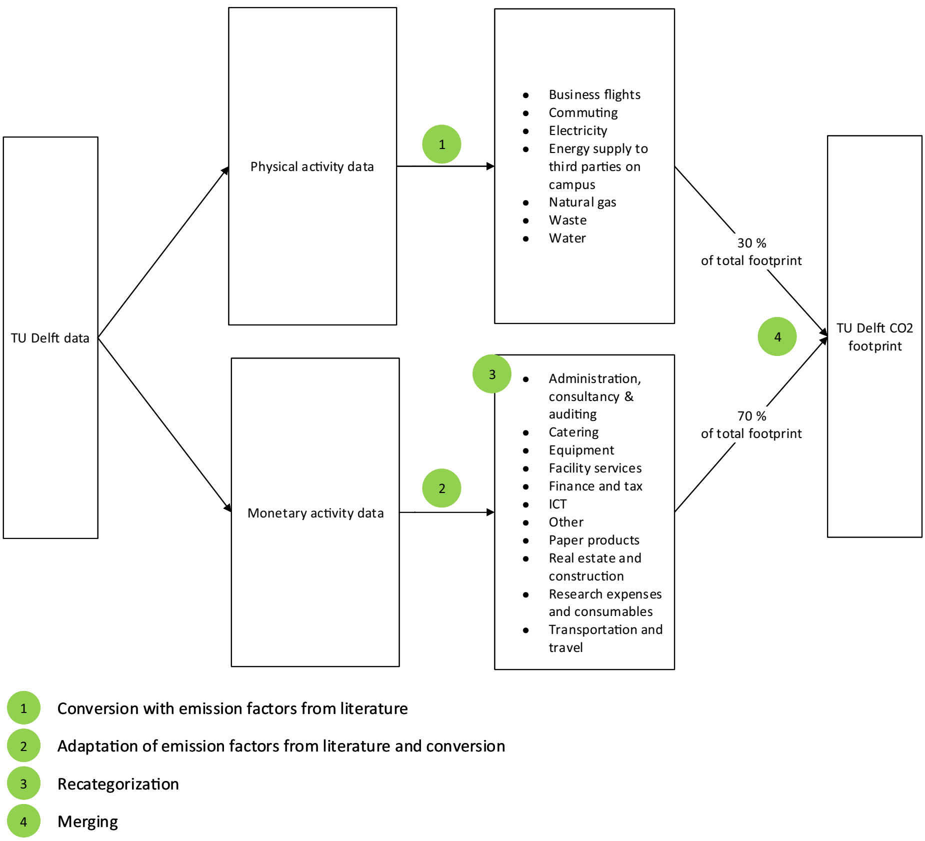

Figure 1.
Overview of the calculation process

process analysis is used for the primary process of a product's life cycle; for secondary processes, an input-output analysis is used (Vringer *et al.*, 2010).

Primary data from various university departments for the year 2018 were collected: Electricity, natural gas and water consumption data were provided by the Campus and Real Estate Department, flight data by the Human Resources Department, waste data by the Facility Management Department and commuting data by the Education and Student Affairs and the Human Resources Departments. All are specific activity or process data derived from bills, meter readings, registrations or purchase lists. For procurement and on-campus expenditures on food, financial data were obtained from the Finance Department and the university's caterer. In this case, emissions are expressed per economic value spent, thus kgCO_2/€. Emission factors were derived from literature based on EIO models (Defra, 2014) and a HMR model (Vringer *et al.*, 2010).

3.2 Emission sources

According to the GHG protocol, all university-relevant emission sources were included in the carbon footprint calculation process to obtain a comprehensive overview of the carbon emissions. In general, no scopes or emission sources were excluded. However, relevant emission sources for the university (e.g. canteens and restaurants on campus) were added to scope 3, whereas irrelevant ones (e.g. sold products, their use and end-of-life treatment) were disregarded. Figure 1 shows an overview of the calculation process and the emission sources considered in this study.

3.3 Data description of emission sources calculated with a process approach: Physical activity data and emission factors

Table 2 explains the origin of used input data and assumptions around them per emission source. Emission factors are described, and physical activity data from TU Delft for 2018 are shown. A description of the monetary-based input data and the process of adapting and matching emission factors to procurement-based emission categories is explained in more detail later.

3.4 Data description of emission sources calculated with an economic input-output approach: Monetary activity data and emission factors

3.4.1 Emission factor adaptation and matching process The Finance Department provided monetary-based procurement data for 2018, comprising all goods and services procured by the university (ca. 1,400 entry points). The spend data were presented in three layers. *Category level 1* was divided into eight aggregated categories (i.e. person-related matter, office and operational means, transportation and buildings and building-related installations and services). *Category level 2* provided more specific accounts. Person-related matters, for example, contained ten sub-categories on the second level. Examples are: Study, coaching, training and education; Business trips, external accommodation, catering; and Recruitment, selection and outplacement. The most detailed level was *Level 3, "Description."* The datasheet comprised 128 description titles at this level.

Emission factors were obtained from Vringer *et al.* (2010) and Defra (2014). Emission factors from Vringer *et al.* are based on a hybrid method model for households in The Netherlands, whereas Defra used an input-output model for the UK. As both sources use historic (and different) base years, the emission factors were adjusted with a correction factor based on the GHG/GDP ratio for the European Union (EU 28) (European Environment Agency, 2020; Eurostat, 2022). This ratio was chosen to account for the decrease in the carbon emissions of products and services over time and inflation. Trading balances of the European Union show that most products and services were traded within the Union (Eurostat, 2021). The calculated GHG/GDP ratio resulted in static correction factors for the year 2018: 0.57 for the emission factors from Vringer *et al.* (2010) and 0.81 for emission factors from Defra (2014).

The most detailed level (Level 3, Description) was considered to match specific emission factors to the spending (for the assigned emission factors see the Appendix). Matching was done in four ways (Figure 2):

(1) If there was a direct match between the description item and an emission factor, then that emission factor was used.

(2) If the description item matched different emission factors, then the average of those was used.

(3) If no matching emission factors were available for an item, then the average of an emission factor group was used, for example, an average emission factor of all hardware emission factors or service-related emission factors.

(4) If none of the above-mentioned ways was possible, then the average of all used emission factors was assigned to the remaining items.

