Journal of Physics: Conference Series

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To cite this article: Giovanni Mori *et al* 2019 *J. Phys.: Conf. Ser.* **1343** 012118

Journal of Physics: Conference Series **1343** (2019) 012118 doi:10.1088/1742-6596/1343/1/012118

Geospatial analysis and optimization of the incoming and stored CO2 emissions within the EPFL campus

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Abstract. All the projected scenarios agree on the immediate necessity of reducing greenhouse gas emissions, especially carbon dioxide (CO_2). This research proposes an analysis on the EPFL campus of all the potential reductions of CO_2 emissions: energy refurbishment, the request of heat and cooling of the buildings, emissions deriving from commuting and business travel as well as the embedded emissions of the buildings through their Life-Cycle Assessment. Subsequently, compensation strategies have been evaluated: Vertical Greenery Systems, CO_2 uptake from trees of the campus through an automated computing technique and Direct Air Capture technology. Together, all these contributions allow to significantly reduce the annual emissions of the campus, by up to 60 %, getting below the critical threshold of 1 ton of CO_2/person/year.

1. Introduction

Carbon dioxide is the most emitted greenhouse gas that is increasing the global mean temperature. The world already saw a rise of the global mean temperature of more than 1 K. The concentration of CO_2 in the atmosphere before the industrial era was far below 300 ppm, while in 2012 it hit the threshold of 400 ppm. The world is rapidly heading towards 450 ppm, the limit defined by the International Panel on Climate Change (IPCC) in the so-called +1.5° C scenario. The cost of total inaction could shrink the global Gross Domestic Product (GDP) by up to 23% by 2100 [1] and further create and widen global inequality. At the Swiss Federal Institute of Technology of Zürich (ETH Zürich), researchers developed a vision of a sustainable society called 2000-Watt Society: one where the total consumption per capita is 2000 W, including all the needs, from transportation to food, from infrastructure use to services. In this vision, the emission of CO_2 should be limited to 1-ton CO_2/year per person. Currently, the world has an average production of 5 tons CO_2/year per person. Therefore, many researchers are now focusing on the most emitting sectors to tackle CO_2 emissions. Big companies and institutional subjects are assessing CO_2 emissions, especially linked with the energy use in urban districts, or with regard to future climatic scenarios.

We studied the École Polytechnique Fédérale de Lausanne (EPFL) campus located in Ecublens, on the shores of Lake Geneva, in the Vaud canton. The campus hosts a high number of structures and people – more than 15,000 according to the 2017 official statistics. It represents a densely populated urban district, with a very elevated demand of electricity and primary energy. As such, it is the second main energy consumer of the entire Vaud canton, also due to the several laboratories located on the campus.

2. Methodology

The aim of the research is to assess all the CO_2 emissions released by people living on the EPFL campus and the CO_2 emitted to satisfy all the services, infrastructures and means of transportation during the course of a year. Much of the data of CO_2 emissions comes from research carried out over the last years by the EPFL Sustainable Campus team in collaboration with Quantis, a spin-off company of EPFL. Once all the quantities have been analysed, this research explores the potential solutions to cut those emissions and subsequently the compensation strategies, with the aim of obtaining a carbon neutral campus.

2.1. The CO_2 emissions at EPFL

The emission sources can be grouped into three main categories: energy refurbishment, commuting and business travels. Table 1 shows how they account for about one third each. The data refers to the year 2017. The largest contribution comes from commuting (36%), followed by business travels (34%), and then the entire energy sector (30%), subdivided into three different vectors: oil, gas, and electricity.

Table 1. Subdivision of the CO2 emission sources in 2017

	ton CO_2	% weight
Electricity	810	3.9%
Oil	2'241	10.8%
Gas	3'086	14.9%
Commuting	7'352	35.5%
Business travel	7'208	34.8%
	20'697	**100.0%**

Table 2. Evolution of the CO2 emissions according to the different sectors

		2011	2012	2013	2014	2015	2016	2017
Tot energy	[MWh]	110'999	114'286	116'757	104'012	109'619	111'441	109'481
Energy	[ton CO_2]	32'081	5'590	4'650	4'173	4'942	5'112	6'137
Commuting	[ton CO_2]	8'116	7'722	7'717	7'583	7'728	6'623	7'352
Business Travel	[ton CO_2]	5'930	6'308	6'692	6'655	6'892	6'514	7'208
CO_2 total	[ton]	**46'128**	**19'620**	**19'059**	**18'411**	**19'561**	**18'248**	**20'697**

2.2. Energy sector

2.2.1. Electricity

Electricity represents a very limited share of the energy sector – only 4% in 2017. There has been a huge reduction of the CO_2 emissions from electricity since 2011, as visible in Table 2. As a matter of fact, EPFL decided to feed the entire campus relying entirely on certified 100% renewable energy, 97% hydraulic and 3% photovoltaic. Before 2012, electricity accounted for around half of the entire EPFL emissions. Through a partnership with the energy supplier Romandie Energie, a huge roof area has been covered by PV panels: the green energy potential has thus been expanded, thanks to a 2MW new plant which provides around 2.2 MWh of electric energy every year. A third of it has been bought by EPFL.

