LOW-COST ELECTRIC CAR CHARGING WITH FRONIUS

Feature Guide

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Product marketing

Solar Energy

.

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1 GENERAL INFORMATION

The integration and electrification of all energy sectors is a significant part of Fronius' vision of 24 hours of sun. Mobility is one of the most energy-intensive sectors. If we want to drive the energy revolution forward and pave the way for a sustainable future, it is essential that we move to electric vehicles, both for private transport and in the commercial sector. Fronius inverters allow the e-mobility sector to be easily integrated into photovoltaics. This paper will cover the various charging versions with Fronius inverters and explain the advantages. It will also provide an overview of the most common e-mobility charging solutions.

1.1 The advantages of combining photovoltaics and e-mobility

Photovoltaics and e-mobility are a perfect match. This section will explain the financial effects of combining PV and e-mobility as well as the impact on the electric vehicle's battery.

1.1.1 Monetary benefits

When photovoltaics was still in its infancy, it was common for 100% of the generated solar energy to be fed into the public grid because feed-in tariffs were high – up to 40 euro cents/kWh. In recent years, however, most countries have seen a trend towards self-consumption. It is now more cost-effective to use the self-generated energy from the PV system in your own home, as the feed-in tariffs are less than the cost of electricity. Therefore, the aim should always be to maximise self-consumption.

Electric vehicles also require (a lot of) electrical energy. So you can benefit in a number of ways from using energy from your own PV system to charge your electric vehicle:

/ Significant increase in the PV self-consumption rate
/ Faster ROI of the photovoltaic system
/ Cheapest form of energy for powering your electric vehicle
/ Emission-free energy for your electric car
/ Reduced dependence on the public grid

An electric car typically consumes between 15 and 18 kWh per 100 km. On a conventional electricity tariff of around €0.3 per kWh (Germany), a 100 km trip in an electric car would therefore cost around five euros. However, if you were to 'fill up' your car with solar power alone, it would **cost just one euro per 100 km.** How did we arrive at one euro? A typical PV system involves an investment of around €1200 per kWp of installed power. We also assume a yield of 1000 kWh/kWp (Germany) and a useful life of at least 20 years. If you now calculate the price per kWh of self-generated PV energy, it comes to 6 cents per kWh. **Therefore, if an electric car consumes 16**

kWh/100 km, it results in a cost of around one euro*. Meaning it is five times cheaper to charge your car with your own PV energy!

Section two will take a detailed look at the different charging variants in monetary terms.

*These calculations have been simplified. They do not include cost of capital, repairs, maintenance or module degradation. However, the system can also be operated for longer than 20 years.

1.1.2 Preserving the electric vehicle's battery

The service life of the battery is an important factor when deciding to buy an electric car. This depends heavily on aspects such as the type of charging. Too much or too little strain on the battery can have a negative effect on its service life. For example, charging a battery with a capacity of 30 kWh with a power of 60 kW or more will charge it more quickly. But it will put an excessive amount of strain on the battery's cells and this can have a negative impact on the service life. You might then incorrectly assume that batteries should therefore be charged as slowly as possible. But this is not the right approach either. During the charging process, a higher voltage is applied to the cells than under normal condition. This degrades the battery cells during the charging process. The longer the charging process lasts, the stronger the aging effects are. Therefore, it is advisable to find a good middle ground with regard to charging power.

This is another advantage of charging with surplus PV. Combined with a PV system, a vehicle is normally charged with a power between 4 and 8 kW. This charging power represents an optimum compromise, that is neither too fast nor too slow. Charging combined with a PV system therefore has a positive effect on the electric vehicle's battery life.

1.2 Different charging options

There are two ways of charging the battery in an electric vehicle. A distinction is made between alternating current (AC) and direct current (DC) technology. These have different charging plugs and charging infrastructure. There are charging standards from which three main plug types have developed in Europe: Type 2, CHAdeMO and CCS.

