PhotoVoltaic
EUROPEAN TECHNOLOGY
& INNOVATION PLATFORM

VIPV POSITION PAPER

Vehicle-integrated Photovoltaics (VIPV) as a core source for electricity in road transport

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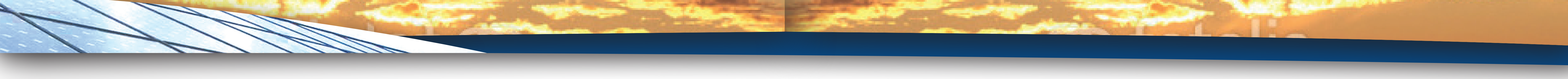

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Disclaimer

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SCOPE AND MISSION

The growing awareness of the global need for sustainable mobility empowers the application of new technological innovations to the road transport sector. Vehicle integrated photovoltaic technology (VIPV), however, is still considered a questionable issue in the automotive community. The ecological and economic value of VIPV is not yet evident. This paper aims to give an overview of the global VIPV market, in particular, the current status and future potential of PV-powered vehicles. Additionally, it studies possible added value for users, communities and stakeholders mostly focusing on battery- operated electric vehicles (BEVs). Other VIPV applications for solar race vehicles, as well as ships, planes, trains and other small vehicles are outlined and evaluated as well. Concentrating on different Use Cases, the paper estimates the economic and environmental viability of PV from technical viewpoints. In conclusion, this paper outlines strategies for integrated research and development and clarifies the main obstructions to VIPV introduction.

This study has been made under the framework of the European Technology and Innovation Platform for Photovoltaics (ETIP PV)

1. POLITICAL CONTEXT

Figure 1: Flag of Europe (BMWI, 2019)

Transport in the EU and 2030 Targets

For decades, road transport has been a significant source of greenhouse gas (GHG) emissions in Europe by being the 3rd highest source for GHG after energy supply and industry. Back in 2009, the renewable energy directive recognised renewable energy sources in transport as one of the most effective tools to limit the transport sector's impact on climate change. Ten years later, transport remains the only energy sector that shows increased emissions, proving the strong need for new actions and adaptations of stricter limits. (European Environment Agency, 2018)

New strict targets of the European Parliament force the reduction of average CO_2 emissions of vehicles. For the year 2030, a 37.5% reduction of EU fleet-wide CO_2 emissions for new cars was decided on. The reduction target for new vans was set to 31%. Additionally, rewards for manufacturers meeting the benchmarks and penalties for those with average emissions exceeding the targets, were approved. Beginning in the year 2020, new emission rules will require an average fuel economy of 95 g CO_2/km for new passenger cars.

This legislation is an ambitious and necessary step towards decarbonisation of the transport sector. The first quarter of 2020 is consequently widely prophesied to see dramatic changes in vehicle sales. (Press release EU Parliament 2019)

To meet the goals set by the EU, the manufacturers are currently forced to invest intensely in innovative technologies of sustainable mobility, such as electric vehicles (EVs), hybrid vehicles (HVs), plug-in hybrid vehicles (PHVs), and fuel cell vehicles (FCVs). For petrol and diesel vehicles, CO_2 credits are already established.

However, the calculation of emissions of specific technologies is still an issue. Under the condition of the rollout of the renewables, energy generation cannot always be timely matched to the typical charging behaviour, which is usually every evening. At this time, fossil power plants dominate the power generation in most countries. Therefore, the main contribution to the reduction of the emissions of electric vehicles can be achieved by modifying the source of electricity for charging of EVs and guaranteeing integration of low emission energy instead. Integrating solar modules can help to make EVs environmentally friendly and reduce fleet-wide emissions. When the vehicle is equipped with a PV, the solar radiation is used to charge the battery. It guarantees that the vehicle´s consumption is at least partly covered by renewable energy which reduces the grid power demand.

2. INTRODUCTION TO THE VIPV MARKET

VIPV was initially supposed to be an add-on, providing an auxiliary source of energy for lighting or air-conditioning. Since then, the PV market has been continually growing due to the increase of module efficiency and a reduction of the cost. Solar electricity has recently become the lowest-cost source of electricity in most parts of the world.

The VIPV market benefited from this development and different passenger cars with PV mounted on the roof and other surfaces were introduced to the automotive market. VIPV is mostly used on hybrid and battery electric vehicles, which experienced similar industrial and commercial success as PV, as demonstrated in Figure 2.

