KEY PERFORMANCE INDICES OF PHOTOVOLTAIC CARPORTS

Matthias Loup, Cyril Allenspach, Hendrik Hofmann, Roman Vogt, Fabian Carigiet, Franz Baumgartner

ZHAW, Zurich University of Applied Sciences, School of Engineering, IEFE
Technikumstrasse 9, CH-8401 Winterthur, Switzerland
Email: franz.baumgartner@zhaw.ch, Website : www.zhaw.ch/=bauf

ABSTRACT: PV carports are an ideal solution to produce electricity locally and sustainably, while taking advantage of the dual use of the space. On average, large carports have a power output of 0.17 kWp/m^2. The average costs amount to 2'100 CHF/kWp. The price per kWp decreases slightly when the power clearly increases. The costs of the PV modules are lower than the costs for the carport's foundation and supporting structure, which represent generally between 30 % and 60 % of the total costs. The amount of steel is estimated to 155 kg/kWp and the quantity of concrete required is approximately 650 kg/kWp. The specificities of the terrain naturally have an impact on these values. A carport parking space emits 690 kg-CO_2-eq during the construction phase and an electric vehicle (EV) 11.2 kg-Co_2-eq/100 km on average. Innovative projects include retractable roofs to offers the potential to reduce the amount of material used in the mounting structure, due to storing the PV modules in a safety box during heavy wind or snow load. The use of wood instead of metal, and screws anchor instead of concrete, as well as the addition of greenery, greatly reduces total CO_2 emissions.
Keywords: PV carport, distribution of costs and material, CO_2 footprint, e-mobility, durability.

1 INTRODUCTION

The share of newly registered electric vehicles (EV) in Switzerland doubled from 2019 to 2020 reaching eight percent, while other countries like Norway recorded more registrations for electrical cars than combustion engine passenger cars in 2020 [1]. Many countries and regions aim to reduce their greenhouse gas emissions to zero by 2050, e.g., the whole European Union. It is widely known that the total greenhouse gas emission will further rise if EVs are charged with electricity by coal fired power plants, which are predominant in countries such as Poland, China, South Africa [2]. In many countries, the total mobility sector accounts in average for about one third of total greenhouse gas emission, forcing the change to mobility system powered by renewables [3]. One solution is the local PV electricity supply by PV carports. A 2 kWp PV carport for passenger cars is able to power an EV to drive about 10'000 km annually in Switzerland [1, 4].

This publication presents the key performance indicators of today's PV carports, including a comparison of the overall costs of an installation in CHF/kWp depending on its power or the number of parking spaces. The distribution of costs between the technical study, foundations, supporting structure and PV modules is also given. The study then shows the amount of steel or concrete required for the supporting structure and the corresponding CO_2 emissions. Finally, innovative projects such as PV carports with greenery or retractable roofs are proposed.

Figure 1 : PV carport of 6.7 MWp in Courgenay, Switzerland [5].

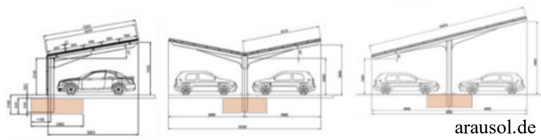

Figure 2 : Different types of PV carports, for one or two rows of cars, with variations in roof tilt. Concrete volumes are shown in light orange [6].

2 METHOD

The study determines the distribution of costs, material quantities and equivalent CO_2 emissions for the construction of small private carports with 2 places, medium ones with 10 to 20 places for blocks of flats and large ones with more than 100 places for companies and supermarkets. The results were determined by analysing already built carports, surveying engineering offices and evaluating the products offered by various suppliers in Switzerland and Europe.

3 KEY PERFORMANCE INDICES

3.1 Use of space – Costs

PV carports offer the advantage of producing electricity directly on top of infrastructure space where it is needed for EV charging. The energy can therefore be transmitted directly to the vehicles by the shortest route, minimising losses without the need of expensive storage. This technology makes it possible to take advantage of these spaces while protecting the vehicles from certain environmental influences, e.g., excessive heating by sunshine and hail. The power of large carports is on average 0.17 kWp/m^2 [6].

Figure 3 shows a slight downward trend in the price per kWp when the power increases significantly. This becomes visible when comparing carports with less than 2 MWp (Estavayer, Monthey, Dukovany, Aigle) with those of 6.7 MWp (Courgenay) and 9.8 MWp (Saint-Aignan). In contrast, this trend is not observed for the 4 carports with less than 2 MWp. The specificities of these and especially of the terrain have more influence at this scale.

