Putting solar in the driver's seat

Solar Mobility report

SolarPower Europe

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Project information: The Solar Mobility Task Force has been launched in May 2017 and gathers experts from the solar and mobility sector. The Task Force has held regular calls and meeting since then, that allowed the identification of the key solar mobility solutions and the benefits and downsides to them, as well as the regulatory barriers to these models. This report is based on the findings of the Task Force as well as with interviews with solar mobility solutions providers and project managers.

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FOREWORD

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Transforming and cleaning transport is pivotal to decarbonising our economies. The sector is responsible for a quarter of the global total CO_2 emissions,[1] which makes it the third largest emitting sector and the only sector that has increased its emissions since 1990. Transport is also responsible for air pollution through the emission of nitrogen oxides and noise pollution, particularly in cities. As a result, transport pollution is responsible for 4.2 million premature deaths worldwide according to the World Health Organisation.[2]

It is therefore urgent to make transport more sustainable.

Electrification, direct and indirect, appears clearly as the fastest and most cost-efficient technological solution to decarbonise transport. Electric Vehicle battery costs have achieved important cost reduction in the past years, with prices decreasing by 85% between 2010 and 2018,[3] allowing the Total Cost of Ownership (TCO) of small and medium electric vehicles to be the same as conventional vehicles by 2024.[4] Technology improvements and investments in fuel cells and electrolysis technologies have enabled a reduction in vehicle and fuel costs that could support the future cost-competitiveness of indirect electrification for certain segments of transport.[5]

In the EU, the European Commission has evaluated that battery-electric vehicles (BEVs) and fuel cells vehicles (FCEVs) will represent more than 90% of the vehicle stock by 2050 in a net-zero scenario[6]

The electrification of transport makes even more sense when done in parallel with the deployment of renewables in the EU electricity mix. Without significant additons of renewable capacities in Europe, the full potential of electrification to reduce CO_2 emissions in transport cannot be harvested. A study from the Paul Scherrer Institute shows that electric vehicles charging on fossil fuel-based electricity (e.g gas or coal) do not lead to an optimum reduction in CO_2 emissions compared with conventional gasoline and diesel cars, while the CO_2 emissions decrease by 50% with electric vehicles driving on CO_2 -free electricity.[7] The electrification of transport must therefore be thought of in synergy with the deployment of renewables in the power mix.

Solar energy is the ideal candidate to fuel green, electric mobility. As an illustration, in light road transport only, a typical rooftop, 5-kW solar panel can easily produce the daily amount of electricity needed for the average commute of an electric vehicle, even though the adequacy of the PV system will depend on its geographical location and on time variations, including seasonal.

Solar energy is also a **cost-competitive** fuel for transport. It has achieved important cost reductions in the past years. The Levelised Cost of Energy (LCOE) has reached €0.04/kWh worldwide and keeps decreasing,[8] as a result of decreasing manufacturing costs and increasing cell performance. The deployment of solar can therefore support a cost-efficient energy transition with limited public support. Furthermore, in many countries, direct sourcing of solar energy is already cheaper than grid electricity.

Solar installations are **modular** and can adapt perfectly to the energy needs of the end-consumer or various means of transportation. Solar installations are made of an assemblage of photovoltaic panels and can vary from a few kW to several GWs. Small solar installations can therefore fit well in urban landscapes, on rooftops, parking lots, rail infrastructure, etc. and can be installed as close as possible to the consumption point, be it a charging point or a refuelling station, thereby reducing reliance on the power grid.

1 8.04 gigatons of CO_2 emitted per year (data from 2017). Source: IEA (2018) CO_2 Emissions from Fuel Combustion 2019.

2 Data from the Global Health Observatory of the World Health Organisation.

3 Bloomberg New Energy Finance (2018). Battery Price Survey.

4 Bloomberg New Energy Finance (2018). EV Outlook 2018.

5 National Renewable Energy Laboratory (2019).

6 European Commission (2018). In-depth analysis in support of the Communication of the Commission A Clean Planet for All (COM (2018) 773f).

7 Paul Scherrer Institute (2018). Hintergrundbericht Die Umweltauswirkungen von Personenwagen: heute und morgen.

8 Lazard Bank (2018). Levelised Cost of Electricity.

FOREWORD

Looking at the physics, solar is **complementary** to electric mobility, particularly in certain use cases like day charging at work places or combined with battery capacity at home. Solar has a predictable generation curve and produces electricity during the day. This PV generation curve matches well with the time at which the majority of electric vehicles are parked and can be charged, for instance at workplaces or public parking – a match that can be optimised with smart charging devices. Solar generation also matches perfectly the load curve of trains, trams or metros that run and consume energy during the day, making them good candidates for solar consumption.

Finally, recent surveys show that solar is **the most popular source** of energy and can support **the public acceptance** for sustainable transport policies. In Europe, solar has the highest level of support among citizens.[9] Solar empowers consumers to invest into their own energy transition and gives them a sense of independence. As a result, one can easily observe the mutually reinforced dynamic between solar energy and electromobility: a recent survey by EuPD Research on electric-mobility has shown that for 77% of the respondents, the main reason to purchase an electric car was to charge it using their own solar energy, making it the most important motivator for purchase.[10]

The synergies between solar and clean mobility can unlock significant benefits to accelerate the European energy and transport transition. The solar industry must therefore be imaginative and forward-looking to exploit these synergies and offer solutions to consumers that wish to drive on solar energy.

“Solar mobility” refers to all the models exploiting the synergies between solar energy and clean transport. It also about adopting a comprehensive approach to the energy and climate transition across all sectors.

This aim of this report - the first of its kind developed by SolarPower Europe’s Solar Mobility Taskforce - is to look at existing and promising business cases of solar mobility and draw a first benchmark of renewable mobility models. It features existing case studies and pioneering projects. Based on this extensive work, the report includes key recommendations to promote the uptake of solar mobility solutions in Europe, and support Europe’s ambitions to become the first carbon neutral continent.

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9 European Social Survey (2018). European Attitudes towards Climate Change and Energy.

10 EuPD Research (2019). EndCustomer Monitor 9.0. The German PV Market from an End Customer Perspective. Focus: Digitalization and post EEG.

EXECUTIVE SUMMARY

The decarbonisation of the European transport sector has been high on the political agenda in the last year, and for a good reason: transportation is responsible for about a quarter of global CO_2 emissions, as well as significant air and noise pollution in cities across the world. A deep transformation of the transport sector is urgent to achieve Europe's climate ambitions, and electrification – direct and indirect – appears as the most effective and efficient solution to clean transport.

According to a recent survey charging one's car with solar energy is the main reason to purchase an electric car for 77% of people.

With that said, the electrification of transport implies a deeper integration withthe power sector, which is responsible for 38% of energy-related emissions globally. It must therefore go hand in hand with the deployment of renewables in the electricity mix, and should not lead to a growth of CO_2 intensive fuels. The concept of 'additionality' of renewables in electricmobility has been present in transport policy for many years but was never implemented. As the market for electric vehicles has experienced rapid growth in the past few years, the penetration of renewables in the transport sector continues to be a key issue for policy-makers, as well as for consumers who are increasingly sensitive to the sustainable sourcing of their electricity. According to a recent Eurobarometer survey by the European Commission,[11] 93% of Europeans see climate change as a serious issue, which has to be adressed by European and national public policies. It is therefore urgent to deliver a forward-looking model for transportation, for which the electrification of transport and renewable electricity go hand in hand.

Solar and mobility: A perfect match

With this perspective in mind, Solar Mobility refers to all the use cases where solar energy powers electric mobility – either directly, or through innovative supply solutions, or smart charging.

Solar presents itself as an ideal companion for clean mobility. With falling costs over the past years, it is a competitive and fully sustinable electric 'fuel'. It is also modular and can thus be installed close to electric mobility infrastructure. It presents synergies between its generation curve and the daytime charging process of vehicles. Perhaps the most significant benefit of solar to electric mobility is that it is a popular source of energy that can be owned by consumers. A recent survey by EuPD Research found that for 77% of respondents, the principal reason to purchase an electric car was the ability to charge on their own PV production.

Mapping the use cases and learning from experience

The Solar Mobility Report presents the world's first mapping of use cases regarding solar in mobility. This mapping is based on a catalogue of existing research, pilot projects, and business cases. The report summarises the lessons learnt from these experiences, providing an overview of the benefits and challenges of each model. Three main types of solar mobility models are distinguised: solar-powered mobility, vehicle-integrated PV, and smart solar charging.

Choosing solar as fuel: solar-powered mobility

Solar-powered mobility refers to models where solar electricity is used directly or indirectly to 'fuel' clean mobility. Various models exist and offer different options for particular transport cases.

For direct electrification of transport, **on-site solar supply** solutions imply the direct connection of a solar system to the charging point, following the logic of self-consumption. This model allows for savings on the energy bill, including grid

11 https://ec.europa.eu/clima/citizens/support_en

tariffs and taxes, by covering part of the energy consumption with self-generated electricity, which is particularly attractive in countries that have a high cost of electricity. This model also has non-financial benefits in terms of public image. Smart management of the charging process maximises the penetration of solar energy and can allow for peak-shaving (i.e. reducing the peak loads of charging stations), reducing the necessary grid connection capacity and the associated costs. This solution is particularly appropriate during the day – slow to fast charging – where vehicles are parked for several hours, such as public parking spaces or workplaces. It is also promising for ultra-fast charging stations when coupled with battery storage, which can store the excess PV generation.

Off-site solar sourcing models offer an alternative to on-site charging, which is especially relevant when space is lacking. The solar electricity is not produced at the charging point but is supplied commercially to the electromobility consumer through innovative supply contracts, where it is traced from generation to consumption through Guarantees of Origins. Purchasing unbundled Guarantees of Origins or Utility Green Procurement products is an easy solution for smaller consumers, or consumers unwilling to invest in a solar system. In parallel, Power Purchase Agreements offer the opportunity for consumers to invest in additional solar capacities. Consumers directly benefit from the power generated by the plant at a competitive and stable price agreed on over a 10 to 25 year period. This option is thus particularly attractive for large electricity consumers such as trains, metros, or trams.

For transport sectors and use cases where direct electrification is not suitable, solar e-fuels – synthetic fuels produced from solar electricity – could be a suitable solution for powering alternative, clean mobilities. Solar Hydrogen, produced from electrolysis, can power Fuel-Cell Electric Vehicles (FCEVs), provided that the cost of electrolysis technology and of hydrogen vehicles continues to fall. Solar synthetic fuels, produced from Solar Hydrogen and CO_2, such as methane, methanol, or electro-diesel could be used in vehicles that can neither be electrified directly nor indirectly; for instance, in the aviation or maritime sector. Yet these technologies are only at the stage of research and development, and significant cost reductions will be required before market roll-out.

Driving on the sun: Vehicle-Integrated Photovoltaics

Vehicle-Integrated Photovoltaics (VIPV) are solutions where a clean vehicle is equipped with directly-integrated PV cells. The term and the technologies come from Building-Integrated Photovoltaics (BIPV), a group of solar technologies where PV cells replace conventional building materials. In recent years, thanks to the falling cost of solar cells and improvement in cell integration, VIPV vehicles have been deployed in the market, offering a clean and affordable alternative.

VIPV solutions have been developed in all transport sectors – passenger cars, trucks, buses, boats, trains, aviation – and offer specific benefits in each case. Depending on the models, the PV cells can offer a simple power source for auxiliary services, but in most advanced cases provide additional power to the EV battery and extend its driving range, thereby allowing savings on 'fuel costs'. It can also power specific applications, such as the liftgate systems of trucks, or refrigerated trailers. By limiting the number of charging cycles, VIPV solutions can further improve the lifetime of the battery and reduce maintenance costs.

Smart solar charging

Solar mobility is also smart mobility, with smart charging technologies playing a central role. At the charging station level, smart charging can help to optimise the solar self-consumption ratio. It also has relevant applications at the system level: by unlocking the flexibility of EV batteries, smart charging can support the grid integration of solar and contribute to 'greening' the electricity system and the power used by electric vehicles. IRENA has modelled that in 2050, a global fleet of more than 1 billion EVs could provide approximately 14 TWh of batteries, compared to the 9 TWh estimated capacity of stationary batteries.

Smart charging technologies still face a number of technical and economic barriers; for instance, in terms of access to electricity markets. Regulation will be key to support the roll-out of such technologies.

Solar Mobility: business cases for all users

The Solar Mobility Report consists of a large variety of specific business cases, each with particular benefits and challenges, for virtually all forms of mobility and transportation. All mobility users and stakeholders could benefit from investing in solar mobility solutions, contributing to a truly green mobility by adding renewables to the power system.

Enabling these models requires a forward-looking, integrated political vision, bridging the gap between transport and energy policy.

REGULATORY ASKS

SOLAR MOBILITY REGULATORY ASKS

1 **Develop an enabling framework for the electrification of transport.** Electrification is currently the most cost-effective and impactful solution for the decarbonisation of transport: thanks to falling battery costs, Battery-Electric Vehicles (BEVs) are increasingly cost-competitive, while indirect electrification with hydrogen sourced from renewable electricity can provide clean solution for certain long-range or high-utilisation rate vehicles. A dedicated, comprehensive strategy is needed to support the roll-out of such zero-emission vehicles. This includes measures to ensure the availability of sufficient charging solutions for BEVs and FCEVs or the interoperability at charging stations to facilitate seamless payments.

2 **Value the renewable electricity used in transport.** The Renewable Energy Directive requires 14% of the total energy consumption of the transport sector to be acquired from renewable energy sources. To keep track on the achievement of this objective, the right methodologies should be developed to account for and value renewable electricity used in transport, either at charging points through on-site or off-site supply solutions, or in the production of synthetic fuels.

3 **Support the additionality of renewables in electric transport.** The electrification of transport can only be sustainable if accompanied by the deployment of renewables. Article 27.4 of the Renewable Energy Directive must therefore be implemented properly, by developing a methodology to measure additionality in member states and setting up dedicated monitoring mechanisms.

4 **Unlock the potential of on-site solar charging models, in residential areas as well as in workplaces or park-and-ride stations.** Enabling frameworks for self-consumption and collective self-consumption must be developed in National Energy and Climate Plans. It must be accompanied with adapted regulation to enable solar charging in multi-occupancy buildings or in neighbourhoods. Taxation rules and the design of charges and fees should not disincentivise the deployment of on-site solar supply.

5 **Facilitate the uptake of off-site solar sourcing.** The uptake of Power Purchase Agreements (PPAs) continues to be hampered by a number of regulatory obstacles and a lack of standard approach in this area. Member states must therefore take measures to facilitate the uptake of PPAs as part of their National Energy and Climate Plans.

6 **Deploy smart charging solutions.** The deployment of smart-charging infrastructure in homes, residential and commercial buildings and public charging stations should be strongly encouraged and access to vehicle's data should be facilitated. The value of smart charging should be reflected by the clear implementation of the Market Design provisions on the deployment of time-of-use tariffs, and ensuring market access to aggregators. The review of the Energy Taxation Directive is also critical to ensure the prohibition of double taxation on EV batteries used for flexibility services.