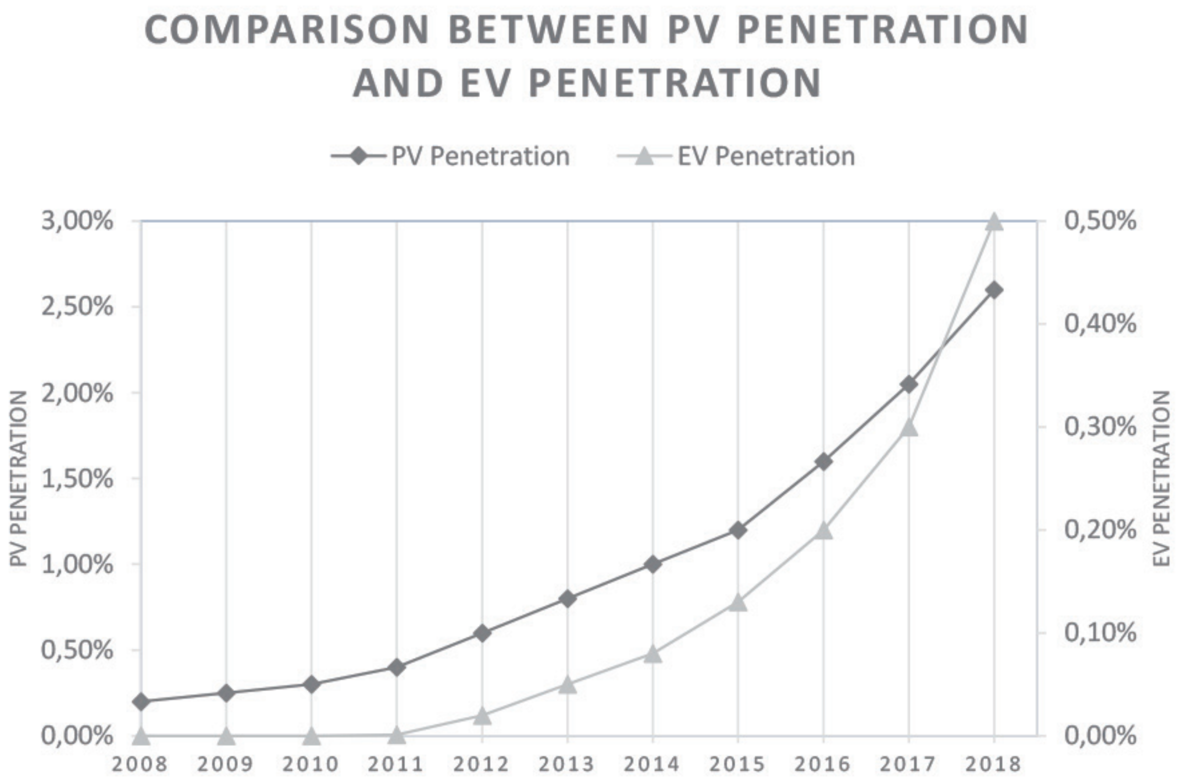


Figure 2: PV and BEV Penetration (IEA-PVPS-Task 12 2019)

The first solar-powered car was introduced in 1955 by General Motors: the Sunmobile (Kevin R, 2017). Later, in 1985, the first Tour de Sol competition in Switzerland combined solar and automotive technologies in a race. Other races like the well-known World Solar Challenge in Australia made solar vehicles continuously more famous. A 3,000 km World Solar Race distance separating Darwin from Adelaide was a challenge to the technology and made solar cars compete on speed and the vehicle's efficiency. The South African Solar Challenge from Pretoria to Cape Town is a similar race that has become quite popular and encouraged ingenious minds to improve solar vehicle technology.

2.1 Passenger Cars

The first commercial models of solar passenger cars that attracted wide public attention were models of plug-in hybrids equipped with solar roofs. Audi e-Tron Quattro is one of the most popular joint projects of Audi and Alta Devices, a US company owned by the Chinese company Hanergy. The efficiency of Alta Devices' thin-film, flexible gallium arsenide (GaAs) solar cells is around 25%. At a size of 1,940 x 1,300 mm2 the panel on the vehicle roof of e-Tron can generate 400 Wp. Thin-film solar cells embedded in a panoramic glass roof contribute to seat heaters and the air conditioning system.

Figure 3: Audi e-tron Quattro (Audi 2019)

The first generation of the Toyota Prius Plug-in Hybrid was introduced to the market in 2012. The car was equipped with a 180 Wp solar system, mostly used for ancillary services. In 2019, Toyota released the comeback demo of the Prius PHEV with a more efficient solar photovoltaic roof. High-efficiency III-V triple- junction solar cells with a conversion efficiency of 34% were integrated into the vehicle. The panels with indium gallium phosphide, gallium arsenide and indium gallium arsenide cells reach 860 Wp. Together with Japanese New Energy and Industrial Technology Development Organization (NEDO) and Japanese company Sharp, Toyota performed public road trials. The maximum charge and power supply to the driving and auxiliary battery while driving is stated to be 56 km per day. (Toyota Deutschland GmbH, 2019)

Figure 4: Toyota Prius Plug-in Hybrid, 860W (Toyota Deutschland GmbH 2019)

Figure 5: Sono Motors Sion (Sono Motors 2019)

The company Sono Motors from Germany use monocrystalline silicon solar cells to cover the body of its solar car Sion. Under best conditions in Germany, the cells generate 1,200 Wp and add up to 34 kilometres per day to the battery range of 255 km (WLTP capacity of 35 kWh). After a successful funding compaign that ended in January 2020, the vehicle is now on commercial sale, starting already from €25,500. Sion is optionally available with the bidirectional charging technology that might be quite interesting for the mid-term future of smart grids. With this option Sion can power high-voltage devices with up to 11 kW, allowing V2G services like refeeding the grid with VIPV power. (Sono Motors GmbH 2019)

Figure 6: 2020 Lightyear one, 1250W (Lightyear 2019)

The Dutch company Lightyear, in cooperation with Siemens and NXP, announced a luxury solar vehicle for 2020. The Lightyear One will have more than 5 m² of integrated solar cells that can generate 1,250 Wp. Under optimal conditions, the cells will contribute up to 200 km to the charging of the 60 kWh battery. Almost 780 km range can be achieved under the best PV contribution. The reason for this high number is an impressively low energy consumption of the vehicle of 83 Wh/km (WLTP). Besides the technical specifications, the company also put a high priority on the design, which additionally influences the price of the vehicle, which starts at €119,000. (Lightyear 2019)

2.2 Light- and Heavy-Duty Vehicles

Figure 7: Solar Powered trucks, tsscgroup (2019)

Besides passenger cars, light commercial vehicles and trucks also show high potential for VIPV. The installable area on these vehicles is usually large and often in a horizontal position, which is less challenging for the integration process of PV. In addition, the electricity provided by the PV modules can be used not only for driving but also for on-board auxiliary services, such as air-conditioning or for cooling systems (Mallon et al. 2017).

