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Carbon footprint assessment tool for universities: CO2UNV

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ABSTRACT

Universities, as organisations engaged in education, research and community services, play an important role in promoting sustainability and should be an example of a sustainable organisation. The Carbon Footprint (CF) is a very useful decision-making tool that allows organisations to measure and communicate the effect of their activities on the environment. To do so, it is necessary to have tools capable of calculating, tracking and reporting their greenhouse gas (GHG) emissions, as well as guiding the actions for reducing and offsetting them. The aim of this article is to present a tool specifically designed to calculate the carbon footprint of universities, called CO2UNV. This tool is able to quantify the CO_2 equivalent (CO_2e) emissions for scopes 1 (direct GHG emissions), 2 (electricity indirect GHG emissions) and 3 (other indirect GHG emissions), for a university as a whole and for the different buildings/units that it is made up of. It includes, by default, the typical emission sources of an education centre and their corresponding emission factors. However, it is totally adaptable to any other type of organisation thanks to the possibility of including new emission sources and of updating all the emission factors (by default and new). It is also capable of evaluating the evolution of the CF over time, and the CO_2e offsets achieved by contributing to offset projects. The results report includes input data and the graphical representation of results. Finally, CO2UNV is applied to calculate and offset the CF of the Universitat Jaume I (Spain), and the study concludes with its validation according to applicability and accuracy criteria.

1. Introduction

One of the biggest challenges in the world today is climate change because its impact has a great influence on humans and the environment. Towards the 1970s, governments around the world became fully aware of the need to address sustainable development. In 1983 the World Commission on Environment and Development (WCED) was appointed the mission of uniting countries to pursue sustainable development together and it popularised the term "Sustainable Development" with the publication of the Brundtland Report (WCED, 1987). From the Rio Declaration (United Nations, 1992a), Agenda 21 (United Nations, 1992b) and the United Nations Framework Convention on Climate Change (United Nations, 1992c), society's awareness of the environment and, in particular, greenhouse gas (GHG) emissions started to grow. Later, in 2015, the Agenda 2030 for Sustainable Development (United Nations, 2015) proposed a set of 17 Sustainable Development Goals (SDGs) to be achieved by 2030, one of which is SDG 13 (Climate Action - Take urgent action to combat climate change and its impacts). Recently, in 2019, the European Commission (EC) presented the European Green Deal (COM, 640, 2019), a plan including fifty specific actions to combat climate change, with the aim of making Europe the first climate-neutral continent by 2050.

The main factor that contributes to climate change is global warming, which is measured by the concentration of GHG emissions released into the atmosphere. For organisations that aim to contribute to achieving the climate-neutral goal, the first step is to determine their current environmental performance in terms of their Carbon Footprint (CF). Afterwards, based on the analysis of the current situation, organisations can propose action plans to reduce or even offset their GHG emissions.

The most notable regulatory framework for accounting GHG emissions is the GHG Protocol (2004), which defines the CF as the total amount of GHG emissions generated directly or indirectly by the activities carried out by the organisation, usually expressed by the carbon dioxide equivalent (CO_2e). To help delineate emission sources, improve transparency and better manage the full spectrum of GHG risks and opportunities, three "scopes" (scope 1, scope 2 and scope 3) are defined for GHG accounting and reporting purposes. According to the GHG Protocol (2004), Scope 1 (direct GHG emissions) accounts for GHG emissions from sources

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owned or controlled by the organisation, Scope 2 (electricity indirect GHG emissions) accounts for GHG emissions from the generation of purchased electricity consumed by the organisation and Scope 3 (other indirect GHG emissions) is an optional reporting category that includes emissions that are a consequence of the activities of the organisation but occur from sources not owned or controlled by the organisation.

Due to the fact that Scope 3 is optional (each organisation can therefore include different emission sources) and the emission factors to be used are not standardised (only a set of recommendations for choosing them are offered), the GHG Protocol (2004) recommends the use of GHG calculation tools rather than proprietary methods, as they are peer-reviewed and regularly updated.

Universities, as organisations engaged in education, research and community services, play an important role in generating knowledge, integrating sustainability in education and research projects, and promoting environmental issues in society (Güereca et al., 2013; Klein-Banai and Theis, 2013; Larsen et al., 2013; Moerschbaecher and Day, 2010), as well as in preparing responsible graduates capable of maintaining sustainable development (Cordero et al., 2020). In addition, universities typically consist of a mix of buildings used for classrooms, laboratories, offices, canteens, residences, etc. that generate significant GHG emissions (Moerschbaecher and Day, 2010; Valls-Val-and Bovea, 2021). Moreover, the CF is a highly useful decision-making tool that allows organisations, including universities, to exert a greater degree of control over their activities that impact on the environment (Robinson et al., 2018), provides a tangible value that allows the environmental impact to be compared with other academic institutions (Letete et al., 2011) and offers a baseline on which to evaluate the effect of future mitigation efforts on campus (Letete et al., 2011). For these reasons, it is necessary for universities, as innovation drivers in science and technology, to assume a leadership role in calculating, tracking, reporting, reducing or even compensating their carbon footprint as an example of sustainable organisations that promote the transformation towards a carbon-neutral society (Güereca et al., 2013; Helmers et al., 2021; Larsen et al., 2013; Valls-Val-and Bovea, 2021).

In fact, the role of universities in sustainability is already recognised by different international declarations such as the Talloires Declaration (TD, 1990) or Cre-Copernicus University Charta (Copernicus, 1993), associations/networks such as the Sectorial Commission on CRUE Sustainability (CRUE, 2002), Association for the Advancement of Sustainability in Higher Education (AASHE, 2020), American College and University President's Climate Commitment (ACUPCC, 2007a), which was rebranded as the Carbon Commitment (CC, 2015), International Sustainable Campus Network (ISCN, 2007) or Global Universities Partnership on Environment for Sustainability (GUPES, 2012), and rankings such as Times Higher Education-World University Ranking (THE, 2004), Sustainability Monitoring, Assessment and Rating System (STARS, 2013) or UI GreenMetric World University Ranking on Sustainability (GreenMetric, 2010).

Hence, it is observed that there is a need, on the part of universities, to calculate and communicate their CF, for which they require tools adapted to their specific emission sources. Taking this context into account, the aim of this study is to analyse the current research in this area and to develop a CF assessment tool for universities (CO2UNV) capable of modelling GHG emissions for scope 1 + 2 + 3, but flexible enough for it to be applicable to any other type of education centre worldwide.

2. Literature review

The empirical evidence on the interest in calculating the CF of universities is reflected by the number of documents offering recommendations/guidelines that have emerged recently, which have demonstrated that there is more than one way to calculate it (Yañez et al., 2020). The ACUPCC (2012, 2007b) provides ACUPCC signatory institutions with guidance on reporting, planning for climate neutrality and creating programmes to advance sustainability on campus. BriteGreen (2016) consists of a series of guidelines and recommendations for different phases (leadership and management, planning, implementation and delivering improvement) and was developed with the aim of helping university teams to achieve their emission reduction targets. Furthermore, it is complemented by a series of examples of good practice and innovation from several universities. Cool Campus (Simpson, 2009) is a guide for university climate action planning and provides tips for calculating the CF as well as proposing different actions to mitigate emissions. UNEP (2014) considers the GHG inventory as a basis for recognising the current state of emissions, recommends the use of the CA-CP (2020) tool and the guidelines developed by the Association for the Advancement of Sustainability in Higher Education (AASHE, 2020), although it does not offer any specific detailed methodology for that purpose. Santovito and Abiko (2018) offered recommendations on how to prepare the university GHG inventory, identifying some relevant emission sources and allowing a better visualisation of GHG mitigation opportunities. Finally, the Second Nature Platform (Second Nature, 2020) offered a series of recommendations for selecting the emission sources, calculating GHG emissions and analysing their evolution or identifying mitigation strategies. However, the existence of different recommendations, methods or tools for calculation of the CF usually implies non-comparable results (Helmers et al., 2021; Valls-Val-and Bovea, 2021).