7 **Bridge the gap with the energy sector when planning the alternative fuels infrastructure network.** Local renewable energy resources and grid constraints should be considered when planning the roll-out of charging and refuelling stations, in order to optimise the integration of local renewables in transport. In solar-intensive countries, specific measures should be taken to encourage daytime charging, including a 'right-to-plug' in workplaces or park and ride stations.

8 **Dedicate financial support to innovative solar mobility technologies and pilot projects.** The current negotiations on the Multi-Annual Financial Framework (MFF) should include targeted funding to support renewable transport technologies and business models, notably as part of the Horizon Europe programme. This should be achieved by mainstreaming the European budget for climate.

9 **Differentiate synthetic fuels produced from renewable power, from those produced from non-decarbonised energy sources.** Synthetic fuels such as Hydrogen can support the decarbonation of mobility segments which are difficult to electrify directly. Yet, synthetic fuels are today mostly produced from highly carbon-intensive methods such as coal gasification or steam methane reforming. However, renewable-based electrolysis offers an opportunity to complement electrification strategies and fully decarbonise the transport sector. A clear terminology of synthetic fuels used in transport, is a pre-requisite to ensure transparency and promote the use of fully sustainable renewable-based synthetic fuels.

TABLE OF CONTENTS

FOREWORD 3

EXECUTIVE SUMMARY 5

REGULATORY ASKS 6

1 SOLAR-POWERED MOBILITY 10

1.1 On-site solar supply 11
1.1.1 Solar charging stations 11
1.1.2 Building-integrated solar charging solutions 16
1.1.3 On-site ground mounted solar solutions for trains and metros 20

1.2 Off-site solar sourcing 22
1.2.1 Unbundled Guarantees of Origins 22
1.2.2 Utility green procurement 26
1.2.3 Power purchase agreements 26

1.3 Solar e-fuels 29

2 SOLAR SMART CHARGING 33

2.1 What is smart charging? 34

2.2 Smart charging and solar mobility 35

3 VEHICLE-INTEGRATED PHOTOVOLTAICS: SOLAR-POWERED VEHICLES 41

3.1 Solar cars 42

3.2 Solar trucks and buses 45

3.3 Solar boats 47

3.4 Solar trains 47

3.5 Solar airplane transportation 49

THE RENEWABLE ENERGY TARGET IN TRANSPORT

The recast Renewable Energy Directive updates the EU target for renewable energy in transport: the European Union must collectively reach 14% of renewable energy in the energy consumed in transport by 2030. This target should be translated through dedicated targets for each fuel suppliers that should be defined by member states.

Yet, this target has to be filled at least at 3,5% with advanced biofuels and biogas. In addition, the consumption of conventional, food-based biofuels is limited to 7%, but the share of biofuels in transport can be subtracted from the 14% target.

MOBILITY

CASE STUDIES

SOLAREDGE: the first combined solar inverter and EV charging point tested in the UK	12
WE DRIVE SOLAR: A car sharing scheme running on solar	13
DRIVECO PARASOL: A technological breakthrough from the French company DRIVECO enables electric vehicles to completely eliminate their carbon footprint	14
INNOGY Duisburg solar fast charging stations	15
SMARTLY powering a workplace charging station with solar	17
TESLA: powering local charging points with local solar generation and storage	18
FRONIUS: E-mobility solutions for commercial and industrial customers	18
LIDL Belgium's solar charging stations	20
SOLAR FARMS to power the electric trains fleet of ÖBB	21
ECOHZ providing green electricity supply solutions for e-mobility	23
ENERGY WEB FOUNDATION: Using blockchain to track and trace renewable electricity used for charging electric bikes	24
CHARGEPOINT: partnering with a local utility to source renewable energy in charging stations	25
SANTIAGO DE CHILE METRO: The first metro running on solar and wind	27
SNCF AND VOLTALIA: A solar CPPA for French trains	28
LAST MILE PROJECT: Akuo Energy decentralised solar hydrogen refuelling stations	30
FRONIUS SOLH$_2$UB: a decentralised hub for solar energy with green hydrogen	31
ENGIE: Solar hydrogen for city buses in Pau	32
SOLAREDGE solution combining smart charging and solar mobility	35
IBERDROLA'S Smart Mobility and Smart Public Recharge Hub Solutions	37
CHARGEPOINT: A smart charging solution for buses	38
THE MOBILITY HOUSE: Unleashing the flexibility potential of EVs in Porto Santo Island	39
ENEL X: Deploying solar and storage to charge on solar	40
SOLAR Hybrid Electric Cars	43
SOLAR full-electric vehicles	44
TECNALIA'S technico-analysis for solar-powered reefer trucks for the long-distance transportation of refrigerated goods	46
CITY BOATS AND BARCO SOLAR: Solar vessel solutions in Poland and Portugal	47
SOLAR trains	48
SOLAR IMPULSE, the pioneer solar airplane	49
SOLARSTRATOS	50


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1 SOLAR-POWERED MOBILITY

As electric vehicles still have a high purchasing cost, the competitiveness of the fuel – electricity – is key to supporting the shift to electric vehicles by enabling a low operating cost. This is were solar offers a good opportunity: solar PV energy is already cheaper than grid electricity costs in a large number of countries, and its cost is only decreasing with time. It is an unlimited resource, available domestically, thereby reducing the dependence on fuel imports from foreign countries.

Most importantly, solar panels generate CO_2-free electricity, and is the gateway for a truly sustainable and low-carbon mobility.

Solar can support many existing and novel transport solutions, from cars, to trains, to aviation, and beyond. Not only this, it addresses the needs of all types of consumers, from households to businesses, and many daily commuters. This report therefore identifies various models of "solar-powered mobility".

On-site solar supply solutions refer to models where a solar installation is directly connected to the charging point of the vehicle. Off-site solar sourcing includes models where solar is not directly connected to the charging point, but where solar is provided through specific supply contracts. Finally, the report also looks at solar e-fuels, the synthetic fuels produced from solar – and to a larger extent renewable – electricity.

SOLAR MOBILITY

	On-site electricity supply			Off-site solar sourcing		
	Solar Charging Stations	Building-integrated solar charging solutions	On-site ground-mounted solar solutions	Unbundled guarantees of Origins	Utility green procurement	Power Purchase Agreements
Residential Charging		X		X	X	
Non-residential charging (workplaces, fleets)	X	X		X	X	X
Public charging points	X			X	X	X
Other electrified means of transport: trains, metros, trams			X	X	X	X

1.1. On-site solar supply

Solar PV is an affordable technology with a high degree of flexibility and scalability. It can be installed at the closest of consumption points, guaranteeing a direct and fully renewable electricity supply to electromobility infrastructures. The "electric mobility environment" provides many types of passive surfaces - such as carports, parking roofs or rail companies' land - which can be used to deploy on-site solar charging solutions.

Such solutions are referred to in this report as "on-site solar supply" solutions, many of which have been the subject of various research and demonstration projects throughout the world.[12] They are the flagship model for solar mobility, as these business models directly contribute to the additionality of renewables in transport,[13] supporting investment in additional solar capacities and the fully sustainable electrification of transport.

The advantages of "on-site solar supply" model are similar to those of self-consumption in buildings: by maximising self-consumption ratios of solar electricity generated on-site (rooftop, solar charging stations), the EV owner reduces the need to consume from the grid, saving on their electricity bill while also reducing grid congestion. This is reinforced by additional regulatory measures, such as a tax or fee exemption on the self-consumed electricity.

A solar charging station allows even more optimal use of the grid (just like a solar and storage installation in buildings). The solar electricity generated helps reduce the volume of electricity absorbed from the grid – especially during the day – by providing an additional renewable electricity supply which is directly consumed or stored on-site. It avoids grid reinforcement or limits grid fees for high power charging (such as the demand charge in the USA) and can facilitate the deployment of charging infrastructure, particularly in regions in which there is not enough local grid capacity to connect the charging station.

To achieve a high self-consumption ratio, as the output of the solar system varies during the day, a certain amount of flexibility is often required. On the supply side, the addition of a battery storage allows the solar PV electricity to be stored when there is no consumption or charging needed, so that the vehicle can be charged at a later time when the sun is not shining and complement the intake from the grid. On the demand side, the modes of transport consuming or charging during the day and for considerable periods of time (e.g. cars parked at workplaces, commercial centers, park and ride stations etc.) are the most suitable candidates. This can be supported by a flexible charging process for vehicles, so-called "smart charging", where the charging process is altered on command.

The economics of on-site-solar charging solutions depend on a variety of parameters: the costs of purchase and construction of the PV installation, the cost of electricity, which can vary based on the country and type of charging station (fast or slow), the grid connection and usage costs, or the framework for self-consumption including potential tax exemption or reduction.

Last but not least, on-site solar EV charging can be one of the options used by transport fuel suppliers to comply with the obligation outlined in RED II (to be implemented by the 30th of June 2021 the latest), which require them to incorporate 14% renewable energy in their fuel sales by 2030.

This report highlights three viable on-site solar supply solutions: standalone solar charging stations, building-integrated solar charging solutions and on-site ground-mounted solar solutions for trains and metros.

1.1.1 Solar charging stations

Standalone charging stations, such as public charging stations in cities or on the highway, can be equipped with a solar system. Most of the time, the solar panels are integrated into a solar canopy covering the vehicles parked at the charging station.

The economics of this model rely on the possibility to maximise the charging time on the solar energy. This may be challenging, particularly for fast to ultra-fast charging stations which are more common for public charging solutions along highways. Fast and ultra-fast charging stations deliver a high-power current to charge the car (above 50kW for fast charging and above 150kW for ultra-

12 Major research on this topic include:

- Matthias Zech, Ingo Wizemann, Isabel Augenstein, Mathias Müller, Uwe Thomas, Gerd Becker (2012) Analysis of a PV-powered Charging Station for Electric Vehicles
- Merten, Jens & Guillou, Hervé & Ha, Long & Quenard, Mathieu & Wiss, Olivier & Barruel, Franck. (2012). Solar Mobility: Two Years of Practical Experience Charging Ten Cars With Solar Energy.
- Jessica Robinson, Gary Brase, Wendy Griswold, Chad Jackson, Larry Erickson (2014). Business Models for Solar Powered Charging Stations to Develop Infrastructure for Electric Vehicles

13 The concept of additionality derives from the Renewable Energy Directive, article 27. It refers to the fact that the growth of electric consumption in transport must be accompanied with a growth of renewable capacities, to ensure that the electrification of transport is not realised with carbon-intensive electricity.

fast charging), which is not comparable to the output of the solar panels. In addition, the parking time is often more limited, with charging behaviours very similar to gas station refuelling. Maximising the solar charging behind the meter therefore requires agile solutions.

Models of solar charging stations exist for slower public charging stations (for instance with a 22kW to 50kW capacity), for instance in an urban or suburban context. Solar panels are installed on the rooftop of the charging station and generate electricity that can be used to

CASE STUDY
SOLAREDGE: THE FIRST COMBINED SOLAR INVERTER AND EV CHARGING POINT TESTED IN THE UK

Completely Green is a highly knowledgeable sustainable energy specialist that constructed a unique showroom in Midsomer Norton, in the South-West of England. The showroom allow people to view and test various clean technologies, including test drive a selection of electric cars.

In October 2018, the showroom partnered with SolarEdge to create a completely green EV charger car port, using the world's first EV charging single phase inverter from SolarEdge.

How does it work?

The drive-in station is equipped with a compact solar array on the roof of the carport. The SolarEdge EV charging inverter is mounted on a pillar inside the car port. The all-included solution can be installed altogether, thereby optimising the installation costs and time.

The construction allows motorists to conveniently charge their electric vehicles on the side of the road, using the power of the sun to reduce reliance on the grid and cut their electricity bills. In addition, the "Solar Boost" mode allows drivers to charge their vehicles fastly using simultaneously the electricity from the PV panel and the grid power.

Furthermore, the monitoring feature that's seamlessly integrated into the SolarEdge EV charging inverter, allows Completely Green to view charge duration and charge energy, carry out smart scheduling and also remote operation. This has proven to be a handy tool in the company, providing a complete service to all EV owners using their car charge point.

Source: SolarEdge.

power the charging process. The solar charging can be maximised if the public charging station is capable of smart charging and gives such option to its clients. The use of a hybrid inverter for both the solar output and the generation can also reduce the costs of charging.

Some of these models also imply the aggregation of solar resources and charging stations in a virtual power plant. If the sun is not shining for the two vehicles charging at station A, the power generated in the empty station B can be used. This model requires a smart energy management system capable of collecting the generation curve and the various charging needs. It therefore allows the penetration of solar generation in charging points to be maximised.

CASE STUDY
WE DRIVE SOLAR: A CAR SHARING SCHEME RUNNING ON SOLAR

We Drive Solar is a car-sharing scheme aimed at charging mostly on solar PV energy. The scheme has been created in the neighbourhood Lombok in the Dutch city of Utrecht as part of the EU project “Smart Solar Charging”. Since then, it has extended to several Dutch cities. The car-sharing scheme is composed of 70 Renault Zoe cars and counts 500 customers.

The electricity used to charge the cars mainly comes from solar panels installed locally on rooftops in the neighbourhood rooftops and by LomboXnet (more than 8,000 in the region, representing 2MW capacity), including on the roofs of 25 schools. If the sun is not shining, electricity can also come from the company’s solar and wind systems installed in the Netherlands, using Power Purchase Agreements. In total, the solar panels owned by We Drive Solar produce enough energy for 10,000,000 electric kilometers each year.

We Drive Solar 22kW charging stations are also capable of bidirectional charging, which allows them to optimise their charging profile depending on the electricity price and the availability of solar energy, as well as providing flexibility to the grid. The cars can also provide flexibility services to the grid, for instance by discharging when the electricity supply is too low. Recently, Renault provided the first electric Zoe cars capable of bidirectional charging.

In the next years, the We Drive Solar programme aims at rolling out additional electric cars as part of the car sharing system.

Source:The King Willem-Alexander of the Netherlands at the launch of the partnership between We Drive Solar and Renault. © We Drive Solar.

CASE STUDY
DRIVECO PARASOL: A TECHNOLOGICAL BREAKTHROUGH FROM THE FRENCH COMPANY DRIVECO ENABLES ELECTRIC VEHICLES TO COMPLETELY ELIMINATE THEIR CARBON FOOTPRINT

DRIVECO is a subsidiary of Corsica Sole, operator and producer of solar energy, which develops and designs complete charging solutions for electric vehicles. Aiming to be a pioneer in the field of renewable energy, DRIVECO has created a cutting-edge technological innovation: the PARASOL.