Many other companies are already working on electrically powered delivery vehicles, e.g. MAN (CitE, eTGE) or VW (e-Crafter), but there are no VIPV solutions commercially available on the market yet. The key challenge that might hinder market growth is similar to passenger cars: the lack of knowledge about the added value of VIPV. Since the benefits strongly depend on the technology, specific driving patterns, geographic location, and solar irradiance, the performance cannot be easily quantified by the standard test cycle measurements and must be studied explicitly. (Energy, 2014)

The North American Council for Freight Efficiency (NACFE) is studying the potential of VIPV. NACFE helps truck companies to evaluate potential benefits for automobiles and to calculate the reduction of the CO_2 emissions (Gunter Nitzschea 2018). NEDO in Japan is likewise continuously researching automotive photovoltaic systems and environmental issues. The results are promising, but due to the geographical dispatching, they cannot be applied for VIPV in Germany or other countries since the settings, electricity mix and solar radiation vary a lot (PV-Powered Vehicle Strategy Committee 2018). German research centre Fraunhofer ISE also explored VIPV technology, analysed the yield of PV power supply for commercial vehicles and refrigerating trucks with solar powered cooling and calculated fuel savings of various routes. In a similar project, funded by the German Ministry for Economic Affairs and Energy, German Logistics Company Deutsche Post, DHL Group is currently integrating PV on electric light utility vehicles. The study focuses on “WORK L” which is an electric drive model from the company StreetScooter operated in the fleet of German logistics company Deutsche Post DHL Group. TNO has also contributed to the research. The experts from Netherlands not only developed technology for the Lightyear One but also conducted research on energy flow models analysing battery size, charging strategies and shading conditions, thus quantifying the benefit of VIPV for both passenger and commercial vehicles.

VIPV in other transportation applications

Solar Boats: *Electrification of the maritime sector can also be an opportunity to reduce emissions of the sector. Especially for ships with feasible power-to-weight ratio used for short distances, VIPV is a great chance. Series production of battery electric ships can already be found in Europe. Barco Solar from Portugal, for example, produces solar boats with range extension of 56 km (30 nmi) under ideal weather and sailing conditions. Similar to other transportation applications, VIPV in the maritime sector can be used to run lighting, air-conditioning, fridge, communications services, navigation tools (auto- pilot, navigation computer, radar) GPS and charge the battery.*

Solar Trains: *The remarkably big rooftop of trains can also provide a sophisticated surface to install PV to power on-board services. Examples like Indian Railways or Byron Bay Train in Australia prove the feasibility. With the combination of 30 kW solar on the train´s storage building and 6.5 kW VIPV the distance of the train of 3 km can be completely covered by VIPV.*

Solar Aviation: *Complete electrification of aeroplanes is almost impossible, but VIPV can be used to partly meet power demand on the bigger planes or provide integration opportunities for smaller electric aircraft on the shorter flights. Since the integration of PV is hardly profitable solar vehicles are yet very unlikely to become a commercial option in the near future.*

3. THE MOTIVATION FOR VIPV

3.1 General Benefits of VIPV

Apart from the previously discussed political circumstances, the success of VIPV in the automotive market will be directly linked to the added value of PV integration in specific cases. For example, through increased self-consumption due to electricity generated by VIPV, the grid power demand decreases, which in most cases of daily mobility might have a positive influence on private costs and contribute to further decarbonisation of the transport sector in general. This chapter gives an overview of the main benefits of VIPV.

Increased Autonomy and Battery Life

The core advantage of on-site supply is rising autonomy and thus longer driving range of the vehicles. Since the charging infrastructure is still being set up, it is attractive for the customers to reduce power demand from the grid and thus limit their “range anxiety”. VIPV might additionally improve the lifetime of the battery and reduce the need for maintenance if the number of charging cycles of the battery can be decreased. Under best conditions VIPV shows potential for charge-free seasons in the summer. (New Energy and Industrial Technology Development Organization, 2018)

Unburdening the Grid

To estimate the rough advantage of VIPV in general, it is important to mention that considering the complex future electricity system or smart grids, decentralisation caused by on-site applications such as VIPV could simplify the grid operation. The self-consumption on-board avoids the negative impacts that larger scale PV installations sometimes have on power systems, such as voltage rise and overloading of local components and reduces the challenge of BEV charging for the grid. (Kenji Araki, 2018) (New Energy and Industrial Technology Development Organization, 2018)

New Business Models

VIPV additionally creates public awareness for new business models like solar-powered Vehicle2Grid, where the VIPV cars could generate power for the grid supply. The option of bidirectional charge (Share Sion by Sono Motors) also enables sharing battery energy to power other electronic devices. Integrating solar electricity in such models improves their sustainability image.