2.2.2. Heating and Cooling

Almost the entire EPFL campus is fed by a trigeneration system with a centralized heat pump, which exploits the water of Lake Geneva as a heat-cold source. Through the pumping system located next to the lake, the heat pump is able to satisfy up to 70% of heating and 95% of cooling with renewable energy. The remaining portion is covered by fossil fuels, like oil and diesel to power both the gas-turbine back-up systems and some other local generators, especially in the very recent buildings, mostly detached from the central system.

2.3. Mobility

The commuting of people coming to EPFL represented the majority of the CO_2 emissions in 2017. The biggest role is played by private vehicles, which produce 90% of the emissions due to private mobility, although cars and motorbikes make up only 21% of the means of transportation. During the last 11 years, a positive evolution in commuting became evident: low emitting vehicles such as public transport, bikes and walking to the workplace gained +11% over private vehicles.

2.4. Business travels

The business travels of EPFL campus members have increased over the last years, along with the campus population growth (around +3'000 from 2011 to 2017). About 94% of the related emissions are caused by flights. The remaining 6% are emitted travelling by train or other vectors. This represents the second cause of CO_2 emissions in the whole campus. The total amount has risen from less than 6,000 tons of CO_2 in 2011 to more than 7,200 tons in 2017. An internal research carried out in 2017 found that it could be possible to reduce business related CO_2 emissions by 22% without avoiding travelling, but simply by choosing to travel in economy class instead of business/first class [2].

3. Reduction strategies

In our work we consider two ways of reducing the impact that EPFL has on the rise of atmospheric concentration of CO_2: (i) improving energy efficiency and (ii) relying on renewable energy sources. In the first case, there is an actual decrease in consumption, which in turn would reduce the requirements of the entire system. An example is energy refurbishment of buildings: this could be a beneficial investment, which would provide robust economic savings in the mid-term.

3.1. Operational emissions of buildings

The CitySim software [3] aims at simulating and optimizing the sustainability of urban settlements. CitySim allowed to build and run a model for the entire campus and to assess the energy consumption in the actual scenario, and in the case of a retrofitted campus. The first scenario runs with a climatic file which represents the present conditions: the resulting energy demand of the entire district simulation is 32 GWh a year, with a specific consumption of circa 77 kWh/m^2/year. Renovation reduces the heating energy demand of the site by 33 %, moving from an average demand of 77 kWh/m² to 52 kWh/m². Retrofitting has been applied to the buildings which do not satisfy the Minergie standard (i.e a maximum consumption of 55 kWh/m^2/year). As a consequence, the heating requirements diminished from 32.2 GWh to 21.6 GWh, saving up to 10.5 GWh, an equivalent of 3'915 ton of CO_2 (table 3).

Table 3. Comparison between actual and retrofitted

		Heating				
		specific			global	
Actual scenario		77.5	kWh/m^2		32.20	GWh
Retrofitted scenario		52.1	kWh/m^2		21.66	GWh
Saving	-	25.4	kWh/m^2	-	10.54	GWh
CO2 reduction				-	**3'915**	**ton CO2**

The saving of CO_2 due to retrofitted buildings is not immediately visible on the total balance. As a matter of fact, the heating and the cooling would be provided by a heat pump that will operate with 100% renewable energies. Nevertheless, every saved kWh implies a lower demand of green electrical energy, and consequently there will be more renewable energy circulating in the grid for other uses.

3.2. Operational emissions and embedded emissions

The CitySim software was also used to assess all the carbon embedded in the built campus. A brand-new tool was implemented. The code of CitySim was modified so as to evaluate the total GWP of every single component of every layer for all the buildings.

The tool starts from the properties of every material used to compose the layers and evaluates the specific contribution according to the relative surface area and thickness. As a matter of fact, the GWP is provided in kg CO_2-eq/kg of material, whereas the conversion made by the software allowed to find the kg CO_2-eq/m^2, in order to be able to deal directly with surfaces.

After classifying them according to their different materials (*table 4*), we notice that the most emitting one is concrete, which appears in basically all of the buildings in a consistent percentage. Second in the ranking there are two insulating materials: foam rubber and rubber coating, as both of them have a very high GWP.

Noticeably, in Table 5 the filling materials have a strong impact, but actually the insulation materials sum up to 40% of the total impact, followed by windows with frames and then external layers.