The PARASOL is a 100% solar-powered charging station for electric vehicles. It is compatible with all electric vehicles on the market and can charge eight cars simultaneously. The PARASOL produces its own energy using the 29kW solar PV rooftop of the carport, stores it in its batteries and delivers it to all 70kW charging points. To ensure a 100% solar charge, the power supplied to the vehicles is managed in real-time by the DRIVECO Smart Grid. DRIVECO mutualises and balances the solar generation from the solar charging station portfolio with the charging demands. For instance, a station in Ajaccio will share its excess solar energy with electric vehicles charging in Bastia in real-time. This smart management system was developed in partnership with the CEA, bringing a technological breakthrough to market that will help mitigate climate change.

Today, the emissions from a diesel vehicle have the same carbon footprint as the emissions from an electric vehicle charged on a high-carbon content electric grid, which represent 50% of the world's power grids. By designing a solution linking energy and transportation systems, DRIVECO proved that it is possible to build and operate a "smart solar mobility" infrastructure that can decrease harmful transport-related emissions by 95%.

Source: DRIVECO.

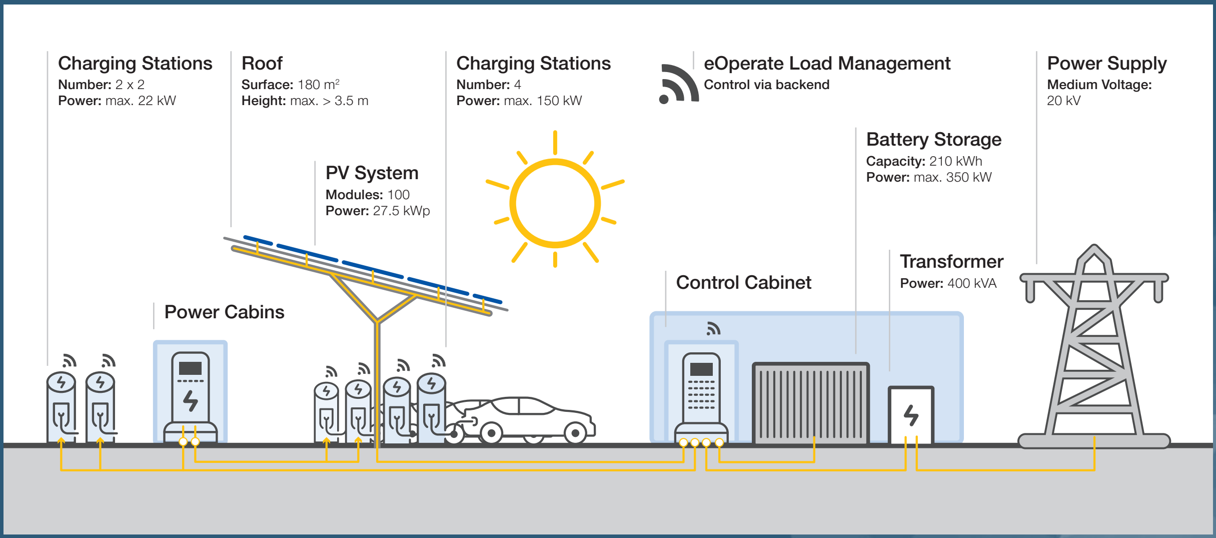
Ultra-fast charging stations (150 kW) present a priori the most challenging models, with lower charging times. Yet, the increasingly common addition of battery storage to ultra-fast charging stations to support the high-power demand of fast and ultra-fast charging stations could create a case for solar charging solutions. In such a case, a PV system can generate electricity that is stored in the battery added to the charging station, thereby limiting the amount of power withdrawn from the grid and optimising the direct use of self-generated electricity. It can also provide direct power to the electric vehicles when they are charging. In recent years, Tesla, innogy or the Polish company Greenway have thus developed solar charging solutions.

CASE STUDY
INNOGY DUISBURG SOLAR FAST CHARGING STATIONS

The German energy company innogy has launched its first semi-autonomous fast charging station, located in the German city of Duisburg, in a rest area off the A42 and A59 highways. The 150 kW fast charging station is equipped with a 180 m2 27.5 kW solar rooftop and a 210 kWh battery storage facility. The project is a result of innogy's research and development teams.

The battery storage minimises the pressure on the electricity grid by buffering peak load periods with green electricity from the solar panel when several vehicles are using ultra-fast chargers on full power at the same time. In addition, it maximises the use of the solar electricity which can be stored when vehicles are not charging or the sun is not shining: the charging station can even operate completely off-grid at times. When solar power is not available, grid green power is sourced to supply the additionally needed kWh.

While the local grid capacity is often not sufficient to connect the fast charging station, with this innovative project, innogy facilitates the integration of a fast charging station into the grid with green electricity.



Source: innogy.

Source: innogy.

The adoption of on-site solar charging solutions may be hampered by the capital cost of investment in solar charging stations, where the installation of the solar system and possible battery storage add to the investment cost of the electric charging stations.

Nonetheless, investing in a solar charging station can also bring important economic benefits, by allowing savings on the energy bill and on energy taxes and tariffs if the right self-consumption scheme is in place.[14] In addition, a smartly managed solar charging station can optimise the reliance on the grid and reduce the peak load of the electric vehicles, resulting in lower grid costs.

Additionally, solar charging stations bring many indirect benefits. The solar carport or canopy provides shade for the vehicle, which reduces the internal temperature of the vehicle and limits the need for air conditioning. It also protects the car from sun damage, rain or ice.

Most importantly, solar is a popular source of energy, and the idea of charging on solar is increasingly attractive for consumers. Integrating a solar canopy or carport can support the image of the charging company while educating consumers about energy the electricity sources used for electric mobility. One example is the company Fastned, which has been one of the first charging point operator rolling out solar fast-charging stations. It also supports the public image of charging operators, providing them with a competitive advantage towards highly environmentally conscious customers. Providing a solar-based charging stations in working spaces and semi-public spaces also fits well in corporates' sustainability goals.

1.1.2 Building-integrated solar charging solutions

Building-integrated solar charging solutions refer to models where the charging solution is connected to a building equipped with rooftop solar. It is increasingly successful, partly driven by high demand from building owners in the private sector.

In this model, the solar system is installed on the full rooftop surface of a building and is larger than the average carport size. It supplies both the electric vehicle charging and the building's energy consumption. This configuration allows consumers to make use of the full solar potential of their roofs instead of undersizing their solar systems to fit the sole energy needs of their buildings - an issue that has been observed in countries which have phased out net-metering or other support schemes. It can also support a higher self-consumption ratio and avoids losses of green energy when the solar panel is generating electricity but no electric vehicle is charging.

In practice, building-integrated solar charging solutions are interesting when the charging happens during the day and the output of the solar system can be maximised. Longer parking times also allow a slower charging process more adequate to the power level of the PV system. Smart charging can also be applied for the charging to be modulated to the generation curve of the PV system.

Therefore, the optimal charging models are charging at workplaces or in public parking areas such as park and ride stations, where vehicles are parked for a duration of around eight hours. Airport parking lots are a very good example, as several cars typically remain parked for a minimum number of hours (at least one hour). Today, if a large part of the charging happens in residential charging stations, there is a clear opportunity to encourage these solutions. The availability of charging points at workplaces or in public places would encourage consumers to purchase an electric vehicle by providing assurance on the amount of available charging options or by removing the cost barrier of the high investment required to install a private charging station. This has been encouraged by the recently adopted Energy Performance of Buildings Directive, which requires the installation of at least one charging point and one ducting infrastructure per five parking spaces in all new and renovated non-residential buildings.

14 The Renewable Energy Directive, article 21, states that all renewable self-consumers shall be exempt from any tax or fee if the capacity of the renewable installation is lower than 30 kW.

CASE STUDY
SMARTLY POWERING A WORKPLACE CHARGING STATION WITH SOLAR

ValEnergies is a French company and pioneer of solar self-consumption solutions for corporates with its solution Ellybox. Active in the sector since 2012, the company has started imagining tailor-made solar charging solutions for its clients.

SAPS Labs is a German company and global leader in the production of software for company applications. The company is engaged in an ambitious sustainability strategy, as it has decided to electrify the entirety of its company's fleet by 2020. Therefore, the company's offices in Mougins, France, have installed 26 electric charging stations, including two 50 kW charging points. To supply electricity to the charging points, the company has decided to install a solar rooftop installation of 66 kW capacity (a total of 240 panels each with a capacity of 275 W). The system was installed by ValEnergies, which has designed, invested, installed and is operating the station, requiring no investment from SAPS Labs.

SAPS Labs has developed a smart algorithm to monitor the charging process of the vehicles. The solar generation and the various loads of the buildings are monitored through a platform developed by ValEnergy. The charging curve of the vehicles is therefore smartly monitored to maximise the self-consumption rate of solar energy.

In total, the company estimates that the solar system covers about 30% of the electricity consumption of the building and the charging stations on average, and up to 60% on sunny days. This results in savings on the energy bill of the company, but also has positive consequences on the company's image. This solution has also helped the company reduce the peak loads due to the charging process of the vehicles and avoid upgrading its grid connection point, with financial benefits for the company.

After positive feedback on this first experience, in 2020, SAPS Labs France is planning to extend the solar system by installing PV panels on the parking places' carports. In addition, further improvements will be made to the smart charging solution and battery storage systems will be added to the installation in order to reach a complete solar self-consumption rate.

Source: SAPS Labs.

CASE STUDY
TESLA: POWERING LOCAL CHARGING POINTS WITH LOCAL SOLAR GENERATION AND STORAGE

Tesla has pioneered the transformation of transport and is committed to enabling consumers to drive on renewable power. To this end, the company has partnered with the British renewable energy developer EvoEnergy in 2018 to demonstrate the possibility to charge on local renewable electricity.

The project was commissionned by the University of Nottingham for its local energy community and its local EV charging stations. The energy community has been created in the new neighbourhood of Trent Basin which will eventually host around 500 houses. The houses are equipped with around 900 rooftop solar panels as they are built. In addition, the community is connected to two solar farms of 190kW and 440kW capacity respectively.

The project consists in designing a 2100kWh / 500kW battery system for the community created. This represents the largest community battery in Europe to date. An energy management system has also been set up and connected to all the loads of the energy communities, notably the local solar farm, the heat pumps and the charging stations.

The project will enable the university to study how the community energy consumption, including at charging points, can be optimised to maximise the charging on solar power. The provision of frequency response services to the British grid operator by the community will also be demonstrated.

Source: EvoEnergy.

Building-integrated solar charging solutions require monitoring the solar generation curve and smart management of the charging process and the energy consumption of the building. Such solutions are already being developed and adapted to charging systems.

CASE STUDY

FRONIUS: E-MOBILITY SOLUTIONS FOR COMMERCIAL AND INDUSTRIAL CUSTOMERS

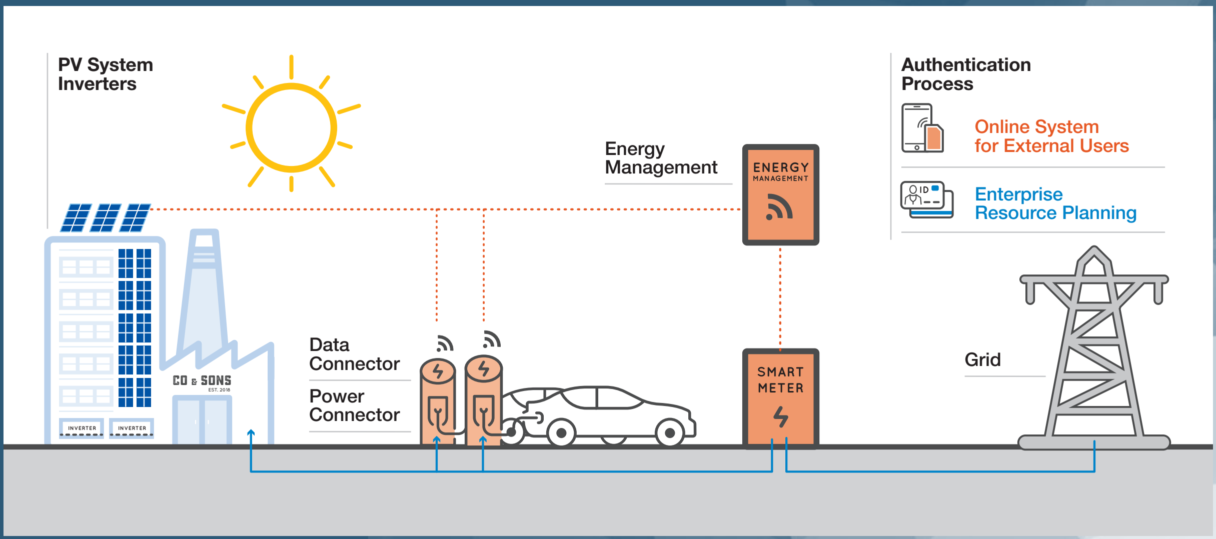
Fronius helps commercial and industrial customers investing in large photovoltaics (PV) systems on their roofs. As the same companies electrify their fleets and invest in electric charging stations, using the self-produced, renewable PV energy to power domestic e-mobility charging is the natural goal.

In general, from the electricity generated by a commercial or industrial rooftop solar PV system, there is sufficient energy volume to charge a typical e-car fleet. For instance, a 3 kWp PV system, on a 30 m^2 flat roof in Central Europe, can power a typical e-car for a range of 20,000 km annually. Yet, the charging time of different cars has to be managed to avoid power peaks, which can be very cost intensive in local infrastructure and result in high grid connection costs for the company.

Fronius has developed a solution for its commercial and industrial consumers investing in PV and mobility. The key component is the energy management system, which an interface linking to the main components like the PV inverters and the charging points. The system can manage the charging process of the fleet on the basis of the local PV generation and the user preferences. This allows the company to avoid power peaks in the morning when the e-cars are plugged in at similar times and you benefit from on-site PV production to increase the charging power during daily sunshine hours.

The company can also open its charging infrastructure not only to its employees' fleet but also to the public, allowing a diversification of revenues. The smart control algorithm can also include different user profiles, distinguishing their load profile: for instance, an employee's car will have low charging demand and will remain parked for eight hours, while a visitor's car will need to charge faster and remain parked for a shorter time period. An authentication system for the different profiles gives the algorithm the appropriate input.

Fronius smart solution therefore allows the company to avoid power peaks in the morning when the electric cars are plugged in simultaneously and to maximise the benefit from on-site PV production by increasing the charging power during daily sunshine hours. There is no energy problem in combining e-mobility with photovoltaics. The power challenge is addressed with a smart system, PV inverters, energy management and authentication platform.



Source: Fronius.

This model provides important economic benefits to the EV driver, following the logic of self-consumption. Maximising the charging on the self-generating energy lowers the energy costs by saving on the energy component of the bill, the grid tariffs and the energy taxes. In addition, bundled offers are being developed, where the installation time and costs of the charging station and the solar system are combined.

However, this model also allows important non-financial benefits for building owners, be they corporates or landlords, in terms of public image of the building. These benefits can be particularly interesting for commercial buildings.

1.1.3 On-site ground mounted solar solutions for trains and metros

On-site solar solutions can be found in sectors, not just road transport: electric trains, trams or metros consume electricity mostly during the day which makes them the perfect candidates for a solar supply solution. In addition, railway companies often own land that can be used to install solar panels, for instance, on the side of the tracks or on railway infrastructure, such as tunnels.