Reduced Mobility Costs

VIPV can additionally help to yield economic advantages. NEDO evaluated economic benefits of different utilisation ranges of on- board power and found economic benefit at utilisation rates from 42% upward. (New Energy and Industrial Technology Development Organization, 2018). The benefit, of course, depends on the local price of electricity and PV costs, but the general improvement of energy efficiency between energy generation and consumption avoids unneeded steps of energy conversion and distribution, and thus provides a potential for cost savings (see Figure 8). General gross benefit for electric vehicles can be calculated based on the amount of grid power usage saved due to VIPV multiplied by the electricity price for charging the battery. The net economic benefit is then the difference between the gross benefit and the costs of integration. Especially in the countries with high electricity prices (e.g. Germany 27 ct/kWh) and charging prices the benefit of VIPV can very likely be achieved during the operation time.

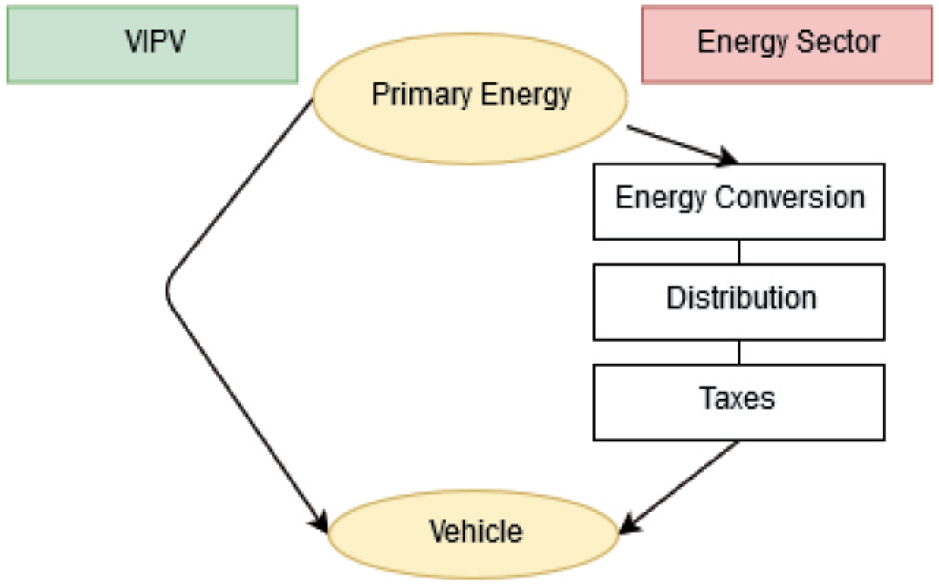


Figure 8: VIPV Efficiency

VIPV is consequently beneficial for:

- ***Car manufacturers to reduce emissions per vehicle and meet the goals***
- ***Political institutions to reduce environmental impacts of the transport sector***
- ***Solar market to identify further application possibilities assuming 50% losses, VIPV can provide***

3.2 VIPV Energy Flow Model

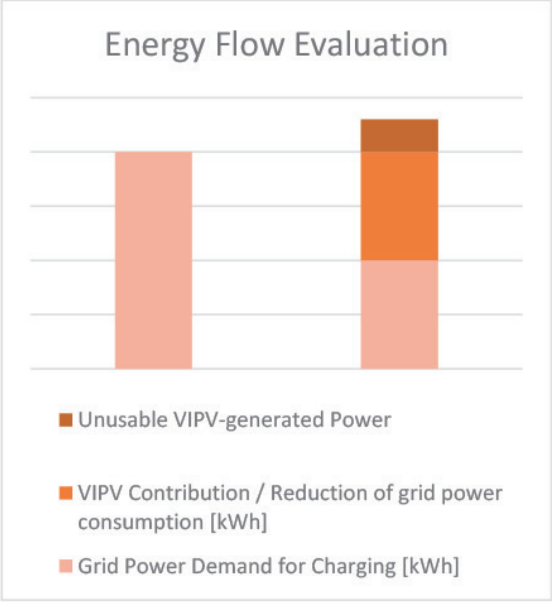


Figure 9: Evaluation of the VIPV Contribution

The reduction of grid power usage is the difference between the generated power by VIPV and the power consumption of the vehicle (Figure 9). Once the generated power is greater than the consumed power, the remaining amount is stored in the on-board battery and after the battery is full, electricity generated by VIPV remains unused.

Thus far, the difficulty is to predict how much PV electricity can contribute to the charging. The charging profile depends strongly on the vehicle specifications and lifestyle of its owner just as solar output depends on the used technology and the local radiation and different use cases. The presence of physical obstacles such as buildings or trees prevents the vehicle roof from receiving total solar irradiance and increases short-period fluctuations in solar radiation. (New Energy and Industrial Technology Development Organization, 2018)

NEDO states that 10% to 20% of the average annual vehicle distance could be covered by currently available PV technology, with a maximum daily contribution of over 20% in the summer and around 10% in the winter. Some studies show an increased ratio of VIPV usage of up to 20-40% under the condition of parking outdoors in regions with sophisticated solar radiation. (Kenji Araki, 2018; Gunter Nitzschea, 2018)