3.4.2 Recategorization process of bookkeeping categories to carbon footprint categories The description items were recategorized from bookkeeping categories to the carbon footprint emission sources explained in Table 3 – reducing the number from 128 to 10. Several description items were disregarded. Cost accounting items purely for accounting and

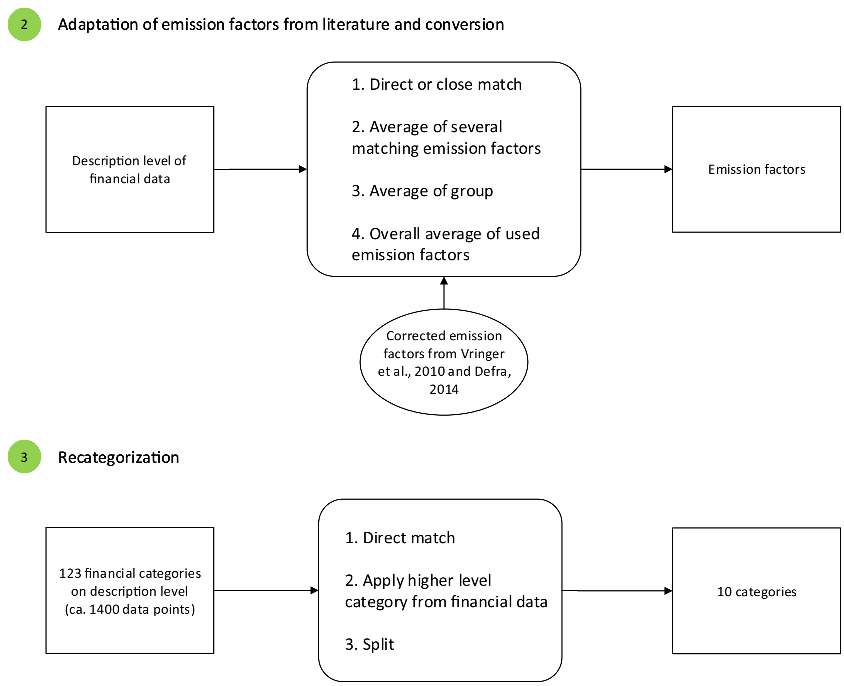

Figure 2. Matching of emission factors and recategorization of purchased goods and services, relating to Steps 2 and 3 of Figure 1

Table 3.
Monetary-based carbon footprint emission sources

Emission source	Activity data
Administration, consultancy and auditing	Purchases and spending related to management costs, personnel, consultancy and auditing costs
Catering	Spend data from canteens and restaurants on campus
Equipment	Purchases and spending related to scientific and other equipment, its maintenance and the renting of equipment
Facility services	Purchases and spending related to office supplies, cleaning, furniture, its maintenance and renting, faculty catering and disposal of environmentally unfriendly waste
Finance and tax	Banking costs, subsidies, tax expenses and charges
ICT	Purchases of hardware and software and audiovisual equipment, telephone costs, renting and maintenance of hardware and software
Other	Other indeterminable spending
Paper products	Purchases and spending related to books and copying and printing costs
Real estate and construction	Purchases and spending related to buildings and the campus, technical installations and maintenance, rent of buildings, moving costs, replacements, construction and general real estate services
Research expenses and consumables	Purchases and spending related to congresses and symposia, intellectual property, dissertations and research consumables like gasses and chemicals
Transportation and travel	Spending related to travel and accommodation costs for employees, applicants and third parties, rent and maintenance of transportation means. Employees' flights and staff's and students' commuting are excluded and calculated separately (Table 2)

bookkeeping purposes were excluded, as no action and, thus, no additional carbon emissions result from them. This was the case for depreciation items, received advance payments and scholarships, for example. Items calculated separately based on physical activity data (electricity, natural gas, flights and water) were also deducted. Moreover, items considered the same for TU Delft and a third party (e.g. cooperation and collaboration with universities and guest lecturers) were disregarded to avoid the double-counting of emissions. Thus, it was assumed that TU Delft receives as many guest teachers and lecturers as it sends. Emissions are, therefore, already included in scopes 1 and 2 footprints.

Recategorization was done in three ways (Figure 2). In general, if one of the merged items within a description (originating from various category levels 1 and 2) contributed more than half of the financial sum of that description's total, then the totality was assigned on that basis to one of the emission sources (Table 3):

(1) The description items could be directly matched with a specific carbon footprint emission source.

(2) Description items were traced back to their original category 2 level to assign them to the carbon footprint emission source.

(3) When there was no single significant contributor and too many category 2 level relations, items were assigned individually to a carbon footprint emission source.

Catering spend data from on-campus canteens and restaurants were obtained from the catering company and internally, comprising a list of sold food and beverage items. Emission factors are based on Vringer *et al.* (2010), corrected as described above. Meal ingredients were approximated to match the emission factors, as received data were based on meals sold, not ingredients.

4. Results

4.1 Results obtained

The calculated consumption-based carbon footprint of TU Delft in 2018 is 106,000 tCO_2eq. Divided into the scopes of the GHG protocol, scopes 1 and 2 together account for 17% of emissions, while scope 3 accounts for 83% (see also the Appendix for a comprehensive table with the detailed calculations of all emission sources). This distribution is similar to results from other organizations and universities that included procured goods and services in their carbon footprint calculations, which again emphasizes the importance of including scope 3 in an organization's carbon emission reduction strategy and implementing practical reduction measures within that scope.

Figure 3 shows the breakdown of TU Delft's carbon footprint by scope and by emission source. Scope 3 emissions were divided into emissions influenced mainly by the university's operation (Real estate and construction; Equipment; ICT; Facility services; Research expenses and consumables; Administration, Consultancy and auditing; Transportation and travel; Energy supply to third parties on campus; Other; Paper products; Finance and tax; Water; and Waste) and those mainly influenced by its staff and students (Business flights; Catering; and Commuting). The vast majority of the total carbon emissions are scope 3 operation related (69%), while only a small part is related to staff and students (14%).

Real estate and construction is the most significant emitter (18%), followed by *Natural gas* (17%), *Equipment* (13%), ICT (8%), *Facility services* (8%), *Business flights* (5%), *Catering*

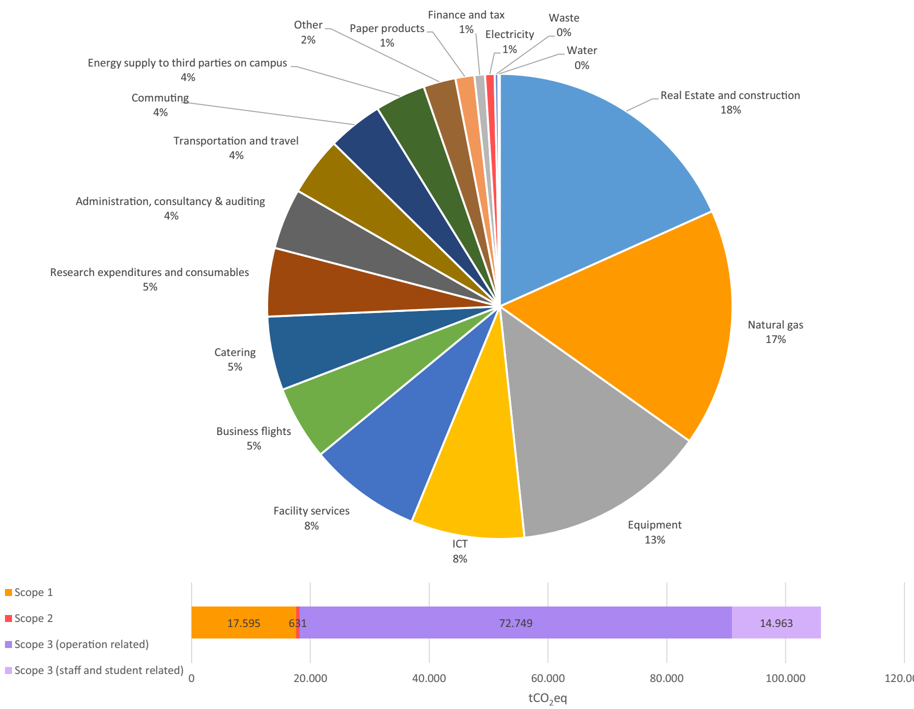

Figure 3. Total carbon emissions of Delft University of Technology by emission source and by scope (Scope 1: Natural gas and electricity generation PV; Scope 2: Purchased electricity; and Scope 3: rest of emission sources)

(5%) and *Research expenses and consumables* (5%). The "big five" emission sources are responsible for 64% of total carbon emissions. The eight emission sources contributing 5% or more account for almost 80% of the total footprint. The remaining ten account for only 21%. This highlights the need to address the most significant emission sources specifically. At the same time, the authors see the potential to significantly reduce the carbon footprint by focusing reduction strategies on the limited number of major emitters.