One challenge lies in the equipment required for the connection of the solar system to the overhead lines. Most European countries now use an alternative current of 25 kV voltage and 50 Hz frequency for their catenary, but

CASE STUDY
LIDL BELGIUM'S SOLAR CHARGING STATIONS

Lidl is a German supermarket chain present in Europe and the United States and operating more than 10,000 stores globally. The company currently owns 305 stores in Belgium.

Since 2017, the Belgian branch of the company offers its clients the possibility to charge their electric vehicles with solar electricity for free using the charging stations at their stores in Belgium. As part of its sustainability strategy, the company is equipping its stores and distribution centres with solar panels as well as with charging stations for electric cars and bikes and is designing all of its future stores in this way. The electricity produced by the solar panels is used to power the building and the charging stations.

This initiative allows the company to support renewable mobility in an innovative way and is a good representation of the link between solar energy and electric mobility, while supporting the attractivity of its stores. Early feedback on the experience at the 37 stores already equipped with a green charging station is already positive.

All of Lidl Belgium's new stores are built with a solar rooftop system and charging stations. In total, the company aims to equip 100 stores with a solar rooftop system and charging stations by the end 2020.

Source: Lidl.

many countries use different currents: for instance, Switzerland, Germany, Austria, Norway and Sweden use an alternative current of 15 kV with a 16.7 Hz frequency, while the USA uses a current with a 25 Hz frequency. This requires railway companies to develop specific equipment able to convert the DC generation from the solar system into AC power at the specific frequency of the catenary, equipment that is not currently widely available.

CASE STUDY
SOLAR FARMS TO POWER THE ELECTRIC TRAINS FLEET OF ÖBB

The Austrian railway company ÖBB runs national and urban trains in Austria. The company has been pioneering renewable mobility. With nearly three-quarters of its lines electrified, and an ongoing transition to electric trains, since July 2018, ÖBB has been covering all of its traction power with renewable energy sources, 35% of which are supplied by the company's own hydropower plants.

In 2015, the company launched a new pilot project to test the opportunity of a directly connected PV system, a world's first. A 7,000 m2 solar PV plant was installed in Wilfleinsdorf in Lower Austria. The plant generates over 1,100 MWh annually – an amount that supplies the demand of 200 trains from Vienna to Salzburg. The system is directly connected to the railway's catenary. As ÖBB's grid is running at a frequency of 16.7 Hz (compared to the 50 Hz of the European public grid), the project has required the development of a specific transformer to convert the DC power of the PV system to the right frequency.

The new system allows ÖBB to increase the share of their own electricity production. PV generation generally coincides with peak loads of railway traffic during daytime. In addition, the volatile generation can be balanced with the flexible generation of ÖBB's hydropower plants. The set-up allows ÖBB to realise economic benefits as it limits its reliance on the grid electricity and its exposure to the variability of power market prices. Furthermore, the direct integration of supply and demand sectors offers technical benefits: it relieves the strained public grid and reduces losses of frequency conversion. Yet, the profitability of the model, and the opportunity to replicate it, will depend on further criteria, notably the existence of incentives for electricity consumers to invest in renewable energy generation in order to limit their reliance on the grid. In addition, the availability and the cost competitiveness of the transformer technology at 16.7 Hz frequencies will also influence the roll-out of the pilot project.

Source:ÖBB.

1.2. Off-site solar sourcing

Using solar to run electric vehicles does not necessarily require an on-site solar installation, thus solutions exist for those consumers that cannot deploy a direct connection to a solar installation. Such solutions are referred to as 'off-site solar sourcing'. In this model, solar electricity is produced at different points of the grid but is commercially supplied to the electromobility consumer through innovative supply contracts. The solar electricity is traced from the moment of generation to the consumption by the end consumer through Guarantees of Origin.

Off-site projects can overcome local logistical problems, such as availability of space at or close to charging stations[15] or rail companies' land, and insufficient solar power resources to meet the demand. With regards to larger solar plants, they allow EV owners or charging station operators to benefit from economies of scale in terms of the installation, operation and maintenance costs, and thus, benefit from a lower electricity cost.

There are different off-site sourcing strategies for solar procurement, each of them providing different benefits to meet both the power and the financial requirements of the mobility solution. This report presents three strategies for off-site solar sourcing: Unbundled Guarantees of Origin (GOs), utility green procurement and Power Purchase Agreements (PPAs).

GOs are a crucial instrument for solar power sourcing as they track the origin of the solar generation and certify that the electricity comes from solar. Utility green procurement provides solar electricity to the EV owner (or charging station operator), via their generation portfolio or through the parallel acquisition of renewable GOs. PPAs are associated with a concrete generation asset and have the potential to secure low-cost "solar mobility offers" over a long-term horizon: for this reason, they are becoming increasingly popular. Nonetheless some EU member states still pose barriers to such strategic sourcing tools, despite the fact that PPAs are now less complex and easier to negotiate and approve than before.

These strategies may contribute to the additionality of solar in electric mobility. In the following section, we explain the characteristics and advantages for solar mobility arising from the off-site solar sourcing strategies.

1.2.1 Unbundled Guarantees of Origins

Guarantees of Origin (GOs) are an important element in the purchasing of solar power. They are an instrument which can help EV owners 'track' the electricity purchases related to their charging stations and ensure that a given, or total, share of this electricity originates from renewable sources.

GOs can be acquired 'bundled', where both the solar electricity and the certificates are sold and delivered together; in this case the EV owner can directly connect the GO to a specific solar installation, and electricity generation source. GOs can also be bought 'unbundled', whereby the certificates are purchased from a third-party supplier or broker, separate from any concrete purchase of physical electricity. In the latter case, there is no direct connection between the electricity sold (when the renewable energy asset generates electricity) and the electricity consumed by the charging station or EV.

The advantage of unbundled GOs for the EV owner or charging station operator is that there is no infrastructure investment required (e.g. rooftop or ground mounted solar installation) from the consumer and it requires no long-term commitment.

The limitations of this instrument are associated with the price of the certificate. The price varies depending on the location and technology type associated with the GO. Therefore, if charging point operators decide to use this instrument, it may represent a substantial extra cost for them on top of the electricity price and, as such, may work as a disincentive.

In addition, the main purpose of GOs is to act as an 'accounting vehicle' to prove that the electricity consumed at the charging point originates from a renewable energy source, which does not necessarily comply with the principle of additionality. This principle applies when an EV owner or charging station operator closes an electricity purchase contract that contributes to the construction of a new solar asset.

Yet, GOs remain an interesting accounting vehicle to keep track of the renewable electricity used in transport. Recent digital technologies such as blockchain have important potential to facilitate the issuance and the tracking of GOs in a cost-efficient manner. Blockchain allows a secured and automated certification of renewable kWhs that do not require a centralised operator to issue GOs for every single renewable plant, allowing savings in costs and time.[16]

15 Such as public charging ports, carports, rooftop parking lots.

16 See Energy Web Foundation Case study below.

CASE STUDY
ECOHZ PROVIDING GREEN ELECTRICITY SUPPLY SOLUTIONS FOR E-MOBILITY

ECOHZ

ECOHZ's vision is to change energy behaviour. Supporting the e-mobility movement is one way that ECOHZ attempts to fulfill this vision. For the past seven years, ECOHZ has actively worked with electric vehicle (EV) communities around Europe, including suppliers of charging equipment, infrastructure developers and car manufacturers, as well as key power producers, to promote renewable electricity as the fuel of choice. ECOHZ has run two pioneer projects providing a green electricity supply solution to e-mobility users.

Norway: e-mobility based on renewable electricity
In cooperation with the Norwegian EV Association, for years ECOHZ made sure that all EVs in Norway consumed only renewable electricity. The 100% renewable guarantee follows the car independent of the chargers. This can be achieved by providing Guarantees of Origin for the annual electricity need of these EVs. Based on an average annual driving distance of 15,000 km for an EV, charging the EVs batteries will need approximately 2,200 kWh of power per year.

Paris: carbon-free travel to COP21
In November 2015, the network of trains that travelled to Paris from Asia and across Europe, bringing official delegates and journalists to COP21, ran on carbon-free electricity. This was made possible by ECOHZ which provided a green electricity supply to the International Union of Railways through Guarantees of Origin. While enabling truly green transportation to Paris, it contributed to generating additional investments in renewable energy.

Renewable energy supply powering Dutch trains
The Dutch national rail service decided to ask its clients and travellers about their opinion regarding the energy procurement of the company: the results of the surveys show strong support for sourcing Dutch renewable energy. Therefore, the company decided to set up a 10-year wind power purchase agreement with an annual volume of 1.3 TWh, set up with the participation of ECOHZ. The PPA included wind energy from Sweden, Finland and Belgium, but the share of Dutch wind was to increase over the years to 100%.

Source: ECOHZ.

CASE STUDY
ENERGY WEB FOUNDATION: USING BLOCKCHAIN TO TRACK AND TRACE RENEWABLE ELECTRICITY USED FOR CHARGING ELECTRIC BIKES

energy web

The Energy Web Foundation (EWF) is a global nonprofit organisation created in 2018. The company has created the Energy Web Chain, a blockchain solution, accessible in open source, specifically designed for energy use as well as specific toolkits for certain commercial applications.

One of these toolkits is the 'Energy Web Origin': this toolkit automatically records renewable energy certificates (volume, origin, ownership, etc.) for each kWh and allows their trading on a blockchain-based platform.

The EWF is working at adapting its solutions to the electric mobility sector to support the penetration of renewable electricity in transport.

In 2018, the EWF partnered with the German company Wirelane to demonstrate the application of the EWF toolkit to an electric bike charging solution. The blockchain solution developed by EWF automatically records the electricity used to charge electric bikes at the stations. The amount of electricity is then paired with renewable energy certificates, or Guarantees of Origin in Europe, to ensure charging on renewable energy. A user interface, developed by Wirelane, allows consumers to follow the amount of renewable electricity they use to charge as well as track the carbon emissions that have been avoided.

The Foundation is working to expand the use of this electromobility toolkit, but also at developing other use cases, such as facilitating EV charge payments across charging points or documenting the flexibility services provides by an EV battery.

Source: Energy Web Foundation.

CASE STUDY

CHARGEPOINT: PARTNERING WITH A LOCAL UTILITY TO SOURCE RENEWABLE ENERGY IN CHARGING STATIONS

ChargePoint is the largest electric-vehicle charging network in the world. In 2019, ChargePoint set up a partnership with one of the largest utility in Germany that would allow electric-vehicle charging station operators to purchase renewable certificate in order to green the charging process.

Providing renewable power generated on site is not always possible if there is no direct connection between the generation source and the electricity consumption point. The electricity used to power electric cars cannot always be 100% renewable at the time of charging but the utility can compensate by purchasing green certificates of the desired quality (e.g. Gold Standard that ensures additionality of renewables, solar only GOs, etc.). The certificates can only be issued for renewable electricity that has not received subsidies via the feed-in-tariffs law (EEG). They compensate the grey part of their electricity consumption through a trading system.

ChargePoint provides the exact kWh per site, per multi-site customer and per fleet real time and on a yearly basis to the utility. The utility then deals with the purchase of certificates.

The first purchases will take place for customers applying for the federal transport ministry 4th funding call, so for publicly available AC and DC chargers in early 2020. A first estimate is a purchase deal for 50 charging points in 2020.

Source: Chargepoint.

1.2.2 Utility green procurement

Utility green procurement allows an EV owner or the charging operator to purchase solar electricity via 'green premium products' or via a tailored renewable electricity contract, such as 'green tariffs' offered by an electricity provider. Both concepts are explained in more detail below.

Green Premium Products

The advantage of 'green premium products' is that they allow the EV owner (or charging station operator) to purchase renewable electricity directly from a utility without requiring a binding long-term contract (as opposed to power purchase agreements described in the next section). The disadvantage, however, is that this 'limited commitment' usually results in higher electricity prices than those of PPAs,[17] which reduces the opportunity to save on electricity the bill.

The utility or electricity supplier acquires renewable GOs either through its own renewable generation portfolio or from a third-party supplier or broker. Then the utility 'cancels the GOs' once the renewable electricity is sold to the EV owner or charging operator, who pays for the GOs through a premium price on his electricity bill: this is the essence of green electricity procurement.

Green Tariffs

'Green tariffs' are long-term contracts under which EV owners or charge point operators can purchase electricity and associated GOs bundled into a concrete renewable energy facility. The utility supplies the electricity and GOs to the consumer/buyer who, in this case, may have the possibility to benefit from savings on their electricity bill.

One difference between green premium products and green tariffs is that the former normally targets residential or small-scale commercial customers (typically more adapted to EV owners), while the latter typically targets large-scale industrial customers (better adapted for a charging point operator).

In Europe, most large utilities offer green premium products supported by the European GO scheme, however, some use green tariffs. Such offers have been taken up by electromobility providers to bring green mobility services to their clients.

1.2.3 Power purchase agreements

A power purchase agreement (PPA) is a long-term power purchase contract between a power consumer (EV owner, charging station operator) and an independent power producer (utility or a financier). As part of this agreement, the consumer commits to purchase a specific amount of solar electricity, or all the electricity generated by a solar installation, at a price per kWh agreed in advance. The PPA is bundled with a specific solar installation, and therefore they ensure direct 'solar mobility offers', which run over a certain period of time, typically 10-20 years. There are various models of PPAs, which can be tailored to meet the buyer's needs.

Renewable PPAs have been increasingly popular in Europe, with a cumulative capacity of over 6 GW.[18] This type of power purchase contract presents some advantages. For the charging operator and EV owner, they guarantee a competitive power price in regions where electricity costs are high. In addition, PPAs provide a stable electricity cost for the medium to long term, where electricity prices may be uncertain or even volatile. For the solar producer, the PPA provides security in terms of revenue. This allows for the financing and the building of a solar asset with limited or even without public subsidies. Solar PPAs may also secure the prolongation of the operation of an existing solar generation asset after the expiry of its subsidy period.

For large electro-mobility players, which are highly exposed to market risks and to electricity costs due to their large electricity consumption, PPAs are particularly interesting. Moreover, as electric trains, trams and metros begin to operate and penetrate the market consuming electricity during the day, a solar PPA may be a suitable candidate, with additional consumption needs covered by other renewable generation.

17 "Higher electricity costs (from green tariffs) compared to 'standard' grid electricity (which will become more and more of an issue if the GO price continues to grow)." in IRENA (2018). Corporate Sourcing of Renewable Energy: Market and Industry Trends.

18 RE-Source Platform (2019). Introduction to Corporate Sourcing of Renewable Electricity in Europe.

CASE STUDY
SANTIAGO DE CHILE METRO: THE FIRST METRO RUNNING ON SOLAR AND WIND

With more than 2.7 million daily journeys, the metro network of Santiago de Chile is one of the largest in the country. In the last year, the metro network has been expanding, with the opening of the new metro line 6 in November 2017 and the planned construction of three additional metro lines by 2027.