1.2.1 Charging with alternating current (AC)

Charging with alternating current is the most common way to charge an electric car. All electric cars are suitable for charging with alternating current. The vehicle's on-board battery charger converts the alternating current into direct current so that the battery can be charged. The AC charging power may vary depending on the type of charger installed. A VW e-up!, for example, charges with just 3.7 kW, whereas the latest Renault ZOE charges with up to 22 kW and therefore takes a lot less time to fully recharge. A charging box is needed for fuse protection and for communicating with the vehicle. This is a safe and convenient charging method, mainly used at home or in semi-public locations – such as company premises or car parks. Classic 230 V domestic sockets should not be used due to the long charging times and the issue of continuously high loads. Therefore, type 2 plugs, as shown below, are mainly used for charging with alternating current in the European Union:

Figure 1: Type 2 charging plug for electric vehicles

1.2.2 Charging with direct current (DC)

Some electric cars offer a faster alternative to AC charging: direct current or DC charging stations. Here the current is charged directly into the battery. These rapid charging stations enable high charging powers. The Nissan LEAF, for example permits up to 50 kW of charging power, while the Hyundai Ioniq allows up to 70 kW and the Tesla currently permits up to 250 kW. However, DC charging stations are considerably more expensive than AC charging stations and are therefore mainly used in public areas. In addition, rapid charging can have a negative effect on the battery's service life as described in section 1.1.2.

1.3 Range and consumption

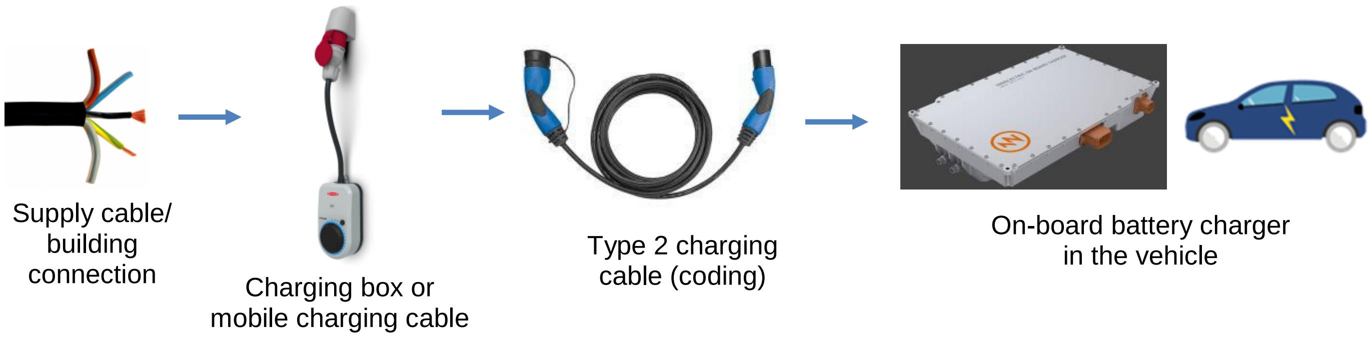
The usable battery capacity of a vehicle varies significantly depending on the type and manufacturer. Small city cars offer capacities of 20 kWh, while touring saloons can store up to 120 kWh. Depending on the battery size and the vehicle consumption, the range can vary from 150 to 700 km. The majority of electric vehicles typically consume around 16 kWh per 100 km. This means, for example, that a vehicle with a 64 kWh battery can achieve a range of 400 km with a consumption of 16 kWh/100 km.

1.4 Limiting factors when charging electric vehicles

The maximum achievable charging power for an electric vehicle basically depends on 4 factors:

- The supply cable (connection cable) used/the fuse protection for the building's power connection
- The mobile charging cable/charging box used
- The type 2 charging cable used (amperage coding)
- The on-board battery charger in the vehicle (1, 2, or 3-phase version, and maximum charging current)

The weakest link in this chain always decides the actual charging power that can be achieved. When designing and installing a charging solution, all four factors must be taken into account.



2 CHARGING SOLUTIONS COMBINED WITH A FRONIUS INVERTER

The following section presents different options or solutions for charging an electric car cost-effectively with energy from a photovoltaic system.

We distinguish between three different charging solutions:

- Dynamic PV surplus charging
- Charging using the integrated energy management function of the Fronius inverter
- Manual charging with PV energy

2.1 Dynamic PV surplus charging

Dynamic surplus charging involves charging an electric vehicle using the energy from a PV system that is not required at that very moment by other electrical loads in the household or company and therefore would otherwise be fed into the public grid.