On the other hand, several tools have been developed with the aim of calculating the CF of organisations in general and of specific sectors in particular.

On an international level, general CF tools such as Carbon Footprint (CF, 2020), Carbon Fund (CFund, 2021), Cool climate (CoolCalifornia, 2021; Simpson, 2009), Simplified GHG Emissions Calculator (SGEC, 2020), myclimate (Foundation myclimate, 2021), Simple Carbon Calculator (National Energy Foundation, 2017) and Terrapass Calculator (Terrapass, 2021) can be highlighted for application to any organisation. In addition, the GHG Protocol (2004) has created its own tool (GHG Protocol, 2021), which is currently under development in the beta version. Regarding specific sectors, tools worth highlighting include BioGrace GHG Calculation Tool (Biograce, 2015), Cool Farm Tool (CFT, 2015) or Illinois Farm Sustainability Calculator (IFSC, 2009) for the agricultural sector; in addition, some authors have targeted specific sectors, such as Lu et al. (2015) for the construction sector, Pirlo and Carè (2013) for the milk sector and Sevigné Itoiz et al. (2013) for the MSW management sector.

Regarding higher education, only one specific tool has been found, Campus Carbon Calculator (CA-CP, 2020). This tool, developed by the US-based organisation Clean Air-Cool Planet (CA-CP) in cooperation with the University of New Hampshire, can be freely downloaded, allows scope 1 + 2 + 3 to be modelled, has the form of a Microsoft Excel spreadsheet and uses the emission factors garnered from the Environmental Protection Agency (EPA, 2020a). However, it has been discontinued since 2018 and replaced by the SIMAP (2020) tool. SIMAP is a proprietary tool (a subscription fee is required) that includes scope 3 for staff/student commuting, travel, solid waste and wastewater and paper, but it is still applicable only to the USA due to the emission factors it includes.

As this article presents a case study for a Spanish university, the tools developed in Spain to calculate the CF have been analysed in greater depth. Thus, on a national level (Spain), general CF tools such as CEACV (2015), ENECO (2015), which is now obsolete, (IHOBE 2021) and OCCC, 2020a,b can be highlighted. Moreover,

Table 1
Analysis of Carbon Footprint calculation tools

TOOL	Country application	Scope 1	Scope 2	Scope 3			Offsets
				Consumptions	Transport	Other	
Carbon Footprint (CF, 2020)	WW	S,R,V	P		BT,C		OP
Carbon Fund (CFund, 2021)	USA	S,V	P		BT,S		OP
Cool climate (CoolCalifornia, 2021; Simpson, 2009)	USA	S,V	P	P,LC,EE	BT,C	W,C	OP
GHG Protocol Calculator (GHG Protocol, 2021)	AU, CA, CH, USA	S,R,V	P		BT,C,S		
myclimate (Foundation myclimate, 2021)	WW	S,V	P	P,F,EE	BT,C	W	OP
Simple Carbon Calculator (National Energy Foundation, 2017)	WW	S,V	P				
Simplified GHG Emissions Calculator (SGEC, 2020)	USA	S,R,V	P		BT,C,S	W	A
Terrapass Calculator (Terrapass, 2021)	USA	S,V	P		BT,C,S		OP
CA-CP (CA-CP, 2020)	CA, USA	S,R,V	P,G	P,FE	BT,C	W,WW	A
SIMAP (SIMAP, 2020)	CA, USA	S,R,V	P,G	P,FE	BT,C	W,WW	A
CEACV (CEACV, 2015)	ES	S,V	P,G		BT,C,S		
ENECO (ENECO, 2015)	ES	S,R,V	P,G	Wt,P,F,LC,EE	BT,C,S	W,WW,C	
IHOBE (IHOBE, 2017)	ES	S,R,V	P	Wt,P,EE	BT,C,S	W	A
MITECO (MITECO, 2020)	ES	S,R,V	P,G				A
OCCC (OCCC, 2020)	ES	S,R,V	P,G	Wt,User-owned	BT,C,S	W, EI	A

Country application: AU (Australia), CA (Canada), CH (China), ES (Spain), USA (United States), WW (worldwide)
Scope 1: S (stationary consumption), R (leakage of refrigerants), V (vehicle fleet)
Scope 2: P (purchased), G (generated)
Scope 3: Material consumption: Wt (water), P (paper), F (food), LC (laboratory chemicals), EE (electronic equipment), FE (Fertiliser)
Transport: BT (business travel), C (commuting), S (supplies)
Others: W: waste, WW: wastewater, C: construction, EI: transmission and distribution losses from purchased electricity
Offsets: OP (offers offset projects), A (calculates the absorptions of own projects)

OCCC, 2020ab,c has a general version and other specific versions for the agriculture and city council sectors. However, no specific tool has been developed for calculating the CF of universities and none of these general CF tools includes all the significant emission sources of a university.

The tools mentioned above are analysed in Table 1, in terms of which countries they apply to, which emission sources they include and whether they include emission offsets. As can be seen, there are large differences between the tools and most of them (except those specific to Spain) are specific to the USA and do not include the most representative emission sources in universities.

On the other hand, in recent years, numerous studies around the world have focused on calculating the CF of universities. As Table 2 shows, 10 studies have been carried out in Asia, 8 in North America, 7 in Europe, 3 in South America and Oceania, and 2 in Africa. Focusing on the use of CF tools, only Bailey and LaPoint (2016), Klein-Banai and Theis (2013) and Moerschbaecher and Day (2010) – all for US universities – used the CA-CP (2020) tool to calculate their CF and Sangwan et al. (2018) employed the Umberto NXT Software (Umberto, 2020), which is general Life Cycle Assessment (LCA) software. However, none of them employed any of the general tools mentioned above, which may be due to the fact that they do not include all Scope 3 emission sources that occur in a university, such as commuting, that Valls-Val-and Bovea (2021) showed to be one of the major contributors to the CF in universities. Therefore, 88% of the universities use their own methods (they do not use specific CF tools to calculate their CF) to prevent some emissions from not being included in the calculation.

Hence, from this background it is possible to conclude that there is a gap in the literature, since general tools do not include all the emission sources typically found in universities and there is no tool (public or commercial, of an international or national–Spanish scope) that has been specifically developed for calculating the CF of universities and which can be adapted to the particularities of any university – SIMAP (2020) is only applicable to US universities. Given the recommendation of the GHG Protocol (2004) to use a GHG calculation tool and the conclusions of Helmers et al. (2021) and Valls-Val-and Bovea (2021), who demonstrated that the use of proprietary tools/methods implies obtaining results that are not transparent or comparable, it is necessary to develop a specific tool for calculating the CF of universities and general education centres worldwide. The goal is to unify, standardise and promote its calculation, in order to obtain results that can be compared among universities and that allow them to identify and model opportunities for reducing and offsetting their CF.

3. Methods

The methodology used to develop and test the CO2UNV tool for universities consists of six stages, as illustrated in Fig. 1 and described below.