Another analysis has been conducted on buildings by comparing their embedded emissions with the operational emissions. The ratio between them has been calculated and, as expected, it reveals how the ratio embedded to operational is higher for those buildings where thicker insulation and a higher use of GWP material provokes a rise on the total impact. On the other hand, these buildings have a much more efficient thermal insulation which strongly decreases their impact due to operational emissions of the year.

Table 4. Impact of the different building materials

Concrete, 2% steel	36.85%
Aluminium Windows	20.30%
Foam rubber	17.10%
Rubber Coating	8.09%
Foamglass	6.84%
Aluminium	2.82%
Rockwool 60+100	2.01%
Screed	1.56%
Asphalt	1.30%
Ceramic brick	1.23%
Extruded polystiren	0.98%
Flooring of plastic	0.59%
Roof gravel	0.10%
Glass	0.10%
Strand Board	0.07%
Wood Hard	0.04%
Mortar rendering	0.01%

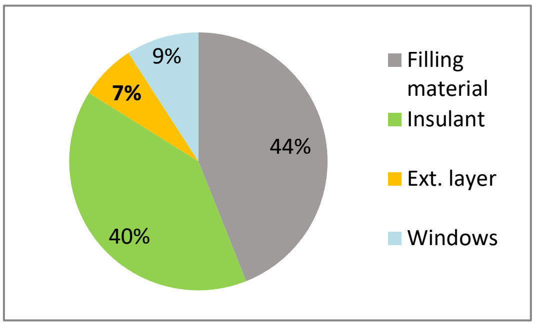

Figure 1. Impact of the different building layers

Table 5. Embedded CO2 per component

	Area		CO_2 Emission	
Total Floor	141'134	m^2	21'425	t CO_2
Total Roof	147'042		17'807	
Total Wall	138'996		16'720	
Total Windows	63'309		5'417	
Total campus	**490'481**	m^2	**61'368**	t CO_2

4. Compensation of emissions

The way of compensating the emissions is investigated by means of four strategies: (i) the CO_2 uptake by the trees present on the site, (ii) the CO_2 uptake with an artificial vertical greenery system, (iii) Direct Air Capture (DAC), (iv) the typical solution of offsetting, through forest certificates or reduction projects.

4.1. CO_2 stored by EPFL trees

The lands and trees absorb nearly 30% of total fossil fuels and anthropic emissions [4]. The novelty of our approach lies in the possibility to quantify and to locate the stem of trees on the campus, and not only their occupied volume in space. The biomass stored can hence be derived from the wood mass instead of the tree volume. The carbon percentage inside plants is in fact surprisingly constant across a wide variety of species and tissues and it amounts to about the 50% of the entire mass [6]. The methodology developed here allows to assess the precise area of the trees thanks to data obtained from LIDAR satellite images. To evaluate the uptake of CO_2 by the trees present on the campus, we started from the raw data provided by the Canton Vaud and by SwissTopo. This dataset is based on LIDAR

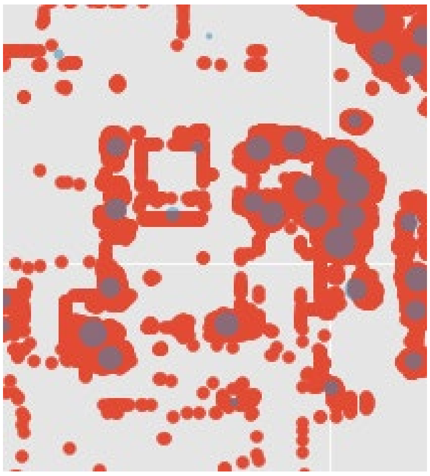

Figure 2. Identification of trees through algorithm starting from LIDAR points

Table 6. Total stored CO2 in trees on EPFL campus

Total trees vol			1'543	*m^3*
	different case scenarios			
Density	0.550	0.620	0.760	*ton/m^3*
Total C mass	1'061	1'196	1'466	*ton*
Tot 2017 emission			**20'697**	**ton CO2**
	percentage with respect to 2017 emissions			
Stored C	5.13%	5.78%	7.08%	
Stored CO_{2eq}	**18.81%**	**21.20%**	**25.99%**	