In 2016, the Chilean president Michelle Bachelet announced that the metro company would transition and 60% would be powered by renewable electricity.

This is possible thanks to two 15-year power purchase agreements signed with the 110 MW solar plant El Pelicano and the 185 MW wind plant San Juan. El Pelicano started operating in November 2017 and provides 42% of the electricity consumed by the metro (roughly 300 GWh per year). Another 18% of the metro's consumption is supplied by the San Juan plant. In total, 60% of the electricity consumption of the metro comes from renewables.

As the metro is running mostly during the day, from 5am until midnight, solar was the best matched resource to supply the metro with electricity. The mix with wind electricity, which has a load profile that is complementary to solar generation, allows to maximise the penetration of renewable electricity in the metro's consumption.

The project takes part in the sustainability strategy of the metro operator, Red Metropolitana de Movibidad, and its will to reduce its greenhouse gas emissions: the project will allow it to reduce its carbon emissions by 130,000 tonnes. The project also allows the company to reduce its electricity bills by reducing its exposure to the power grid costs as well as to the high and volatile Chilean electricity prices.

Source: Metro de Santiago de Chile.

Solar PPAs could also be a solution for charging station operators to supply electricity to an aggregated pool of charging stations. A group of charging stations can aggregate the electricity demand and therefore maximise the solar electricity consumed. It also supports the electrification of transport by securing competitive and stable electricity prices for charging, while supporting subsidy-free investments in additional solar power capacities.

However, regulatory and administrative barriers remain, particularly for direct wire PPAs and cross-border PPAs. The recently adopted Clean Energy Package could support further regulation as it requires member states to develop an enabling framework for PPAs. In addition, various initiatives, such as the RE-Source Platform,[19] are currently working to increase awareness of PPAs and develop more accessible standard contracts.

CASE STUDY
SNCF AND VOLTALIA: A SOLAR CPPA FOR FRENCH TRAINS

SNCF is the French national railway company and transports 14 million travellers per year in France and in the world. However, it is also the top electricity consumer in France with a volume of 9 TWh of electricity consumed yearly (part of a total consumption of 17 TWh/year). Willing to act on its carbon footprint, but also confronted with a changing electricity prices environment, the company has committed to using at least 40-50% of renewable electricity sources in the electricity mix that it uses to power its trains as of 2025.

As part of this strategy, in June 2019, SNCF Energie announced that it signed a 143 MW 25-year Corporate Power Purchase Agreement (CPPA) with the French renewable energy company Voltalia. The CPPA relates directly to the electricity generated by three solar plants to be built in the South of France. The solar plants will start commercial operation by 2022. In total, they will produce more than 200 GWh of green electricity per year, which represents between 3 and 4% of the consumption of the electric trains of SNCF. In September 2019, this contract is one of the largest CPPAs signed in Europe.

The project will allow SNCF to benefit from a guaranteed, competitive electricity price over 25 years. In addition, it supports the deployment of additional solar capacities in France, without relying on public subsidies. This paves the way for future similar initiatives: the company aims at filling up half of its 40-50% renewable target through CPPAs. SNCF is therefore working on the set-up of several other CPPAs in the coming years.

Source: SNCF.

1.3. Solar e-fuels

Solar e-fuels are synthetic fuels produced from solar, or to a larger extent renewable, electricity. While Battery Electric Vehicles (BEVs) are a very promising technology to replace most conventional vehicles, solar e-fuels could be a suitable solution to decarbonise the transport sectors and certain use cases where electrification presents challenges. In road transport, this would refer to vehicles with a long driving range or with high utilisation rates requiring ultra-fast refuelling, such as heavy-duty vehicles, taxis or buses. E-fuels could also be a clean alternative for the maritime or aviation sectors, where electrical motors are unlikely to power large vehicles and direct electrification would be limited to a marginal part of the vehicle's energy consumption.

Solar e-fuels are currently associated with high costs, as well as low efficiency rates,[20] hampering their large-scale roll-out. Yet, future technological improvement and further cost decrease can support the competitiveness of solar e-fuels and make them an efficient solution to the decarbonisation of transport.

Solar Hydrogen

Solar hydrogen is used as a clean fuel for Fuel Cell Electric Vehicles (FCEVs). FCEVs are equipped with an electric motor that is fuelled with electricity produced by oxydation of the hydrogen in the fuel cells. Therefore, similarly to BEVs, FCEVs do not emit greenhouse gases or pollutants such as Nox (oxides of nitrogen) and are not noisy when running. The refuelling times and driving range are similar to internal combustion engines (ICE) vehicles. Hence, FCEVs can be a solution for certain sections of transport such as taxis and buses: Hydrogen taxi and bus projects have already been deployed in Europe.[21] Hydrogen could also represent a suitable solution for rail transport, in particular where railways are not or cannot be electrified. Currently, the deployment of FCEVs is limited, notably due to the high cost of vehicles as well as the lack of hydrogen refuelling infrastructure. Yet, a number of countries have published targets or incentive schemes to support the deployment of FCEVs and refuelling infrastructure. These measures should support a decrease in the cost of fuel-cells vehicles.

Hydrogen has been traditionally produced via steam reforming using fossil fuels as an input, mostly natural gas, therefore generating CO_2 emissions. On the contrary, Solar Hydrogen refers to hydrogen produced from solar, and renewable, electricity. This production is based on electrolysis, a chemical process where water molecules are separated into hydrogen and oxygen by an electrical current (also referred to as Power-to-Gas). If the electrolyser is supplied with renewable electrons, either through on-site, a directly connected installation or through a power purchase agreement, the generation of solar hydrogen supports investment in additional renewable capacities. Yet today, the electrolysis processes remain more expensive than traditional hydrogen generation.[22] This is partly due to the high energy losses happening in the conversion process. However, the decrease in renewable electricity costs, the increase in CO_2 price and further technology improvement can support the competitiveness of green hydrogen. In particular, solar PPAs are promising to lower the cost of hydrogen.

Solar Hydrogen production can be centralised (large electrolyser) or decentralised (small electrolyser, closer to charging stations or, for example, for fleet charging points). The arbitrage between centralised or decentralised solutions will depend on the deployment of efficient and cost-effective transportation solutions. Dedicated hydrogen pipelines are not rolled out and limited to the supply of hydrogen for industrial application. Alternatively, transporting liquid hydrogen by road entails additional costs for liquefaction and regasification of hydrogen in addition to direct transport costs.[23]

Solar synthetic fuels

Solar synthetic fuels refer to the fuels produced from solar hydrogen and using CO_2 (Power-to-Liquid), before being liquefied and further refined, such as methane, methanol or electro-diesel. The advantage of such fuels is that they can be used in traditional internal combustion engines (ICE), and therefore do not require a roll-out of new vehicles. They could therefore be used in the transport sectors that are hard to decarbonise or unlikely to be electrified, such as the maritime or the aviation sector. Similarly, they can be supplied through traditional refuelling infrastructure.

19 For more information: visit http://resource-platform.eu/.

20 Transport and Environment estimates that the efficiency rates (the rate between the original renewable energy and the final energy used in transport) are 22% for FCEVs using hydrogen and 13% for ICE vehicles using synthetic fuels, comparing to a 73% for electricity in battery-electric vehicles. Agora Energiewende and Agora Verkehrswende estimate the efficiency rates at 26% for FCEVs using hydrogen and 13% for ICE vehicles using synthetic fuels, against a 69% rate for battery-electric vehicles.

21 125 buses currently in operation in Europe (Fuel Cells and Hydrogen Joint Undertaking)

22 USD3 to 7.5/kg for hydrogen produced from electrolysis from renewables, against USD 1 to 2/kg for hydrogen produced from natural gas. Source: IEA (2019) The Future of Hydrogen.

23 Agora Energiewende and Agora Verkehrswende estimate the cost of liquefaction at 0,69c€/kWh and that of gaseifaction at 0.15c€/kWh in 2020.

The production techniques of solar synthetic fuels are still at the research and development stage. Currently, the cost of solar synthetic fuels is not competitive with conventional fuels (Transport and Environment has estimated their cost at €3,000/tonne, around six times more expensive than current conventional fuels).[24] Yet, technological improvements enabling higher conversion efficiency, as well as the availability of inexpensive renewable energy, are likely to support the cost decrease of these fuels.[25]

Further investment in research and development in that sector is therefore needed. In addition, the sourcing of the CO_2 used in the synthesis process must not hinder CO_2 emission reduction policies.

CASE STUDY

LAST MILE PROJECT: AKUO ENERGY DECENTRALISED SOLAR HYDROGEN REFUELLING STATIONS

Akuo Energy is the first independent renewable energy producer in France, with 246 MW of solar capacity owned or developed by the company worldwide.

In 2019, Akuo Energy launched the project 'Last Mile' which deploys an end-to-end zero emission transport system for last mile actors, based on renewable hydrogen. The project will deploy 33 renewable hydrogen refuelling stations in the region of Paris and in France, experimenting with both centralised hydrogen production and transport as well as the decentralised production of hydrogen through onsite electrolysers. In all cases, the hydrogen will be produced from renewable electricity obtained from Power Purchase Agreements with renewable plants. Akuo Energy has partnered with Atawey, a French producer of decentralised hydrogen refuelling stations.

In total, the refuelling stations will be able to supply about 400 Fuel-Cell Electric Vehicles (FCEVs), notably from the fleets of JCDecaux, a French company managing urban property, as well as the French department stores Galeries Lafayette. Hence, it aims to deploy carbon-neutral solutions for last mile delivery transport. Altogether, it will avoid the emission of 1,182 tonnes of CO_2 per year, and 35,500 tonnes over the 15 years of the project's lifetime.

Source: Atawey.

24 Transport and Environment (2017) What role is there for electrofuel technologies in European transport's low carbon future?

25 Agora Energiewende and Agora Verkehrswende (2018). The Future Costs of Electricity-Based Electrofuels .

CASE STUDY

FRONIUS SOLH$_2$UB – A DECENTRALISED HUB FOR SOLAR ENERGY WITH GREEN HYDROGEN

Fronius is an Austrian company leading in the hydrogen production from renewable electricity. Their vision is a future with 100% renewable energy, where hydrogen will play a central role as a sustainable alternative to fossil fuels and as seasonal storage for renewable energy.

One of their flagship service, SOLH$_2$UB is a state-of-the-art system for producing, storing, distributing and re-electrifying green hydrogen for mobility or energy supply for municipalities and businesses.

How does it work?

By means of electrolysis, green hydrogen is produced from water and solar power. It can be stored and used for fueling H_2 vehicles. The hydrogen can also be stored seasonally and then transferred back to electricity and heat from the entailed fuel cell.

By producing green hydrogen from solar power, the decentralised hub allows the innovative integration of the electric, transport and heating sectors.

Fronius SOLH$_2$UB enables the refuelling of H_2 vehicles such as municipal vehicles, cars, buses, trucks and so on. Such vehicles transform hydrogen into electricity which is used to power an electric motor, the only emission produced is steam.

Source: Fronius.

CASE STUDY
ENGIE: SOLAR HYDROGEN FOR CITY BUSES IN PAU

ENGIE, via its subsidiary GNVert, has been active in the sustainable mobility business, including hydrogen. GNVert offers services in the design, building, financing, and operation and maintenance of refuelling stations and in the distribution and sale of hydrogen to customers. The company has already built and is operating four hydrogen stations in France.

GNVert, in partnership with ITM POWER, specialised in the design and manufacturing of hydrogen production systems, has been selected by the French City of Pau to create, build and operate a renewable hydrogen fuelling station, as part of the municipality's decision to acquire eight 100 kW fuel cell buses by the end of 2019.

The project, named Fébus, includes the construction of a renewable hydrogen production facility in the city of Pau. The hydrogen will be produced by electrolysis from 100% renewable electricity. At first, the electricity will come from the grid using Guarantees of Origin, but as time goes on, electricity will come from on-site solar panels to be installed at a later stage. The solar installation will be directly connected to the electrolysis station. In total, the electrolyser will produce between 174 and 268 kg of hydrogen daily.

The buses and the charging stations were inaugurated in September 2019 and will be operating from December 2019. The €74.5 million Fébus project is part of the JIVE2 project, co-funded by the Fuel Cells and Hydrogen 2 Joint Undertaking under the Horizon 2020 programme.

Source: City of Pau.

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2 SMART SOLAR CHARGING

The deployment of electromobility comes with new challenges for the electricity system, which will need to adapt to accommodate these new loads.

The additional electricity demand induced by EVs in a large-scale rollout scenario by 2035 is estimated to lead to an average increase of 0.5% in electricity demand per year, while the annual growth of electricity consumption has amounted to 1.3% per year since 1990.[26] However, natural charging behaviours, if they remain unchanged and similar to conventional fuel charging (5-minute charging, independent of the time), can contribute to increased existing peak loads (typically at night when drivers will come home and charge their electric vehicles). In addition, these new loads, connected to the low voltage grid, can create new congestion challenges on local distribution grids that will accelerate the grid's ageing or lead to service interruptions. Ultimately, the connection of charging stations could simply be refused due to the lack of adaptation of the grid or could come at a high cost for the consumer.

To mitigate the impact of EVs on the grid and facilitate their large-scale deployment, smart charging will be necessary, but it is also a real opportunity for the greening the power system.

By making the use of electric vehicles' batteries more flexible, smart charging allows the use of EV batteries in synergy with solar mobility supply solutions to be optimised. At system level, EV batteries are an untapped source of local flexibility that could support the grid integration of renewables, particularly for distributed energy resources such as photovoltaics.

Enabling 'smart solar charging' technologies is therefore a prerequisite for solar mobility. Furthermore, adopting a 'smart solar charging' approach to electromobility can unlock important benefits for the integration of photovoltaics and of electromobility into the grid.

26 Platform for Electromobility (2019). Brochure 'Electromobility is ready to transform the way we move. 'If electric cars were to represent 50% of the automotive fleet in 2035 in the EU (about 125 million vehicles according to the European Automobile Manufacturers' Association), the entire electric fleet would consume less than 9% of the total electricity consumption in Europe.

2.1 What is smart charging?

According to the CEN-CENELEC, smart charging refers to the alteration of the natural charging cycle of electric vehicles allowing for adaptive charging habits and providing the EV with the ability to integrate into the whole power system in a grid- and user-friendly way.[27]

Several smart charging solutions and systems exist. This report distinguishes three main types of smart charging. Each of these models differ in the amount of flexibility they can unlock from the car and, therefore, the possibility to maximise the charging process on solar energy.[28]

- Uncontrolled charging based on price incentives, such as Time-of-Use tariffs, which provide the consumer with simple price signals at peak and off-peak times.

Examples of such price incentives can already be found in the world. In Maryland, USA, the local utility Baltimore Gas and Electric (BGE) has introduced an EV dedicated tariff with peak and off-peak periods (the peak periods being 10 AM to 8 PM in summer, 7 AM to 11 AM and 5 PM to 9 PM in non-summer season).[29] A similar EV tariff distinguishing day charges and night charges has been introduced in Spain by Iberdrola. Furthermore, dynamic pricing will also provide a key signal to the consumers to adapt their charging behaviours.

