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GHG Accounting for sustainable mega-events: How lessons learnt during the Milan Expo 2015 world fair could lead to less carbon-intensive future mega-events

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ABSTRACT

World Fairs such as the Expo events are major events organized to generate tourism revenues, attract people and investments, but which result in environmental impacts that need to be accounted in a reliable and comprehensive way. In particular, accounting the greenhouse gases of a mega-event and comparing the emissions of different events is a very challenging task due to the large amount of data to be collected and to the lack of a specific methodology. In this paper, the quantification of greenhouse gas emissions and removals of Milan Expo 2015 international exposition is presented. Calculations, performed according to the international standard ISO 14064-1, includes office activities, construction of expo site and pavilions, operations and decommissioning process. Detailed information on data collecting methods and sources is shown in the paper. Furthermore, the obtained GHG results normalized to the number of visitors were compared to other mega-events, i.e. the latest Olympic Games, FIFA World Cups and Shanghai Expo 2010. With all the limitations described in the paper, the results showed a total impact of World Expos of about one ton of $CO_{2\text{-eq}}$ per square meter of exhibition and averagely 60 $kgCO_{2\text{-eq}}$/visitor. Olympic Games and FIFA World Cups have an average impact respectively of 400 $kgCO_{2\text{-eq}}$/visitor and 600 $kgCO_{2\text{-eq}}$/visitor. The performed analysis was presented in the form of requirements and guidelines with the aim of refining the existing standard methodology highlighting the specific aspect of mega-events and transferring the findings to future world fairs.

1. Introduction

Mega-events are major events that occur in a city or even larger area mainly used to generate tourism revenues, attract people and investments in order to increment and create economic development opportunities, to regenerate parts of cities, to attract foreign investment and to preserve cultural values. On the basis of a review of existing definitions, in 2015 Müller proposes four constitutive dimensions of mega-events: visitor attractiveness, mediated reach, costs and transformative impact (Müller, 2015). The most well-known mega-events are the Olympic Games, FIFA World Cup and a World Fair such as the Expo events (Parkers et al., 2016). In particular, world fairs are events aiming at educating the public, sharing innovation, promoting progress and fostering cooperation between nations. Since the 1928 Convention Relating to International Exhibitions came into force, the International Bureau of Exhibitions (BIE, Bureau International des Expositions) has served as an international sanctioning body for international exhibitions. There are two types of world fairs organised under the auspices of the BIE: World Expos (formally known as International Registered Exhibitions) and Specialised Expos (formally known as International Recognised Exhibitions). World Expos encompass universal themes that affect the full gamut of human experience, and international and corporate participants are required to adhere to the theme in their representations. Due to the diversity of its participants, a World Expo is an event where extraordinary exhibitions, diplomatic encounters, business meetings, public debates and live shows take place at the same time. Briefly, an Expo can be defined as a dialogue platform for progress and cooperation between nations and cultures. Their duration may be between six weeks and six months. Since 1995, the interval between two World Expos has been at least five years. The latest World Expo - Expo 2015 - held in Milan, Italy, from 1 May to 31 October 2015, is the case study presented in this paper. Hosting a mega-event can help a

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country to modernize and make an area more competitive, but it involves environmental aspects that need to be accounted in a comprehensive way, including sustainable planning approaches, sustainable practices and sustainable legacies (Gaffney, 2013). Therefore, in the last decade, also thank to the increasing global awareness on climate change, interest in implementing sustainability and green strategies and practices has been introduced into the organization of mega-events as a challenge faced by hosting cities and countries (Coakley and Souza, 2013; Laing and Frost, 2010; Liang et al., 2016; Wang, 2011; Reverberi, 2011). Following their generally wider and greater attractiveness to populations, sports mega-events were the first to be analysed in terms of opportunities and frameworks to increase their sustainability starting from the planning stage (Ma et al., 2011) and in terms of methodologies for the accounting and reporting of multiple impacts and the contribution to territorial development for hosting areas related to the organisation of the event (Frey et al., 2007). From this point, the debate on sustainability accounting and reporting has been extended to different types of mega-events, such as fairs, and different assessment models have been proposed (Lobato, 2014; Iraldo et al., 2015). Yet despite the growing interest in adopting sustainable practices in tourism policy making and research, tourism is less sustainable than ever unless environmental measures are promptly adopted (Balsas, 2017; Deng and Poon, 2013; Ferrari and Guala, 2017; Hall, 2012; Holmes et al., 2015; Nichols et al., 2017). For example, temporary structures created during mega-events have to respond to sustainable design rules as regards speed of execution, architectural design, safety, thermal, acoustic and other performances. Sometimes it is difficult to meet all these requirements and also achieve good environmental performance (Cipollini et al., 2016; Grosso and Thiebat, 2015; Kirk, 2015; Petersson et al., 2017). Furthermore, the renewal or construction of new buildings and the implementation of strategies for their management are crucial factors for achieving sustainability (Magrassi et al., 2016). Regarding sustainable practices while hosting a mega event, waste management and air emissions are other significant issues to be managed aiming at sustainability enhancement of mega-events. Waste monitoring and measuring as a sustainability initiative has a key role in many mega-events in order to implement actions to reduce waste (Rajan and Booth, 2016). A good example of sustainable strategies applied to mega-events is the Beijing Olympic Games of 2008, presented by Wu et al. (2011). Beijing enhanced and guaranteed an air quality level during the whole period of the Olympic Games by adopting different measures to reduce and control air pollution. Moreover, measures to reduce the SO_2, NO_X, PM10, CO and VOC emissions from stationary sources were implemented during the event. In particular the reduction of CO_2 emissions was assessed (Wu et al., 2011; Jiang, 2011) according to a purposely created standard applied to the new buildings of the mega-event. This specific case goes to show how a mega-event can create specific conditions through which sustainability can be increased in the hosting area. However, the sustainability of the area should also be tied to the continuity of the actions after the event itself, which not coincidentally, generate environments propitious for multi-national corporations to sell and recycle their own goods (Gaffney, 2013). Despite the strong appeal, additional research is required to provide useful analysis of the real sustainability of mega-events. Focusing on climate change, some research has been published on the impacts of sport mega-events. Besides the aforementioned Beijing Olympic Games (Wu et al., 2011), GHG inventories were developed for London 2012 and Rio 2016 Olympics Games (Parkes et al., 2016; Lindau et al., 2016; Collins et al., 2009), for FIFA World Cups (Pereira et al. 2017) and for other sport events (Scrucca et al., 2016, Pereira et al., 2019, Dolf and Teehan 2015). In addition to the scientific literature reported above, there are official reports available for Olympic Games (UNEP 2009, LOCOG 2010, COJOPR 2016), FIFA World Cups (UNEP 2012a, FIFA 2014, FIFA 2016) and EXPO 2010 (UNEP 2012b). Despite several GHG accounting were performed for mega-events, there is consensus that a standardized methodology for measuring, calculating and reporting the GHG emissions of major events does not currently exist (COJOPR, 2016, UNEP, 2012b). Therefore, we can affirm that there is a lack of knowledge on carbon accounting methodology which is specific for mega-events and, in particular, for Expo events. In this paper, the quantification of greenhouse gas (GHG) emissions and removals of Milan Expo 2015 is presented. The GHG inventory of this world fair was accounted by the authors in accordance with the international ISO 14064 (ISO, 2006a), standard, revised in 2019 (ISO, 2019b), starting from the construction of the site through to the decommissioning process of the facilities at the end of the event. Detailed information on data collecting methods and sources is shown in the paper to provide guidance for practitioners in improving the effectiveness of data collection for reliable greenhouse gas accounting of mega-events. Furthermore, the obtained GHG results normalized to the number of visitors were compared to other mega-events, i.e. the latest Olympic Games, FIFA World Cups and Shanghai Expo 2010, with the aim of refining the existing standard methodology highlighting the specific aspect of mega-events and transferring the findings to other world fairs, thus leading to less carbon-intensive future mega-events.

2. The case study

Milan Expo 2015 was focused on a current topic of extreme interest: to provide healthy, safe and sufficient food for all people, while respecting the planet and its natural balances. The opening event took place on May 1, 2015, and the closing event on October 31, 2015. Therefore, the event phase lasted six months. Preparatory events and the construction phase of the site started in 2012 and ended on April 30, 2015, while the decommissioning phase began in November 2015 and ended in June 2016. The exposition area chosen was located in Italy, in the Municipalities of Rho and Pero about 15 km northwest of Milan, covering an area of 1.1 million m^2. The construction site was developed around two main roadways called Cardo (from North to South) and Decumanus (from East to West) representing the structure of the Ancient Roman cities where heterogeneous structures (the pavilions) were built, giving the idea of an ancient fair where different cultures and products are melted. For the purpose of the GHG inventory, the Milan Expo 2015 boundaries were broken down into the following installations: offices, base camp, exhibition site, pavilions, and waterways. All of these installations, shown in Fig. 1, were realized by Expo 2015 S.p.A. or by its subcontractors for the purpose of the Expo, except the already-existing offices and of the pavilions directly set up by the host Countries.

3. Greenhouse gas inventory

3.1. Methodology

The quantification of GHG emissions and removals of Milan Expo 2015 was performed according to the ISO 14064:2006-I (ISO, 2006) standard. This ISO standard specifies principles and requirements at organization level for the quantification and reporting of GHG emissions and removals. In accordance with the standard, the GHG emissions were divided into the following categories: sources of GHG emissions under the direct control of the organization; indirect GHG emissions from consumption of purchased energy; other indirect emissions. As the inclusion of other indirect emissions is a voluntary decision, the Expo 2015 S.p.A. organization decided which GHG sources to include in the inventory itself on the basis of the significance or quality of available data. In particular,

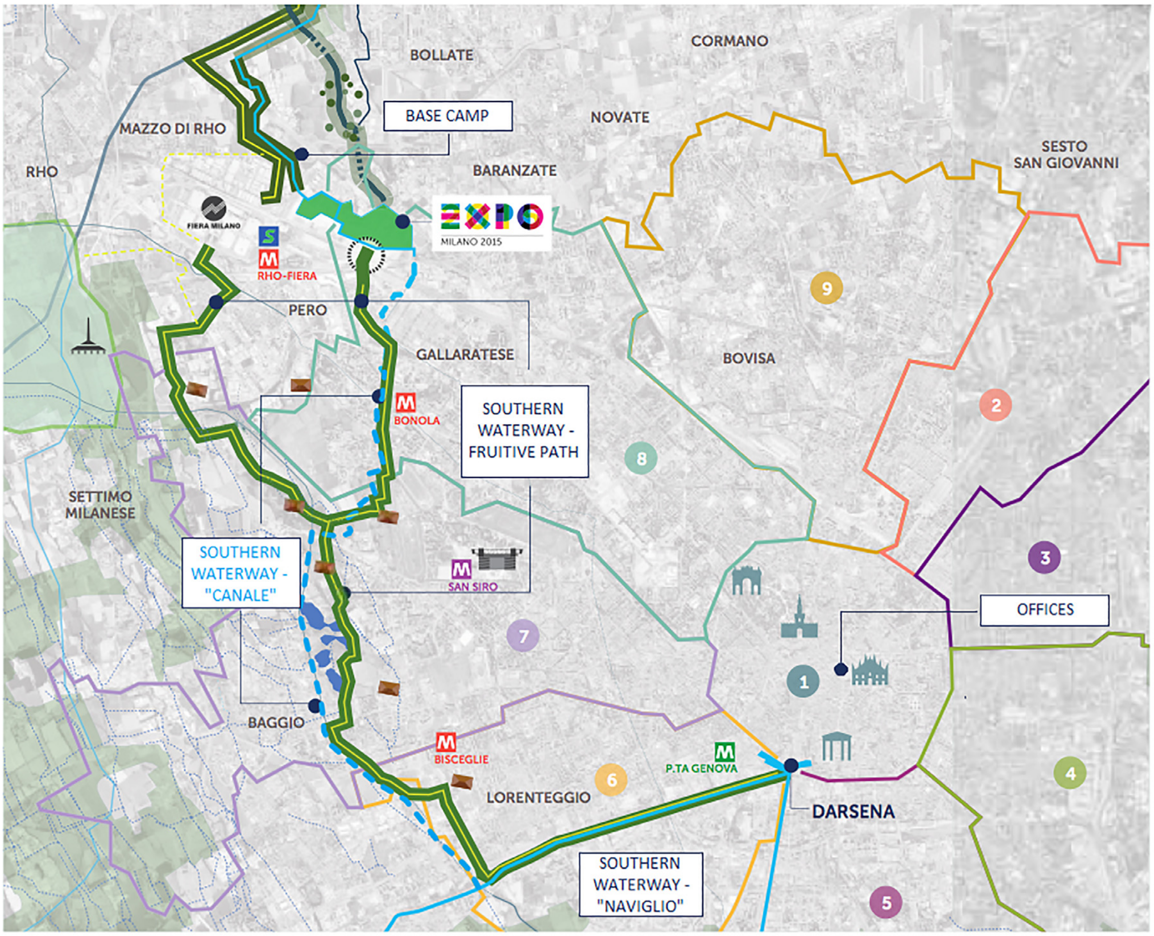

Fig. 1. Organization boundaries and installations of Milan Expo 2015.

among such sources, the journeys made by visitors could have a high impact on climate change. In this category of indirect sources, in accordance with the principle of additionality as provided for in current methodology, only public transport for visitors additional to existing local lines, including railway lines, subway, tram, bus and trolleybus to the exhibition site, were included in the GHG inventory contribution. Instead, Expo 2015 S.p.A. decided to exclude from its official GHG inventory travel of visitors from around the world towards the site as they didn't involve new flights or trains upon the standard situation (MATTM, 2016a). Anyway, due their significance and to the need of enhance comparability with other mega-events inventories, the estimation of GHG emissions of visitors were nevertheless reported in the paper (MATTM, 2016b). The study was performed along the lifecycle of the event, starting from its construction through to its decommissioning. Therefore, the sources of GHG emissions were identified for each phase and for each installation (offices, base camp, exhibition site, pavilions, and waterways). According to the standard, the GHGs considered were: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (WRI – WBCSD, 2013). The GHG emissions were calculated using specific emission factors (EF) retrieved from the Ecoinvent 3.1 (Wernet et al., 2016) database or from literature. The Ecoinvent database includes information about the production and distribution of a wide range of raw materials used, for example, in the construction as well as in the transport sector. To determine the EF, i.e. the tCO_2-eq (carbon dioxide equivalent) per unit of product/process considered, the IPCC 2013 (IPCC, 2014) method was used. Once all the factors had been defined, the emissions of each product/process were calculated by multiplying the specific data collected for the corresponding EF. The GHG emissions and removal for each scope are summarized in Table 1.