satellite measurements from which it was possible to extract the points corresponding to the green surface classified with a specific band (five for this specific case). The resolution of the image provided a grid of pixels with a dimension of 0.25 m^2 (0.5 m x 0.5 m). The highest point reached a height of 34.4 m. A filter has been applied to the lowest points, eliminating those inferior to 3m to neglect points due to their very low carbon content. The overall number of points (279,917 for an area of 69,976 m^2) are then grouped in clusters, namely for our case plants able to store carbon. An unsupervised Machine Learning (ML) clustering algorithm called k-nearest neighbors [5] has been implemented in Jupyter Python Notebook to reconstruct, starting from points in a 3D space, the trees centroids. The clustering algorithm is calibrated on the EPFL campus so as to obtain the most realistic number of centroids around which to cluster the points (extraction of the results is visible in Figure 2). The Stand Density Index (SDI) represents the average density of trees over a surface. In the literature, the densities of the most common trees on the campus (beech trees, oaks and birches) are listed but their spreading is too irregular to use those default values of SDI. The order of magnitude of is ranging from 50 to 200 trees/ha [6]. For this reason, the performance of the ML algorithm has been tested for several values of SDI, starting from 30 to 200, using the Averaged Distance Method [7]. We found the optimal value at around 82. The area of crown diameter is exploited to obtain the diameter breast height (dbh) and to calculate the total volume.

$$crown\ diameter = 0.7581 + (20.356 \times dbh)$$ [6]

The height of the trunk is provided by the weighted average of the points which constitute the tree. The total stored CO2 (table 6) is obtained through the stochiometric index of the photosynthesis: as visible from the table, all the trees have been able to store along their entire lifetime just 26% of the campus CO_2 emissions of 1 year. Their contribution is thus negligible in the overall balance.

4.2. CO2 uptake by Vertical Greenery Systems

Vertical Greenery Systems (VGS) are configurations which allow the growth of lawns and small shrubs also on vertical surfaces. It is also possible to choose types of grass which are particularly CO_2 absorbing. In every case, considering even the maximum possible percentage of wall exploitable, the contribution of this system is really limited in dropping the 20’697 tons CO_2 emitted in 2017: from 0.10% to 2.01% ranging from 5% to 100% of vertical surface covered.

4.3. Direct Air Capture system and offsetting systems

The Direct Air Capture system is a brand-new system developed in the last years. Climeworks, a Swiss company, has developed a fan system which, by means of absorption filters, is capable of trapping CO_2. The main requirement is a 100°C source of heat in order to free CO_2 from the filter and to capture it. The entire system is extremely compact and, moreover, it could exploit heat waste at just 100°C, relatively diffused in many different industries. In this case, the machine would work even in a carbon-negative cycle. The captured CO_2 must then be used in some way. There are commercial uses or, according to suitable ground, it is possible to inject the CO_2 in a basaltic terrain to make it solid again.

Given the difficulty to adapt this kind of plant to every user, they are selling CO_2 certificates of the experimental plant located in Iceland, to cover up to 2,000-ton CO_2/year. The cost is rather high since technology and business are still in their developing phase – about 600-800 $ per ton of CO2. The final reduction could therefore be limited to a maximum amount of 9.7%, and with an initial price ranging from 1,200,000 to 1,600,000 $. There are other ways to reduce carbon footprint through companies which offset the emissions. Planting trees is one of the most used offset strategies. The price of the most classical offsetting system can vary a lot according to the financed project: the range can go from 10 to 100 $/ton of CO_2. There are drawbacks as well, if this solution were to evolve to a large-scale level: from biodiversity losses to exceeding land requirements, or excess water usage.

5. Result

The overall sum of all the potential improvements we quantify shows the potential of a very significant decrease in the annual CO_2 emissions. It would be possible to reduce them up to 60%. As shown, the carbon dioxide absorbed by aVGS and by the already existing trees is really negligible, especially when compared to other reduction measures. This shows very well how reduction plays a more important role compared to compensation. The first contributes up to 50%, whereas the second to about 11% of the overall 60% potential reduction. There are no silver bullets able to reset the amount, but energy efficiency proves to be the most effective one, and the one with the largest margin for improvement. With this reduction, we found that the amount per capita of emitted CO_2 is around 0.50 ton of CO_2/year/person. This result could potentially meet the 2000-Watt Society target, considering that there are many others sources that have not been considered in the final result, such as food, services and other travels.

Table 7. Total potential reduction from reduction and compensation

CO2 emission 2017			**20'697**	**t CO2**
Reduction	Business Travel opt	7.7%	1'586	t CO2
	Energy Efficiency	29.7%	6'137	
	Commuting evolution	12.4%	2'573	
Compensation	VGS + forest	1.0%	207	
	DAC (ClimeWorks)	9.7%	2'000	
Remaining CO2		**39.6%**	**8'194**	**t CO2**

6. Conclusion

It is very difficult to obtain absolute carbon neutrality, but it is then very important to stress how the reduction of CO_2 emissions is much more effective than their compensation. The shift toward a sustainable society is certainly a hard challenge – yet it is a feasible one, and the universities should be at the forefront to demonstrate how sustainability goals can be reached, to make people aware of the fact that we already know solutions which can be put in place. The only thing we lack is the global, economic, and political will to do so.

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