The recently adopted Clean Energy Package will lead to a gradual phase-out of regulated prices, with exceptions, and will therefore favour the introduction of more dynamic pricing tariffs.

- Unidirectional controlled charging, sometimes referred to as V1G, where the time and rate of charging are controlled.

Unidirectional controlled charging is based on automated control of the charging process, which can be stopped and resumed, managed by an algorithm on the basis of external signals. This solution is rather mature and several offers already exist in Europe.

- Bidirectional controlled charging, also referred to as V2X (vehicle-to-everything), where the battery not only charges but also discharges on command and the time and rate of the charging and discharging can be controlled.

Bidirectional controlled charging includes several types of bidirectional charging processes. This report will mention the following three types:

- Vehicle-to-grid (V2G) where the electricity battery withdraws and injects electricity to and from the electricity grid and provides flexibility mostly in front of the meter.
- Vehicle-to-building (V2B) or Vehicle-to-load (V2L) where, generally, a group or a fleet of electric vehicles' batteries are managed to support provision of demand flexibility in buildings, but also minimise interaction with the grid and, where applicable, maximise the self-consumption ratio behind-the-meter.
- Vehicle-to-home (V2H), similar to V2B on a smaller-scale, where the residential vehicle battery is used mostly to reduce interactions with the grid and, where applicable, maximise the self-consumption ratio behind-the-meter.

Bidirectional controlled charging is a solution that is ready. A couple of companies, such as the US-based Nuvve or the automotive company Renault, have been actively working on bidirectional charging and are offering some solutions.

Yet, regulatory and market barriers still hamper the business model of V2G. In particular the possibility for aggregators and EV batteries to access power markets or qualify as a flexibility provider is a key enabler to boost the business case of V2G. In addition, bidirectional charging has raised concerns over the effect it has on battery degradation, as little assessment had been made on this topic. However, some studies[30] show that such concerns are limited provided the smart algorithm controlling the charging/discharging process of the vehicles takes the impact on the battery into account.

27 CEN-CENELEC-ETSI Smart Grid Coordination Group: Smart charging of electric vehicles in relation to smart grid, 2015

28 For more information, see IRENA (2019). Innovation Outlook. Smart charging for electric vehicles.

29 For more information, see Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., and Jahn, A. (2019). Start with smart: Promising practices for integrating electric vehicles into the grid.

30 Kotub Uddin, Matthieu Dubarry, Mark B. Glick (2018). The viability of vehicle-to-grid operations from a battery technology and policy perspective, in Energy Policy, Volume 113, February 2018.

2.2 Smart charging and solar mobility

Smart charging could offer a number of benefits to support the grid integration of solar, particularly decentralised solar.

Concerning buildings, advanced smart chargers could allow homeowners with solar systems to further increase their self-consumption by enabling their cars to only charge with 100% self-generated solar power or to charge faster by combining PV generated energy with

CASE STUDY
SOLAREDGE SOLUTION COMBINING SMART CHARGING AND SOLAR MOBILITY

SolarEdge is committed to providing innovative solutions that help more people gain control of their energy usage. For this reason, they recently launched the world's first 2-in-1 EV Charger and Solar Inverter for the European market. Whether homeowners already own an electric vehicle or may own one in the future, charging their EV with solar energy ensures that driving is both cost efficient and sustainable.

SolarEdge's EV charging single phase inverter enables homeowners to charge their electric vehicles directly from the power of the sun, maximising their solar usage and further reducing their electricity bills. They will also benefit from the ability to charge EVs up to 2.5 times faster than a typical mode 2 charger through an innovative solar boost mode that utilises grid and PV charging simultaneously.

By installing the EV charging inverter, homeowners benefit from the reduced hassle of separately installing a standalone EV charger and a PV inverter, as well as integration with the SolarEdge monitoring platform.

The solution supports full network connectivity and integrates seamlessly with the SolarEdge monitoring platform. Homeowners can track their charging status, control vehicle charging, and set charging schedules. Smart charging and monitoring features include:

- Smart-scheduling for use with Time of Use (TOU) rates – charge from the grid during off-peak hours
- Track solar, EV, and grid consumption for visibility and control of household energy usage
- Remote operation via mobile app – turn charging on and off
- View charging duration, energy used for charging, and the percentage charged by solar energy
- Easy inverter commissioning directly through your smartphone using the SetApp mobile application

Source: SolarEdge.

energy supplied by the grid surpassing circuit breaker limits, while still complying with electrical standards.

Bidirectional charging technologies will enable V2B or V2H, as they could increase the flexibility potential of EV batteries. More specifically, with bidirectional charging, the EV battery could also be used as back-up storage in case of an electricity shortage. This is currently limited to very specific markets, such as Japan, which is subject to frequent power outages, or the US in locations with weak electricity infrastructure.

At power system level, smart charging can unlock additional sources of flexibility that will support the rapid deployment of electric vehicles, but will also enable the grid integration of solar, particularly decentralised solar. As private vehicles are parked 95% of the time, the battery capacities could provide ancillary services to the grid operator, such as very fast frequency regulation or voltage control. The flexibility provided can also be used used to relieve local congestion in the distribution grid. This could support in particular the deployment of distributed solar and solar self-consumers.

To sum up, according to IRENA,[31] by 2050, more than 1 billion EVs will be on the road globally which could provide around 14 TWh of batteries, compared to an estimated capacity of 9 TWh of stationary batteries. The organisation has modelled the impact of the penetration of smartly charged vehicles in a solar-based system and found that it would decrease curtailment levels and reduce the yearly peak load, enabling a higher penetration of solar generation. This leads to lower overall system costs due to a higher penetration of low marginal cost energy resources and cheaper sources of flexibility. The model also shows that the benefits in terms of grid integration of solar increase when bidirectional charging is deployed.

Yet, all the smart charging models where electric vehicles provide flexibility services are still facing barriers. Indeed, they rely on the availability of aggregation where a third-party manages a fleet of vehicles. This means that balancing and other flexibility markets should be fully open to aggregators, which is not the case in all markets. Another challenge lies in the metering system and the possibility to use the internal meter of the electric vehicle to count the flexibility provided. Finally, some flexibility markets are not even designed – for instance, markets for local congestion management or other ancillary services – and there is no possibility for electric vehicles to get value from their flexibility.

In addition, such business models require a clear schedule of the periods for which the EV battery is connected and can be used by aggregators and charging operators for providing flexibility to the system. This implies a deep behavioural change for the EV owner, which has to explicitly define its preferences and accept additional use restrictions. The uncertainty regarding the consumer acceptance of these constraints could also be a barrier to the deployment of the technology. However, automation and consumer-friendly interfaces can facilitate the adoption of smart charging habits. The recent successes of smart charging solution providers in Europe are a good example and show good promise for the deployment of similar solutions in Europe. The Dutch company Jedlix for example has developed a user-friendly mobile application allowing consumers to manage the charging of their vehicles and convey their preferences to the charging operator. The company is the first smart charging provider in Europe, partnering with Renault Nissan, BMW and Tesla. Since 2019, Jedlix is providing balancing services to the grid operator TenneT with its fleet of vehicles in the Netherlands, in a pilot project developed with the aggregator Next Kraftwerke.

31 IRENA (2019). Innovation Outlook. Smart charging for electric vehicles.

CASE STUDY
IBERDROLA'S SMART MOBILITY AND SMART PUBLIC RECHARGE HUB SOLUTIONS

Keeping people connected to an ever-increasing smarter world is a challenge for utilities. Iberdrola is at the forefront of the deployment of smart grids and customer solutions which improve quality of service, enable new products and services, and enhance customer choice.

Smart Mobility is one of the smart products that Iberdrola offers. Its objective is to facilitate the development of electric vehicles by offering integral solutions for customers:

a) Domestic charging points and 100% renewable tariffs to charge at home

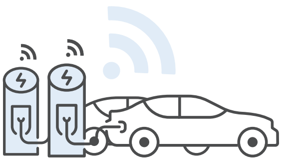
b) Workplace and business solutions for employees, customers and fleets

c) Public charging points

Domestic charging points with 100% renewable tariffs

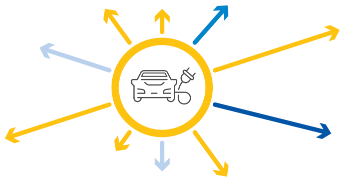
- Sale and installation of the charge point.
- 100% renewable tariff. 10 times cheaper than fuel (0.5€/100km).

Workplace / Business



- Solutions for employees.
- Solutions for business fleets.

Public charging points



- Nationwide rapid public charging network with 400 points in 2019.
- Provided with 100% renewable electricity.
- Additional public charge points in urban areas; public parking, supermarkets, shopping centers...

Source: Iberdrola.

Smart Public Recharge Hub is an innovative project that Iberdrola is currently working on. It consists of:

- 2 double charging points of 50 kW each
- 2 double charging points of 22 kW each
- Smart PV canopy (6 kWp)
- Smart storage (70 kW/100 kWh)

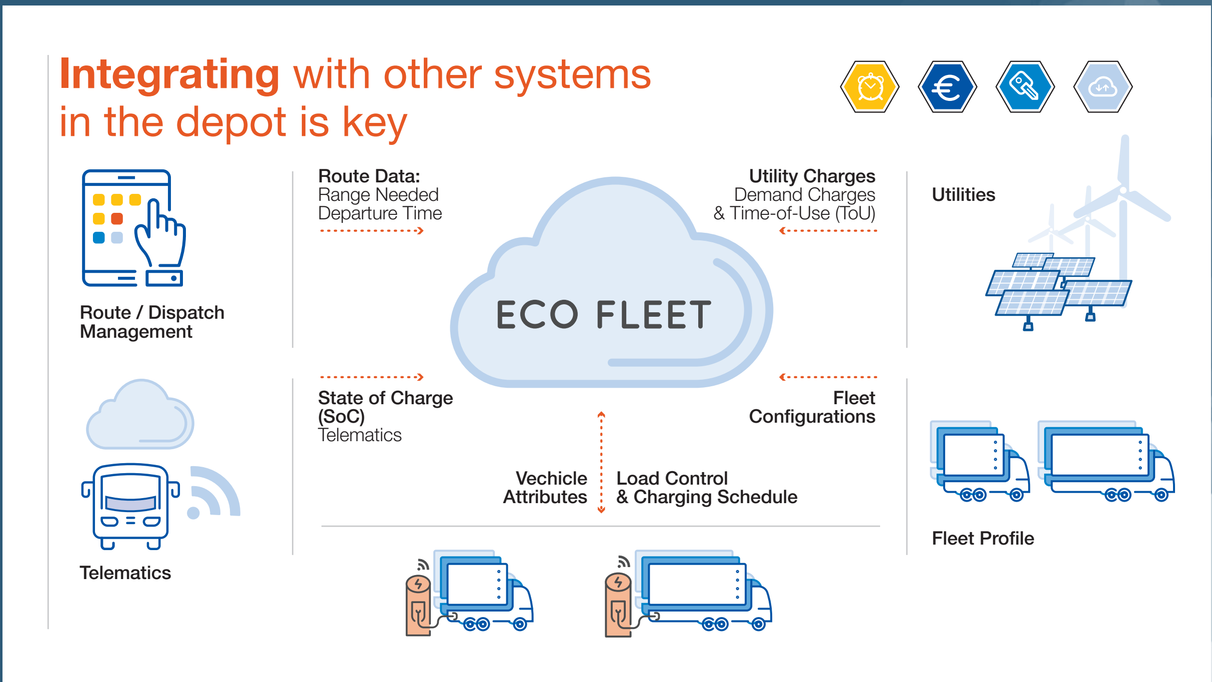
CASE STUDY
CHARGEPOINT: A SMART CHARGING SOLUTION FOR BUSES

Santa Clara Valley Transportation Authority (CA, USA) is piloting, since 2019, a cutting-edge solution that manage operation, charging and energy consumption of electric buses while reducing the impact on the State electricity grid. The goal is to maximize the efficiency of the charging through a smart charging process that takes into account the cost of electricity and the cost of demand peaks charges from the public utility.

The ChargePoint energy management platform creates an optimal charging plan for the whole fleet based on the knowledge of the fleet schedule received from the bus scheduling system and the real-time updates as vehicles arrive in the depot. The interface to the bus telematic system allows the optimization engine to get real-time updates for estimated vehicle return times and updated state of charges. The Santa Clara Valley Transport Authority project is funded by California Energy Commission.

The Smart energy management for EV charging can help in different ways:

- Peak energy use reduction: this allows more chargers to be installed without increasing expensive utility infrastructure as well as a reduced charge from utilities that charge for peak demand usage.
- Workflow management: Having visibility into the charging process and the confidence at a glance that the vehicles will be fully charged well before pull-out time. The workflow software also sends out alerts when there are issues with charging process. Examples of alerts are: "Not enough time to complete charging" and "Vehicle hardware error. Manual intervention needed to resolve".
- Support the local grid to manage EV charging stations by integrating solar and stationary battery storage for corridor of DC fast charging applications.



Source: ChargePoint.

CASE STUDY
THE MOBILITY HOUSE: UNLEASHING THE FLEXIBILITY POTENTIAL OF EVS IN PORTO SANTO ISLAND

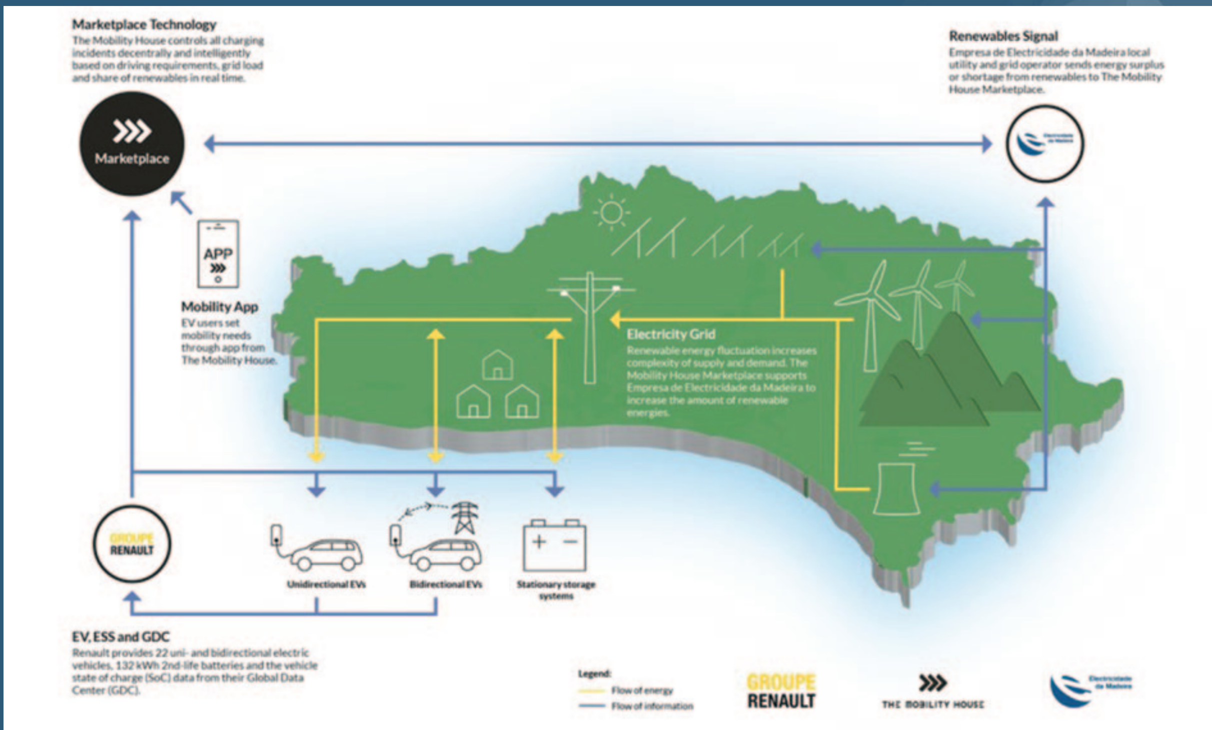
The Mobility House is a German technology company offering innovative storage and electric vehicles charging solutions.