3.1. Conceptual design

The CF assessment tool for universities (CO2UNV) should be based on the GHG Protocol (2004) and fulfil the following requirements:

- Be easy to use, simple and implemented in a software package that is widely known and available to the general public, which allows the use of tables, pre-established functions needed for internal calculation, graphical representation of results (i.e. Microsoft Excel software or similar).
- Allow the selection of the characteristics of emission sources in universities for scopes 1, 2 and 3. For all the scopes, it should incorporate a list of default emission sources and should also allow the incorporation of different emission sources not previously listed.
- Incorporate default emission factors for all the default emission sources and allow the user to modify all of them and to include the emission factor for the new emission sources added by the user.
- Calculate the CF for a university as a whole and/or for its individual buildings/units.
- Compare the CF from different years and verify whether the CF is reduced over time.
- Calculate CO_2e offset based on the absorptions of CO_2 by tree species included in a reforestation project. Tree species and their corresponding absorption factors should be included as defaults, although the user should be able to include new species and update or add absorption factors for the default or added tree species, respectively.

Table 2
Literature on calculating CF for universities

Continent	Country	University (country)	CF tool	Reference
Europe	Spain	Technical University of Madrid: Forestry Engineering	-	Alvarez et al. (2014)
		University of Castilla-La Mancha	-	Gómez et al. (2016)
		University of the Basque Country	-	Rodríguez-Andara et al. (2020)
	United Kingdom	Keele University	-	Gu et al. (2019)
		Montfort University	-	Ozawa-Meida et al. (2013)
		Leeds University	-	Townsend and Barrett (2015)
	Norway	Norwegian University of Technology and Science	-	Larsen et al. (2013)
Oceania	Australia	University of Sydney	-	Baboulet and Lenzen (2010)
		University of Melbourne, Parkville Campus	-	Stephan et al. (2020)
	New Zealand	Massey University	-	Butt (2012)
Asia	Indonesia	University of Diponegoro	-	Budihardjo et al. (2020)
		Trisakti University	-	Iskandar et al. (2020)
		Universitas Pertamina	-	Ridhosari and Rahman (2020)
		University of Diponegoro	-	Syafrudin et al. (2020)
	South Korea	Pusan National University	-	Jung et al. (2016)
	Thailand	Valaya Alongkorn Rajabhat University	-	Kandananond (2017)
		Mea Fah Luang University	-	Laingoen et al. (2016)
	India	Birla Institute of Technology and Science, Pilani	U-NXT	Sangwan et al. (2018)
	Saudi Arabia	Qassim University	-	Almufadi and Irfan (2016)
	Malaysia	University Technology Malaysia (UTM)	-	Yazdani et al. (2013)
Africa	South Africa	University of Cape Town	-	Letete et al. (2011)
	Nigeria	Fed University of Agriculture Abeokuta	-	Ologun and Wara (2014)
South America	Ecuador	Escuela Superior Politécnica del Litoral (Ecuador)	-	Criollo et al. (2019)
	Chile	Talca University	-	Vásquez et al. (2015)
		Talca University	-	Yañez et al. (2020)
North America	United States	St. Edward's University	CA-CP	Bailey and LaPoint (2016)
		Clemson University	-	Clabeaux et al. (2020)
		University of Illinois	CA-CP	Klein-Banai and Theis (2013)
		Louisiana State University	CA-CP	Moerschbaecher and Day (2010)
		Yale University	-	Thurston and Eckelman (2011)
	México	National Autonomous University Mexico	-	Güereca et al. (2013)
		Autonomous Metropolitan University	-	Mendoza-Flores et al. (2019)
		Autonomous University of Baja California	-	Quintero-Núñez et al. (2015)

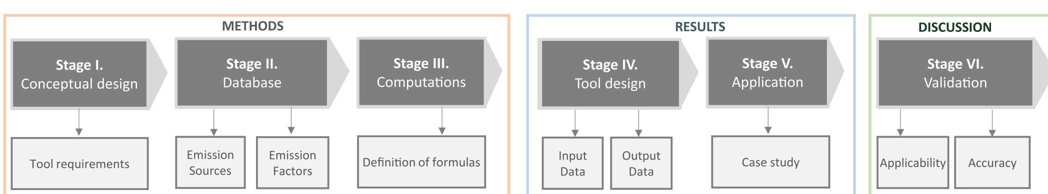

Fig. 1. Methodology.

- Allow calculations to be performed automatically, the results then being shown in table and graphic format.
- Incorporate help comments and explanations to guide users and make it easier to calculate the CF and to use the tool.

3.2. Database

3.2.1. Emission sources

In order to select the emission sources (ES) to be included in the tool, the ES included in the literature on CF in universities are analysed and reported in Table 3.

As can be seen in Fig. 2, CO2UNV includes all the ES of scopes 1 and 2, the ES of scope 3 that are considered in more than 40% of the studies reviewed and the laboratory chemicals and electrical equipment because they are widely used in any university.

A complete list of the default emission and absorption sources included in the CO2UNV database is reported in Tables S1 and S2 of the Supplementary Material, respectively. It is important to remark that the tool offers the option of including new emission and absorption sources with their corresponding emission or absorption factor in order to adapt them to the specific requirements of the case study under analysis.

3.2.2. Emission factors

The database includes default emission factors (EF) for the default emission sources. As described above, since a Spanish university is selected as a case study, the default EF corresponds to the case of Spain. These default EF come from official/governmental Spanish sources such as MITECO (2020b) or OCCC (2020b) and international sources such as the WARM model (EPA, 2020b) or Ecoinvent Database (2019) using the CML Baseline (Guinée et al., 2002) impact assessment method. The absorption factors are those provided by MITECO (2019). Default EF for emission and absorption sources are fully detailed in Tables S3–S8 of the Supplementary Material. The use of these default EF allows the use of the results obtained with CO2UNV to register the CF calculated in the "National (Spanish) Register of Carbon Footprint, Offsetting and Carbon Dioxide Absorption Projects" (MITECO, 2020c). However, in the same way as with the source emissions, the factor emissions can be updated and expanded by the user in order to adapt them to

Table 3
Emission sources considered in the literature

	Scope 1	Scope 2	Scope 3 Material consumption	Transport	Other
Almufadi and Irfan (2016)	V	P		C	
Alvarez et al. (2014)	S,V	P	Wt,P,LC,EE	BT,S	W,El
Baboulet and Lenzen (2010)	S,R	P	P,F,LC,EE	BT	
Bailey and LaPoint (2016)	S,R,V	P	P	BT,C	W,WW,El
Budihardjo et al. (2020)		P	Wt		W,WW
Butt (2012)	S,V	P		BT,C	WWW
Clabeaux et al. (2020)	S,R,V	P	P,FE	BT,C	W,WW,El
Criollo et al. (2019)	S,R,V	P			WW
Gómez et al. (2016)	S,V	P	Wt,P,F,LC,EE,FE	BT	W,C,El
Gu et al. (2019)	S,V	P,G	Wt,F		W,WW
Güereca et al. (2013)	S,V	P	P	BT,C,S	W
Iskandar et al. (2020)	V	P	Wt,P,F	BT,C	W
Jung et al. (2016)	S,V	P	Wt	C	W,WW
Kandananond (2017)	V	P			
Klein-Banai and Theis (2013)	S,V	P		C	W,El
Laingoen et al. (2016)		P			
Larsen et al. (2013)	S,R,V	P	P,F,LC,EE	BT,C	W,C
Letete et al. (2011)	S,V	P	P	BT,C	W,WW,El
Mendoza-Flores et al. (2019)	S,R,V	P	Wt,P,F,LC	BT,C	W,WW
Moerschbaecher and Day (2010)	S,R,V	P		BT,C	W,WW,El
Ologun and Wara (2014)	S,V	P		C	
Ozawa-Meida et al. (2013)	S,V	P	Wt,P,F,LC,EE	BT,C	W,C,El
Quintero-Núñez et al. (2015)		P	Wt,P	C	C
Ridhosari and Rahman (2020)		P		C	W
Rodríguez-Andara et al. (2020)	S,R,V	P	Wt,P	C	W,C,El
Sangwan et al. (2018)	S,V	P	Wt,P,F,LC,EE	BT,C	W,WW
Stephan et al. (2020)	S	P	Wt,P,F,LC,EE	C	W
Syafrudin et al. (2020)		P	Wt	C	W,WW
Thurston and Eckelman (2011)	S,V	P		BT,C	
Townsend and Barrett (2015)	S,V	P	P,F,LC,EE	BT	W,C
Vásquez et al. (2015)	S,R,V	P		BT,C,S	
Yañez et al. (2020)	S,R,V	P		BT,C	W
Yazdani et al. (2013)	V	P		C	W