PV Contribution to the Mobility of a Typical German Passenger Car

According to recently published Statistics for Road Transport the average power of 8 kW is needed for traction of a passenger car in an urban environment. Taking into account ageing losses and cold winter and hot summer days, an average consumption of 20 kWh/100 km can be assumed for an average passenger car (Helmers, 2017). The average yearly driving distance of private passenger cars in Germany is around 12,000 km per vehicle. The distance on weekdays is around 39 km (Follmer, 2019), meaning a daily energy demand for a vehicle of around 8 kWh. Considering the insolation in Germany of around 1,000 W/m2, and a yearly outcome of 1,000 kWh/year a passenger car that is equipped with ca. 3.5 m^2 of solar panels with 30% efficiency could consequently generate 1 kWp per vehicle and roughly 2.7 kWh daily. In an urban environment, buildings, trees, streetlights, poles, and similar structures will reduce direct solar irradiation. But even when assuming 50% losses, VIPV can provide 1.4 kWh per day, thus covering 17.5% of the daily charging load. In contrast, commercial passenger cars drive around 66,000 km per year, light duty trucks 21,000 km and medium/heavy duty trucks 70,000 km per vehicle per year (Verkehrsforschung und Infrastrukturplannng GmbH, 2012). For commercially attractive integration energy forecasting is required for business case calculation.

Depending on the solar intensity and the amount of direct solar irradiation, the value of VIPV output varies. In (Lodi et al. 2018), a typical urban situation has been defined, identifying the average height of the obstacles and the common geometrical characteristics of roads and vehicles as main variables for influencing the shading. By comparing the yearly solar irradiance received in real-world driving conditions, results for the USA show that on average VIPV receives 58% of the yearly global horizontal solar irradiance with resulting value of 83.5 W/m2. Another study (Mallon et al. 2017) verified the modelling results with empiric measurements and estimated that efficiency is reduced to 70%, meaning that 30% of all direct radiation is lost due to shading (Ota et al. 2018; Birnie 2016). Similar results of an average loss of 30% were found by (NEDO) in Japan. On sunny days, a ratio of 50%-70% was quantified. On cloudy days, the ratio was over 70% (PV-Powered Vehicle Strategy Committee 2019)

3.3 Environmental Benefits in Comparison to the German Grid Mix

Environmental impacts of VIPV are wide- ranging. Based on the findings of the last chapter an estimation of the environmental benefits of VIPV on eco-efficiency of vehicles can be projected for the representative cases. The integration of solar cells into the cars shows potential to reduce GHG emissions.

A high number of environmental impact studies was published in recent years, analysing different alternative technologies regarding their environmental benefits. The overall conclusion of most case studies is that battery electric vehicles (BEV) are clearly preferable over petrol and diesel cars, when charged with renewable energy. As integrating solar cells into cars guarantees that part of the battery charge is provided by renewable energy, VIPV is clearly environmentally advantageous in comparison to carbon-intensive electricity generation. The core question from a holistic perspective of cradle to grave is, therefore, whether a BEV partly charged by VIPV is better for our climate than BEV charged from the grid. Fossil power plants dominate the power generation in Germany. Many other European countries also emit high amounts of carbon dioxide into the atmosphere due to power generation (Figure 10). Known studies considering carbon footprints of the grid power plants caused by the life cycle of the plant (construction, fuel production, operation etc.) show average emissions in Germany of around 350 g/kWh for the year 2020 till 2025 and less than 250 g/kWh for the year 2030 (Agora Energiewende, 2018).

Even under the condition of positive plans for the rollout of the renewables, the emission factor of photovoltaic electricity in Germany of around 67 g/kWh is below the grid average. The emission factor for VIPV is therefore also very likely to be below that of the grid. (Memmler, 2018)

The calculation of the emission factor of VIPV mainly depends on the manufacturing of PV, the integration process and the PV performance. The operation time of VIPV is expected to be around 10 years, which is half of the time of residential PV. Due to modified operation conditions such as the shorter operation time and performance losses caused by increased shadowing, the emission factor of the VIPV generated electricity rises and the emissions per kWh increase significantly. The highest potential for reduction can be confirmed for cases, where "green" renewable electricity is used for the manufacturing process. Prolonged operation time and reusing the PV system in second life applications, e.g. residential PV, provides an additional ecological benefit.

Grid Power Case Study

Reduction of grid power usage through VIPV can, therefore, decrease CO_2 emissions of the vehicle. By installing solar modules with 800 W on passenger cars in Japan it was possible to reduce CO_2 emissions by 63%. Different percentages of VIPV utilisation were investigated, showing the effect of reducing CO_2 emissions for a PV utilisation rate of at least 28%. (New Energy and Industrial Technology Development Organization, 2018) These results are, however, only representative for Japanese electricity. European research investigated a German setup and reported a similar observation that placing a PV system on- board of existing light-duty vehicles can reduce the emissions by 18% assuming a shadowing factor of 30% and operation time of at least 8 years. Further investigations are needed for proper evaluation of diverse Use Cases and charging profiles. (Kanz, 2019)