Since 2018, the Mobility House has developed in partnership with Groupe Renault and Empresa de Electricidade da Madeira (EEM), the local utility, a pilot projet aiming on the Portuguese island of Porto Santo. From a current penetration of 15% of renewables in the electricity mix, the Porto Santo island has committed to becoming the first fossil free island, but faces the challenge of system integration of renewables in an island context. The pilot project therefore aims at optimising the penetration of renewable energies by unlocking the flexibility sources from electric vehicles and battery storage.

The project rolled out 20 vehicles able of unidirectional controlled charging and 2 vehicles able to bidirectional charging, as well as a stationary storage system made of second-life batteries, as well as charging points able of controlled charging. A user interface has been developed to allow consumers to indicate their preferences. The vehicles will made available to various consumers in order to study the behaviours of various types of consumers.

In parallel, the Mobility House setted up a platform, called 'The Marketplace', aimed at harmonizing the demand and supply of the different producers and consumers. The local utility inputs its flexibility needs – energy surplus or shortages. The energy needs and the flexibility resources of electric vehicles and the battery storage are inputted in the platform, and are matched with the flexibility needs of EEM.

The project will allow the optimisation of the grid integration of electric vehicles and the reduction of the needs for grid reinforcements. It will thus demonstrate the feasibility of a renewable-based system and of the grid integration of electric vehicles.



Source: The Mobility House.

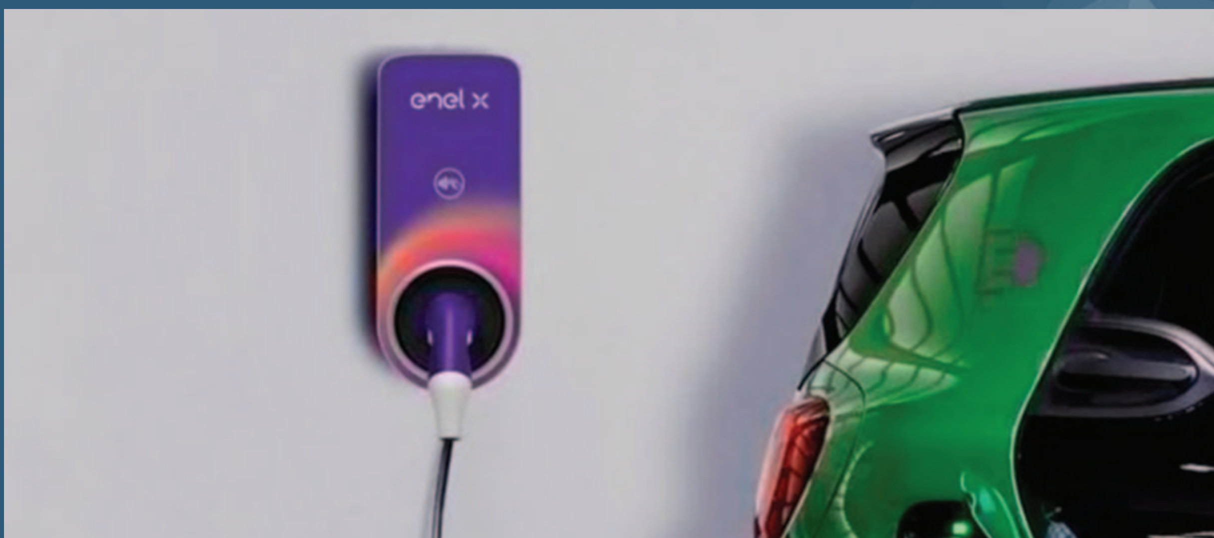
CASE STUDY
ENEL X: DEPLOYING SOLAR AND STORAGE TO CHARGE ON SOLAR

With a goal of 100% renewable energy and commitment to clean transportation, Hawai'i represents a unique opportunity for integrating EVs and clean energy to support clean transport as well as a greener electricity mix on an island context.

In this perspective, Enel X has launched in 2019 the Smart Charge Hawai'i programme. The demonstration project is developed in partnership with Elemental Excelerator and Hawaiian Electric Companies and aims to showcase EVs' ability to deliver grid services and integrate renewable energy on O'ahu, Maui, and Hawai'i Island. The project will focus on maximizing charging in the middle of the day when solar generation is highest, and reducing charging on days of high electricity demand in the evening hours.

Enel X deploying its JuiceNet Platform, its charging management platform. The platform optimises the charging of the EVs in the island, by matching the consumers' preferences, the historical data on charging patterns and the real-time signals from the grid operators on the grid constraints. Customers using Enel X's smart charging stations, powered by JuiceNet software, will earn JuicePoints, redeemable for cash, for participating in the scheme by connecting their charging station to the internet and using the smart charging station. In addition, Hawaiian Electric Companies offer a Time-of-use tariff for drivers, which can allow them to realise savings.

As Hawai'i has a high share of rooftop solar installations, this initiative will allow to have a better understanding of the benefits of smart charging for the integration of more electric vehicles and renewables, and pave the way for Hawai'i 100% renewable energy target.



Source: Enel X.

3

VEHICLE-INTEGRATED PHOTOVOLTAICS: SOLAR-POWERED VEHICLES

It has long been a dream of the transport sector to integrate solar panels onto the body of the vehicle (particularly on the roof, but also on the side panels and bonnet) to directly power the electric motor and/or other features such as heating and cooling.

High-performance solar cells have long been used to power spacecrafts through their journeys in outer space, and now, thanks to technological improvements, cost reduction of solar modules, and the increased electrification of transport, solar-powered vehicles are ready to launch on Earth.

Onboard solar power is referred to as Vehicle-Integrated Photovoltaics (VIPV). VIPV can contribute to charging the car battery, powering the electric motor, or heating and cooling the vehicle directly. Today, prototypes of solar-powered and integrated passenger cars, trucks, are becoming increasingly common and commercially available.

From Building-Integrated Photovoltaics to Vehicle-Integrated Photovoltaics

Building-Integrated Photovoltaics (BIPV) technologies have been in development for several years in Europe. BIPV refers to innovative photovoltaic technologies that can be used as construction materials while being equipped with PV cells capable of producing electricity. They can replace conventional materials – for example, roofing tiles, glass facades, or windows.

The key benefit of installing a solar system directly connected to the vehicle is increased autonomy and a longer driving range. This is particularly relevant as the availability of charging infrastructure continues to be an issue, and so-called ‘range anxiety’ remains one of the main barriers to the uptake of electric vehicles.

Relying on free, self-generated electricity clearly results in fuel savings: the consumer saves on taxes and the supplier’s margin by reducing the amount of electric charging cycles or reducing the reliance on a conventional motor. The economic benefits vary depending on the price of electricity. The gross benefit of VIPV can be calculated by the amount of grid power usage savings due to VIPV production onboard multiplied by the electricity price. The calculation of the net economic benefit can be understood as the difference between the gross benefit of VIPV and the additional costs of its installation and extra costs while in operation. The Japanese institute NEDO evaluated the economic benefits of different utilisation ranges of onboard PV-generated power (0 to 100%). The result demonstrated that it is advantageous to install a PV system when the VIPV utilisation output is 42% or higher.[32]

Integrating solar directly onto the vehicle can also improve the lifetime of the battery; by reducing the number of charging cycles, there is less maintenance needed.[33] Additionally, further regulatory incentives rewarding this 'eco-innovation' could also support the deployment of solar-powered vehicles. Good examples include tax reductions on the purchase of the vehicle, or extra value to OEMs regarding their CO_2 target for vehicles.[34]

One of the key challenges of VIPV is finding the appropriate vehicle usage patterns to maximise the ratio between the running time on the energy generated by the solar panels, and the running time on external fuel, which may be conventional fuels or grid electricity. The weight of the vehicle plays a significant role here: the lighter the vehicle, the lower the amount of electricity needed. Apart from the weight, the cost-efficiency of VIPV is another important factor. On the one hand, innovative, high-efficiency cells can be used to increase the average generation of the solar body. On the other hand, these cells also come with high costs, thus increasing the total cost of a VIPV solution. Vehicle manufacturers must therefore make a choice between PV energy performance and the total cost of the vehicle.

Another significant factor is the integration of solar cells onto the vehicle. In most cases, the limited area of the roof cannot generate enough power to cover the energy consumption of the vehicle. The location and the orientation of the cells on the vehicle must be optimised to harvest as much solar power as possible.

Furthermore, the aesthetic component of the vehicle, in terms of colour and design, is also important to take into account in order to make it attractive to consumers. The integration of the solar cells must also be consistent with the external protection of the vehicle, and equipped with a protective coating in order to shield the body from vandalism and general wear and tear.

A final challenge lies in the ease of mounting and dismounting. This is crucial in case of damage or if there is ever a need for replacement. It is also key to ensure a sustainable end-of-life for the PV system, since the cells have a lifetime of 20 to 30 years, which is longer than the average vehicle's lifetime. The end-of-life of the PV cells can be ensured either through a second-life use or through a recycling process. In particular, the recycling of PV cells implies their extraction from the vehicle's body, which can be more challenging than conventional component separation. No guidelines or standards have yet been published on the extraction and recycling technique for BIPV and VIPV components.

3.1 Solar cars

Beginning with the first Tour de Sol competition in Switzerland in 1985, solar cars have had their own races that saw engineers compete in order to innovatively combine solar and automotive technologies. The very well-known World Solar Challenge in Australia is a race across the 3,000 kilometres separating Darwin from Adelaide, where solar vehicles compete in terms of speed, efficiency, and practicality. The South African Solar Challenge invites competitors to drive as far as they can from Pretoria to Cape Town, via Port Elisabeth. A similar competition has recently been launched in Latin America, the Carrera Solar Atacama in Chile's Atacama Desert.

The first commercial solar cars were specific models of plug-in hybrid vehicles equipped with solar roofs. The most well-known is Toyota's Hybrid Prius; since 2012, the car has been equipped with a 180W solar system, mostly used for onboard services and additional battery charging. In the following years, Ford released the C-Max Solar Energi, and Hyundai put out the Sonata Hybrid. The Volkswagen hybrid, Tiguan GTE, featured an innovative solar system with a sliding roof made of two PV modules, both measuring 980 x 1067mm in size and 110 Wp. In 2016, a2-solar launched the solar roof for its New KARMA Revero electric vehicle, with a module power of 200 Wp – the most powerful and spherically-curved solar car roof module at the time of the release.

32 New Energy and Industrial Technology Development Organization (2018). PV-powered Vehicle Strategy Commitee Interim Report.

33 North American Council for Freight Efficiency (NACFE) (2018). Confidence Report – Solar for trucks and trailers.

34 In 2019, the European Union adopted new targets for the CO_2 emissions of vehicles (Regulation 2019/631), setting an EU-wide fleet target of 95g CO_2/km for the average emissions of new passenger cars, and an EU-wide fleet target of 147g CO_2/km for the average emissions of new light commercial vehicles. In addition, the following CO_2 emissions reduction targets are set for the year 2030: a 37.5% decrease for EU-wide fleet CO_2 emissions for new cars, and a 31% reduction for new vans. These targets are complemented by additional specific CO_2 emissions targets applying to each manufacturer.

CASE STUDY
SOLAR HYBRID ELECTRIC CARS

Toyota Hybrid Prius

In 2012, Toyota developed a solar version of the Prius, the Solar Hybrid Prius. The silicon photovoltaic panels featuring heterojunction technology had a 180 Wp capacity and an efficiency of 20.7%. While driving, the solar panel contributes to the onboard system, charging the lithium-ion battery and providing an additional 3 to 6 km daily solar range. A small daily extension to the range was offered for the additional price of €1,700, for a total price of around €39,600.

In July 2019, Toyota released the new demo of the Prius PHEV, which is already a 400% performance jump compared to the previous commercial model Prius PHV that Toyota released in 2017, which had a solar photovoltaic car roof of high-efficiency, triple-junction solar cells with a conversion efficiency of 34%. Toyota integrated the panels including indium gallium phosphide (InGaP), gallium arsenide (GaAs), and indium gallium arsenide (InGaAs) onto the roof, bonnet, and rear hatch door garnish, achieving a rated power generation output of 860 Wp.

NEDO and the battery company Sharp helped Toyota with the public road trials of the solar-powered vehicle. First estimations expected a maximum daily contribution of 44.5 km to the battery in BEV-mode while parked. The maximum charge and power supply to the driving and auxiliary battery while moving is equivalent to 56.3 km.

Source: Toyota.

Audi's Solar e-tron Quattro

Audi's e-tron Quattro was launched in 2017 and is the result of a partnership with the Chinese solar-cell specialist Alta Devices. Thin-film solar cells were integrated onto the entire roof, designed mainly to contribute to seat heaters and air conditioning systems. The efficiency of Alta Devices' thin-film flexible GaAs solar cells is around 25%, and measures 1940 x 1300 mm. The panel's power reaches 400 Wp.

Source: Audi.

Hyundai's Solar Sonata Hybrid

In 2019, Hyundai presented a version of its Sonata Hybrid equipped with a solar roof. The car manufacturer claims that the solar cells can cover up to 60% of the power needed to charge the battery and can fuel the vehicle for 1,300 km a year with an average 6 hours of daily charging. The company plans to roll out this technology to other vehicles.

Source: Hyundai.

3 VEHICLE-INTEGRATED PHOTOVOLTAICS: SOLAR-POWERED VEHICLES / CONTINUED

Newest VIPV technology can already contribute to the charging of the battery, thus extending the range of the vehicles. European start-ups Sono Motors and Lightyear One have been working on commercial models of fully electric vehicles equipped with solar roofs with the aim of maximising the autonomy of the car on the solar panel. The design of the vehicle has been revamped to lower the electric power needed: lighter and a more distributed weight of the vehicle, a new aerodynamic approach, and a more efficient braking system. This results in a reduction of the energy usage of the car (15.6 kWh/100km for the Sion and 10.3 kWh/100km for the Lightyear One).