Scope 1: S (stationary consumption), R (leakage of refrigerants), V (vehicle fleet)
Scope 2: P (purchased), G (generated)
Scope 3: Material consumption: Wt (water), P (paper), F (food), LC (laboratory chemicals), EE (electronic equipment), FE (Fertiliser)
Transport: BT (business travel), C (commuting), S (supplies)
Others: W: waste, WW: wastewater, C: construction, El: transmission and distribution losses from purchased electricity

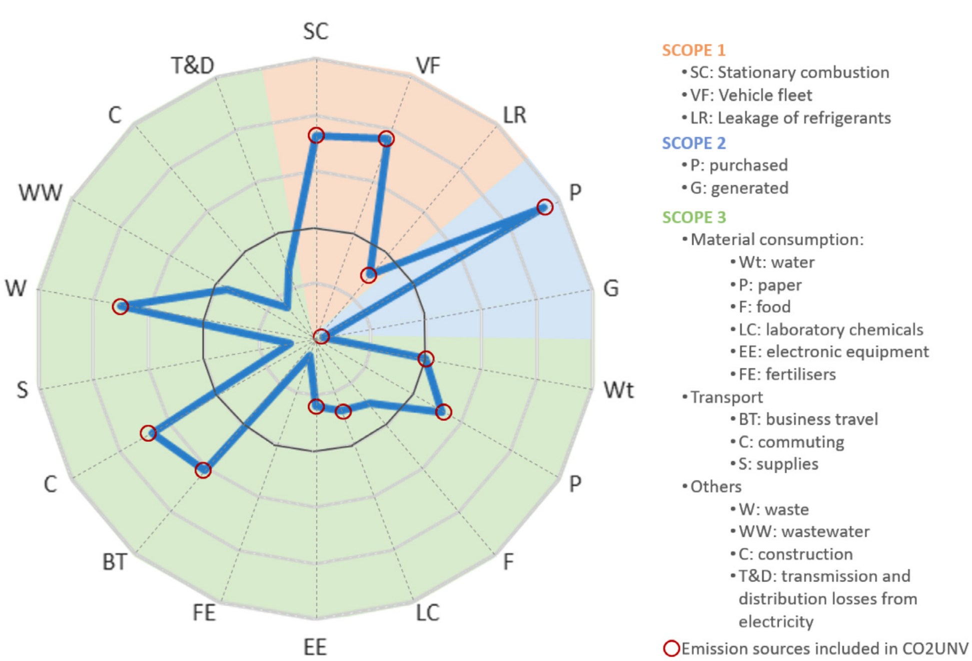

Fig. 2. Percentage of studies including each Emission Source and which of them are included in the CO2UNV tool.

the specific requirements of the case study under analysis or other registries.

3.3. Computations

For all emission sources, the CO_2e emissions are automatically calculated by the tool as the sum of the products between the Activity Data (AD) and the Emission Factor (EF) using this formula:

$$CF = \sum_{i=1}^{n} AD \ x \ EF \qquad \text{(Eq. (1))}$$

where:

- *i* is the number of emission sources.
- *AD* is the quantification of an activity in units that can be combined with the emission factor.
- *EF* is the value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity ($kgCO_2e$/unit).
- *CF* is the carbon footprint expressed in metric kg of carbon dioxide equivalents ($kgCO_2e$).

Analogously, CO_2 absorptions are calculated automatically as a result of the sum of the products between the number of tree units (TU) and the corresponding absorption unit (AU), for each type of tree species.

$$ABS = \sum_{i=1}^{n} TU_i \ x \ AU_i \qquad \text{(Eq. (2)}$$

where:

- *i* is the number of types of tree species (absorption sources).
- *TU* is the number of tree units, for each type, that are expected to exist after the project period.
- *AU* is the rate of absorption of CO_2 per tree unit for a given period (which depends on the type of project).
- No timber exploitation: the unit absorptions are estimated according to the species and the period of permanence.
- Intensive timber exploitation: the unit absorptions are estimated, according to the species and the cutting time (corresponding to half of the absorptions produced during the cutting time interval).
- *ABS* is the absorptions expressed in metric tons of carbon dioxide (tCO_2).

Finally, CO_2 available absorptions (AA) are calculated automatically in accordance with Eq. (3).

$$AA = RUA - WMA \qquad \text{(Eq. (3))}$$

where:

RUA is the recordable useful absorptions, corresponding to 20% of *ABS* (*RUA = ABS x 0.2)*
WMA is the warranty market absorptions, corresponding to 10% of RUA (*WMA = RUA x 0.1*)
AA is the available absorptions to offset the carbon footprint, expressed in metric tons of carbon dioxide (tCO_2)

3.4. Tool design

The tool was designed using the programming language Visual Basic for Applications (VBA) in Microsoft Excel (Microsoft Office Professional Plus, 2019. It was structured in two modules (input data and output data) and included the database and computations described above.

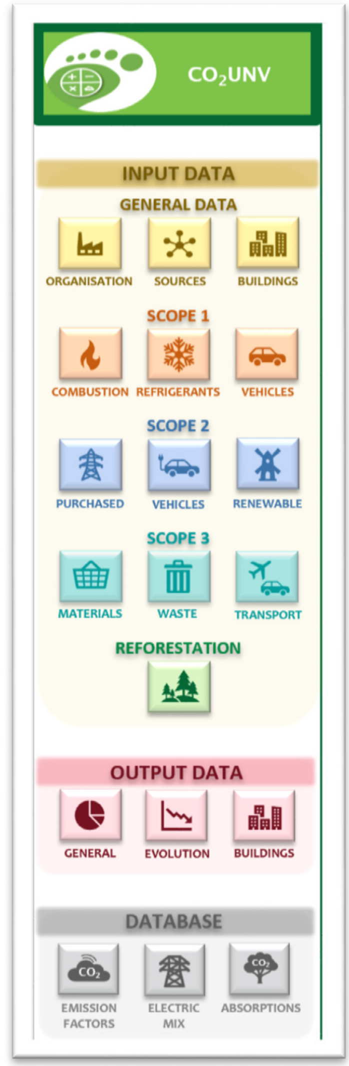

Fig. 3. Tool main menu.

3.5. Case study

The Universitat Jaume I was selected as a case study for calculating the carbon footprint by applying the CO2UNV tool, because it is the university where the authors of the manuscript are affiliated and, therefore, where they can obtain the activity data for calculating the CF.

3.6. Validation

The validity of the tool was tested in two areas: the applicability (through the case study) and the level of accuracy (by comparing the results obtained with those of another tool).