4.2 Analysis of results

Some emission sources showing specificities concerning input data, their content, reduction plans or potentials are discussed in more detail in this section, as a framework for HEIs is missing.

Real estate and construction, the most significant emission source (18%), includes many service costs with relatively low emission factors, such as guarding buildings, rent and leasehold and daily maintenance. Although no major construction was carried out in 2018, the total emissions from the bookkeeping item "projects" account for almost 90% of the total Real estate and construction emissions. Attempts to investigate what kind of projects this entails were challenging. So far, the authors have been unable to discover the specific content as would be desirable.

Regarding *Natural gas* emissions (17%), TU Delft has decided to invest in a sustainable heat source, an on-campus geothermal well (TU Delft, 2022). Consequently, natural gas emissions will drop. However, with the geothermal energy, formation gas will be extracted from the earth, which will count toward the carbon footprint. To provide a CO_2 neutral campus, the university must develop plans to deal with this issue.

Equipment is the third most important carbon emitter (13%). It includes emissions from purchasing, maintaining and renting equipment and technical items. About 75% of the calculated emissions originate from the bookkeeping category "equipment." As with "projects" in *Real estate and construction*, the exact content of the description item "equipment" is not always entirely transparent.

Business flights were responsible for 5% of the university's emissions. In all, 70% of flights were long-distance (> 2,500 km). Short-distance flights (< 700 km) contributed only 10% of emissions. This means that a strict university regulation to justify the need for a flight will be a more effective reduction tool than the prohibition of business flights within a range of 700 km, for example. Schmidt (2022) discusses university's air travel policies in detail.

Commuting by employees and students was another relatively small emission source (4%). The Dutch are known for being a biking nation, which benefits the commuting footprint. Thus, the most reduction potential is seen in the 32% of employees who currently come to the campus by car. TU Delft has set a 10% reduction target for car commuting by 2025, compared to the base year of 2018 (van de Klugt *et al.*, 2018).

Electricity accounts for only 1% of TU Delft's carbon emissions, including life cycle emissions from installed PV and purchased wind energy; thus, emissions from different scopes are combined to show the complete picture. If the university had bought its electricity from the grid, then it would have resulted in 34,139 tCO_2eq, almost double the biggest emission source. As the input for the CHP to generate electricity is natural gas, originating emissions are accounted for in *Natural gas*.

Surprisingly, although the authors expected the university to be a "paper organization" with a considerable amount of paper being bought and many books being produced and printed, emissions from *Paper products* play a negligible role in the overall footprint (1%).

Finance and tax (1%), *Waste* (0%) and *Water* (0%) are the emission sources with the least impact on the total footprint. However, this does not suggest that measures to reduce waste or increase waste sorting have no impact. Waste recycling can play a vital role in achieving carbon neutrality by closing material loops and avoiding embodied emissions. Additionally, waste should be investigated in relation to procured goods.

4.3 Uncertainty analysis

Knowing TU Delft's carbon hotspots enables the university to develop reduction strategies that will have the biggest possible impact on the total footprint. However, the results are still at a high level of abstraction and subject to uncertainty.

The uncertainty of results is substantial for some emission sources – especially in the case of emissions calculated on a spend basis, which account for the most significant part of the footprint (70%). Consequently, variations in those calculations will have a significant impact.

The uncertainty of the input data and that of the used emission factors was considered to assess the results' uncertainty level, according to the IPCC and GHG Protocol guidelines (IPCC, 2000). Uncertainties were estimated by emission source, and the IPCC error propagation equation was used to evaluate their impact on the results, as described in the following paragraphs.

Combined uncertainty levels were estimated to be high for emission sources calculated on a monetary basis, for Business flights and Commuting of staff and students (± 30% for most of them). For all emission sources calculated on a monetary basis, *activity data uncertainty* was considered 10% because of the recategorizations of bookkeeping categories and non-transparency of specific contents. Moreover, in 2018, the financial department's accounting system was renewed, resulting in some inconsistencies in bookkeeping categories. An activity data uncertainty of 30% was considered for Catering, Business flights and Commuting. *Emission factor uncertainty* was estimated to be 30% because of the correction of emission factors and their combination from different sources, often based on households. For Business flights, emission factor uncertainty was estimated at 20% because of detours, non-European departure locations, emissions in great heights and flight lengths. For Commuting, 10% were estimated.

Waste (± 14%), Electricity (± 10%) and Energy supply to third parties on campus (± 10%) are estimated to have moderate to low combined uncertainty levels from activity data and emission factor uncertainty. Natural gas and water are considered to have very low combined uncertainty levels (both ± 1%).

The authors estimate the combined uncertainty levels of this study to be moderate. Repetition of the calculation with precisely the same input data would lead to another calculated amount of carbon emissions because of different data allocation and (sub-) categorization; however, the deviation is estimated to be about 10%. Moreover, a significant shift in the order of contributing emission sources would not be expected. A previous study estimating TU Delft's carbon emissions from procurement in 2015 came to about the same results (Mauro, 2017). Additionally, the result is in line with the calculations of other universities. Despite the uncertainty, the result is, thus, considered robust.

Nevertheless, the authors see a need for better-investigated input data and more specific emission factors, especially for procurement. TU Delft has started submetering buildings to investigate electricity consumption patterns inside buildings and a project to better register suppliers and their environmental emissions. In addition, a framework defining boundaries for HEIs' scope 3 calculations (including the scope of the emission source itself) is needed to facilitate comparisons and benchmarking of carbon footprints in the sector.

5. Discussion

5.1 Comparison of results with other universities

The most common comparison ratios relate the carbon footprint to the number of students and staff, the gross internal area of campus buildings and the spending (Helmers *et al.*, 2021; Valls-Val and Bovea, 2021). Compared to previous studies of universities, which included procurement emissions in their calculations, TU Delft's emission ratios generally align. However, there are some exceptions, as described beneath. Table 4 compares the carbon emissions of the mentioned studies per gross internal area, per person (staff and students) and euro spent.