3.2. Data collection

To carry out the aforementioned activities, the mega-event inventory was divided into the following categories:

1 Offices and Travel (OT)
2 Construction Site (CS)
3 Construction of Pavilions (P)
4 Preparatory Events (PE)
5 Exhibition (E)
6 Decommissioning Process (DP)

Each category may include one or more physical installations as defined in chapter 2. Specific data on materials, energy consumption, means of transport used, waste treatments and surfaces subject to the land use change process were collected through different procedures, such as:

- Specifically designed questionnaires filled in by the subcontractors to collect all the information about the materials used, fuel and energy consumption and waste management related to the construction/disposal processes;
- Invoices issued by various suppliers (e.g. energy consumption bills) and lease contracts;
- Specific registers to collect travel information (e.g. passenger car mileage, boarding passes, train tickets).

Table 1
GHG emissions and removals of Milan Expo 2015.

Description	GHG emissions and removals
Source of GHG emissions under direct control of the organization	– Fuel use (natural gas and diesel) for energy purpose – Company car fleet for business travel of the employees – Refrigerant leakages
Indirect GHG emissions from consumption of purchased energy	– Electricity used by Expo 2015 S.p.A. subcontractors for the Exhibition Site, the Base Camp and the Waterways construction and decommissioning – Electricity used by the Offices of Expo 2015 S.p.A. during all the phases – Electricity used by the Exhibition Site and the Pavilions during the event
Indirect emissions	– Materials used by Expo 2015 S.p.A. subcontractors for Base Camp, Exhibition Site, Pavilions and Waterways construction and decommissioning – Energy (fuels and electricity) used during the construction and decommissioning phases of the Pavilions, not in scope II as the Pavilion construction is not under the control of the Expo 2015 S.p.A. organization – Business travel of Office workers by car, train and plane – Paper consumption by the Offices – Waste transport and disposal, generated by all the installations during all the phases – Change of land use due to the construction of the new installations: Base Camp, Waterways, Exhibition Site and Pavilions. The Offices were rented and not built for the event – Preparatory events managed by the Offices such as conferences and meetings before the event, considering energy and material consumption and transport – Public transport for visitors when dedicated and additional to existing local lines, including railway lines, subway, tram, bus and trolleybus to the Exhibition site – Logistics, including cargo transports of goods and transport of people inside the Exhibition site.

Table 2
Data collected for OT category – OFFICE (referred to m^2).

Offices and Travel (OT)		2012	2013	2014	2015	2016	Total
Electricity (kWh/m^2)	–	34.65	60.44	162.24	242.25	85.59	585.18
Fuel use	Natural gas (Stdm^3/m^2)	0.279	0.126	0.253	–	–	0.658
	Diesel (kg/m^2)	–	–	0.009	0.031	0.015	0.055
Refrigerants leakages (kg/m^2)	R410A	–	–	0.0008	0.0007	0.0003	0.0018
Paper consumption (kg/m^2)	–	0.158	0.211	0.532	0.666	0.115	1.682

Table 3
Data collected for OT category – TRAVEL.

Offices and Travel (OT)		2012	2013	2014	2015	2016	Total
Company cars (km)	Cars	39,660	75,223	220,868	923,680	16,200	1,275,631
Business travel (km)	Domestic flight	131,041	177,236	424,003	310,672	103,557	1,146,509
	Continental flight	123,707	167,316	326,240	283,683	94,561	995,507
	Intercontinental flight	653,798	884,278	2,298,627	5,389,043	1,796,348	11,022,094
	Train	257,895	327,500	564,452	496,899	165,633	1,812,379

Detailed information on the considered categories as well as data collecting methods and sources are reported separately in the following paragraphs for each installation and category. Data were collected on an annual basis.

3.2.1. *Offices and travel (OT)*

Concerning the Offices and Travel (OT) category, all emissions associated with offices, including administrative issues and business travel, were collected. In particular, the following data were gathered:

- Total square meters of the office buildings available from the lease contracts;
- Fuels (natural gas and diesel) and electricity consumption from the supplier's bills;
- Losses of refrigerants estimated from the weight of refrigerants of the air conditioners;
- Paper consumption from purchase invoices;
- Type of cars used by the personnel and mileage. For each vehicle, specific fuel consumption were considered according to the type of car and the actual km from the odometer readings;
- Number of trips and distance travelled by train and plane for business travel of Expo personnel from purchasing office.

The total office surface area was equal to 21,473 m^2. Data collected for the OT category from 2012 to 2016 are summarized separately for office and travel subcategories in Tables 2 and 3.

3.2.2. *Construction site (CS)*

The Construction Site (CS) category includes only buildings and structures – including some permanent buildings – built by the hosting country (Italy) or by Expo 2015 S.p.A. subcontractors: i.e. exhibition site, base camp, waterways. Data belonging to this category are: energy use (electricity and fuel use), construction materials (building materials, metals and other materials), generated waste and the operations producing a land-use change. Fuel use refers only to the on-site consumption and the electricity con-

Table 4
Data collected for CS category (referred to m^2 of site surface area).

Construction Site (CS)		2012	2013	2014	2015	Total
Electricity (MWh/m^2)	–	0.00006	0.00043	0.00077	0.00021	0.00147
Fuel use	Diesel (kg/m^2)	0.02281	1.47338	0.00314	0.00098	0.00150
	Gasoline (kg/m^2)	–	0.0002	0.0203	0.0062	0.0267
	Natural Gas ($Stdm^3/m^2$)	0.0155	0.0073	–	–	0.0227
	GPL (kg/m^2)	0.00109	0.00332	0.00267	0.00005	0.00714
	Acetylene (kg/m^2)	–	0.0003	0.1205	0.0298	0.1505
Building materials (ton/m^2)	Concrete	0.052	0.093	0.259	0.089	0.493
	Cement	–	–	0.04645	0.00050	0.04695
	Brick	–	0.00009	0.00199	0.00165	0.00373
	Inert	–	–	0.128	0.111	0.239
	Bitumen	–	0.03037	0.01901	0.00538	0.05475
	Bentonite	–	0.00011	0.00004	–	0.00015
	Lime	–	–	0.00003	0.00027	0.00030
	Oil	–	0.00080	0.00000	–	0.00080
	Polycarbonate	–	–	0.00003	–	0.00003
	Print	–	–	0.00001	–	0.00001
	Resin	–	–	0.00002	–	0.00002
	Plasterboard	–	–	0.00081	0.00051	0.00132
	Linoleum	–	–	0.00001	0.00019	0.00020
	Insulating materials	–	–	0.00004	–	0.00004
	Gres	–	–	0.00001	–	0.00001
Metals (ton/m^2)	Steel	0.0001	0.0064	0.0251	0.0081	0.0396
	Copper	–	0.00001	0.00008	0.00002	0.00011
	Iron	0.00182	0.00127	0.00548	0.00116	0.00973
	Aluminium	–	–	0.00004	0.00002	0.00005
	Cast Iron	–	0.00020	0.00001	0.00002	0.00024
Other materials (ton/m^2)	Wood	0.00008	0.00070	0.01425	0.00233	0.01736
	PVC	0.00014	0.00277	0.00098	0.00018	0.00407
	Glass	–	–	0.01217	0.00001	0.01219
	Water	–	–	0.0445	0.0213	0.0657
	Paper and paperboard	–	–	0.000002	0.000001	0.000003
Waste (ton/m^2)	Plastic Disposed	–	0.00014	0.00005	–	0.00019
	Recycled	–	0.00000	0.00001	–	0.00001
	Wood Disposed	–	0.00012	0.00072	0.00032	0.00116
	Recycled	0.0236	0.0003	0.0001	0.0376	0.0381
	Inert Disposed	–	–	0.00443	0.00832	0.01274
	Recycled	–	0.00107	–	–	0.00107
	Iron and steel Disposed	–	0.00041	0.00057	0.00011	0.00109
	Recycled	0.00100	0.00006	0.00002	0.00593	0.00601
	Sludge Disposed	0.011	0.064	0.095	0.033	0.203
	Recycled	0.087	0.149	0.137	0.070	0.444
	Paper and Disposed paperboard	–	–	0.00003	0.00001	0.00004
	Recycled	–	0.0000022	0.0000000	0.0000003	0.0000025
	Batteries Disposed	–	0.00000032	–	–	0.00000032
	Recycled	–	–	0.00000014	–	0.00000014
	Mixed waste from construction and demolition operations Disposed	0.01000	0.00504	0.01270	0.01388	0.04162
	Recycled	0.015	0.064	0.045	0.009	0.132
	Building materials of plaster Disposed	–	–	0.00010	0.00005	0.00015
	Recycled	–	–	0.0001	0.0119	0.0120
	Packaging materials Disposed	–	–	0.00016	0.00015	0.00031
	Recycled	0.100	0.001	0.001	0.074	0.175
	Mixed waste Disposed	–	0.0017	0.3868	0.0023	0.3908
	Recycled	0.2599	0.0899	0.0010	0.0002	0.3509
	Asphalt and bituminous mixtures Disposed	–	–	0.00355	0.00494	0.00849
	Recycled	0.00182	0.01541	0.01595	0.00332	0.03650
	Glass Disposed	–	–	0.000003	0.000003	0.000007
	Packaging of dangerous substances Disposed	–	–	0.0000004	–	0.0000004
	Recycled	–	–	–	–	–
	Insulating materials Disposed	–	–	0.000001	–	0.000001
	Recycled	–	–	0.000002	–	0.000002
	Oil Disposed	–	0.0000003	–	–	0.0000003
	Recycled	–	–	–	–	–
Land use change (m^2/m^2)	Cut trees	0.076	0.576	0.495	–	1.147
	Replanting	–	–	0.0981	–	0.0981

sumption is meant as purchased from the grid, so no double counting is involved for the electricity production from fossil fuels. Specific questionnaires were filled in by each subcontractor in charge of the construction operations in order to ensure good quality of the data collected from the suppliers. Data on quantity and quality of waste produced were collected by the organization's waste registers on the basis of the European Waste Catalogue (EWC) (Fortunati et al., 1994). GHG inventories, and thus data collection, were created on an annual basis from 2012 to 2015 until the start of the exhibition on May 2015. All the data gathered by the 41 subcontractors involved in the construction of the site referred to the total surface area of the construction site are summarized in Table 4. The construction site covered a total area of 110 hectares.

Table 5
Data collected for P category (referred to m^2 of building surface area).