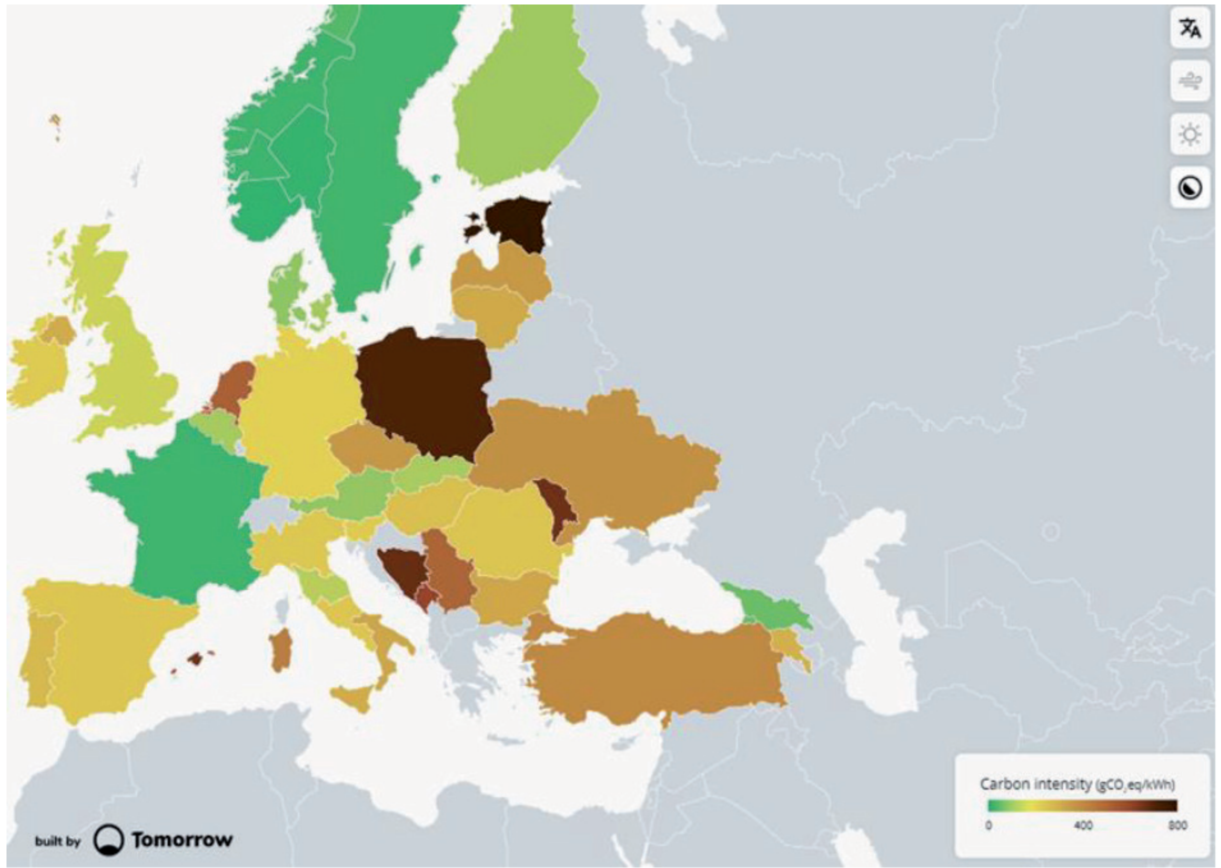


Figure 10: Grid Emissions in the EU (Electricity Map, 2019)

4. REQUIREMENTS AND TO-DOS FOR VIPV

4.1 Important Selection Criteria for VIPV

Although more than 25 PV cell types are available on the market, not all technologies show potential for vehicle integration. High specific power density, high efficiency, acceptable performance under partial shading and increased temperatures, light-weight design and low cost are fundamental requirements of VIPV. The market of standard single- and multi-crystalline silicon show excellent efficiency growth in the last years as shown in Figure 11. However, the theoretical limit of the most-common crystalline Si solar cells is not very high and is being approached fast. Besides, common silicon module technology has not been adapted for partial shading environments and perform badly under partial shading. This makes the technology unsuitable for VIPV.

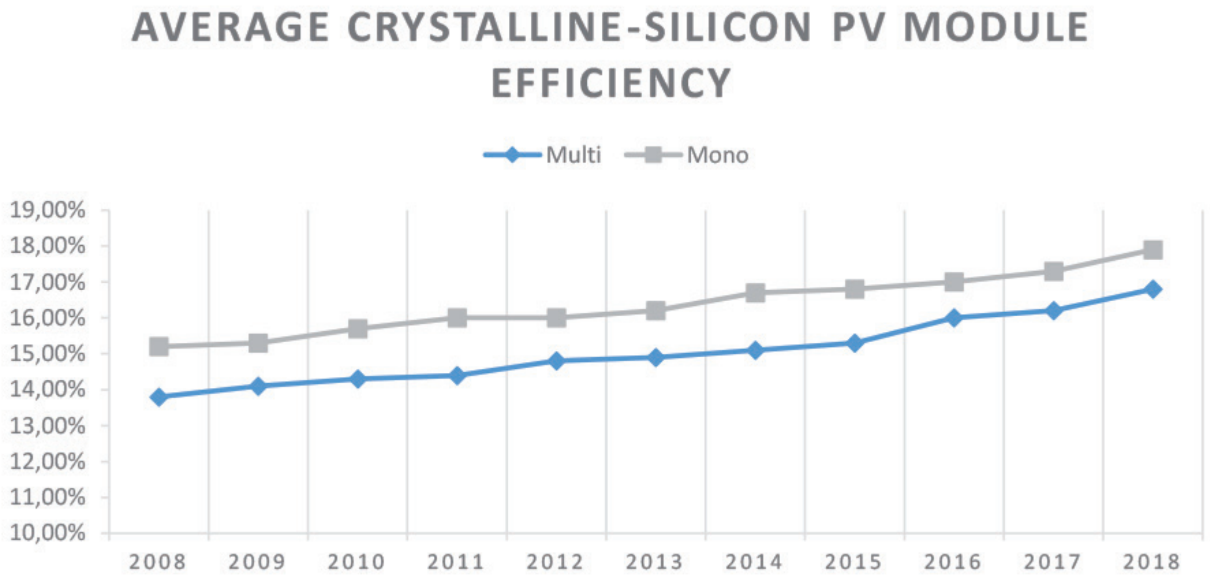


Figure 11: Average crystalline-silicon PV Module Efficiency (Fraunhofer ISE 2019)

Studies in Japan show that for representative Use Cases of passenger vehicles, the capacity of 1 kW is necessary for VIPV. To achieve this on a typical 3 m² area, high-efficiency PV cells with a conversion efficiency of at least 30% are required. The absolute efficiency record of 46.1% is held by a III-V multi-junction cell.