4. Results

4.1. Tool design

The tool was designed using two modules (input and output data) connected to the database described in Section 3.2 through the main menu shown in Fig. 3. This menu is permanently visible on the left-hand side of the screen of the tool and allows access to the data entry and results display screens by means of graphical buttons that guide users on how to run the different functionali-

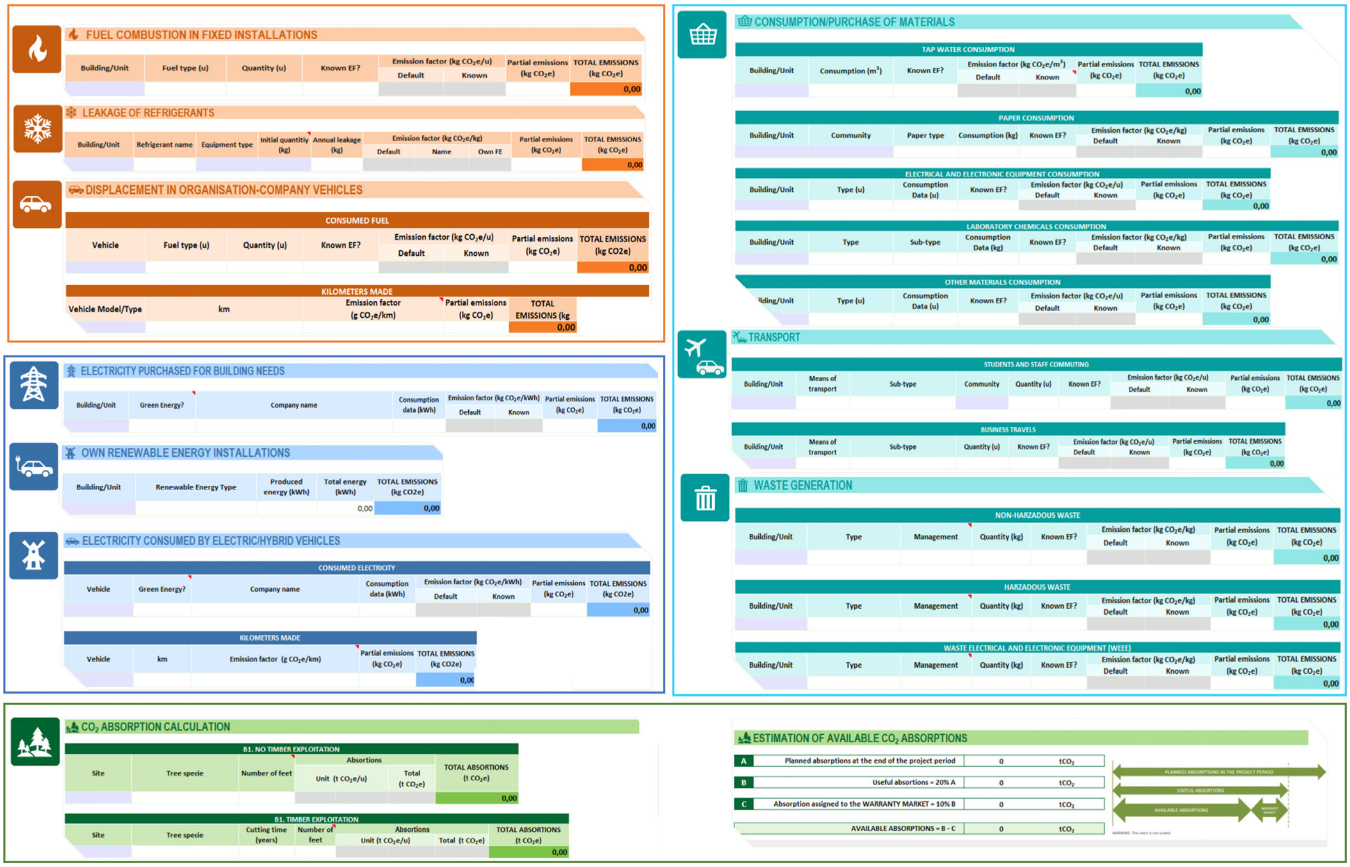

Fig. 4. Input data spreadsheets (header and first row of the input data tables for each scope and absorption project).

ties of the tool. In addition, it has an instruction sheet (see Fig. S1 of the Supplementary material) with the information included in each module and which is accessible by clicking on the logo of the corresponding tool.

4.1.1. Input data

The input data required by the tool includes general information about the organisation and the aim and scope of the CF calculations, and the specific spreadsheets required for the input data according to the scope selected (Fig. 4).

General data. This spreadsheet requires information related to:

- ***Organisation data***. General information about the university: name, intensity rates such as surface area, students, employees and/or persons, and year of calculation. Finally, the user should indicate whether the CF has been calculated in previous years.
- ***Emission sources.*** It is necessary to select the emission sources to be included in the CF calculation.
- ***Offset projects***. The user should indicate whether any offset projects are to be considered.
- ***Buildings***. If the CF is to be disaggregated by building/unit, they should be named and sized.

Fig. S2 of the Supplementary material shows the full layout of this spreadsheet. The graphical button in the main menu (Fig. 3) corresponding to those emission sources that have not been selected will change to light grey and will not be accessible in the following spreadsheets. The same will happen with the buttons related to CF evolution, CF disaggregated by buildings and CF offset in the output data module.

Scopes and carbon offset projects. The modules dealing with scopes 1, 2 and 3 are divided into three blocks, have a Help button with instructions on how to fill in cells, and two buttons for inserting and removing lines. These two buttons allow the input data to be introduced for the organisation as a whole or for individual buildings, which have been detailed in the "General Data" module (accessible on a dropdown menu).

CO2UNV has specific spreadsheets for each scope:

- Scope 1 (direct GHG emissions). CO2UNV includes spreadsheets for fuel combustion in fixed installations, leakage of refrigerants and fuel consumption by the vehicles used by the organisation. The main structure of the input data of each spreadsheet is shown in Fig. 4, while the full layout is shown in Fig. S3 of the Supplementary Material. CO2UNV includes default options for selecting the emission sources for each type of direct emission, which are reported in Table S1 of the Supplementary material, although new emission sources can be added by the user.
- Scope 2 (indirect GHG emissions). CO2UNV includes spreadsheets for electricity purchased to meet the needs of buildings, electricity consumed by the organisation's electric vehicles and the generation of renewable energy. The main structure and the full layout of the input data of each spreadsheet are shown in Figs. 4 and S4 of the Supplementary Material, respectively. As in scope 1, default source emissions can be selected (Table S1 of the Supplementary material) or new source emissions can be added.
- Scope 3 (other indirect GHG emissions). CO2UNV includes specific spreadsheets for the consumption of materials (water, paper, electrical and electronic devices, laboratory chemicals, etc.), waste generation (non-hazardous, hazardous, and electrical and electronic equipment, etc.) and transportation (commuting by

employees and students, and business trips). As in scopes 1 and 2, the main structure of the input data of each spreadsheet is shown in Fig. 4, while the full layout of each spreadsheet and the default options for selecting the emission sources for each type of indirect emission are reported in Fig. S5 and Table S1, respectively, of the Supplementary Material.

Regarding the **carbon offset projects**, CO2UNV includes spreadsheets where the user should enter the project information (name, location and developer), the period of permanence and optionally the areas where it is located. The estimation of the absorptions is divided into two blocks depending on whether there is timber exploitation. For timber exploitation there is an information button showing how the absorptions are calculated. See the main structure of this spreadsheet in Fig. 4, while the full layout of the spreadsheet is shown in Fig. S6 of the Supplementary Material.