TU Delft's footprint is 0.17 tCO_2eq/m^2, 19.54 tCO_2eq/FTE, 4.29 tCO_2eq/student and, thus, 3.52 tCO_2eq/capita and 0.44 $kgCO_2eq$/€ spent. Those numbers particularly align with the case of the Norwegian University of Technology and Science (Larsen *et al.*, 2013). Previous studies have shown that social science faculties have a smaller footprint than their technical counterparts (Kulkarni, 2019; Larsen *et al.*, 2013). Furthermore, Klein-Banai and Theis (2013) showed that laboratory spaces of research-intensive institutions affect the carbon footprint manifold more than offices, lecture halls and classrooms. This might explain the emission rates of both universities. However, Helmers *et al.*'s (2021) comparisons do not confirm this. Noteworthy is furthermore the high result per euro spent by Alvarez *et al.* (2014), for which they reason in their study.

In Helmers *et al.*'s (2021) rankings, which did not include procurement emissions, TU Delft would be situated in the top ten of the least emitting universities in all three ratios. Procurement emissions from the TU Delft's carbon footprint were excluded for this comparison. Ranked by emission per capita, with 1.1 tCO_2eq/capita, TU Delft would come in the eighth or ninth best place [2] (meaning least emitting) from then 23 HEIs. However, it would come in the second-best place with 52 $kgCO_2eq/m^2$. Likewise, it would come in the second-best place relating emissions to university expenditure (without salaries and purchasing power corrected), namely, 90 $kgCO_2eq$/1,000$. The good rankings might be explained by the fact that TU Delft exclusively buys green electricity (to which life cycle emissions were assigned), which reduces the carbon footprint significantly compared to other universities.

5.2 Assessment of calculation method

Calculating scope 3 emissions calls for the making of qualified boundary choices. It was chosen to integrate all emission sources to obtain a complete picture of the footprint, knowing that some uncertainty levels were elevated. Comprehensiveness versus accuracy is a debatable issue. Another point is boundary setting, that is, what to include in scope 3 emission sources without adding the emissions of whole supply chains and personal choices of employees and students to the university's account.

Table 4. Comparison of carbon emissions per gross internal area, per person and per euro spent by different universities

University and country	tCO_2eq/m^2	tCO_2eq/person	$kgCO_2eq$/€	Authors
De Montfort University, GB	0.40	2.00	0.34	Ozawa-Meida *et al.* (2013)
Norwegian University of Technology and Science, NO	0.13	3.61	0.38	Larsen *et al.* (2013)
Technical University of Delft, NL	0.17	3.52	0.44	
Technical University of Madrid, School of Forestry Engineering, ES	0.07	1.55	2.81	Alvarez *et al.* (2014)

For example, many people working and studying at TU Delft come from abroad. Whereas business trips made on behalf of the university were included, trips to the home countries of staff and students were not. They were considered to be accounted for in personal carbon footprints. However, commuting was included in the university's carbon footprint, so where people lived did impact the footprint. Another example is calculated catering emissions. Food and beverages sold on campus were considered. It is debatable whether food brought from home should also be included in the footprint, as people must eat to work. As these boundaries impact the results, the examples show that it is not enough only to define which emission sources to include or exclude. It is essential to provide guidelines in a HEI framework defining where to draw boundaries within those emission sources to assure comparability, also stated by Ozawa-Meida *et al.* (2013) and Valls-Val and Bovea (2021).

Regarding the calculation method, estimating the footprint based on spending might result in wrong conclusions for several reasons. Sustainable suppliers, for example, might charge more. Choosing such a supplier will result in higher calculated emissions when in reality, emissions might be reduced (Larsen *et al.*, 2013). Also, economy-of-scale-effects, which might be substantial for a university, are not included (Larsen *et al.*, 2013; Alvarez *et al.*, 2014). In addition, emission reductions occurring over life cycles will not appear in future spend-based carbon footprints. This is especially the case for the construction and renovation of buildings. Next, large investments in a specific year affect and distort the carbon footprint of that year, as they are not spread over the lifetime. Thus, vast expenditures (like renovations or the purchase of large laboratory equipment, for example) will significantly increase calculated carbon emissions when in reality they might reduce scopes 1 and 2 emissions in the future (Ozawa-Meida *et al.*, 2013). However, allocating historic emissions over the years may not solve this problem, as it distorts the momentary picture and prevents perspectives for immediate actions. Therefore, future research is called to investigate and develop a method to deal with extensive investments to level out underestimating and overestimating carbon emissions.

Likewise, spend-based emission factors could result in overestimating or underestimating carbon emissions. For example, Vringer *et al.* (2010) based their emission factors on Dutch households. Using them for an institution like a university might distort the results because of a scale-up that the authors neither intended nor included in their calculations. Nevertheless, they are the most detailed and specific to the Dutch system and culture at the moment.

Concise calculation of procurement-related emission sources involves specifying and investigating each one in depth. This makes the calculation process time-consuming. Moreover, various people's commitment in different departments is needed to thoroughly analyze and interpret the financial data, its layers and categories. The authors reached a point where they could not analyze the specific content of financial categories any further. Container terms like "projects," "equipment" and "technical items" did not convey what was included and led, even after consultations, to investigative dead ends. As other case studies also stated the necessity to interpret spending categories and the need for a more detailed uniform category breakdown (Ozawa-Meida *et al.*, 2013; Alvarez *et al.*, 2014), the general suitability of the calculation method used is questioned by the authors.

Calculating on a spending base depends on the accounting system's consistency in the long term. A change of systems or categorization will also affect the footprint calculations. Therefore, accounting systems should not be the base for monitoring carbon footprints over time. Ideally, procured goods' physical activity data should be available, that is, material data stored in a material database. This aligns with the aim of a circular campus for which the university needs to know about its material stocks, inflows and outflows. Consequently, the carbon footprint could be calculated on a material base instead of a spending base, leading to more precision.

Another risk accompanying the chosen approach is the double-counting of avoided CO_2eq. First, avoided carbon emissions are included in the emission factor of waste streams. Second, avoided CO_2eq might be included in emission factors for products with a recycled material content. This would result in double-counting of the same avoided emissions. Therefore, organizations need to consider where avoided emissions are included to prevent whitewashing in upstream or downstream scope 3 calculations.

All other studies, which included procurement emissions, call for adjustments in the calculation methods. These include: Hybridization also for scope 3 emission sources (thus using a process approach); the development of a set of indicators for the most significant contributors calculated on an EIO basis (Larsen *et al.*, 2013); a common reporting framework for HEI with defined organizational boundaries and a uniform breakdown of procurement categories, considering product carbon footprints of goods and services and LCAs of waste streams and recycled materials; monitoring embodied emissions and refurbishments (Ozawa-Meida *et al.*, 2013); and the consideration of the geographic location, more recent IO data and economies of scale (Alvarez *et al.*, 2014). Nevertheless, all consider their approach practical and applicable for other HEIs, which the authors of this study question for the reasons mentioned above.