Construction of Pavillions (P)		Kiosks	Wood pavilions	Steel pavilions	Mixed structure pavilions	Average
Electricity (kWh/m^2)	–	0.12508	–	–	0.00013	0.00008
Fuel use (kg/m^2)	Diesel	0.001	0.025	0.011	54.172	38.249
	Gasoline	–	–	–	0.0004	0.0002
Building materials (ton/m^2)	Concrete	–	0.00258	–	0.00009	0.00005
	Cement	–	0.00024	–	0.00029	0.00022
	Asphalt	–	–	–	0.00003	0.00002
	Bentonite	–	–	–	0.00032	0.00018
	Paint	–	0.00142	–	–	0.00038
	Plasterboard	–	0.00747	0.00204	0.00007	0.00004
	Linoleum	–	0.00015	–	–	0.00004
	Mineral wool	–	0.00542	–	0.00003	0.00002
	Stucco	–	–	–	0.00101	0.00056
	Glue	–	0.00056	–	–	0.00015
Metals (ton/m^2)	Steel	–	0.00005	0.00048	0.00035	0.00027
	Copper	–	0.00052	–	0.00863	0.00495
	Iron	0.00284	0.00306	–	0.00002	0.00001
	Aluminium	–	0.00022	–	0.00661	0.00375
Other materials (ton/m^2)	Wood	0.00873	0.00022	–	0.00393	0.00006
	PVC	0.00022	0.01196	0.00479	0.00003	0.00002
	Glass	–	0.00183	0.01336	0.00003	0.00002
	Water	–	0.00064	–	0.00006	0.00021
	Paper and paperboard	–	–	–	0.00079	0.00044
Waste disposed (ton/m^2)	Plastic	–	0.00157	–	–	0.00042
	Wood	–	0.00239	–	0.00038	0.00085
	Inert	–	0.00299	–	0.01575	0.00960
	Iron and Steel	–	–	–	0.00456	0.00254
	Sludge	–	0.00086	–	0.00014	0.00008
	Mixed waste	–	–	0.02939	0.00007	0.00004
Land use change (m^2/m^2)	Cut trees	–	–	–	0.00090	0.00050
	Replanting	–	–	0.00134	0.00126	0.00087

3.2.3. Construction of pavilions (P)

Each country participating in Milan Expo 2015 was hosted in a self-constructed pavilion/kiosk built by the countries themselves and by their main sponsors. The category related to pavilions (P) includes all emissions associated with their construction. The dataset to be collected for P category was comparable with the one collected for the CS category, but the two categories were divided since data quality decreased when the activities were not performed under the direct control of the organization, such as for the construction of pavilions. Due to the high number of pavilions (96) and to the absence of direct control by Expo 2015 S.p.A., it was not possible to collect direct data for all the buildings: therefore, for the purpose of the study, some estimations were needed. All the pavilions were temporary buildings Gathering data on pavilion construction was difficult mainly due to the high number of data holders: therefore, specific datasets on a sample of 10% of pavilions were collected and then proportionate to the total square meters of each specific macro-category. The selection criteria for the definition of the sample include the following rules: size representativeness (big pavilions, small pavilions, kiosks), prevailing material representativeness (wooden pavilions, steel pavilions, mixed-structure pavilions -concrete, glass, metals, etc...), availability of reliable data (questionnaires validated by Expo 2015 S.p.A.). Table 5 summarizes the data collected for the following four similar macro-categories of buildings realized by host countries in the exhibition area: kiosks (4581 m^2), wooden pavilions (26,763 m^2), steel pavilions (12,725 m^2) and mixed-structure pavilions (55,490 m^2). Data are referred to the specific surface area of each building macro-category. The weighted average value is also shown.

3.2.4. Preparatory events (PE)

Five preparatory events (PE) were held in 2012, 2013 and 2014 to disseminate the principles and purposes of the Milan Expo 2015 on food, equality and food availability for all people. In this category, all the emissions associated with the preparation of these events were accounted. In particular, all the consumption in terms of energy, materials and transportation were collected from administrative reports. Table 6 shows the data collected for each event.

3.2.5. Exhibition (E)

The exhibition category (E) includes all emissions associated with the event phase, from June 5 to October 31, 2015. More specifically, energy consumption (electricity), refrigerant gas leakages, public transport, waste generated during the event and all the emissions associated with logistic operations (i.e. goods transport) are summarized in Table 7. Data were collected directly by Expo 2015 S.p.A. and came from invoices, lease contracts and specific travel registers.

3.2.6. Decommissioning process (DP)

All the sources of GHG emissions associated with the decommissioning process of the site at the end of the process were included in the DP category. In the case of Milan Expo 2015, disposal began as soon as the event ended. However, in accordance with the project of future reuse of the exhibition area, not all the mentioned structures and buildings were dismantled. Therefore, calculation included only the structures directly built by the participating nations and dismantled at the end of the event (i.e. pavilions and kiosks). The dismantling process, even if carried out by subcontractors, was under the direct control of Expo 2015 S.p.A.. Good quality of the data collected from the suppliers was therefore achieved. A specific questionnaire was filled in by each subcontractor responsible for dismantling operations. Data collection refers to the period November 2015-June 2016. Table 8 summarizes the data collected in this phase for each of the four main categories of buildings realized in the exhibition area. Data refer to the specific surface area of each building category. No impacts are reported for kiosks, as they were manually dismantled and reused.

Table 6
Data collected for PE category.

Preparatory events (P)		Event 1 2012	Event 2 2012	Event 3 2012	Event 4 2013	Event 5 2014	Total
Electricity (kWh)	–	1224	1368	15,000	1344	7900	26,836
Fuel use	Diesel (kg)	–	–	–	–	1907	1907
	Natural gas (Stdm^3)	–	–	2000	–	–	2000
Materials (kg)	Paper	84	52	1000	1809	216	3161
Transport (km)	Train	9600	30,000	–	–	–	39,600
	Underground	–	–	33,000	–	–	33,000
	Bus	–	–	7200	–	–	7200
	Semitrailers	800	1200	–	1000	–	3000
	Trucks and vans	16,800	7200	5400	300	–	29,700
	Passenger car	1200	600	–	–	–	1800
	Replanting	–	–	17,012	70,083	–	87,095

Table 7
Data collected for E category.

Exhibition (E)		2015
Electricity (kWh)		1,604,423
Refrigerants leakages (kg)	R410A	–
	R407C	–
Public Transport (km)	Underground	7,890,000
	Tram	475,000
	Bus	1,105,000
	Trolleybus	87,000
	Railways	491,122
Logistic (km)	People mover	103,835
	Shuttle service	651,328
	Passenger car	1,146,934
	Delivery van < 3.5t	9,810,634
	Delivery van 3.5÷7.5t	2,450,518
Waste (ton)	Plastic, aluminium and steel packaging	657
	Wood	152
	Paper	1065
	Glass	888
	Organic	1487
	Mixed waste	1800
	Sweeping refuse	271

Table 8
Data collected for DP category (referred to m^2).

Decommissioning Process (DP)		Kiosks	Wooden pavilions	Steel pavilions	Mixed structure pavilions	Average
Electricity (kWh/m^2)	–	–	–	–	–	–
Fuel use (kg/m^2)	Diesel	–	5.5	11.3	3.5	4.9
	Gasoline	–	0.037	–	–	0.010
Metals (ton/m^2)	Steel	–	0.0039	–	–	0.0010
	Aluminium	–	0.0073	–	–	0.0020
Water (ton/m^2)	Water	–	0.048	0.010	–	0.014
Waste disposed (ton/m^2)	Plastic	–	0.00157	–	–	0.00042
	Wood	–	0.0024	–	0.0004	0.0009
	Inert	–	0.0031	–	0.0158	0.0096
	Iron and Steel	–	–	–	0.0046	0.0025
	Sludge	–	0.001	–	0.136	0.076
	Mixed waste	–	–	0.029	0.074	0.045

4. Results and discussion

4.1. Milan Expo 2015 greenhouse gases emissions

Based on the data collected and summarized in the previous paragraphs, the corresponding GHG emissions expressed in tonnes of carbon dioxide equivalent ($tCO_{2\text{-eq}}$) were calculated using specific EF. The list of the EF used are shown in Annex 1. Fig. 2 reports the total emissions for the OT category for all the years examined. The results indicated in the illustration show that the OT category emissions were mainly due to electricity consumption and to business flights. Refrigerant gas leakages and paper consumption, as well as land use change in an already urbanized context, are not significant in terms of GHG emissions. Fig. 3 summarizes the total emissions for the construction of the site. Construction phase GHG emissions are mainly due to the use of construction materials for new installations, i.e. the exhibition site, the base camp and the waterways. The major impacts derive from concrete and cement for the building materials, steel and iron for the metals, wood and glass for the other materials: the impacts are related to the manufacturing of each material. Energy consumption, which includes both electricity and fuel consumption such as diesel consumption of machines during the construction phase, accounted for a lighter impact. The emissions shown in Fig. 3 refer to the total impact deriving from the construction of the exhibition site: nevertheless, the impacts deriving from the construction of permanent buildings may be allocated. Considering an allocation method based on economic return and lifetime of these buildings and assuming that one-third of the total lifetime of permanent structures was in charge to Expo 2015 S.p.A. while the remaining two-third

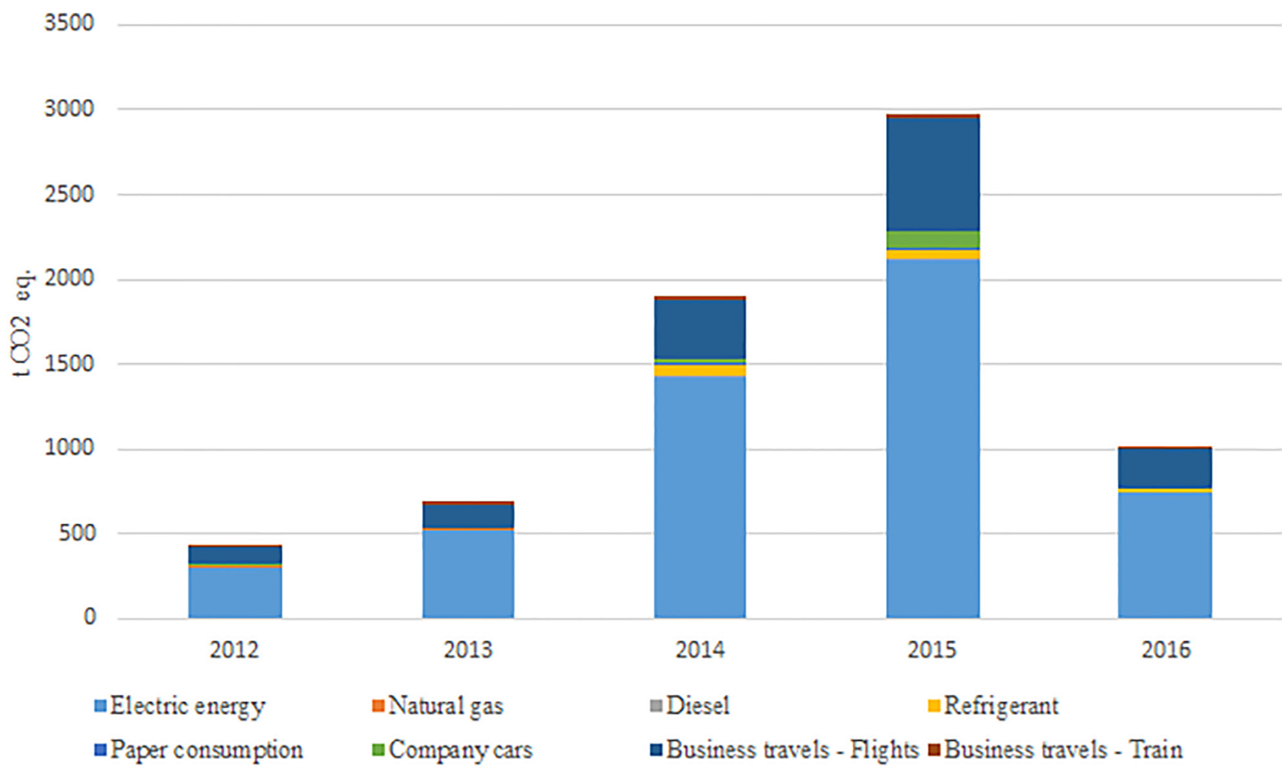

Fig. 2. GHG emissions ($tCO_{2\text{-}eq}$) for OT category.