4.1.2. Output data

Once the CF has been calculated, CO2UNV allows the results to be represented automatically in both table and graph format (Fig. 5), in order to make them easier to interpret. This module is divided into three blocks of results analysis:

- ***Global results.*** The results are represented in a detailed table for the different emission sources included in the scopes selected, and the carbon intensities are calculated according to the intensity rates defined in the "General data" module. This allows the environmental performance of different universities to be compared. In addition, there are two comparative graphs, and if the CO_2 absorptions in carbon offset projects have been estimated, the tool in turn estimates the percentage of CO_2 emissions for Scope 1 + 2 that have been offset. See Fig. S7 of the Supplementary material.
- ***CF evolution.*** This module only appears if the option "YES" has been selected in the “CF calculation for previous years” box in the General Data Module. The user can introduce the intensity rates and the result of the CF calculated for scopes 1 + 2 and 1 + 2 + 3 from previous years. The tool automatically calculates the carbon intensity for previous years, represents it in a table and offers two graphs depicting the evolution of the carbon intensity and two other graphs displaying the evolution of the CF. In addition, if the university introduces the carbon intensity of the previous three years, the tool automatically verifies whether the average carbon intensity of the last triennium is less than that of the previous triennium (an assumption considered to validate a reduction in CF over time). See Fig. S8 of the Supplementary material.
- ***Campus / building results.*** This module only appears if the option "YES" has been selected in the “data disaggregated by building” box in the General Data Module, and all cells are automatically completed by the CO2UNV tool. The results are represented in an individual table for each building or campus and eight ring charts are used to show the contribution of each building to the university’s carbon footprint (in terms of both carbon footprint and carbon intensity disaggregated by scopes 1, 2, 3 and 1 + 2 + 3). See Fig. S9 of the Supplementary material.

4.2. Case study

The Universitat Jaume I is a Spanish public higher education and research institution with around 14,000 registered students and over 2000 workers including researchers, teachers and administrative staff. It was established in 1991, on a single university campus, located in Castelló de la Plana. The campus consists of five faculties and schools (School of Technology and Experimental Sciences (ESTCE), Faculty of Law and Economics (FCJE), Faculty of Humanities and Social Sciences (FCHS), Faculty of Health Sciences (FCS) and Doctoral School (DS)), Research Areas, Science Park, Office of the Rector and Central Services building, Library, Auditorium, the Sports Area, etc., and external services, such as shops, University halls of residence, nursery school, etc.

Table 4
Data collection. Intensity rates.

Activity rate	Units	2016	2017	2018	2019
Constructed area	m^2	225,647	225,647	235,460	235,460
Students	number	14,424	13,923	13,789	13,685
Employees	number	2276	2275	2308	2199
People	number	16,700	16,198	16,097	15,884

4.2.1. Data collection

The information was requested from different services, departments and offices of the university, and as a result the data was in different formats. The process of collecting information was a time-consuming task because the university’s systems were not prepared for it. For this reason, the data collected had to be submitted to a refinement process to adapt them to the format and units required for input data in the CO2UNV tool.

Data were collected for the last four years (2016–2019) so that the evolution of the CF could be analysed over time. Tables 4, Table 5 and Table 6 report the intensity rates, activity data and reforestation projects, respectively, for each year analysed and for the university as a whole. The Supplementary material reports these data for each university building (Tables S9, S10 and S11).

4.2.2. Carbon footprint calculation

After the process of refining, or cleaning, the data collected from the university, data from Tables 2–4 were introduced into the CO2UNV tool, as described in Section 4.1.1 for the general data and input data modules. Figs. S2–S6 of the Supplementary Material show screenshots of the CO2UNV input for this application case, while Figs. S7–S9 of the Supplementary Material show screenshots of the CO2UNV results, all of them for 2019. The default emission sources and the default emission factors reported in the Supplementary material were applied for the calculation.

The annual CF for the Universitat Jaume I from 2016 to 2019 is reported in Table 7 for the three scopes independently, and for scopes 1 + 2 and 1 + 2 + 3. In addition, Table 7 also reports the CF for the different intensity rates defined in Table 4 and the percentage of CF offset each year by the reforestation projects reported in Table 6.

Regarding the results, the average CF of the Spanish universities registered in the “National (Spanish) Register of Carbon Footprint, Offsetting and Carbon Dioxide Absorption Projects” (MITECO, 2020c) is 0.35 tCO2e/student and the intensity of the emissions of the Universitat Jaume I in 2019 was 0.30 tCO2e/student. It can thus be concluded that the Universitat Jaume I is an environmentally responsible university. On the other hand, the CO_2 absorptions and percentage of offset for the years 2016, 2017, 2018 and 2019 were 17 tCO_2 (0.33%), 9 tCO_2 (0.12%), 26 tCO_2 (2.32%) and 14 tCO_2 (1.11%), respectively (Table 7). Therefore, currently, university reforestation projects are not sufficient to completely offset the CF.

4.2.3. Action plan

According to the results obtained, the following actions for reducing the CF are proposed, based on a combination of the following improvement actions (IA):

- **IA1. Closing of buildings at Easter and Christmas.** In this case, the advantage is the disconnection of installations that con-

Table 5
Data collection. Activity data.

Scope	Emission source	Type (units)	2016	2017	2018	2019
Scope 1	Fixed combustion	Natural Gas (kWh)	3629,377.93	4144,728.52	4730,659.12	4285,575.91
		Gasoil C (l)	578.00	600.00	590.00	592.00
	Leakage of refrigerants	R-134A (kg)	11.00	97.40	1.00	4.45
		R-404A (kg)	16.50	3.00	11.00	32.50
		R-407C (kg)	115.00	232.50	105.00	154.00
		R-410A (kg)	9.60	26.20	10.44	8.80
		R-422D (kg)	6.60	0.00	0.00	17.00
		R-434A (kg)	0.00	58.00	0.00	0.00
		R-600A (kg)	0.07	0.00	1.00	0.00
	Mobile combustion	Diesel A or B (l)	3178.17	3869.64	2681.32	4178.82
Scope 2	Purchasing electricity (kWh)		14,169,897.00	14,545,585.00	14,885,079.00	14,892,645.00
	Generation of renewable energy (kWh)		147,166.00	159,013.00	240,757.00	266,834.00
Scope 3	Consumptions	Water (m^3)	48,431.04	49,956.28	46,276.90	48,326.63
		Virgin paper (kg)	14,974.13	13,325.00	15,694.00	12,300.00
		Recycled paper (kg)	4307.63	3485.00	2891.00	2870.00
		Toner (u)	230.00	180.00	149.00	164.00
		Nitric acid (kg)	4.00	4.00	0.00	0.00
		Sodium chloride (kg)	0.50	0.00	0.00	0.00
		Sulphuric acid (kg)	0.00	0.00	0.00	1.00
		Ammonia (kg)	0.00	0.00	0.00	2.00
		Sodium fluoride (kg)	0.00	0.00	0.25	0.00
	Waste	Laboratory reagents (kg)	25,150.00	30,343.00	28,680.50	20,842.10
		Lamps and lights (kg)	488.40	537.30	421.75	380.25
		WEEE (kg)	8945.00	3280.00	11,100.00	6530.00
		Batteries (kg)	295.00	330.00	328.00	370.00
		Paper and cardboard (kg)	45,273.00	38,867.00	37,890.00	38,425.00
		Plastic (kg)	8720.00	12,660.00	11,280.00	11,660.00
		Glass (kg)	2980.00	3260.00	2820.00	3200.00
		Toner (kg)	642.00	521.00	1251.00	726.00
	Commuting	Car (km)	24,865,026.00	24,249,515.00	24,190,648.00	24,190,648.00
		Motorcycle (km)	1021,533.00	998,242.00	997,207.00	997,207.00
		Bus (km)	10,725,668.00	10,373,732.00	10,288,384.00	10,288,384.00
		Train (km)	7503,825.00	7261,675.00	7204,787.00	7204,787.00
		TRAM (km)	11,409,706.00	11,049,625.00	10,968,753.00	10,968,753.00
		Bicycle (km)	7454,407.00	7227,266.00	7180,059.00	7180,059.00
		Walk (km)	10,080,702.00	9761,035.00	9688,523.00	9688,523.00

Table 6
Data collection. Reforestation projects: tree species, type and number.