6. Conclusion

The calculated direct and indirect carbon emissions of TU Delft were 106 ktCO_2eq in 2018. Of the total footprint, 83% were scope 3 emissions, highlighting the need to consider organizations' upstream and downstream activities to achieve carbon neutrality. This 20/80 distribution across the three scopes was also seen in other cases that included emissions from procurement. The five most significant emission sources (Real estate and construction, Natural gas, Equipment, ICT and Facility services) were responsible for 64% of the total carbon footprint. Efficient carbon emission-reducing strategies can, therefore, focus on these hotspots.

The authors see several limitations in this study. First, as in other studies, activity data lacked accuracy or had a high aggregation level. Second, the latter was also true for the emission factors from EIO and hybrid method models. Therefore, they cannot account for product differences, production processes and recycled material content. The elevated uncertainty levels of some emission sources and the limitations of the calculation process imply several avenues for future research. The authors call to discuss and develop calculation methods that improve results' accuracy and precision. Those methods should clarify emission source boundaries and consider life cycle carbon emissions and reductions.

This study adds value by reviving the discussion about better-suited calculation approaches, including issues related to spend-based calculation methods; for example, the difference between calculated and actual emissions for (eventually) pricier sustainable products or the increase of the footprint because of substantial investments, which however might lead to emission reductions in the long term.

Real progress regarding these issues only seems possible when suppliers make their product's carbon footprint or material data available. Hence, calculating scope 3 emissions on a material or physical activity data basis would be possible, enabling more precise indirect carbon footprint calculations. Universities can then take up their role model function by including scope 3 emissions in their climate neutrality goals and lead the way in their realization to mitigate climate change.

Notes

1. The impact of the COVID-19 pandemic on student growth numbers is not considered here.
2. Because of the same ratio of three universities, the exact place could not be defined.
3. The 14 waste streams are: residual waste; tires/rubber; construction and demolition waste; electric(al) waste; foil/plastics; hazardous waste; organic waste; glass; wood; coffee cups; paper and cardboard; rubble; swill; and confidential paper.

References

Alvarez, S., Blanquer, M. and Rubio, A. (2014), "Carbon footprint using the compound method based on financial accounts, the case of the school of forestry engineering, technical university of Madrid", *Journal of Cleaner Production*, Vol. 66, pp. 224-232.

Blom, T. and van den Dobbelsteen, A. (2019), "CO2-roadmap TU Delft", available at: https://d2k0ddhflgrk1i.cloudfront.net/Websections/Sustainability/CO2-roadmap%20TU%20Delft.pdf (accessed 11 October 2022).

Botero, L., Bossert, M., Eicker, U., Cremers, J., Palla, N. and Schoch, C. (2017), "A Real-World lab approach to the carbon neutral campus transition: a case study", in Leal Filho, W., Azeiteiro, U., Alves, F. and Molthan-Hill, P. (Eds), *Handbook of Theory and Practice of Sustainable Development in Higher Education. Volume 4, World Sustainability Series, 2199-7373*, Vol92, Springer, Cham, Switzerland, pp. 73-88.

Button, C.E. (2009), "Towards carbon neutrality and environmental sustainability at CCSU", *International Journal of Sustainability in Higher Education*, Vol. 10 No. 3, pp. 279-286.

Defra (2014), "Table 13 - Indirect emissions from the supply chain", available at: www.gov.uk/government/statistics/uks-carbon-footprint (accessed 11 October 2022).

Doyle, K. (2012), "Converting university spending to greenhouse gas emissions: a supply chain carbon footprint analysis of UC Berkeley", available at: https://sustainability.berkeley.edu/sites/default/files/DoyleK_Thesis_UCB2009SupplyChainCarbonFootprint.pdf (accessed 11 October 2022).

European Commission (2019), "The European Green Deal: COM(2019) 640 final", available at: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF (accessed 11 October 2022).

European Environment Agency (2020), "EEA greenhouse gases - data viewer", available at: www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (accessed 11 October 2022).

Eurostat (2021), "International trade in goods, the three largest global players for international trade: EU, China and the USA", available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/International_trade_in_goods#The_three_largest_global_players_for_international_trade:_EU.2C_China_and_the_USA (accessed 11 October 2022).

Eurostat (2022), "GDP and main components (output, expenditure and income)", available at: https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en (accessed 11 October 2022).

Gómez, N., Cadarso, M.-Á. and Monsalve, F. (2016), "Carbon footprint of a university in a multiregional model: the case of the university of Castilla-La Mancha", *Journal of Cleaner Production*, Vol. 138, pp. 119-130.

Government of the Netherlands (2019), "Climate agreement", available at: www.government.nl/documents/reports/2019/06/28/climate-agreement (accessed 11 October 2022).

Hänsch, M. (2020), "KPI's en criteria: Verduurzaaming campus TU Delft – CRE", Delft.

Hänsch, M., Nijs, G., de, Redouani, S. and Herth, A. (2020), "Notitie verduurzaming campus", Delft.

Helmers, E., Chang, C.C. and Dauwels, J. (2021), "Carbon footprinting of universities worldwide: Part I—objective comparison by standardized metrics", *Environmental Sciences Europe*, Vol. 33 No. 1.

IPCC (2000), "IPCC good practice guidance and uncertainty management in national greenhouse gas inventories: Chapter 6 Quantifying uncertainties in practice", available at: www.ipcc.ch/publication/good-practice-guidance-and-uncertainty-management-in-national-greenhouse-gas-inventories/ (accessed 11 October 2022).

IPCC (2018), "Summary for policymakers", in Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor and T. Waterfield (Eds), *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, IPCC, Geneva.

Jain, S., Agarwal, A., Jani, V., Singhal, S., Sharma, P. and Jalan, R. (2017), "Assessment of carbon neutrality and sustainability in educational campuses (CaNSEC): a general framework", *Ecological Indicators*, Vol. 76, pp. 131-143.

Kennelly, C., Berners-Lee, M. and Hewitt, C.N. (2019), "Hybrid life-cycle assessment for robust, best-practice carbon accounting", *Journal of Cleaner Production*, Vol. 208, pp. 35-43.

Klein-Banai, C. and Theis, T.L. (2013), "Quantitative analysis of factors affecting greenhouse gas emissions at institutions of higher education", *Journal of Cleaner Production*, Vol. 48, pp. 29-38.

Klimaatbrief Universiteiten (2019), "Climate letter. Klimaatbrief universiteiten – voor een ambitieus klimaatbeleid op de universiteit", available at: https://klimaatbriefuniversiteiten.nl/open-letter-to-our-universities/ (accessed 11 October 2022).

Kulkarni, S.D. (2019), "A bottom up approach to evaluate the carbon footprints of a higher educational institute in India for sustainable existence", *Journal of Cleaner Production*, Vol. 231, pp. 633-641.

Larsen, H.N., Pettersen, J., Solli, C. and Hertwich, E.G. (2013), "Investigating the carbon footprint of a University - The case of NTNU", *Journal of Cleaner Production*, Vol. 48, pp. 39-47.

Mauro, D.D. (2017), "Estimating indirect GHG emissions of university procurement: TU Delft scope 3 footprint", Delft.