Unfortunately, the costs for these cells are too high for a mass application on cars. (G., 2010) A high-efficiency Si cell alternative is for example the heterojunction (HJT) cell technology. The efficiency of HJT cells by Kaneka reaches 26.7%. They additionally have a considerably lower temperature coefficient than conventional silicon solar cells, meaning better performance at higher temperatures. High-efficiency cells generate more power using a smaller area but are usually more expensive. Organic PV provides the possibility to create transparent roofs and fulfil aesthetic requirements. For vehicles with larger installation area thin-film Si, cadmium telluride (CdTe), or copper indium diselenide (CIS) can be considered as well. These technologies use lower-cost processes resulting in lower efficiency: CIS with 10 to 13% and CdTe around 8 to 9%. (Kenji Araki, 2018).

4.2 Technological Requirements of the Integration Process

Standard PV modules are covered in glass either on both or at least on the front side. Requirements for automotive applications such as high maximum temperatures, temperature gradients, vibrations, crashes, scratches and mechanical shocks favour glass- glass modules. But since the consumption of electric vehicles strongly depends on the weight, this setup appears too heavy.

Integration of the cells in the vehicle can also be achieved with fibre-reinforced plastic. Lamination with resin is an alternative that meets the weight requirements and design demands. Fibreglass materials allow glass-free, highly flexible, soil-resistant, stable and strong modules. The weight is around 2.5 kg/m² in comparison to standard module 3.3 kg/m². Additionally, fibreglass meets optical criteria such as matt roof with a negligible glare. Colouring solar modules can create a perfect match to the appearance of the rest of the car.

Due to local shading, inhomogeneous temperature distribution and the curved shape of the car, the operating voltage of the entire PV array is not easy to control. For this purpose, specific system configurations and control algorithms are required. To enable better utilisation of energy an appropriate PV Control Unit (PVCU) including a DC/DC converter with fast Maximum Power Point Tracking (MPPT) might need to be integrated into the vehicle. MPPT must detect the unique peak of the power and voltage characteristic of the PV array very quickly to prevent loss of system performance.

Another important issue is the need for a replacement process. This may be necessary due to general maintenance or possible vandalism. The manufacturer has to provide the opportunity to replace the cells and also consider offering insurance to avoid costs. A simple process of removing the PV is also beneficial for the recycling. Since the lifetime of the vehicle is normally not comparable to the solar technology (25-30 years), PV can also be used in residential second use after the vehicle application.

So far, there are no regulations for recycling of VIPV. PV in general falls under Commission Implementing Regulation (EU) 2019/290 for electrical and electronic equipment updated on 19 February 2019. However, for automotive parts strict end-of life goals for recycling are to be followed. A producer generally has to manufacture without hazardous substances thus promoting the reuse, recyclability and recovery of waste materials. Most likely producer responsibility will be extended even further in the future, giving this topic increased importance.

In order to achieve a breakthrough it is essential to enforce:

- ***Cost-effective and environmentally friendly VIPV integration that meets automotive specifications (crash, emergency, scratch, reliability, long-lasting lifetime and high number of lifecycles)***
- ***Performance of PV panels (high efficiency under bad lighting conditions)***
- ***Flexible design (size and shape, lightweight aesthetics)***
- ***Performance of PV control system (converter with fast MPPT)***

4.3 To-Dos for R&D

Current research can, in general, be split into two groups of interest: passenger cars and light- and heavy-duty vehicles. As passenger vehicles are normally parked throughout the day, the focus of research is on collecting solar energy while the vehicle is parked. In addition, technical and safety issues like integration of cells into curved surfaces, efficiency under partial shading and reduced degradation are addressed to meet the goals of the automotive industry.

Aesthetics and the weight play a bigger role in passenger cars. The lighter the electric vehicle, the lower the amount of electricity needed for traction. Especially in urban use and resulting operation under partial shading, smart wiring and bypass diodes integration is an important issue. (New Energy and Industrial Technology Development Organization, 2018)

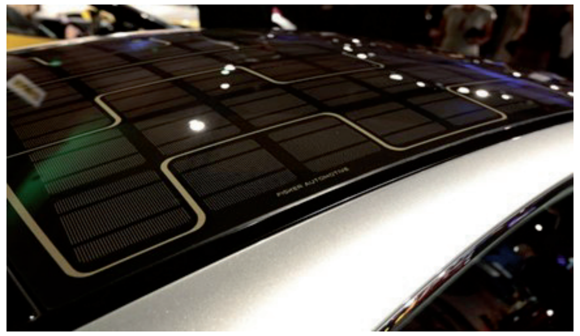


Figure 12: Wiring Technology Innovations (a2 solar panel)

Duty vehicles, on the other hand, are usually in use throughout the day, making powering the vehicle components and battery a main issue of the research. The integration is rather easy and the look of the cells is less important.