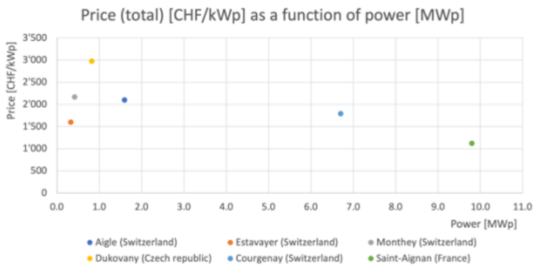

Figure 3 : Price in CHF/kWp as a function of installed power [6].

The average costs were found to be 2’100 CHF/kWp. The decreasing trend of the price per kWp as a function of the number of parking spaces is shown in Figure 4. For small carports (approx. 8 parking spaces), the price varies greatly depending on the geometry; it is generally between CHF 4’000 and 8’000/kWp.

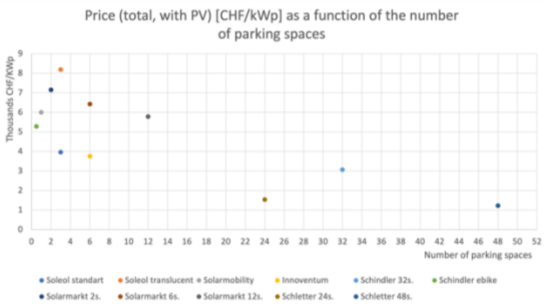

Figure 4 : Price in CHF/kWp as a function of the number of parking spaces [6].

The costs of the PV modules are lower than the costs for the carport's foundation and supporting structure, which represent generally between 30 % and 60 % of the total costs. Figure 5 shows in more detail the cost distribution for a 415 kWp carport in Aigle (Switzerland). Foundations and structure account for 50 % of the total costs, PV panels, inverter and cabling 38 % [6].

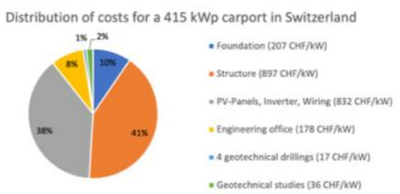

Figure 5 : Distribution of costs for a 415 kWp carport in Switzerland, in an area sometimes subject to strong winds [6].

3.2 Quantities of material used
The amount of steel is estimated to typically 155 kg/kWp. The quantity of concrete required is approximately 650 kg/kWp. The particularities of the site have a strong influence on the work to be carried out (sloping ground, landslide, strong wind, etc.).
For medium-sized carports (approx. 8 places), the price varies greatly depending on the geometry; however, it is generally between 4'000 and 8'000 CHF/kWp. The quantities of concrete required are much larger and can reach up to 1'250 kg/kWp [6].

Figure 6 : PV carport using steel structures and concrete fundaments. Performance index steel: 149 kg /kWp [6].

Table 1 : Key performance indices of amount of used steel in the structure of several PV Carports in Europe [6].

Large carports	Surface [m2]	Park spaces	Power [kWp]	Amount of steel		
				[kg-steel]	[kg-steel/kWp]	[kg-steel/m2]
Estavayer (Switzerland)	1'802	88	327	53'000	162	29
Monthey (Switzerland)	2'500	250	415	75'000	181	30
Dukovany (Czech Republic)	8'267	330	820	115'500	141	14
Courgenay (Switzerland)	43'000		6'700	1'000'000	149	23
Saint-Aignan (France)	53'000		9'800			
Adiwatt (France)			1'350		177	30
Soleol (Switzerland)			100		120	
AVERAGE	21'714	223	2'787	310'875	155	25
MEDIAN	8'267	250	820	95'250	156	29

3.3 CO_2 content
A modern and still little used alternative to the concrete foundations are the bolted foundations. This solution is more ecological but requires more time and a geological analysis of the terrain, which is generally more expensive. The use of a wooden structure instead of metal improves architectural integration and reduces CO_2 emissions.

As shown in Figure 7, a carport parking space emits 690 kg-CO_2-eq in the construction phase and an electric vehicle 11.2 kg-Co_2-eq/100 km on average. In comparison, a gasoline-powered car emits in average 29 kg-CO_2-eq/100 km [7]. Figure 7 summarises the different emissions.