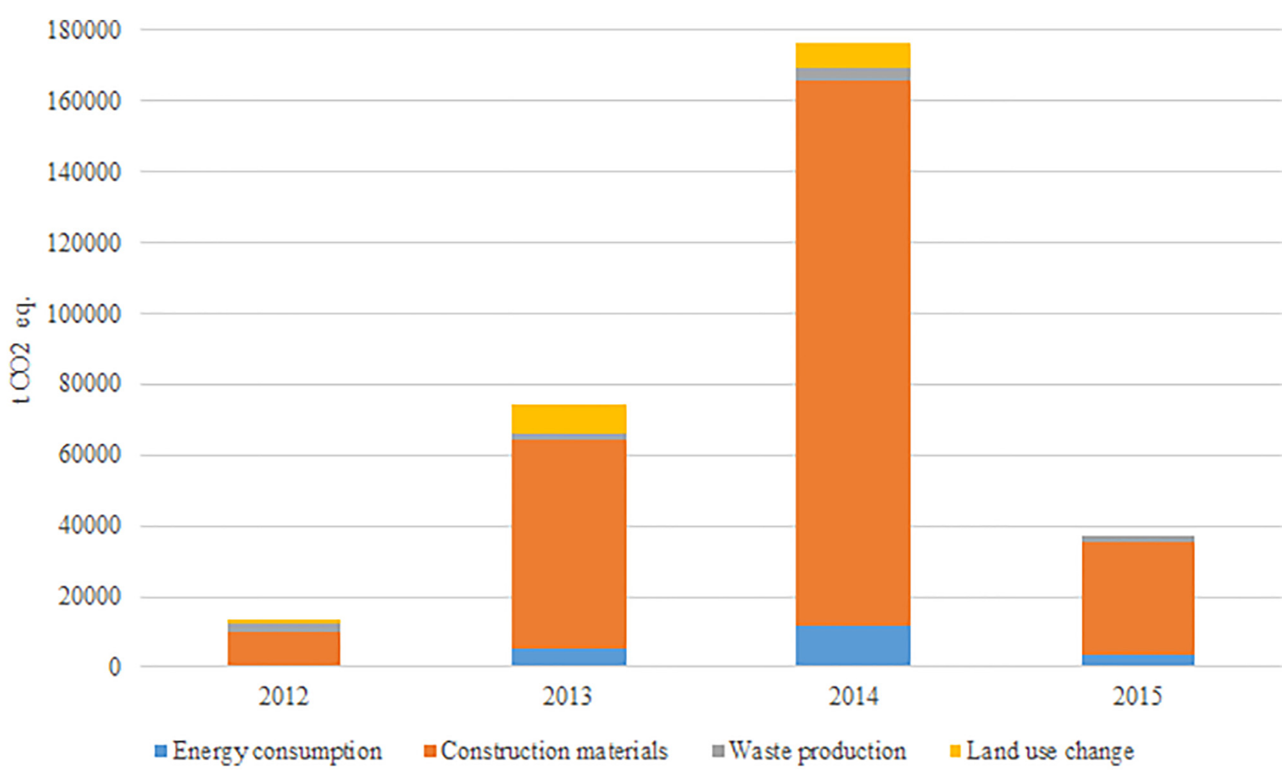

Fig. 3. GHG emissions ($tCO_{2\text{-}eq}$) for CS category.

will be available as legacy for other uses, an overall GHG emission equal to 169,947.5 $tCO_{2\text{-}eq}$ was not attributed to the activities of Milan Expo 2015. Fig. 4 reports the total emissions for the P category. Similarly to the construction phase, in the P category, GHG emissions were also mainly due to the use of building materials for the construction of the pavilions. The major impacts derive from concrete, mineral wool and plasterboard for the building materials, steel and aluminium for the metals, PVC and wood for the other materials. Fig. 5 shows the total emissions for the PE category. The impact of preparatory events, such as press conferences and conventions, strongly depends on the number of events that took place before the exhibition. Regardless of this, the results

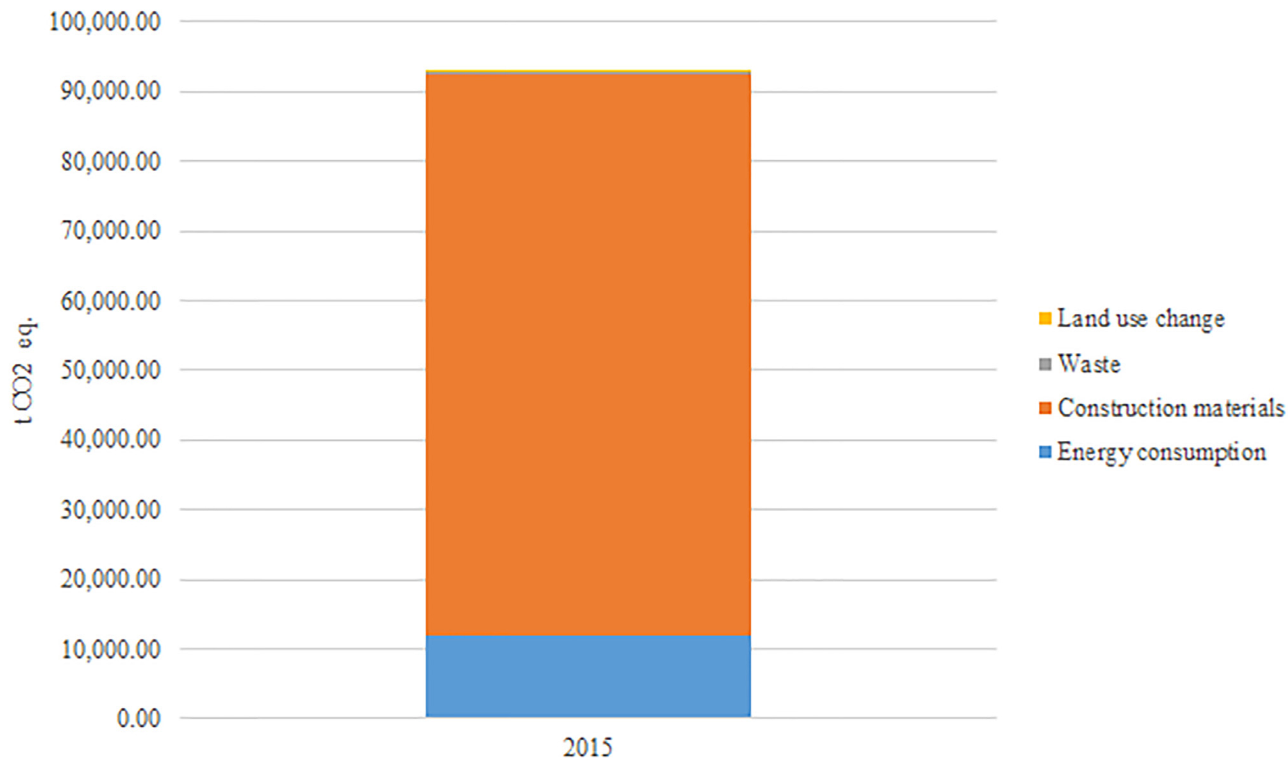

Fig. 4. GHG emissions ($tCO_{2\text{-}eq}$) for P category.

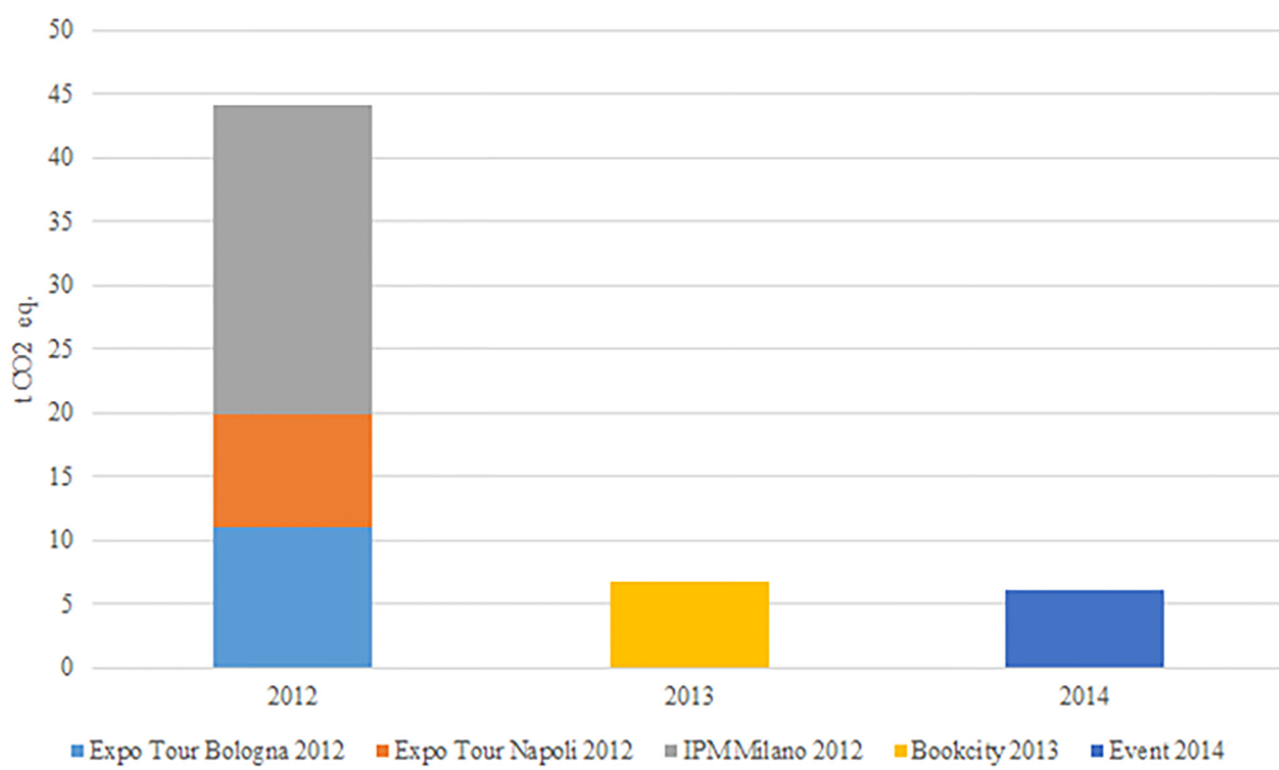

Fig. 5. GHG emissions ($tCO_{2\text{-}eq}$) for PE category.

show that each preparatory event had an average impact that varied between 5 and 25 $tCO_{2\text{-}eq}$. The GHG emissions related to the semester of the Exhibition (E) are reported in Fig. 6. The exhibition (E) impact is mainly due to logistics and transports. On the one hand, transport emissions are related to the mobility of visitors by means of Milan public transport and are mainly due to the use of buses and subways. On the other hand, logistic emissions are related to people and goods transport organized specifically for the exhibition and are mainly caused by goods logistics and shuttle services. In Fig. 7 the GHG emissions related to the Decommissioning Process (DP) are shown. The impact of the decommissioning activities of provisional structures and buildings is mainly due to

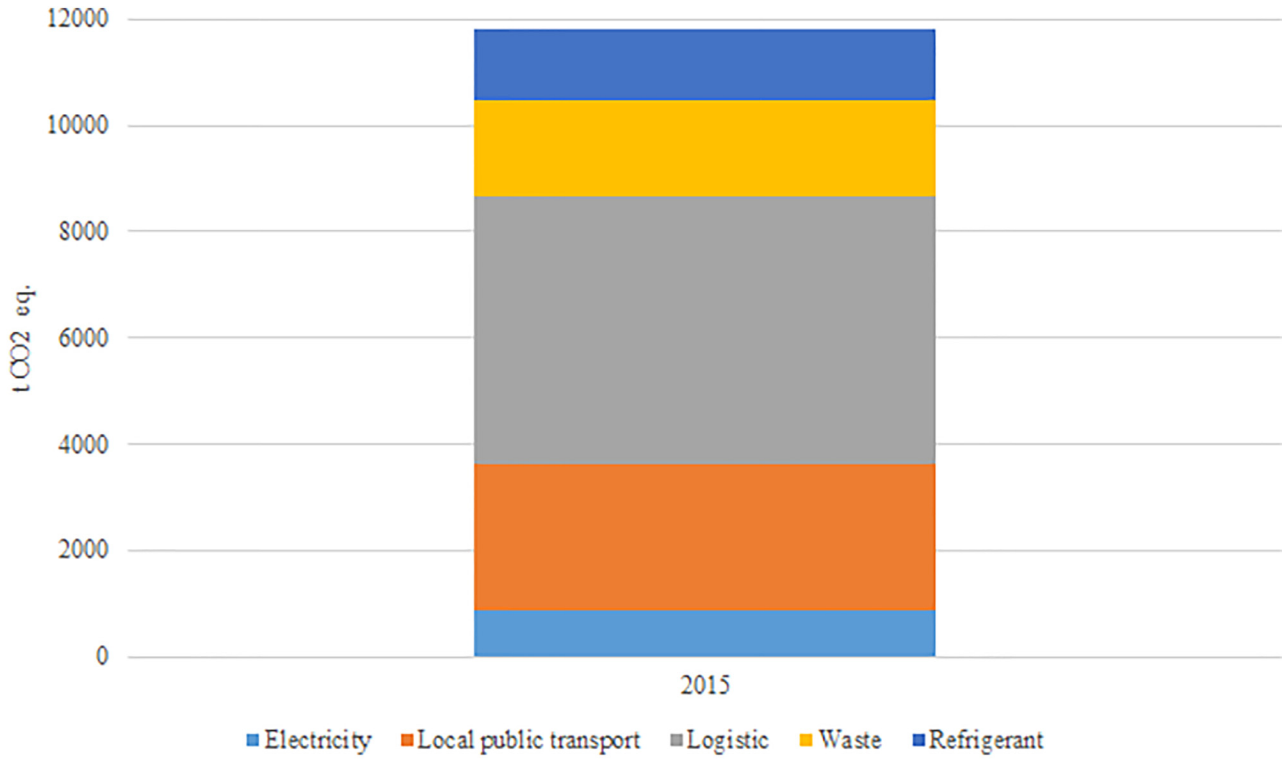

Fig. 6. GHG emissions ($tCO_{2\text{-}eq}$) for E category.