2016 Project 1 Specie	N°	2016 Project 2 Specie	N°	2017 Specie	N°	2018 Specie	N°	2019 Specie	N°
Quercus faginearotrun	60	Quercus suber	50	Quercus faginea	60	Acer monspesulanum	60		40
Quercus rotundifolia	80	Pinus pinea	20	Quercus ilex	120	Arbutus unedo	230	Amelanchier ovalis	40
Juniperus phoenicea	10	Quercus faginea	20	Quercus suber	120	Celtis australis	60	Colutea arborescens	40
Pinus halepensis	20	Quercus rotundifolia	20	Juniperus phoenicea	15	Acer opalus	60	Colutea hispanica	40
Pinus nigra	20	Arbutus unedo	20	Acer monspeliensis	45	Fraxinus angustifolia	80	Prunus mahaleb	40
Pinus pinea	20	Acer granatense	20	Fraxinus angustifolia	15	Pistacea terebinthus	80	Quercus faginea	80
Acer granatense	40	Acer pseudoplatanus	10	Pistacea lentiscus	15	Sorbus domestica	10	Quercus suber	40
Fraxinus angustifolia	10	Mirtus comunis	10	Pistacea terebinthus	15	Malus sylvestris	20	Crataegus monogyna	80
Juglans regia	10	Viburnum tinus	10	Juniperus oxycedrus	15			Fraxinus angustifolia	40
Pistacea lentiscus	10	Crataegus monogyna	10	Arbutus unedo	30			Juniperus oxycedrus	
Pistacea terebinthus	10	Castannea sativa	10						
Junyperus oxycedrus	10	Quercus suber	50						
Arbutus unedo	40	Pinus pinea	20						
Chamaerops humilis	20	Quercus faginea	20						
Mirtus comunis	20	Quercus rotundifolia	20						

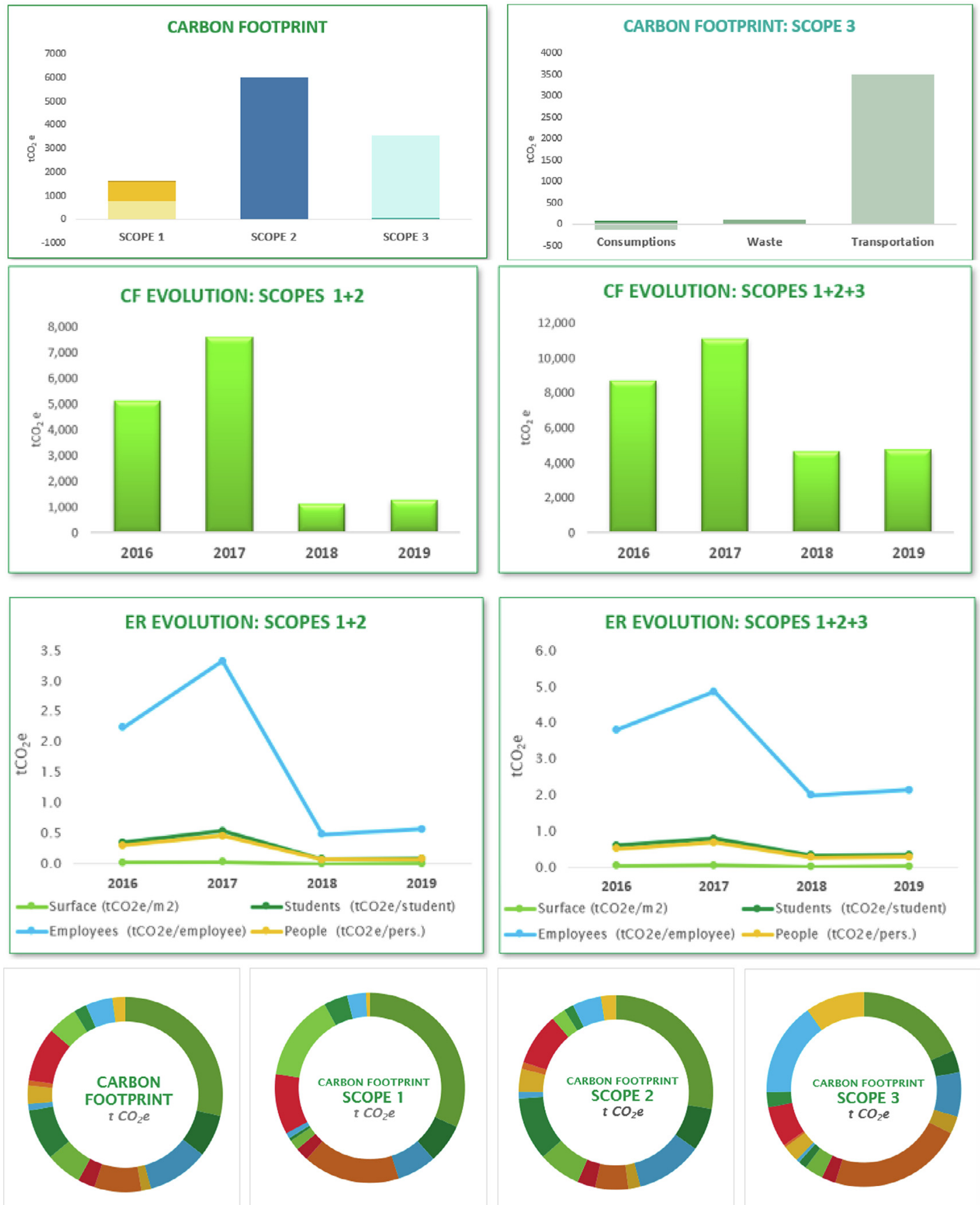

Fig. 5. Example of different graphic results that can be obtained with CO2UNV.

Table 7
Universitat Jaume I annual CF results.

	GLOBAL RESULTS (tCO_2e)					Area	Students	Employee	People	Available offsets	Offset rate
	Scope 1	Scope 2	Scope 3	Scope 1 + 2	Scope 1 + 2 + 3	($t\ CO_2e/m^2$)	($t\ CO_2e$/student)	($t\ CO_2e$/employee)	($t\ CO_2e$/person)	($t\ CO_2e$)	(% Scope 1 + 2)
2016	992.75	4109.27	3587.09	5102.02	8689.11	0.039	0.602	3.818	0.520	17	0.33%
2017	1572.21	6003.14	3507.69	7575.34	11,083.03	0.049	0.796	4.872	0.684	9	0.12%
2018	1121.98	0.00	3486.06	1121.98	4608.03	0.020	0.334	1.997	0.286	26	2.32%
2019	1263.73	0.00	3457.00	1263.73	4720.73	0.020	0.345	2.147	0.297	14	1.11%

Table 8
Action plan

	Energy saving (kWh/year)	Investment (€)	Amortisation period (years)	Annual cost (€/year)	Cost saved (€/year)	Pay-back (years)	CPIP (%) Scope 1+2	CPIP (%) Scope 1+3
AP 1	Electricity: 66,750	0.00	0	0.00	9,000.26	0	0.37%	0.22%
AP 2	Electricity: 510,404.59	0.00	0	0.00	36,685.65	0	2.51%	1.50%
AP 3	Electricity: 43,748.44	9,260.29	12	771.69	2,902.06	4.35	0.22%	0.13%
AP 4	Electricity: 767,767.21; Natural gas: 16,313.00	45,779.00	10	4,577.80	76,877.38	0.63	2.31%	1.33%
AP 5	Electricity: 179,288.00	99,050	12	8,254.17	23,504.66	6.49	0.98%	0.67%

sume large amounts of energy at the university (air conditioning and lighting).