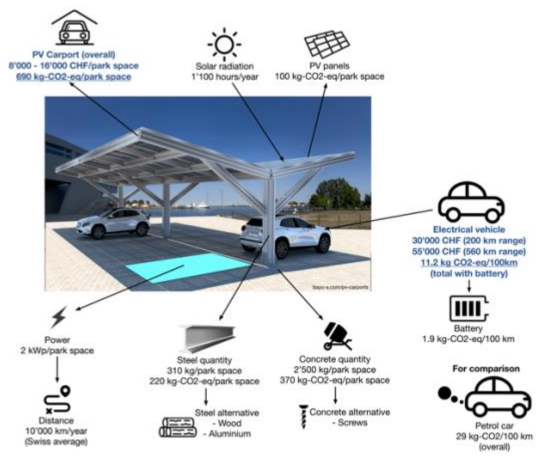

Figure 7 : Visual summary of equivalent CO_2 emissions of a PV carport [6].

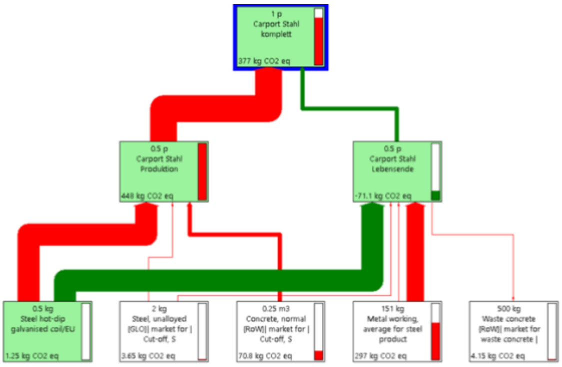

Figure 8 : LCOE of a standard steel concrete carport (foundation and structure) single parking slot results in minimum 377 kg-CO_2 for each parking space in the three phases of production, operation and disposal [8].

Table 2 : Amount of used material in the steel concrete carport (see Figure 8) [8].

Phase	Process/Material	Quantity	Unit
Production phase	Hot galvanised steel	300	kg
	Concrete	0.5	m^3
	Other material	2	kg
End of life	Concrete disposal	1000	kg
	Recycling hot galvanised steel	300	kg
	Recycling metals	2	kg

Figure 9 : Wooden PV Carport from InnoVentum, a Swedish company. Architectural integration seems to be improved.

3.3 New approach – Green PV Carport

A concept of the ZHAW green PV carport was developed to get optimized key performance indices (see Figures 10 and 11). Wood is used for the main structure element together with concrete. The implementation of bifacial PV modules allows the growth of vegetation beneath the PV Generator. This would be beneficial for the ecological and sustainable perception of the carport while reducing overheating of a car without the need of a carport roof. The related CO_2 emission was estimated to be about a factor of 4 to 7 lower compared to the CO_2 emission of standard steel/concrete PV carport.

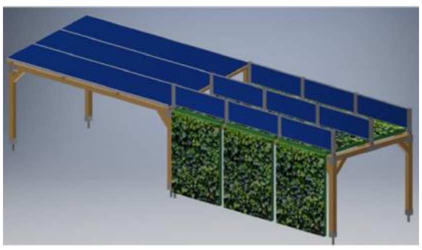

Figure 10 : Sketch of the ZHAW Green PV Carport to be using wood and vertical bifacial PV Modules, to allow growing plants beneath [8].

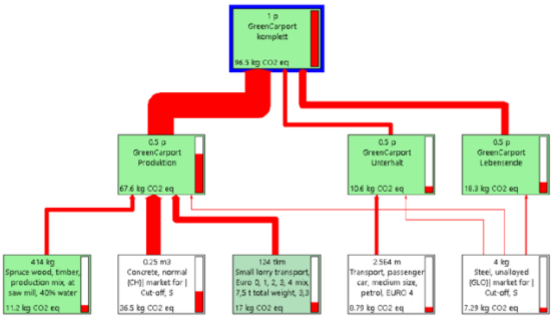

Figure 11 : LCOE of 97 kg-CO_2 (foundation and structure) for each parking space in the three phases of production, operation and disposal of the ZHAW Green Carport (see Figure 10). Thus, in comparison with Figure 8, CO_2 emissions with a wooden construction are about 3 to 4 times lower than with metal [8].

3.4 Retractable carports

Retractable carports are innovative photovoltaic systems for sustainable and local energy production. In case of unsuitable weather conditions, the PV modules are retracted and stored in a protective box. This protects them from strong weather influences (snow, hail, dew, etc.) and considerably reduces the forces impacting the supporting structure. This results in a decrease in the amount of material used and considerably reduces the costs compared to a standard installation.

The structure also offers the advantage of a double use of space and can be placed on a car park (carport), on a highway, on a water treatment plant or even above a football stadium.