A further research focus is the general system integration of VIPV. A scenario in which VIPV is connected to the public grid and excess unused electricity is fed into the grid when vehicles are parking, seems realistic for duty vehicles but also for passenger cars. Vehicle2Grid (V2G) with bidirectional charging concepts can be very profitable, but first, the dependence on state of charge of the battery including an ageing model with charging and discharging losses should be studied. The benefit of VIPV can be regulation of the frequency of the grid or supply for sites without grid connection (such as construction sites or emergency situations).

There is a strong need for introducing standard tests for vehicles that show the effects of panel position and moving roof since standard operating conditions of normal PV hardly ever occur. (Ulrich Eitner, 2017) One of the core challenges for the research is to find the appropriate vehicle usage model, with maximised use of solar energy. (Kevin R, 2017) VIPV should thus be tested under real conditions in operation and performance of MPPT algorithms.

Further general improvement of lifetime, quality and sustainability along the value chain and recycling phase is important to minimise the life-cycle environmental impact of electricity generation and thus mobility. To communicate the environmental advantages of VIPV solid proposals on how to proceed towards realising the concepts within climate policies are needed.

4.4 Strategic Targets

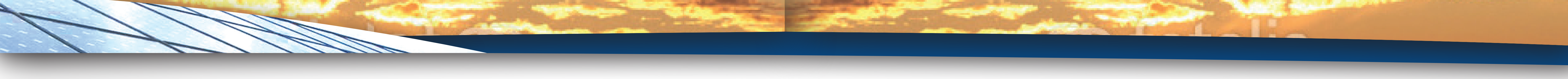
It yet remains unrealistic to easily and reliably quantify the added value for different users. To solve this problem, international methods of evaluating the reduction of grid power, as well as economic and ecological benefits are required, and standardisation of the technology must be introduced. Enhanced communication and cooperation between automotive and PV players can contribute to solve this problem and to communicate the positive image. Likewise, international methods for evaluating the reduction in CO_2 emissions can help communicate the created value and support integration of VIPV into national climate policies in order to create supportive systems for the R&D. Likewise, investigation of the societal impact and the social acceptance of new services and the identification of new business models are also important to state the benefit to the automotive industry to motivate the market players to increase investment into solar vehicles.

Another key issue is the typical volume problem. The investment in adoption of VIPV of larger car manufacturers is not cost effective for small amounts of vehicles and a higher number of VIPV indications higher investment risk. This issue has to be addressed in the regulations or policies.

Energy and environment are one of the main topics of the “The European Green Deal”. This new strategy, which aims to achieve resource- efficient and competitive economy where there are “no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use”, perfectly matches the idea of sustainable transport (The European Committee, 2019). The member states shall update their national energy and climate plans in 2023, reflecting new climate ambitions. VIPV as a sustainable solution combining mobility and energy sectors has to be considered in this legislation and support policies. The European Commission plans to adopt a strategy for sustainable and smart mobility in 2020 addressing emission sources. VIPV can also perfectly fit this strategy to support new sustainable mobility services, possibly financed through its funding instruments, such as the Connected Europe Facility.

Implementation Strategy and R&D Focus

- ***Integration of VIPV into national transport and climate policies (conducted at national and/or at European level) to support safe and cost-effective integration of cells into vehicles and address tasks of monitoring institutions***
- ***Creating regulations, standards and tax incentives, voluntary agreements and investments in R&D***
- ***Build energy flow models and implement standard measurements for evaluating ecological and economic added-value of VIPV***



5. CONCLUSIONS

The VIPV market is still facing barriers and one reason that hinders the rollout is lacking consumer knowledge about the benefits of PV- powered vehicles. Enhanced communication and cooperation between automotive companies and PV players can contribute to the positive image of vehicle integrated photovoltaic systems in order to achieve the goal to change the image of VIPV. One of the key challenges for R&D is, therefore, finding an appropriate vehicle usage model to maximise the ratio of using solar power and performance for VIPV. Measurements with radiation sensors investigating shading and reflection conditions of the vehicles as well as tests with solar modules to validate the calculations are suggested. Likewise, international methods for evaluating the reduction of needed grid power and thus of emissions from PV-powered vehicles can help to communicate the added value for the different driving and charging behaviours. Additionally, it is necessary to improve electrical and technical issues, second- use possibilities and light-weighted design. Constantly decreasing prices on the PV market and emission reduction goals for transport will contribute to the growth of the VIPV market. Governments must additionally support R&D and the standardisation and implementation of the technology by establishing methods of evaluating the benefits and communicating them to the end user and automotive players.

Main conclusions:

Added-value of VIPV:

- ***Self-consumption benefits, thus increased independence of vehicles with high potential of reduced costs and ecological benefits***
- ***Guaranteed use of renewable energy for mobility with cross-sectoral potential for the further integration into the key energy sector (V2G, Smart Grid, Demand Side Management)***

Key Constraints:

- ***Lack of acceptance of new technologies caused by the uncertainty of payback time, technological barriers and missing legislative settings for developing the right implementation strategy***

To-Dos:

- ***Establish a clear EU/national legislative methodology for the evaluation of added value, simple administrative procedures and public support (e.g. European Green Deal, financing from EU and national budgets, public and private investments)***
- ***Indicate Use Cases and develop energy flow models considering solar irradiation on the vehicle for representative vehicle usage patterns of driving and parking; Executing harmonised standard measurements***
- ***Support communication between PV and automotive companies to enforce the R&D and address VIPV solutions for profitable market applications to the right target groups***

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