Milieu Centraal, Stichting Stimular, Connekt, SKAO and Ministerie van Economische Zaken en Klimaat (2018), "co2emissiefactoren 2018", available at: www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf (accessed 11 October 2022).

Otten, M., Hoen, M., t. and den Boer, E. (2015), "STREAM personenvervoer 2014: studie naar transport emissies van alle modaliteiten emissiekentallen 2011", available at: https://ce.nl/wp-content/uploads/2021/03/CE_Delft_4787_STREAM_personenvervoer_2014_1.1_DEF.pdf (accessed 11 October 2022).

Ozawa-Meida, L., Brockway, P., Letten, K., Davies, J. and Fleming, P. (2013), "Measuring carbon performance in a UK university through a consumption-based carbon footprint: De Montfort University case study", *Journal of Cleaner Production*, Vol. 56, pp. 185-198.

Pulselli, R.M., Marchi, M., Neri, E., Marchettini, N. and Bastianoni, S. (2019), "Carbon accounting framework for decarbonisation of European city neighbourhoods", *Journal of Cleaner Production*, Vol. 208, pp. 850-868.

Riddell, W., Bhatia, K.K., Parisi, M., Foote, J. and Imperatore, J. (2009), "Assessing carbon dioxide emissions from energy use at a university", *International Journal of Sustainability in Higher Education*, Vol. 10 No. 3, pp. 266-278.

Robinson, O., Kemp, S. and Williams, I. (2015), "Carbon management at universities: a reality check", *Journal of Cleaner Production*, Vol. 106, pp. 109-118.

Robinson, O.J., Tewkesbury, A., Kemp, S. and Williams, I.D. (2018), "Towards a universal carbon footprint standard: a case study of carbon management at universities", *Journal of Cleaner Production*, Vol. 172, pp. 4435-4455.

Schmidt, A. (2022), “University air travel and greenhouse gas mitigation: an analysis of higher education climate policies”, *International Journal of Sustainability in Higher Education*, Vol. 23 No. 6, pp. 1426-1442.

Stichting Stimular (2018), “Actuele CO2-parameters – 2018, milieubarometer”, available at: www.milieubarometer.nl/CO2-footprints/co2-footprint/actuele-co2-parameters-actuele-co2-parameters-2018-jaar/ (accessed 11 October 2022).

Thurston, M. and Eckelman, M.J. (2011), “Assessing greenhouse gas emissions from university purchases”, *International Journal of Sustainability in Higher Education*, Vol. 12 No. 3, pp. 225-235.

TU Delft (2018a), “Energy monitoring on campus”, available at: www.tudelft.nl/en/sustainability/operations/energy-monitoring-on-campus (accessed 11 October 2022).

TU Delft (2018b), “Impact for a better society: TU Delft strategic framework 2018-2024”, available at: https://d2k0ddhflgrk1i.cloudfront.net/TUDelft/Over_TU_Delft/Strategie/Towards%20a%20new%20strategy/TU%20Delft%20Strategic%20Framework%202018-2024%20%28EN%29.pdf (accessed 9 June 2022).

TU Delft (2019a), “College van bestuur TU Delft steunt klimaatbrief universiteiten”, available at: www.tudelft.nl/2019/tu-delft/college-van-bestuur-tu-delft-steunt-klimaatbrief-universiteiten/ (accessed 11 October 2022).

TU Delft (2019b), “TU Delft position on climate action”, available at: www.tudelft.nl/en/tu-delft-climate-institute/tu-delft-position-on-climate-action/ (accessed 11 October 2022).

TU Delft (2022), “A geothermal research well on TU Delft’s premises”, available at: www.tudelft.nl/en/ceg/research/stories-of-science/a-geothermal-research-well-on-tu-delfts-premises (accessed 11 October 2022).

Turner, D.A., Williams, I. and Kemp, S. (2015), “Greenhouse gas emission factors for recycling of source-segregated waste materials”, *Resources, Conservation and Recycling*, Vol. 105, pp. 186-197.

Udas, E., Wölk, M. and Wilmking, M. (2018), “The “carbon-neutral university” – a study from Germany”, *International Journal of Sustainability in Higher Education*, Vol. 19 No. 1, pp. 130-145.

UNEP (2015), “Climate commitments of subnational actors and business: a quantitative assessment of their emission reduction impact”, Nairobi, available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/9753/-Climate_commitments_of_subnational_actors_and_business_A_quantitative_assessment_of_their_emission_reduction_impacts-2015unep-2015-climate-commitment.pdf?sequence=3&isAllowed=y (accessed 11 October 2022).

UNEP (2021), “Over 1,000 universities and colleges make net-zero pledges as new nature initiative is unveiled”, Glasgow, available at: www.unep.org/news-and-stories/press-release/over-1000-universities-and-colleges-make-net-zero-pledges-new-nature (accessed 11 October 2022).

UNFCCC (2015), “Paris agreement”, available at: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (accessed 11 October 2022).

Valls-Val, K. and Bovea, M.D. (2021), “Carbon footprint in higher education institutions: a literature review and prospects for future research”, *Clean Technologies and Environmental Policy*, Vol. 23 No. 9.

Van de Klugt, S., Oostlander, I., Ykema, P., Lakerveld, E., Walta, D., Numann, M. and Dijk, C. (2018), “Visie mobiliteit en bereikbaarheid campus TU Delft 2018 - 2028”, Delft.

Van den Dobbelsteen, A. and van Gameren, D. (2021), “Sustainable TU Delft: vision, ambition and action plan”, Delft.

Vringer, K., Benders, R., Wilting, H., Brink, C., Drissen, E., Nijdam, D. and Hoogervorst, N. (2010), “A hybrid multi-region method (HMR) for assessing the environmental impact of private consumption”, *Ecological Economics*, Vol. 69 No. 12, pp. 2510-2516.

VSNU (2019), "Universities unanimous in support of climate letter", available at: www.universiteitenvannederland.nl/en_GB/nieuws-detail/nieuwsbericht/500-universities-unanimous-in-support-of-climate-letter.html (accessed 11 October 2022).

World Business Council for Sustainable Development and World Resources Institute (2004), *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, Rev. ed., World Business Council for Sustainable Development; World Resources Institute, Geneva Switzerland, Washington, DC.