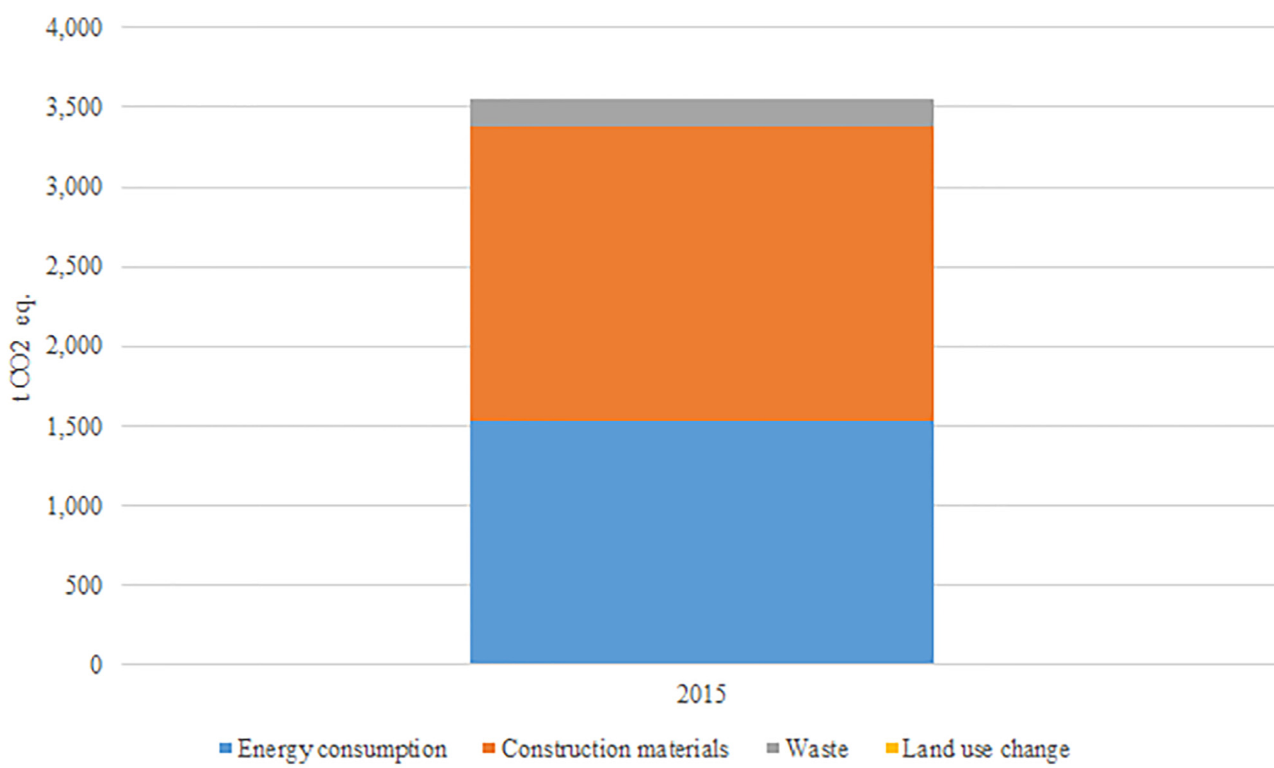

Fig. 7. GHG emissions ($tCO_{2\text{-}eq}$) for DP category.

the end-of-life treatments (disposal or recycling) of the construction materials and to energy consumption. Fig. 8 reports the total yearly emissions accounted for the previously identified categories. The total emissions of Milan Expo 2015 were equal to 416,335 tCO_{2eq}. Fig. 9 shows that about 72% of the total impact was due to the construction materials (CS), which represents the category with the highest impact followed by the construction of the pavilions (P). The impact of permanent structures built by the hosting country is mainly due to the building works necessary for their construction: access roads, waterways, construction of the so-called

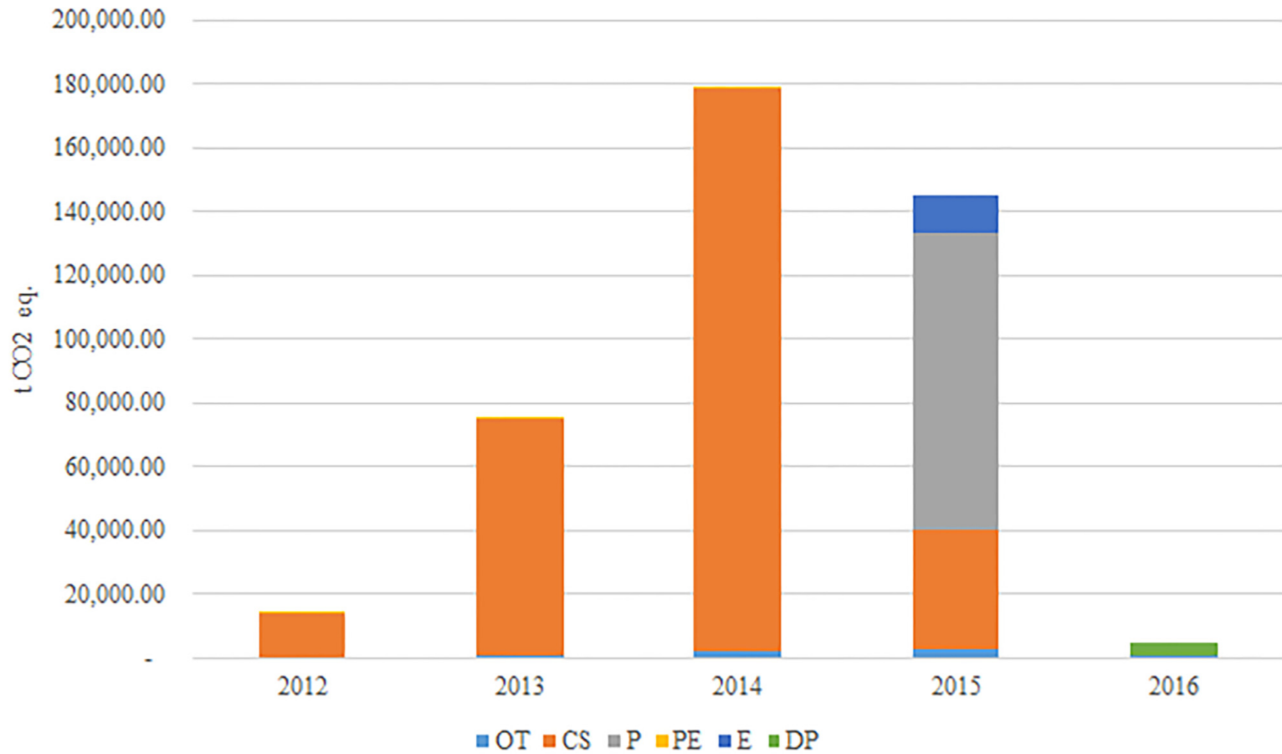

Fig. 8. Total GHG emissions ($tCO_{2\text{-}eq}$) by year.

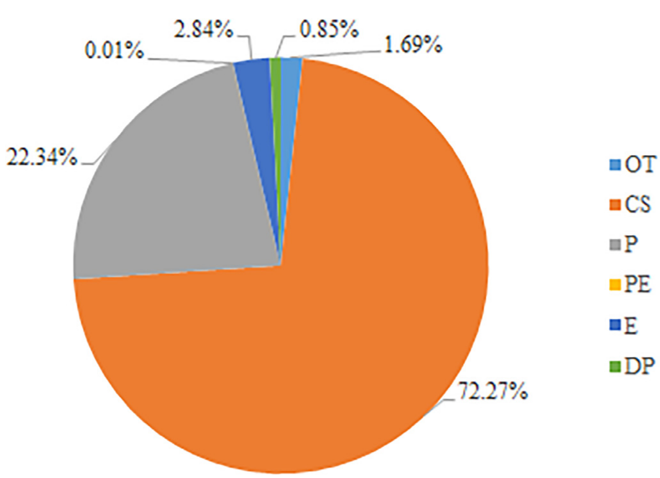

Fig. 9. Total GHG emissions ($tCO_{2\text{-}eq}$).

"piastra" area, used as basement for the pavilions. The impact of the pavilions is instead mainly due to the high emission factor of construction materials, such as metals. Interpreting the results, with the contributions to GHGs classified by the requirements listed in Table 1, it is clear that indirect emissions have the highest impact along all the exhibition. These indirect emissions are mainly due to the materials used by Expo 2015 S.p.A. subcontractors for base camp, exhibition site, pavilions and waterways construction and decommissioning phases. A separate discussion deserves the inclusion of the journeys made by visitors. As stated above, the Expo 2015 S.p.A. organization decided not to include them, despite their potentially high impact on climate change. Anyway, due their significance and to the need of enhance comparability with other mega-events inventories, GHG emissions of visitors were calculated using methodological approach reported in the guidelines for the carbon footprint of travels during mega events published by the Italian Ministry of the Environment (MATTM, 2016b) and reported in the following. The estimated GHG emissions of the travel of visitors to Milan Expo 2015 was averagely equal to 615,000 tonnes of $CO_{2\text{-}eq.}$ The calculation was performed by making assumptions on length of routes and type of means of transport used and included both international and national transportation given that about 7,000,000 of the total 21,500,000 visitors came from outside Italy.

4.2. Comparison of mega-events GHG inventories

As one of the purpose of this paper is to provide guidance for reliable greenhouse gas accounting of mega-events, the results presented above have been normalized and compared to other mega-events. Firstly, different normalization factors were chosen for each event category with the aim of defining indicators reflecting the real impact of the exhibition. Subsequently, the calculated GHG results were normalized to the same basis (number of visitors) in order to enhance comparability with other mega-events, such as the Olympic Games and the FIFA World Cups. The comparison was performed using the latest available data resulting from the official reports for World Expos (UNEP 2012b), Olympic Games (UNEP 2009, LOCOG 2010, COJOPR 2016), FIFA World Cups (UNEP 2012a, FIFA 2014, FIFA 2016). Within each mega-event category, results were referred also to the number of sport events for sports mega-events and to the exhibition area for world fairs.

4.2.1. World fairs mega-events

The characteristics of Milan Expo 2015 are given in Table 9, while impact indicators of Milan Expo 2015 are shown in Table 10.

Table 10 results show that approximately 95% of the total GHG emissions of the event is due to the construction of site and pavilions, with normalized values are respectively equal to 1.42 $kgCO_{2eq}/m^2{}_{structures}$ and 0.41 $kgCO_{2eq}/m^2{}_{pavilions}$. The exhibition itself, referred to the total gross surface area, accounts for 3%

Table 9
Characteristics of Milan Expo 2015.

Description	Milan Expo 2015
Total number of visitors during the exhibition period	21,500,000
Average number of employees simultaneously present on site	575
Pavilions gross surface (indoor and outdoor)	228,558 m^2
Host country structures gross surface (indoor and outdoor)	211,801 m^2
Total gross surface (pavilion + structures)	440,359 m^2
Exhibition Area	1.100.000 m^2

Table 10
Impact indicators of Milan Expo 2015.

Categories	GHGs (tCO_{2eq})	Impact indicators	Unit	Normalization factor
Offices and Travel (OT)	7019	12.21	$tCO_{2\text{-}eq}$/employee	Number of employees of the organization
Construction Site (CS)	300,875	1.42	$tCO_{2\text{-}eq}/m^2_{structures}$	Surface area covered by host country structures
Pavilions (P)	93,010	0.41	$tCO_{2\text{-}eq}/m^2_{pavilions}$	Surface area of the pavilions
Preparatory Events (PE)	57	negligible	–	–
Exhibition (E)	11,819	0.03	$tCO_{2\text{-}eq}/m^2_{total}$	Total gross surface area (pavilions and host country structures)
Decommissioning Process (DP)	3555	0.02	$tCO_{2\text{-}eq}/m^2_{pavilions}$	Surface area of the pavilions

Table 11
Comparison of world fairs mega-events GHG results.

World Expos	Area	Visitors	Emissions			Methodology	Source
	m^2		$tonCO_{2\text{-}eq}$	$tonCO_{2\text{-}eq}/m^2$	$tonCO_{2\text{-}eq}$/visitors		
Expo 2010	5.280.000	73.080.000	4.921.827	0,93	0,07	ISO 14064-1 (ISO, 2016)	UNEP (2012b)
Expo 2015	1.100.000	21.500.000	1.031.335	0,94	0,05	ISO 14064-1 (ISO, 2016)	The present study

of total GHG emissions. Offices and travels and decommissioning categories have a lower impact, while the contribution of preparatory events are negligible if compared to the overall emissions of the mega-event. Table 11 reports Milan Expo 2015 and Shanghai Expo 2010 GHG results, referred to the exhibition area (Area) and to the total number of visitors during the exhibition period (Visitors).