- **IA2. Grouping university activity in the period from 08.00 to 19.30.** Many CO_2e emissions correspond to the electricity consumption, so it is advisable to compact all university activity and end the activity three hours earlier. Classroom occupancy levels indicate that this modification is possible with minimal changes.
- **IA3. Replacement of lighting on library level 1.** The current lamps are replaced by LED lamps because they are more energy efficient. This improvement is carried out because the analysis of the results shows that the library building accounts for a great percentage of the CO_2e emissions in scope 2 of the calculation.
- **IA4. Installation of thermal blankets in the indoor swimming pool.** The indoor swimming pool consumes a large amount of the university's energy resources (18% of the total natural gas consumption and 10% of the total electricity consumption). The use of the thermal blanket reduces the heat loss in the water, which gives rise to a decrease in fuel consumption by the boilers (they are turned off when the pool is not open) and a reduction in electricity consumption.
- **IA5. Cooling machine replacement for the TC building**. The current machine in the TC building of the School of Technology and Experimental Sciences is replaced by one that is more efficient in order to reduce the electricity consumption. Moreover, the new machine uses cooling gases with a lower global warming potential.

Table 8 shows the technical characteristics (energy savings), economic indicators (investment, amortisation period, annual cost, saved cost and pay-back) and environmental impact (carbon footprint improvement potential (CFIP) for scopes 1 + 2 and 1 + 2 + 3) for each individual improvement action. Note that the energy savings are calculated taking into account that the university does not have a 100% supply of renewable energy.

The economic and environmental (CF) indicators for each improvement action can be analysed jointly using eco-efficiency diagrams (Ibáñez-Forés et al., 2013). As Fig. 6 shows, each graph represents the CFIP (%) on the x-axis and the pay-back on the y-axis, and four equal areas are delimited by the maximum, medium and minimum values that each improvement action had on the two axes. Hence, each area represents a different level of environmental and economic efficiency. In this case study, the lower right area, shaded in green in the eco-efficiency graphs in Fig. 6, represents the area of maximum eco-efficiency, where the IA reaches the highest improvement in CF with the minimum pay-back period and can therefore be considered the best action.

Based on the eco-efficiency analysis, an action plan could be defined based on the implementation of three short-term improvements (A1, IA2 and IA4), and with the benefit obtained from these improvements helping to finance two longer term improvements (IA3 and IA5).

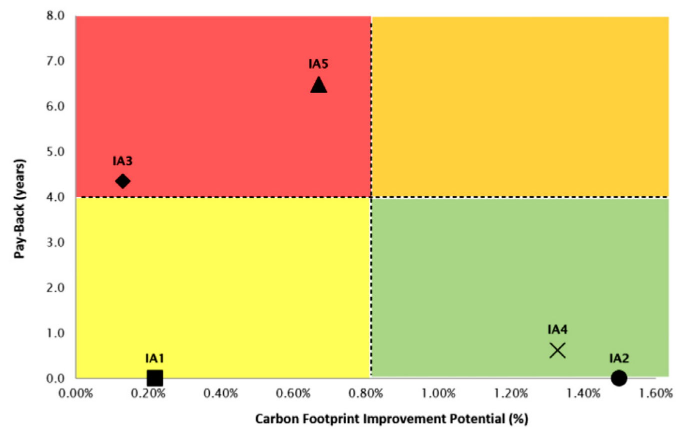

Fig. 6. Eco-efficiency analysis.

5. Discussion

Valls-Val-and Bovea (2021) and Helmers et al. (2021) concluded that universities need tools to calculate their carbon footprint in a complete, accurate and simple way. However, it has been observed that there are clear differences between the existing tools for calculating the CF of organisations in general, and universities in particular, both in terms of the input data (source and factor emissions) and the output data (results report). None of the tools reviewed in Table 1 allowed the calculation of the CF (scope 1 + 2 + 3) to be customised for universities in any geographical location.

For this reason, it was necessary to design a new tool specifically dedicated to calculating the CF of universities, including all the emission sources that are characteristically found in education centres. But, at the same time, the tool was designed to be flexible enough to be adaptable to other types of organisations since both the ES and the EF can be modified/expanded. CO2UNV is thus a fully customisable tool that can be adapted for any case study, in terms of both the number and the type of emission sources as well as the emission factor, even though it has default emission sources and emission factors. Compared to the CF calculation tools, CO2UNV improves the general tools analysed (CF, 2020; CFund, 2021; CoolCalifornia, 2021; Foundation myclimate, 2021; GHG Protocol, 2021; National Energy Foundation, 2017; Terrapass, 2021) by including the most significant emission sources of the universities, using Spanish emission factors, allowing users to introduce new emission sources and to use their own emission factors, and calculating CO_2 absorptions from their own offset projects. In addition, CO2UNV improves university-specific tools (CA-CP, 2020; SIMAP, 2020) because it uses Spanish emission factors, which can also be customised by the user to apply them to any education institution in the world. It also allows new emission sources to be included in order to make the calculation as complete as possible, to disaggregate the calculation by building/site in order to guide improvement actions and to analyse the evolution of CF over time so as to check whether the improvement actions are being effective. Finally, CO2UNV is an improvement on the Spanish tools (CEACV, 2015; ENECO, 2015; IHOBE, 2021; MITECO, 2020a; OCCC, 2020a) since it includes the most significant emission sources of the universities in order to obtain highly accurate results, disaggregates the calculation by building/site and analyses the evolution of CF over time.

To validate the applicability of the tool, a case study has been used, and the results have shown that all the emission sources that occur at Universitat Jaume I are incorporated into the tool. For this reason, the tool is applicable to universities and, also, to other education centres. Moreover, as can be seen in Table 7, the CF for different intensity rates for scope 1 + 2 + 3 over the last three years (2017–2019) (0.492 tCO_2e/student and 0.030 tCO_2e/m^2) is lower than those for the previous three years (2016–2018) (0.578 tCO_2e/student and 0.036 tCO_2e/m^2). It can therefore be concluded that CO2UNV is a useful tool for identifying hotspots from the CF perspective and for analysing the effect that improvement actions have on the CF.

To validate the accuracy of the results of the tool, those obtained with the CO2UNV tool have been compared (only for scope 1 + 2 and only using the default EF) with those obtained with the MITECO (2020a) tool. After modelling the four years used in the case study (2017–2019) in section 4.2, the same results were obtained for both the CF and the estimation of CO_2 absorptions due to the reforestation projects. It can therefore be confirmed that the CO2UNV tool provides valid results.

6. Conclusion

Given the proven importance of universities in leading the carbon footprint calculation and the lack of tools that include all their significant emission sources, it was considered necessary to design a specific tool for universities: CO2UNV. The tool is expected to help support the important goal of increasing sustainability and lead to more institutions fully reporting their emissions. As a result, this better comparability of results would generate confidence in reporting emissions.

CO2UNV is currently a prototype in the form of an Excel file and requires the development of an open source online version with a simple interface. As future developments, it would be interesting to add default European emission factors to the tool, in order to simplify the calculation of the CF of European universities. In addition, the tool could be updated to make it capable of storing data for different years and for different universities, and of simulating different improvement actions. This would facilitate the comparison of case studies. In addition, a graph with the 2030/2050 objective could be incorporated to show the trend in the reduction of emissions of the different alternatives introduced by the user in order to observe their behaviour and select the most appropriate one (for example, replacement of all lighting with LEDs, replacement of cooling machines, etc.). Finally, it would be interesting to export the results in a report in pdf format.

On the other hand, new methods for calculating some emissions need to be developed and followed. The carbon footprint should be complemented by other indicators in order to be used as a decision-making tool. Therefore, the tool should also be extended to be able to consider more aspects of sustainability, for example, the water footprint, environmental footprint, nitrogen footprint or energy footprint.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.11.020.

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