The solar cells allow the vehicles to increase their range but are still not fully autonomous on solar. However, the additional driving range (in Northern Europe, an average of 20 km year-round and a maximum of 34 km for the Sion, and 37 km for Lightyear One) is comparable to the average distance of commuting journeys.

CASE STUDY
SOLAR FULL-ELECTRIC VEHICLES

Sono Motors

The Sion, produced by the German EV-manufacturer and mobility provider Sono Motors, is a Solar Electric Vehicle (SEV), suitable for everyday use with a driving range of 255 km (WLTP standard) for €25,500. It is equipped with mono-crystalline silicon solar cells, seamlessly integrated into the body panels of the car (the bonnet, sides, roof, and boot). The cells are protected by polymer and therefore fulfil the automotive safety requirements. The traction power is 100 W and the battery capacity is 35 kWh.

In Germany, the company claims that the Sion is able to generate a range of up to 5,800 km per year using only solar energy, with a maximum of 34 km per day during the summer months. The start of production for the Sion is scheduled for the second half of 2020. As of October 2019, with over 10,000 reservations for the vehicle, the Sion is already available for presale from €25,500.

In addition, Sono Motors has developed a 2-way charging system for its SEV: biSono. This bidirectional charger turns the Sion into a mobile battery, that allows for services such as vehicle to grid, vehicle to home, vehicle to device, and vehicle to vehicle.

Source: Sono Motors.

Lightyear One

Lightyear One is produced by the company Lightyear, founded by one of the winning teams of the Australian solar race, World Solar Challenge. It is a large, family vehicle, with a range of 725 km, and the price of the vehicle starts at €119,000. The energy consumption of the light vehicle is 83 Wh/km and it has a 60 kWh battery.

The vehicle is equipped with a 5m2 solar roof with a capacity of 1,250 Wp. The cells cover the body of the car and are protected with safety glass. The solar driving range is about 64 to 80 km, and the company estimates that in the Netherlands, a customer driving 20,000 km/year (the Dutch average) can cover about 40% of its charge on solar. Lightyear presented its first prototypes in 2019 and, as of September 2019, plans its first deliveries for 2021.

Source: Lightyear One.

3.2 Solar trucks and buses

Besides individual mobility, PV can also be installed on other vehicles, such as trucks or buses. The placement of solar cells on heavy-duty vehicles has been an object of research in the past years, including by the private research organisation Tecnalia and the research institute Fraunhofer Institute. Since the roof area of trucks is generally larger than a smaller car, and has no curves, the installation of PV is in fact less challenging. While trucks are unlikely to be able to be powered exclusively by solar generation due to their heavy weight and significant power needs, the surface area of the roof has the potential to accommodate solar systems large enough to power certain features.

In heavy-duty vehicles, the solar systems can provide additional power supply to the battery and therefore extend the autonomy of the vehicle. This could also be the case for lighter vehicles such as buses. A simulation from the research organisation Tecnalia has shown that a battery-electric bus equipped with a solar rooftop driving around 300 km daily could extend its driving range by approximately 20 km. However, this additional range would be marginal for heavier vehicles requiring more power, such as trucks.

Most commonly, a solar rooftop is used to power auxiliary services, such as air-conditioning systems or cell phone chargers. They can also power applications in trailers, such as the back liftgate systems, as well as sensors and telematics systems, which are relevant in the context of the increasing digitalisation of heavy-duty vehicle fleets. Another application observed is the use of solar cells to power refrigerated trailers (see case study below).

The economic viability of VIPV for trucks in commercial cases might be achieved earlier then passenger vehicles due to their predictable routes and times. The mobility profiles of trucks show that they generally drive longer distances; the average annual driving distance of private passenger cars is around 12,000 km per vehicle, for commercial use passenger cars it is around 66,000 km per year, while light-duty trucks drive 21,000 km per year, and medium/heavy-duty trucks drive 70,000 km per year.[35]

The North American Council for Freight Efficiency (NACFE) has studied the potential of such applications in the US, and has developed a payback calculator to help companies evaluate the benefits of solar solutions for trucks.[36] Logistics companies are now increasingly finding it to be more economical to switch their fleets to electric vehicles, which brings with it the additional potential of PV application.[37]

Source: EVBox.com.

35 Dr. Wermuth (2012). Verhkehrsforschung und Infrastrukturplanung.

36 North American Council for Freight Efficiency (NACFE) (2018). Confidence Report – Solar for trucks and trailers.

37 Heinrich, D. M. (2012). Photovoltaik auf Nutzfahrzegen. Fraunhofer ISE.

CASE STUDY

TECNALIA'S TECHNICO-ANALYSIS FOR SOLAR-POWERED REEFER TRUCKS FOR THE LONG-DISTANCE TRANSPORTATION OF REFRIGERATED GOODS

Transporting goods by road is the most important means of transportation in Europe. The vast majority of this transport involves diesel-powered trucks, although alternative propulsion systems have been investigated.[38]

A transport company with a fleet of more than 500 trucks transporting refrigerated goods wanted to reduce its huge fuel consumption. Its aim was to reduce the energy costs (operational expenditures – OPEX – and fuel for motion and refrigeration in diesel groups) spent annually to power trucks and trailers for motion, and the cooling system for keeping goods in optimal condition. Additional results pursued were the improvement of energy efficiency, and the acquisition of a sustainability 'green' label. All of this was pursued through the electricity provided by a PV system integrated into the roof of the trailer.

The exercise led by Tecnalia consisted of a techno-economic feasibility analysis of applying a PV system to cover truck consumption and analysing different options for the integration of PV on top of the trailer. For the consumption analysis, both the refrigeration and the motion energy demands were considered; the former powered with cheaper and low-quality diesel. and the latter with diesel of a higher quality. The factors and variables considered in the analysis included the efficiency of the diesel engines in both uses, the usual trajectory of trucks across Europe (Mediterranean corridor), the number of hours per day that trucks were moving, and the cooling temperatures.

For the energy production, the total available surface of approximately 40m^2 was considered, covering the entire roof of the trailer. Among the available PV technologies, those offering a good compromise between cost, weight, and efficiency were used. The weight of the PV system (modules and supporting structure) was restricted to a maximum of 400 kg or 1% of the maximum operating weight of the set truck and container. Several restrictions or requirements important to the truck company were established as well. For instance, the effect of washing the trailers with the PV panels on top (effect of brushes). Similarly, the study aimed at designing an anchoring solution capable of being easily dismounted and mounted again, due to the fact that trailers are usually the object of maintenance every five years, while the lifetime of PV panels is much longer.

Once the PV system was designed and the components selected, daily and annual energy production were calculated and compared to the diesel consumption. By considering the amount of energy directly self-consumed for (1) motion, (2) refrigeration (the PV system generates when the truck consumes the electricity), and (3) the amount of energy that could be stored in a battery, the economic savings in diesel were calculated. The results showed an annual savings of around €600, and a payback-time of around eight years, resulting in an attractive business case for the transportation company.

MOBILITY

38 Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria. Transformers Test Drive Results of a new Hybridisation Concept for Truck-Semitrailer Combinations. Gunter Nitzsche (Fraunhofer Institute for Vehicle and Infrastructure Systems IVI, Dresden, Germany), Sebastian Wagner (TNO, Helmond, The Netherlands), Rik Baert (Volvo Group Trucks Technology, Gothenburg, Sweden), Frank Engels, Christophe Maillet.

3.3 Solar boats

The maritime sector is a large greenhouse gas emitter, with around 940 million tonnes of CO_2 emitted annually. It also contributes to air pollution, particularly in port and coastal cities, and noise pollution.

Electrification of transport could be a solution to decarbonise the maritime sector, at least for short maritime journeys. More specifically, short sea shipping and inland waterway vehicles have a power-to-weight ratio that would made electrification feasible.[39] Indeed, a series of battery electric ships already exist throughout Europe.

The segment of short sea and inland waterway shipping represents an opportunity for solar boats. Such vehicles have already been developed and used in the world. In the tourism sector, they are used for short cruises or for sustainable tourism activities, particularly in protected natural areas, as they cause neither air nor noise pollution.[40] They could also be used as public transport for short journeys.

3.4 Solar trains

The list of solar-powered vehicles would not be complete without mentioning solar rooftop trains. Examples of solar-powered trains can be found particularly in countries with high irradiation levels. The solar systems are not used for traction power, but rather to supply auxiliary services such as lighting, fans, and air-conditioning systems. The large rooftop surfaces of the carriages can be used to install these solar systems.

CASE STUDY
CITY BOATS AND BARCO SOLAR:
SOLAR VESSEL SOLUTIONS IN POLAND AND PORTUGAL

City Boats is a service company operating solar boats for urban mobility and tourism services in Poland. The fleet of City Boats is composed of small vessels able to carry up to 8 to 12 passengers, equipped with a small motor of 2 to 4 kW (4 to 8 hp), a battery facility and a 1 kW solar bimini roof. In Portugal, the service company Barco Solar provides solar boat solutions to private clients, tour operators, and local administrations.

The Polish manufacturer, Green Dream Boats, currently produces several dozen boats a year. It also manufactures other units for other companies – laminate ferries, catamarans of various types, houseboats.

With an engine of 4 kW (approximately 8 hp), the vessels have autonomy for 8 to 10 hours at the speed of 7 km/h and an average daily range of 56 km. Thanks to the solar system continuously charging the battery of the vessels, the range of the boat can be extended up to 100 km on a sunny day, depending on the weather conditions affecting the energy needed for sailing. The range is affected by the wind, river currents, or waves.

Green Dream Boats

39 European Commission (2018). A Clean Planet for All.

40 Examples include: Green Dream Boats cruises.

3 VEHICLE-INTEGRATED PHOTOVOLTAICS: SOLAR-POWERED VEHICLES / CONTINUED

CASE STUDY
SOLAR TRAINS

There are a few examples of solar trains in the world, including the following.

Byron Bay Train

The Byron Bay train is a coastal train linking the city centre of the Australian town of Byron to the North Beach of the city. The historic diesel motors of the train were replaced by electric motors and a Lithium-Ion battery. The rooftop was equipped with solar panels and circulated for the first time in 2017. On a sunny day, the 6.5 kW solar roof provides enough electricity for its 3 km route. The 30 kW solar roof on the train's storage building can produce additional green power to charge the train.

Indian Railways

Indian Railways has undergone a programme of greening its railway stock, including the energy used to power the trains. After an initial demonstration project, Indian Railways has already installed panels on the rooftops of about 42 coaches. The electricity generated by solar panels is used for powering the lighting and fans of the coaches.

Gobierno de Jujuy

In 2019, the Jujuy Province in Argentina opened a tender to build a solar train. The train would run 300 km journeys between the cities of San Salvador de Jujuy and La Quiaca, with additional energy provided from a nearby solar plant. The train should be ready to operate by the end of 2019.

Source: Byron Bay Train.

3.5 Solar airplane transportation

Accounting for approximately 3% of global CO_2 emissions,[41] diverting aviation from fossil fuels is crucial in order to achieve the decarbonisation of the transport sector. This will be a major challenge as the sector is expected to rapidly expand in the coming years, with its emissions doubling or even tripling by 2050.

However, the growing awareness of the need to achieve sustainable mobility empowers the progress towards the decarbonisation of aviation. Coined by the young Swedish activist Greta Thunberg, the phenomenon now even has its own name: 'the shame of flying' (translation of the Swedish 'Flygskam').

While complete electrification is unlikely for long-haul aircrafts, electric planes could be a solution to allow clean air transportation for shorter routes. Indeed, solar could be the perfect fuel for electric aircrafts of the future. After the pioneer project Solar Impulse proved the potential of solar electric propulsion systems for airplanes in 2016, the aviation sector is eager to see electric airplanes ready for take-off.

By 2040, the Norwegian airport network Avinor plans to use electric planes for its journeys that are shorter than 1.5 hours. Further, in 2018, Heathrow Airport in London announced that the first electric aircraft landing on its grounds would be exempt from landing charges for a year.

CASE STUDY
SOLAR IMPULSE, THE PIONEER SOLAR AIRPLANE

Solar Impulse is a Swiss long-range experimental solar-powered aircraft project, as well as the name of the project's two operational aircrafts. The privately financed project is led by Swiss engineer and businessman André Borschberg and Swiss psychiatrist and balloonist Bertrand Piccard, who co-piloted Breitling Orbiter 3, the first balloon to complete a non-stop journey around the world.[42] The goals of the Solar Impulse project were to make the first circumnavigation of the Earth by a piloted, fixed-wing aircraft using only solar power, bringing greater attention to clean technologies.[43] In July 2016, 16 months after departure, Solar Impulse 2 completed the approximately 42,000 km (26,000 mile) circumnavigation of the Earth with a piloted, fixed-wing aircraft using only solar power.[44]

Source: Solar Impulse. Solar Impulse 2 at the Payerne Air Base in November 2014.

41 European Commission.

42 Cardwell, Diane (1 May 2013). Cross-Country Solar Plane Expedition Set for Takeoff'. The New York Times. Retrieved 2 May 2013.

43 'A Speck in the Sky'. The New York Times. 21 March 1999. Retrieved 24 June 2013.

44 Div, Stav. 'Solar Impulse 2: The groundbreaking aircraft demonstrating the possibilities of clean energy', The Independent, 2 June 2016.

3 VEHICLE-INTEGRATED PHOTOVOLTAICS: SOLAR-POWERED VEHICLES / CONTINUED

CASE STUDY
SOLARSTRATOS

The Swiss eco-explorer Raphaël Domjan intends to write a new page in the history of solar energy, by reaching the stratosphere without using any other form of 'fuel'.

SolarStratos is the first-ever commercial two-seater solar plane. It will also be the first manned solar plane penetrating the stratosphere, at an altitude between 6 and 50 km, above the regular air transportation zone. Calin Gologan (Elektra-Solar GmbH – technical partner of SolarStratos) is entrusted with the design of this futuristic plane, drawing inspiration from the design of commercial planes. This tandem two-seater, with a wingspan of 24 m and a weight of 450 kg, will fly like any other aircraft.

The aircraft will be equipped with 22m^2 of solar cells placed on the wings, as well as with a 20 kWh Li-Ion battery that will provide electricity to the aircraft. This will allow the aircraft to be autonomous for 24 hours, with the power required to reach the highest altitudes.

The main requirement for ensuring the success of this project was the need for an ultra-light solution with maximum energy efficiency. The Swiss research centre CSEM has taken up this challenge and produced modules weighing 707 grams per square meter – a technological feat. The cells also have an efficiency of 22 to 24% and can resist very low temperatures (-70°C).

The aircraft will be used for scientific missions, with the intention of one day being used for commercial and tourism purposes.

Source: SolarStratos (https://www.solarstratos.com/). Rollout of SolarStratos on 26/01/2017 in Payerne Air Base.

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