Comparing emissions between these world fairs mega-events requires caution. Above all, the two expos are staged in different countries, thus the comparison may be influenced by local parameters such as the energy mix and travel distances. The methodologies used are both based on the ISO 14064 (ISO, 2006), but the comparison should take into account some issues that can affect the results. Accounting principles and emission factors used in both GHG inventories are similar. However, boundaries, i.e. the scope of activities included in the calculations, can vary, as shown in Table 12.

Therefore, due to these differences, the focus will not be in looking at the absolute numbers, but comparing relative numbers. The first step in making such a comparison is to resize the inventories grouping them by similar and more general categories. The main differences between the two inventories concern the emissions related to civil infrastructure construction and visitors travel and accommodation. Focusing on GHG sources, Milan Expo 2015 GHG inventory includes refrigerants leakages and land use changes. The second step is to allocate emissions from the two events similarly, as per Table 13. Analysing the results, the total impact of both the World Expos amounted nearly to one ton of $CO_{2\text{-}eq}$ per square meter of exhibition and averagely 60 $kgCO_{2\text{-}eq}$/visitor. Using these indicators as a baseline reference to preliminary estimate the GHGs of Expo 2020 Dubai, the mega event that will be host from 20 October 2020 to 10 April 2021 in a 4,380,000 m^2 area located between the cities of Dubai and Abu Dhabi is expected to have a total GHG emission of over 4 million tonnes of $CO_{2\text{-}eq}$.

4.2.2. Sports mega-events

A similar analysis to the one reported in the previous paragraph was made while comparing GHG inventories of the latest Summer Olympic Games and FIFA World Cups. Table 14 reports the comparison of Beijing 2008, London 2012 and Rio 2016 Olympic Games and FIFA 2010 South Africa, FIFA 2014 Brazil, FIFA 2018 Russia World Cups. All Olympic Games GHG inventories reported in the table take into account not only the Games themselves, but all activities related to Game preparation, staging and disassembling. Emissions occurring during the preparation of the event, e.g. the construction of infrastructure required for the Games (venues, transport solutions, urban infrastructure, etc.), are included together with operational activities (venue energy consumption, Olympic family transport) and emissions attributable to spectators during the Games. Beijing 2008 accounted only the Olympic Games emissions, while London 2012 and Rio 2016 total greenhouse gases included both Olympic and Paralympic Games. Beijing 2008 study considered emissions during the construction and operation of new venues, emissions from the activities of athletes, officials, spectators and related services for the Games, including the emissions caused as a result of the torch relay. According to the calculation, the total incremental carbon footprint for Beijing Olympic Games was about 1.18 million tonnes of carbon dioxide equivalents. Beijing's inventory has, for the first time for a global sports event, taken into account the carbon emissions from international flights which accounted for over 64% of the emissions of the Games. London 2012 reference GHG inventory included venues, spectators, operations and transport infrastructure. The total carbon emissions were estimated to be 3.4 million tonnes of carbon dioxide equivalents, most of which occurring pre-Games and arising from the construction of venues, the delivery of the transport infrastructure, and the fitting out of the venues and Olympic Park. Most of the remaining operational activities and emissions attributable to spectators occur at Games-time accounting for over 20%. Rio 2016 inventory included venue construction, spectators, operations and city infrastructure. Based on the chosen methodology, the total carbon emissions of the Rio 2016 Olympic and Paralympic games are estimated at 4.5 million tonnes of carbon dioxide equivalent. More than 35% of emissions occurred pre-Games due venue construction and city infrastructure. The remaining 65% occurred during the Games and is

Table 12
Comparison of world fairs mega-events boundaries.

Categories	Milan Expo 2015		Shanghai Expo 2010 (UNEP 2012b)	
	Phase	Included	Phase	Included
Offices and Travel	Expo 2015 S.p.A.	X	Expo Bureau	X
	- Operations		- Operations	
Office	Electricity	X	Electricity	X
	Fuel	X	Fuel	X
	Paper & paperboard	X	Paper & paperboard	X
	Refrigerants	X	Refrigerants	–
	Waste	X	Waste	X
Travel	Business travel	X	Transportation	X
Construction Site	Expo Site	X	Expo Park	X
	- Construction		- Construction	
Site	Exhibition Site	X	Exhibition Site	X
Other buildings	Base Camp	X	Expo Village	-
Civil infrastructures (Legacy)	Waterways, 'Piastra'	X	City infrastructure	–
Land use change	Cut trees, replanting	X	–	–
Pavilions	Pavilions	X	Pavilions	X
	- Construction		- Construction	
Permanent	"Cascina Triulza" historical architectural structure	X	Country pavilions	X
Temporary	Country/corporate pavilions	X	Country/corporate pavilions	X
Preparatory Events	Conference and Meeting	X	Test visitor travel and travel activities	X
Exhibition	Expo Area	X	Expo Park and Expo Village	X
	- Operation		- Operation	
Event	Electricity	X	Electricity	X
	Refrigerants	X	Refrigerants	-
	Logistic	X	Logistic	X
	Waste	X–	Waste	X
	Wastewater		Wastewater	X
Accommodation	–	–	Hotel - electricity	X
Decommissioning Process	Temporary Pavilions	X	Temporary Pavilions	X
Dismantling	Electricity	X	Electricity	–
	Fuel	X	Fuel	X–
	Materials	X	Materials	–
	Water	X	Water	–
	Waste	X	Waste	
People	Visitors		Visitors, exhibitors, media, performers, organizers, security, volunteers	X
Travel	Only additional local accounted in the official GHG inventory	X	Local, Domestic, International	X
Accommodation	–	–	Hotel - electricity	X

Table 13
Comparison of world fairs mega-events GHG results divided into phases.

Phases	Corresponding category	Milan Expo 2015		Shanghai Expo 2010 (UNEP, 2012b)	
		$tonCO_{2\text{-}eq}/m^2$ total	$tonCO_{2\text{-}eq}$/visitors	$tonCO_{2\text{-}eq}/m^2$ total	$tonCO_{2\text{-}eq}$/visitors
Offices activities	OT	0.006	0.000	0.006	0.000
Construction	CS+P	0.358	0.018	0.037	0.003
Operations	E	0.011	0.001	0.070	0.005
Decommissioning	DP	0.003	0.000	0.002	0.000
Sub-Total		0.38	0.02	0.12	0.01
Visitors - Travel	n.a.	0.56	0.03	0.64	0.05
Visitors - Accommodation	n.a.	–	–	0.17	0.01
Total		0.94	0.05	0.93	0.07

referred to the emissions attributable to spectators and operational activities. Focusing on the comparison of London 2012 and Rio 2016 inventories, which are accounted using the same methodological approach, the following observations can be made. Despite having similar normalized results, the allocation of emissions is different. Brazil has the advantage of a cleaner energy mix and the use of an existing Olympic stadium, but it is characterized by higher travelling distances, which increase spectator emissions. Direct emissions prevail for London 2012, which gave the organizers greater control over the GHG inventory, while Rio's indirect emissions from spectators and city infrastructure clearly prevail. With regard to GHG inventories of World Cup, FIFA proposed a framework based on existing key concepts and experience mainly based to Greenhouse Gas Protocol (WRI – WBCSD, 2013) and ISO 14064-1 (ISO 2019). GHG emissions from the 2010 FIFA World Cup were associated with energy consumption, waste generation, accommo-

Table 14
Comparison of sports mega-events GHG results.

Sports mega-event	Visitors	Venues	Events	Days	Emissions			Methodology	Source
					$tonCO_{2\text{-eq}}$	$tonCO_{2\text{-eq}}$/event	$tonCO_{2\text{-eq}}$/visitors		
Olympic Games									
Beijing 2008	6.700.000	37	302	17	1.181.900	3.914	0,18	Not specified. Only Olympic Games included.	UNEP 2009
London 2012	10.265.774	35	805	29	3.448.000	4.283	0,34	Greenhouse Gas ProtocolISO 14064-1	LOCOG 2010
Rio 2016	10.800.000	33	834	29	4.543.000	5.447	0,42	Greenhouse Gas ProtocolISO 14064-1	COJOPR 2016
FIFA World Cup									
FIFA 2010 South Africa	3.178.856	10	64	31	1.652.156	25.815	0,52	Greenhouse Gas Protocol	UNEP 2012a
FIFA 2014 Brazil	3.429.873	12	64	32	2.457.000	38.391	0,72	Greenhouse Gas ProtocolISO 14064-1	FIFA 2014
FIFA 2018 Russia	3.031.768	12	64	32	1.943.327	30.364	0,64	Greenhouse Gas Protocol	FIFA 2016

dation and transportation (ground and air travel). The calculated GHG emissions for the event was about 1.6 million tonnes of carbon emissions equivalent, of which 70% due to international transport of spectators. The calculated GHG emissions of the 2014 FIFA World Cup was over 2.7 million tonnes of carbon dioxide equivalents (2.457.000 $tCO_{2\text{-eq}}$ excluding preparatory events). The most significant contributor was transport (83.7%), followed by accommodation (5.7%), temporary facilities (4.1%), and food and beverage consumed during the matches (2.3%). The results of the analysis mirrored that of past FIFA World Cups and other large-scale events, where transport of spectators attending the event was the most significant contributor, in particular by air (50.6% of the overall emissions). GHG emissions for 2018 FIFA World Cup are estimated to be over 2.2 tonne carbon dioxide equivalents (1,943,327 $tCO_{2\text{-eq}}$ excluding preparatory events). The majority are indirect emissions mainly from travel (74%) and accommodation (12%) for attendees of the matches in Russia. A lower fraction of the estimated emissions result from the construction of temporary facilities (4%). While comparing GHG emissions among Olympic Games and FIFA World Cups, the following consideration can be made. Accounting principles and emission factors used in both inventories are similar, whilst activities included in the calculations, vary significantly. The main difference lies in the fact that, unlike FIFA World Cups, Olympic Games inventories include permanent venue construction and legacy infrastructure projects. In addition, the Olympic and Paralympic Games are a bigger event than the FIFA World Cup, with more venues, people, technology, transport, equipment, catering, etc. As a consequence, the overall impact of each Olympic Games event almost double the GHG inventories of a single FIFA World Cup. Referring the results to a common reference, i.e. number of events or visitors, the following considerations can be made. The emissions of each Olympic Game's event accounted averagely 4500 $tCO_{2\text{-eq}}$, while each football match causes more than 30,000 $tCO_{2\text{-eq}}$. The total impact amounted averagely 400 $kgCO_{2\text{-eq}}$/visitor for Olympic Games and 600 $kgCO_{2\text{-eq}}$/visitor for FIFA World Cups.

5. Definition of specific requirements for GHG accounting of mega-events

As discussed above, a standardized methodology for measuring, calculating and reporting the GHG emissions of major events does not currently exist and there are significant differences between methodologies used by different event organizers. For example, the definition of the boundaries can vary significantly among various major international events (Savery et al., 2011). Most of the GHG inventories has either not included embodied impacts, such as the carbon emissions coming from the production of construction materials, or amortized the carbon emissions over the lifetime of the venues and infrastructure used. Hence, calculations rarely consider the same criteria or variables, making comparisons indicative rather than scientific. Moreover, even when the methodology is fully aligned, the absolute results cannot be compared, because some parameters, such as the energy mix of the host country, strongly influence emission factors. The inclusion of the journeys made by visitors, especially international travels, is also a key issue to be considered. Travel distances and the location of the host city substantially affect total emissions. According to this, without claiming to be exhaustive, the authors propose specific guidelines that could help researchers and organizations to preliminary account GHG inventory of mega-events. Table 15 reports the list of significant issues - boundaries, GHG sources and categories - to be considered when quantifying GHG of mega-events based on the findings of the performed analysis and on their estimated significance. The criteria for evaluating their significance include the magnitude/volume of the emissions, level of influence

Table 15
List of significant issues to be considered when quantifying GHG of specific mega-events.