Appendix

Table A1. Carbon footprint of Delft University of Technology 2018 (sorted by emissions)

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [kgCO_2eq/unit]	Emissions [tCO_2eq]	Note	EF reference
Scope 3	*Real estate and construction*		*58,055.1*	€	*0.29*	*19,375.3*	Calculated average emission factor	
		Additional costs	29.2	€	0.46	13.4		b
		Daily maintenance	153.5	€	0.20	30.7		c
		Electrotechnical works	1,819.5	€	0.52	946.2		b, c
		Fire safety	305.3	€	0.11	33.6		b
		Guarding buildings	200.0	€	0.17	33.0		b, c
		Other equipment and inventory	309.1	€	0.52	160.7		b, c
		Other housing costs	1,553.2	€	0.12	186.4		c
		Project costs university corporate offices	49,695.4	€	0.33	16,993.1	Emission factor calculated separately	b, c
		Relocation costs	267.3	€	0.12	32.1		c
		Rent and leasehold	833.6	€	0.17	141.7		b
		Replacement maintenance	116.7	€	0.29	34.0		b, c
		Tools	412.7	€	0.52	214.6		b, c
		Architectural works	2,314.6	€	0.24	543.9		c
		Tools rent	5.9	€	0.23	1.4		b
		Tool maintenance	39.0	€	0.27	10.5		b, c
Scope 1	*Natural gas TU Delft*		*9,270.8*	*m3*		*17,521.9*		
		Natural gas consumption	9,270.8	m3	1.89	17,521.9		a
Scope 3	*Equipment*		*28,093.3*	€	*0.48*	*14,278.9*	Calculated average emission factor	

(*continued*)

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Electronic/electrotechnical material	*1,226.2*	€	*0.52*	*637.6*		b, c
		Emergency maintenance	2.4	€	0.39	0.9		b, c
		Equipment	20,778.6	€	0.52	10,804.9		b, c
		Project costs university corporate offices	50.6	€	0.45	26.3		b, c
		Technical mass items	3,737.3	€	0.52	1,943.4		b, c
		Equipment rent	108.8	€	0.46	50.1		b
		Equipment maintenance	2,182.6	€	0.37	814.8		b, c
		Preventative maintenance contract	6.3	€	0.13	0.8		b, c
		Units of account	0.5	€	0.11	0.1		c
Scope 3	*ICT*		*23,140.5*	€	*0.38*	*8,353.7*	Calculated average emission factor	
		ADSL costs	0.5	€	0.23	0.1		c
		Audio visual resources/optical instruments and equipment	1,895.8	€	0.69	1,308.1		b
		Computer equipment	5,774.4	€	0.48	2,742.8		b, c
		Computer parts	109.9	€	0.48	52.2		b, c
		Computer supplies	139.4	€	0.48	66.2		b, c
			49.9	€	0.16	8.0		c

(continued)

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Education Service Provision						
		Office machines	14.9	€	0.56	8.4		b, c
		Other equipment and inventory	24.1	€	0.52	12.5		b, c
		Project costs faculties	7.3	€	0.55	4.0	Average emission factor of ICT hardware group	b, c
		Project costs university corporate offices	2,730.0	€	0.46	1,498.3	Emission factor calculated separately	b, c
		Software	679.8	€	0.16	108.8		c
		Subscriptions	3,502.6	€	0.28	980.7		b
		Telephone/fax costs	715.7	€	0.27	189.6		b, c
		Telephone costs	33.0	€	0.27	8.7		b, c
		Computer equipment rent	8.7	€	0.23	2.0		b
		Audiovisual equipment rent	134.6	€	0.23	31.0		b
		Office machine maintenance	273.5	€	0.37	102.1		b, c
		Software maintenance	5,828.7	€	0.16	932.6		c
		Audiovisual equipment maintenance	128.0	€	0.37	47.8		b, c
		Computer equipment maintenance	66.4	€	0.22	14.3		b, c
		Office machines rent	1,023.4	€	0.23	235.4		b
Scope 3	*Facility services*		*13,089.0*	€	*0.48*	*8,283.2*	Calculated average emission factor	

(*continued*)

Table A1.

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Cleaning buildings	419.4	€	0.79	329.7		b, c
		Furniture and upholstery	2,412.6	€	0.59	1,423.4		b, c
		Furniture maintenance	120.7	€	0.27	32.6		b, c
		Other equipment and inventory	42.2	€	0.52	21.9		b, c
		Project costs university corporate offices	9,282.2	€	0.42	5,702.1		b, c
		Purchase of faculty cafes	31.6	€	0.39	12.4		b, c
		Window cleaning	0.2	€	0.16	0.0		c
		Furniture rent	153.6	€	0.34	52.2		b
		Trading goods	99.2	€	0.39	39.0		b, c
		Removal of environmentally harmful waste	526.9	€	1.27	669.2		c
		Sanitary goods	0.7	€	0.77	0.5		b, c
Scope 3	*Business flights*		*33,332.8*	*passengerkm*		*5,469.2*		
		Regional (< 700 km)	1,833.3	passengerkm	0.297	544.5		a
		European (700–2,500 km)	5,553.3	passengerkm	0.20	1,110.7		a
		Intercontinental (> 2,500 km)	25,946.2	passengerkm	0.147	3,814.1		a
Scope 3	*Catering*		*4,405.0*	€	*1.14*	*5,428.6*	Calculated average emission factor	
			4,405.0	€		5,428.6		b

(*continued*)

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
							Emission factor calculated separately	
Scope 3	*Research expenses and consumables*	*9,362.9*	€	*0.56*	*5,036.0*		Calculated average emission factor	
		Chemicals	1,899.2	€	1.07	2,022.7		c
		Congresses and symposia	2,157.4	€	0.15	323.6		c
		Gasses	730.5	€	0.67	489.4		c
		Intellectual property costs	1,386.9	€	0.13	180.3		b, c
		Other equipment and inventory	181.0	€	0.52	94.1		b, c
		Personal protective equipment	139.5	€	0.40	55.8		b, c
		Project costs faculties	3.6	€	0.34	1.2	Average emission factor from procurement	b, c
		Scientific dissertations	347.6	€	0.21	73.0		c
		Symposium, congress, trade fair	1,030.6	€	0.32	482.8		b, c
		Glassware/plastics/laboratory materials	1,486.4	€	0.88	1,313.0		b, c
Scope 3	*Administration, consultancy and auditing*		*55,600.8*	€	*0.15*	*4,476.4*	Calculated average emission factor	
		Accountant fees	329.3	€	0.11	36.2		c
		Advertising costs	131.4	€	0.19	25.0		c

(*continued*)

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [kgCO_2eq/unit]	Emissions [tCO_2eq]	Note	EF reference
		Audit costs	13.7	€	0.08	2.6		c
		Collection costs	28.5	€	0.14	4.0		c
		Consultancy costs	1,695.6	€	0.16	271.3		c
		Inspections	4.6	€	0.11	0.5		c
		Insurances	1,373.8	€	0.17	233.5		c
		Interactive media	2.2	€	0.52	1.1		b
		Memberships	1,165.2	€	0.13	151.5		b, c
		Other equipment and inventory	113.8	€	0.52	59.2		b, c
		Other personnel costs	99.5	€	0.06	6.0		b
		Other staff advances	80.7	€	0.06	4.8		b
		Project costs university corporate offices	1,452.4	€	0.20	250.4	Emission factor calculated separately	b, c
		Reception services	0.5	€	0.17	0.1		c
		Reimbursement for third party services	28,260.0	€	0.06	1,696.3		b
		Reimbursement of moving and accommodation costs	0.8	€	0.42	0.3		c
		Reintegration costs	7.3	€	0.13	0.9		b, c
		Representation costs	136.6	€	0.34	46.5	Average emission factor from procurement	b, c
		Shipping costs	564.8	€	0.22	124.3		b, c
		Staff recruitment costs	257.0	€	0.19	48.8		c
		Student insurances	0.3	€	0.17	0.1		c
		Study, education and training	2,472.4	€	0.17	408.0		b, c
		Temporary workers	16,860.4	€	0.06	1,011.6		b