For example, the URBANBOX concept is a construction with photovoltaic modules that can be moved horizontally on a fixed support structure. Thanks to the retractable roof, the forces on the structure due to wind are approximated to be 4 times smaller using less metal and concrete. In the final product, modules will have an integrated cleaning system in the protective box, which prevents yield losses due to soiling.

Figure 12 : Retractable PV carport from URBANBOX.

Another example of a retractable carport is that of DHP-Technology. In this application, the modules are suspended by a cable and can be moved in and out of a safety box. In the operating position, the PV modules have a tilt angle of 20° (see Figure 13).

Figure 13 : Retractable PV carport from DHP-Technology, Switzerland.

4 OUTLOOK

The energy transition is progressing and new technologies need to be developed and implemented in order to meet the environmental and climate targets for 2050. In Switzerland, new photovoltaic installations reached a new record of 493 MW in 2020. The final consumption of electricity in 2020 is 55,714 GWh, which means that photovoltaics currently only cover 4.7 % of the annual consumption [9].

However, some projects are in planning, such as covering 2.5 km of motorway in Zürich-Zug and 1.6 km in Wallis in Switzerland with photovoltaic panels for a total capacity of 53 MWp [10]. This enables sustainable electricity production with a double use of the land (production + road), whereas the motorway would be shaded and protected from snow. Since one third of CO_2 emissions come from the transport sector, it is relevant to envisage electricity generation by using the motorways. Since the number of electric vehicles is also increasing rapidly, charging stations could be made available with the electricity generated directly over them. The energy transport route would thus be as short as possible, which significantly minimises losses without the need of expensive storage.

Figure 14 : Motorway project in Wallis covered with PV modules [10].

5 CONCLUSION

The potential of PV carports is significant. In detail, they can be cost competitive when planned correctly. However even more important, they also tackle other relevant key performance indices beside the costs, which will be beneficial to meet customers and people's needs. The construction of a conventional steel/concrete PV carport is associated with the emissions about 480 to 690 kg-CO_2 per parking space. With the new European emission regulation limits of 95 g-CO_2 Emission in 2021 for new combustion engine cars, about 7'000 km driving distance equates to the construction phase of a single steel/concrete PV parking slot. This is close to an annual driving distance of small passenger car in Switzerland.

Taking advantage of the double use of the land, favouring self-consumption, producing locally and sustainably, choosing local wood over steel and screws over concrete, increasing the proportion of green areas and improving air circulation to minimise heating of the modules are key elements of future photovoltaic development.

6 ACKNOWLEDGMENT

We thank the companies that participated in the survey and shared the details of their PV carports.

Many thanks also to Adiwatt, Arausol, Bayo-s, InnoVentum, URBANBOX and Le Temps for their permission to use their illustrations in this publication.

7 REFERENCES

[1] Swiss Confederation, Federal Statistical Office, Mobility and transport, https://www.bfs.admin.ch/bfs/en/home/statistics/mobility-transport.html, 2021.

[2] K.M. Buresh et al. ; Energy for Sustainable Development 57 (2020) 132–140.

[3] Swiss Confederation, Federal Office for the Environment, Switzerland's greenhouse gas inventory, https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/greenhouse-gas-inventory.html, April 2020.

[4] H.M. Neumann, D. Schär, F. Baumgartner; Prog. Photovolt: Res. Appl. 2012; 20:639–649.

[5] Adiwatt, le photovoltaïque, une histoire d'experts, adiwatt.com/ombriere-7/, 2021

[6] M. Loup, Master Theses Project Report, PV Carport, ZHAW SOE IEFE, December 2020.

[7] EnergieSchweiz, Faktenblatt Umweltauswirkungen von Personenwagen, https://www.bfe.admin.ch/bfe/de/home/news-und-medien/publikationen.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvOTQ2MA==.html, February 2020. See also Swiss Confederation, Federal Statistical Office, https://www.bfs.admin.ch/.

[8] H. Hofmann and R. Vogt, Bachelor Project, Green PV Carport, ZHAW SOE IEFE, December 2020.

[9] Statistik Sonnenenergie, Referenzjahr 2020, Bundesamt für Energie BFE, https://www.swissolar.ch/fileadmin/user_upload/Markterhebung/2021/10539-Statistik_Sonnenenergie_Bericht_DE_def.pdf, July 2021.

[10] Zeitung LeTemps, A Fully l'autoroute se fiance avec le soleil, https://www.letemps.ch/suisse/fully-lautoroute-se-fiance-soleil, July 2021.