	World Expos	Olympic Games	FIFA World Cups	Comment
Inventory Boundaries				
Direct GHG emissions	X	X	X	It is recommended to include all the emissions due to sources under direct control of the organization
Indirect GHG emissions	X	X	X	It is recommended to include emissions from consumption of purchased energy and other indirect emissions according to the details specified below
GHG Sources				
Fuel	X	X	X	Fuel use for energy purpose shall be included
Refrigerant leakages	–	–	–	Not significant. It can be included in the cut-off
Electricity	X	X	X	It is recommended to report the related GHG emissions separately. The specific electricity mix and the related emission factor shall be declared
Construction materials	X	X	X	The impacts of materials shall include embodied impacts
Business travel	–	–	–	Not significant. It can be included in the cut-off
Logistic	X	X	X	Significant within the event operations
Purchases (e.g. paper)	–	–	–	Not significant. It can be included in the cut-off
Waste	–	–	–	Not significant. It can be included in the cut-off
Land Use	–	–	–	Significant for non-urban areas
Categories				
Offices activities	–	–	–	Besides having a negligible impact, offices activities require a time demanding data collection
Construction -Permanent venues	X	X	X	Legacies shall be accounted. The impact of construction shall be amortized over the lifetime of the venues and infrastructure used
Construction - Civil infrastructures	X	X	X	Legacies shall be accounted. The impact of construction shall be amortized over the lifetime of the venues and infrastructure used
Preparatory Events	–	–	X	Besides having a negligible impact, the preparatory events require a time demanding data collection. It is recommended to include this category only for FIFA World Cups.
Operations	X	X	X	Despite its low impact, the inclusion of this phase is useful from a management perspective in order to plan the sustainable management of the event. Data quality and availability could be satisfactory for all the exhibitions, as all the data are presumably under the direct control of the Organization and can be retrieved from the purchasing department
Decommissioning	X	X	X	Even if its impact is low, the dissemination of the results is useful and data collection is feasible and reliable
Visitors - Travel	X	X	X	It is recommended to report the related GHG emissions separately. The average travel distance shall be declared
Visitors - Accommodation	X	X	X	It is recommended to report the related GHG emissions separately

on sources/sinks, access to information and the level of accuracy of associated data (complexity of organization and monitoring). A risk assessment or other procedures (e.g. buyer requirements, regulatory requirements, concern of interested parties, scale of operation, etc.) shall be used to refine the list for different events. As the performed study can be representative only of similar mega-events, characterized by long duration, construction of building and journeys of millions of people/visitors, only world fairs and sports mega-events world fairs are included in the table.

6. Conclusion

Mega-events, although time-limited, have a significant environmental impact that needs to be accounted for correctly. In order to estimate this impact, several data must be collected and it is often difficult to assure a good level of accuracy. Moreover, methodological choices can strongly influence the calculations outcomes. Therefore, accounting the greenhouse gases of a mega-event and comparing the emissions of different events is a very challenging task. Despite several mega-events GHG inventories were performed, a standardized methodology for carbon accounting of mega-events does not currently exist. Furthermore, there are significant differences among methodologies used in the past. In this paper, the approach taken and the results of GHG accounting of Milan Expo 2015 were presented. GHG emissions and removal were reported separately for six categories, including offices activities, construction of expo site and pavilions, operations and decommissioning process. Using specific data collection procedures for each category, the total GHG emissions were calculated starting from energy and material flows and using selected emission factors to convert them to tonnes of CO_2 equivalents. The results show that, from 2012 to 2016 (time period considered in the study for the construction, management and decommissioning of the event), the total emissions of Milan Expo 2015 amounted to 416,335 $tCO_{2\text{-eq}}$. GHG results, data collecting methods and data sources were broadly discussed with the aim of providing guidance for greenhouse gas accounting of mega-events. In order to validate the results, they were normalized and compared to Shanghai Expo 2010 and to sports mega-events, i.e. the latest Olympic Games and FIFA World Cups. With all the limitations described in the paper, the results showed a total impact of World Expos of about one ton of $CO_{2\text{-eq}}$ per square meter of exhibition and averagely 60 $kgCO_{2\text{-eq}}$/visitor. Olympic Games and FIFA World Cups have an average impact respectively of 400 $kgCO_{2\text{-eq}}$/visitor and 600 $kgCO_{2\text{-eq}}$/visitor. The performed methodological analysis, together with the experience acquired by the authors in the data collection phase, was presented in the form of specific requirements and guidelines with the aim of helping researchers and organizations to preliminary account GHG inventory of mega-events. A list of issues to be included in GHG inventories of mega-events, such as boundaries, GHG sources and categories, was presented based on their estimated significance. Construction and visitors related emissions resulted to be key elements to be included in the calculations. In particular, the journeys made by visitors, especially international travels, are by far the phases with the greatest impact and have to be accounted properly ex-ante and verified through national surveys at the end of the event (Lee, 2014). Focusing on legacy, when mega-events require new constructions, the final results clearly show that the use of construction materials is one of the main contributor to total GHG emissions. This leads to a significant impact especially if the decommissioning of the event involves the demolition of the structures. If structures and buildings remain operative after the event, the emissions related to their construction can be normalized to their lifetime, thus allocating their impact to all the events hosted on the site. This aspect highlights that, in case of mega-events the use of pre-existing structures and buildings would always be desirable and strongly recommended. On the other hand, when the construction of new structures and buildings cannot be avoided, environmental sustainability principles need to be applied for design and planning, the selection of raw materials (Strazza et al., 2010), the application of proper management strategies for the structures through their life cycle and, potentially, the application of mitigation strategies (Arata et al., 2013; Strazza et al., 2013), thus leading to less carbon-intensive future mega-events.

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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Appendix A

Emission factor	2012	2013	2014	2015	Unit	Sources	Emission
Paper and cardboard	0.44	0.44	0.41	0.41	tCO_2/t	Data 2012-2013 - Source: CEPI Sustainability Report 2011 (Confederation of European Paper Industries). Data 2014-2015 - Source: ICFPA Sustainability Progress Report 2015 - data 2013 CEPI (Confederation of European Paper Industries) pag.14 http://www.cepi.org/system/files/public/documents/publications/sustainability/2015/2015-icfpa-sustainability-progress-report.pdf	Direct emissions (0,31) + indirect (0,10). Only CO_2.
Electric energy	0.407	0.407	0.407	0.407	kg CO_2/kWh	Data 2012/2013/2014/2015 - "Confronti Internazionali 2013 Terna su dati Enerdata" (data 2011) - available on www.terna.it http://www.terna.it/LinkClick.aspx?fileticket=6gMaUp466Bc%3d&tabid=847	Direct emissions. Only CO_2.
"Green" electric energy (100% Wind)	–	–	–	0.023	kg CO_2/kWh	(Ecoinvent DB 2.2) - Electricity production, wind, $<$1MW turbine, onshore	Direct emissions + indirect. Global Warming Potential (GWP).
District heating	–	–	–	0.358	kg CO_2/kWh	Legislative Decree 4 April 2006, n. 216 - Assignment Decision 2008-2012 Table 4.1 emission coefficients. NAP 2008-2012 page 9 - Benchmark set for natural gas (0.358 kg/kWh) and conventional operating hours equal to 1800 h/year http://www.minambiente.it/sites/default/files/archivio/allegati/emission_trading/DecAssegnazione2008_2012.pdf	
Natural gas	1.961	1.968	1.956	1.955	ton CO_2/1000 Sm^3	Data 2012-Table of national standard parameters for EU-ETS for emissions calculation 2011 and 2012 - data processed by ISPRA 2011 - available on www.minambiente.it Data 2013 - Table of national standard parameters for EU-ETS for emissions calculation 2013- data processed by ISPRA 2013 - available on www.minambiente.it Data 2014 - Table of national standard parameters for EU-ETS for emissions calculation 2014 - data processed by ISPRA 2015 - available on www.minambiente.it Data 2015 - Table of national standard parameters for EU-ETS for emissions calculation 2015 - data processed by ISPRA 2016 - available on www.minambiente.it	Direct emissions. Only CO_2.
Diesel	3.173	3.173	3.155	3.155	tCO_2/t	Data 2012 - Table of national standard parameters for EU-ETS for emissions calculation 2011 and 2012 - data processed by ISPRA 2011 - available on www.minambiente.it Data 2013 - Table of national standard parameters for EU-ETS for emissions calculation 2013- data processed by ISPRA 2013 - available on www.minambiente.it Data 2014 - Table of national standard parameters for EU-ETS for emissions calculation 2014 - data processed by ISPRA 2015 - available on www.minambiente.it Data 2015 - Table of national standard parameters for EU-ETS for emissions calculation 2015 - data processed by ISPRA 2016 - available on www.minambiente.it	Direct emissions. Only CO_2.
Gasoline	3.141	3.141	3.140	3.140	tCO_2/t	Data 2012 - Table of national standard parameters for EU-ETS for emissions calculation 2011 and 2012 - data processed by ISPRA 2011 - available on www.minambiente.it Data 2013 - Table of national standard parameters for EU-ETS for emissions calculation 2013- data processed by ISPRA 2013 - available on www.minambiente.it Data 2014 - Table of national standard parameters for EU-ETS for emissions calculation 2014 - data processed by ISPRA 2015 - available on www.minambiente.it Data 2015 - Table of national standard parameters for EU-ETS for emissions calculation 2015 - data processed by ISPRA 2016 - available on www.minambiente.it	Direct emissions. Only CO_2.

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Emission factor	2012	2013	2014	2015	Unit	Sources	Emission
LPG	3.024	3.024	3.024	3.024	tCO_2/t	Data 2012 - Table of national standard parameters for EU-ETS for emissions calculation 2011 and 2012 - data processed by ISPRA 2011 - available on www.minambiente.it Data 2013 - Table of national standard parameters for EU-ETS for emissions calculation 2013- data processed by ISPRA 2013 - available on www.minambiente.it Data 2014 - Table of national standard parameters for EU-ETS for emissions calculation 2014 - data processed by ISPRA 2015 - available on www.minambiente.it Data 2015 - Table of national standard parameters for EU-ETS for emissions calculation 2015 - data processed by ISPRA 2016 - available on www.minambiente.it	Direct emissions. Only CO_2.
Refrigerant R-410A	–	–	2088	2088	kg CO_{2e}/kg	IPPC Fourth Assessment Report AR4 2007 https://www.fluorocarbons.org/uploads/Modules/Library/fs_18_selecting-gwp-values-for-refrigerants_05.2011.pdf	Direct emissions. GWP.
Refrigerant R-407C	–	–	–	1774	kg CO_{2e}/kg	IPPC Fourth Assessment Report AR4 2007 https://www.fluorocarbons.org/uploads/Modules/Library/fs_18_selecting-gwp-values-for-refrigerants_05.2011.pdf	
FIAT 500L Living Multijet Lounge	–	–	0.11	0.11	kg CO_2/km	Fiat catalogue http://www.fiat500.com/it-it/modelli/500lliving/motori/lounge/info	Direct emissions. Only CO_2.
FIAT 500L Natural Power Lounge	–	–	0.105	0.105	kg CO_2/km	Fiat catalogue http://www.fiat500.com/it-it/modelli/500l/motori/lounge/info	Direct emissions. Only CO_2.
FIAT PANDA 4 × 4 Climbing	–	–	0.136	0.136	kg CO_2/km	Quattroruote website http://www.quattroruote.it/auto/fiat/panda-2-serie/panda-13-mjt-16v-4x4-climbing-066698200507	Direct emissions. Only CO_2.
FIAT PANDA	–	–	–	0.133	kg CO_2/km	Quattroruote website http://www.quattroruote.it/news/eco_news/2010/01/15/consumi_ed_emissioni_per_capirne_di_pi_C3_B9.html	Direct emissions. Only CO_2.
FIAT DUCATO	–	–	–	0.193	kg CO_2/km	Il Sole 24 ore http://www.ilsole24ore.com/speciali/emissioni_auto/emissioni_auto_emissioni_tipologia_fiat_professional_gasolio.shtml?refresh_ce=1	Direct emissions. Only CO_2.
Light Duty Vehicles	–	–	–	0.2421	kg CO_2/km	ISPRA - Passenger Cars CO_2 2013 Driving cycle TOTAL http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	Direct emissions. Only CO_2.
Heavy Duty Trucks	–	–	–	0.6027	kg CO_2/km	ISPRA - Heavy Duty Trucks CO_2 2013 Driving cycle TOTAL http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	Direct emissions. Only CO_2.
Passenger Cars	–	–	–	0.1632	kg CO_2/km	ISPRA - Heavy Duty Trucks CO_2 2013 Driving cycle TOTAL http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	Direct emissions. Only CO_2.
ALFA ROMEO GIULIETTA Sprint Berlina	–	–	–	0.127	kg CO_2/km	Quattroruote website http://www.quattroruote.it/auto/alfa-romeo/giulietta/giulietta-14-turbo-mair-150-cv-sprint-106494201505#	Direct emissions. Only CO_2.
JEEP GRAND CHEROKEE	–	–	–	0.198	kg CO_2/km	Quattroruote website http://www.quattroruote.it/listino/jeep/grand-cherokee	Direct emissions. Only CO_2.
LANCIA VOYAGER	–	–	–	0.207	kg CO_2/km	Quattroruote website http://www.quattroruote.it/auto/lancia/voyager/voyager-28-turbodiesel-platinum-177-cv-099321201405	Direct emissions. Only CO_2.
MASERATI QUATTROPORTE	–	–	–	0.163	kg CO_2/km	Quattroruote website http://www.quattroruote.it/auto/maserati/quattroporte/quattroporte-diesel-102595201504	Direct emissions. Only CO_2.
National train	0.0380	0.0380	0.0400	0.0342	kg CO_2/pkm	Data 2012-2013 - "Sustainability Report 2012" by Ferrovie dello Stato Italiane Data 2014 - "Sustainability Report 2013" by Ferrovie dello Stato Italiane Data 2015 - "Sustainability Report 2014" by Ferrovie dello Stato Italiane, page 175 http://www.fsitaliane.it/fsi/Impegno/Rapporto-di-Sostenibilit%C3%A0	Direct emissions. Only CO_2..
Long-distance train	–	–	–	0.001	kg CO_2/pkm	(Ecoinvent DB 2.2) - Operation, long-distance train, SBB mix/CH U. Hp. Load 392 passengers	Direct emissions + indirect. GWP.