(continued)

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Training costs for students	1.5	€	0.17	0.2		b
		Other office costs	548.7	€	0.17	93.3		c
Scope 3	*Transportation and travel*		*7,248.9*	€	*0.53*	*4,318.5*	Calculated average emission factor	
		Accommodation costs of third parties	892.9	€	0.42	375.0		c
		Other equipment and inventory	5.2	€	0.52	2.7		b, c
		Project costs university corporate offices	85.5	€	0.48	40.6	Emission factor calculated separately	b, c
		Transport and transport maintenance costs	251.6	€	0.50	124.5		b, c
		Transport means	119.9	€	0.50	59.3		b, c
		Travel and accommodation expenses abroad	1,690.0	€	0.46	787.2		b, c
		Travel costs applicants	23.3	€	0.48	11.3		b, c
		Travel costs untaxed km	310.3	€	0.48	150.0		b, c
		Travel expenses of third parties	2,737.3	€	0.81	2,225.0		b, c
		Domestic travel and accommodation expenses	835.5	€	0.46	386.2		b, c
		Means of transport rent	297.3	€	0.53	156.6		b, c

(continued)

Table A1.

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
Scope 3	*Commuting*					*4,065.6*		
		Fossil fuel car	16,946.4	vehiclekm	0.22	3,728.2	Employee and student emissions	a
		Fossil fuel carpool	830.1	passengerkm	0.11	91.3	Employee emissions; two persons	d
		Motorcycle	415.0	km	0.137	56.9	Employee emissions	e
		Scooter/moped	415.0	km	0.053	22.0	Employee emissions	e
		Train	5,810.4	passengerkm	0.006	34.9	Employee emissions	a
		Bus/tram/metro (average)	1,245.1	passengerkm	0.106	132.4	Employee emissions	d
		Bike	18,261.4	passengerkm	0.00	0.0	Employee emissions	
		Walk	830.1	passengerkm	0.00	0.0	Employee emissions	
Scope 3	*Energy supply to third parties on campus*				*3,716.5*			
		Natural gas	1,873.3	m3	1.89	3,540.5		a
		Electricity	14,668.8	kWh	0.012	176.0	Emission factor of electricity generated through wind power	a
Scope 3	*Other*		*6,777.5*	€	*0.26*	*2,368.0*	Calculated average emission factor	
		Description Unavailable	2,367.1	€	0.34	804.8	Average emission factor from procurement	b, c
		Other equipment and inventory	1,600.7	€	0.52	832.3		b, c
		Project costs faculties	69.0	€	0.34	23.4	Average emission factor from procurement	b, c

(*continued*)

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Project costs university corporate offices	60.0	€	0.37	22.1	Emission factor calculated separately	b, c
		Other facilities rent	790.3	€	0.17	134.4		b
		Student activity costs	360.1	€	0.14	51.6		b, c
		Maintenance of other consumables	301.4	€	0.26	81.5		b, c
		Mechanical works	1,228.9	€	0.34	417.8	Average emission factor from procurement	b, c
Scope 3	*Paper products*		*2,727.7*	€	*0.49*	*1,395.0*	Calculated average emission factor	
		Books	308.4	€	0.40	123.4		b
		Copy costs	371.5	€	0.54	200.6		c
		Loose purchase collection formation	247.1	€	0.40	98.8		b
		Other equipment and inventory	0.2	€	0.52	0.1		b, c
		Printing costs	1,798.2	€	0.54	971.0		c
		Project costs faculties	2.3	€	0.47	1.1	Average emission factor of paper products group	b, c
Scope 3	*Finance and tax*		*4,835.6*	€	*0.15*	*775.7*	Calculated average emission factor	
		Administrative consumption expenditure	3,149.8	€	0.17	535.5		c
		Banking costs	0.1	€	0.14	0.0		c
		Paid interest	0.2	€	0.14	0.0		c

(*continued*)

Table A1.

Table A1.

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Paid subsidies	1,650.0	€	0.14	231.0		c
		Project costs university corporate offices	20.0	€	0.14	2.8		c
		Various charges	45.7	€	0.14	6.4		c
Scope 1/2	*Electricity TU Delft*					*704.1*		
Scope 1		Electricity generation photovoltaic panels (LCA based)	1,041.5	kWh	0.07	72.9		a
Scope 1		Electricity cogeneration	14,263.2	kWh	–		Emissions calculated in category “Natural gas"	
Scope 2		Purchase of wind energy (LCA based)	52,602.5	kWh	0.012	631.2		a
Scope 3	*Waste*		*2,788.8*	t		*273.5*		
		Recycled waste	1,201.8	t		−195.0	EFs calculated separately based on TU Delft’s waste processor	f, g
		Waste-to-energy	1,194.6	t		131.8	EFs calculated separately based on TU Delft’s waste processor	f, g

(*continued*)

Scope	Carbon footprint category	Description	Activity [× 1,000 units]	Unit	Average Emission Factor [$kgCO_2eq$/unit]	Emissions [tCO_2eq]	Note	EF reference
		Landfill	392.4	t		336.7		h
Scope 3	*Water*		*167.1*	*m3*		*97.8*		
		Tap water (LCA based)	167.1	m3	0.585	97.8		h
Total						105.938		

Table A1.

EF Reference

a Milieu Centraal; Stichting Stimular; Connekt; SKAO; Ministerie van Economische Zaken en Klimaat. (2018). “CO2emissiefactoren 2018”, available at: Www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf

b Adjusted from Vringer, K., Benders, R., Wilting, H., Brink, C., Drissen, E., Nijdam, D., and Hoogervorst, N. (2010), “A hybrid multi-region method (HMR) for assessing the environmental impact of private consumption”, *Ecological Economics*, Vo. 69 No. 12, pp. 2510-2516

c Adjusted from Defra. (2014), “Table 13 - Indirect emissions from the supply chain. UK Department for Environment, Food and Rural Affairs”, available at: Www.gov.uk/government/statistics/uks-carbon-footprint

d Adjusted from Milieu Centraal; Stichting Stimular; Connekt; SKAO; Ministerie van Economische Zaken en Klimaat (2018). “CO2emissiefactoren 2018”, available at: Www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf

e Stichting Stimular. (2018). “Actuele CO2-parameters - 2018: Milieubarometer”, available at: Www.milieubarometer.nl/CO2-footprints/co2-footprint/actuele-co2-parameters-2018/

f Renewi, TU Delft’s waste processor

g Turner, D. A., Williams, I. D., and Kemp, S. (2015). “Greenhouse gas emission factors for recycling of source-segregated waste materials”, *Resources, Conservation and Recycling*, Vol. 105, pp. 186-197.

h Pulselli, R.M., Marchi, M., Neri, E., Marchettini, N. and Bastianoni, S. (2019). “Carbon accounting framework for decarbonisation of European city neighbourhoods”, *Journal of Cleaner Production*, Vol. 208, pp. 850-868.

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