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Emission factor	2012	2013	2014	2015	Unit	Sources	Emission
Metro	–	–	–	0.0011	kg CO_2/pkm	(Ecoinvent DB 2.2) - Operation, metropolitan train, SBB mix/CH U Hp. Load 95 passengers https://www.sbb.ch/content/dam/sbb/en/pdf/en_sbb-konzern/en_ueber-die-sbb/en_corporate-governance/Hintergrundbericht_e.pdf pag.11	Direct emissions + indirect. GWP.
Tram	–	–	–	0.619	kg CO_2/km	(Ecoinvent DB 2.2) - Operation, tram/CH U Expressed in km	Direct emissions + indirect. GWP.
Bus Natural Gas	–	–	–	1.0734	kg CO_2/km	ISPRA - Urban CNG Buses EEV CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	Direct emissions. Only CO_2.
Bus Diesel EURO VI	–	–	–	1.3170	kg CO_2/km	ISPRA - Bus Coaches Articulated >18 t HD Euro VI CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	Direct emissions. Only CO_2.
Bus Diesel EURO V	–	–	–	1.2861	kg CO_2/km	ISPRA - Bus Coaches Articulated >18 t HD Euro V CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	
Bus Diesel EURO IV	–	–	–	1.2884	kg CO_2/km	ISPRA-Bus Coaches Articulated >18 t HD Euro IV CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	
Bus Diesel EURO III	–	–	–	1.3916	kg CO_2/km	ISPRA - Bus Coaches Articulated >18 t HD Euro III CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	
Bus Diesel EURO II	–	–	–	1.2979	kg CO_2/km	ISPRA - Bus Coaches Articulated >18 t HD Euro II CO_2 2013 Driving cycle Urban http://www.sinanet.isprambiente.it/it/sia-ispra/fetransp/	
Trolleybus	–	–	–	0.414	kg CO_2/km	(Ecoinvent DB 2.2)- Operation, trolleybus/CH U Expressed in km	Direct emissions + indirect. GWP.
Airplane - short haul	0.167	0.167	0.167	0.167	kg CO_2/pkm	Source: 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (Annex 6 page 27) The emission factor of domestic flights is assumed to be equal to that of the "Domestic" category of the Defra guidelines.	Direct emissions. GHG.
medium haul	0.095	0.095	0.095	0.095	kg CO_2/pkm	Source: 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (Annex 6 page 27) The emission factor of medium-haul flights is assumed to be equal to that of the "Short Haul" category of the Defra guidelines	Direct emissions. GHG.
long haul	0.109	0.109	0.109	0.109	kg CO_2/pkm	Source: 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (Annex 6 page 27) The emission factor of long haul flights is assumed to be equal to that of the "Long Haul" category of the Defra guidelines	Direct emissions. GHG.
Materials - acetylene	2.31	2.31	2.31	2.31	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Acetylene, at regional storehouse	Direct emissions + indirect. GWP.
Materials - lubricating oils	1.06	1.06	1.06	1.06	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Lubricating oil, at plant	Direct emissions + indirect. GWP.
Materials - concrete	0.11	0.11	0.11	0.11	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Concrete, normal, at plant [kgCo_2/m^3]	Direct emissions + indirect. GWP.
Materials - cement	0.76	0.76	0.76	0.76	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Unspecified cement, at plant	Direct emissions + indirect. GWP.
Materials - bentonite	0.5	0.5	0.5	0.5	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Bentonite at processing	Direct emissions + indirect. GWP.
Materials - bitumen	0.43	0.43	0.43	0.43	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Bitumen, at refinery	Direct emissions + indirect. GWP.
Materials - asphalt	0.04	0.04	0.04	0.04	tonCO_{2eq}/ton	ETH-ESU 96. Calculated assuming 10% bitumen (conservative approach) and 90% gravel (EF gravel: 0.0012 kg CO_{2eq}/kg gravel - gravel from pit, ETH S)	Direct emissions + indirect. GWP.
Materials - bricks	0.24	0.24	0.24	0.24	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Bricks at plant	Direct emissions + indirect. GWP.
Materials - tents in PVC	–	2.02	2.02	2.02	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). PVC at regional storage	Direct emissions + indirect. GWP.
Metals - copper cables	1.9	1.9	1.9	1.9	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Copper at regional storage	Direct emissions + indirect. GWP.
Metals - iron	1.54	1.54	1.54	1.54	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Iron at plant	Direct emissions + indirect. GWP.
Metals - cast iron	1.59	1.59	1.59	1.59	tonCO_{2eq}/ton	(Ecoinvent DB 2.2). Pig iron at plant	Direct emissions + indirect. GWP.
Metals - steel	1.59	1.59	1.59	1.59	tonCO_{2eq}/ton		Direct emissions + indirect. GWP.

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Emission factor	2012	2013	2014	2015	Unit	Sources	Emission
Metals - aluminium	8.71	8.71	8.71	8.71	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Production mix, at plant	Direct emissions + indirect. GWP.
Wood	0.67	0.67	0.67	0.67	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Ecoinvent v2.2 fibreboard hard, at plant	Direct emissions + indirect. GWP.
Plastic materials	2.02	2.02	2.02	2.02	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). PVC at regional storage	Direct emissions + indirect. GWP.
Glass	1.1	1.1	1.1	1.1	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Flat glass, coated, at plant	Direct emissions + indirect. GWP.
Varnishes	1.72	1.72	1.72	1.72	$tonCO_{2eq}/ton$	ETH-ESU 96. paint ETH S	Direct emissions + indirect. GWP.
Inert materials	–	–	0.0024	0.0024	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Construction materials/additives/ gravel, round, at mine = 0.00242 kg CO_{2eq}/kg Construction materials/additives/sand, at mine = 0.00242 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Lime	–	–	0.9852	0.9852	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Construction materials/additives/quicklime, milled, loose, at plant = 0.9852 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Polycarbonate	–	–	7.7855	7.7855	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Plastics/Polymers/polycarbonate, at plant = 7.7875 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Resin for floors	–	–	2.7552	2.7552	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Plastics/monomers/epoxy resin insulator (SiO_2), at plant = 2.7552 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Plasterwall	–	–	0.3536	0.3536	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Construction materials/covering/gypsum plaster board, at plant = 0.3536 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Insulation materials	–	–	4.2120	4.2120	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Insulation materials/production/polystyrene foam slab, at plant = 4.2120 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Linoleum	–	–	1.8333	1.8333	$tonCO_{2eq}/ton$	Source: "Analysis of the carbon footprint in the life cycle of different types of Tarkett linoleum", co-funded by the Ministry for the Environment and Protection of the Territory and the Sea, as part of a public tender for the analysis of the Carbon Footprint of consumer products in 2013 (http://www.minambiente.it/pagina/il-bando-pubblico-2013). The products have been certified according to ISO/TS 14067 by third parties.	Direct emissions + indirect. GWP.
Stoneware	–	–	0.7814	0.7814	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2) Ceramic tiles, at regional storage = 0.7814 kg CO_{2eq}/kg	Direct emissions + indirect. GWP.
Metals - brass	–	–	–	2.27	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Brass, at plant	Direct emissions + indirect. GWP.
Mineral wool	–	–	–	1.0300	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Rock wool, at plant	Direct emissions + indirect. GWP.
Stucco	–	–	–	0.0726	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Stucco, at plant	Direct emissions + indirect. GWP.
Glue	–	–	–	4.4500	$tonCO_{2eq}/ton$	(Ecoinvent DB 2.2). Adhesive for metals, at plant	Direct emissions + indirect. GWP.
Land transformation	124.67	124.67	124.67	124.67	$tonCO_2/ha$	The emission factor has been calculated by means of the IPCC software "*Tool for estimation of changes in soil carbon stocks associated with management changes in croplands and grazing lands based on IPCC default data*" (available on http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/annex4a1.html). According to a conservative approach, a complete concreting has been hypothesized, with consequent zeroing of the soil absorption capacity. The initial carbon stock has been calculated according to the following assumptions: - climate area "Warm temperate, moist"; - soil type "Sandy" (conservative hypothesis with respect to the other types of soil available).	Direct emissions + indirect. GWP.

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Emission factor	2012	2013	2014	2015	Unit	Sources	Emission
Re-planting	1.283	1.283	1.283	1.283	tonCO_2/ha/year	The emission factor has been calculated by means of the IPCC software "*Tool for estimation of changes in soil carbon stocks associated with management changes in croplands and grazing lands based on IPCC default data*" (available on http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/annex4a1.html), with the following hypotheses and assumptions: - replanting intervention in climatic area "Warm temperate, moist"; - soil type on which the intervention took place "Sandy" (conservative hypothesis with respect to the other types of soil available); - soil use transformation from "Set aside" (agricultural non cultivated) to "Native ecosystem/nominal mgmt". According to these assumptions, the carbon stock variation is equal to 0.35 MgC/ha/year.	Direct emissions + indirect. GWP.
Waste transport (all categories)	0.004	0.004	0.004	0.004	tonCO_{2eq}/ton waste	Ademe (Agence de l'Environment et de la Maitrise de l'Energie) - *Application de la méthode "bilan carbone" aux activités de gestion des déchets.* In the absence of detailed EFs available for recycling (and, in some cases, for disposal) of some categories of waste, for these categories it was decided to calculate the only emissions deriving from the waste transport.	Direct emissions + indirect. GWP.
Plastic waste - EWC Code 150102 - 170203 Disposal	2.09	2.09	2.09	2.09	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: PVC to final disposal.	Direct emissions + indirect. GWP.
Wood waste - EWC Code 150103 - 170201 Disposal	0.0138	0.0138	0.0138	0.0138	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, building, waste wood, untreated, to final disposal	Direct emissions + indirect. GWP.
Inert waste - EWC Code 1701 Disposal	0.0142	0.0142	0.0142	0.0142	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, building, cement (in concrete) and mortar, to final disposal	Direct emissions + indirect. GWP.
"Iron-steel" waste - EWC Code 150104, 170405 Disposal	0.0679	0.0679	0.0679	0.0679	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, building, reinforcement steel, to final disposal	Direct emissions + indirect. GWP.
"Sludge" waste - EWC Code 010504 - 010505* - 170503* - 170504 - 170505* - 170506 Disposal	0.004	0.004	0.004	0.004	tonCO_{2eq}/ton waste	EF for waste transport	Direct emissions + indirect. GWP.
Paper-cardboard waste - EWC Code 150101 Disposal	0.0248	0.0248	0.0248	0.0248	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, packaging paper, 13,7% water, to municipal incineration	Direct emissions + indirect. GWP.
Oil/grease waste - EWC Code 130205 - 150202 Disposal	2.85	2.85	2.85	2.85	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, used mineral oil, 10% water, to hazardous waste incineration [in the absence of detailed information on how to dispose of the oils, a conservative approach was followed, choosing the mode that involves the highest emission factor].	Direct emissions + indirect. GWP.
Spent batteries - EWC Code 160601 - 160602 Disposal	0.775	0.775	0.775	0.775	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, treatment of batteries	Direct emissions + indirect. GWP.
Bio-waste - EWC Code 200201 Disposal	0.004	0.004	0.004	0.004	tonCO_{2eq}/ton waste	EF not available: the EF for only waste transport is used.	Direct emissions + indirect. GWP.
Asphalt/bitumen waste	–	–	0.0176	0.0176	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, asphalt, 0.1% water, to sanitary landfill	Direct emissions + indirect. GWP.
"Contaminated packaging" waste	–	–	2.4252	2.4252	tonCO_{2eq}/ton waste	(Ecoinvent DB 2.2). Category: disposal, hazardous waste, 25% water, to hazardous waste incineration	Direct emissions + indirect. GWP.
Waste to recycling	0.004	0.004	0.004	0.004	tonCO_{2eq}/ton waste	EF not available: the EF for only waste transport is used.	Direct emissions + indirect. GWP.
Other waste categories	0.004	0.004	0.004	0.004	tonCO_{2eq}/ton waste	The EF for only waste transport is used.	Direct emissions + indirect. GWP.

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