Dynamic charging allows the available surplus from the photovoltaic system to be used to charge the electric vehicle with great efficiency and to the highest degree.

2.1.1 Monetary effects of dynamic PV surplus charging

The biggest advantage of dynamic surplus charging is that the electric vehicle's charging process can be optimally aligned with the available surplus PV energy. This keeps the amount of power fed into the public grid to a minimum. Another advantage of this solution is that charging begins automatically once it has been configured and surplus PV energy is available.

The following examples illustrate the monetary effects of dynamic PV surplus charging. All assumptions used in the calculations can be found in the appendix.

Example 1*:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: Dynamic PV surplus charging

Charging profile: 'At home during the day'

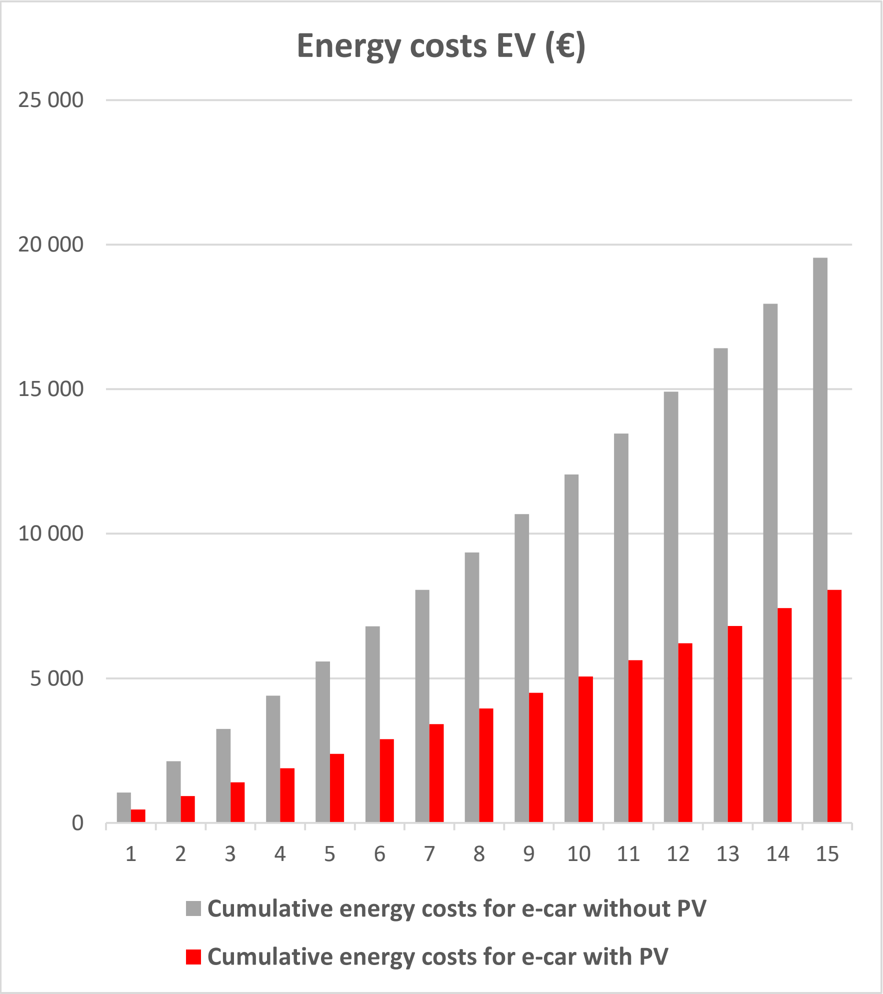


Figure 2: Cumulative energy costs for an electric car with and without PV system

Figure 2 shows a comparison of the cumulative energy costs for an electric car with and without a photovoltaic system using dynamic PV surplus charging (charging profile 'at home during the day').

*For all calculations in this paper (example 1-6), a combination of photovoltaic surplus charging and charging with grid electricity was assumed. More information on the charging profiles can be found in chapter 5.2.

Cumulative energy cost savings from dynamic PV surplus charging over 10 years (charging profile – during the day):

Cost savings									
Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
€595	€1211	€1850	€2511	€3195	€3904	€4637	€5397	€6182	€6994

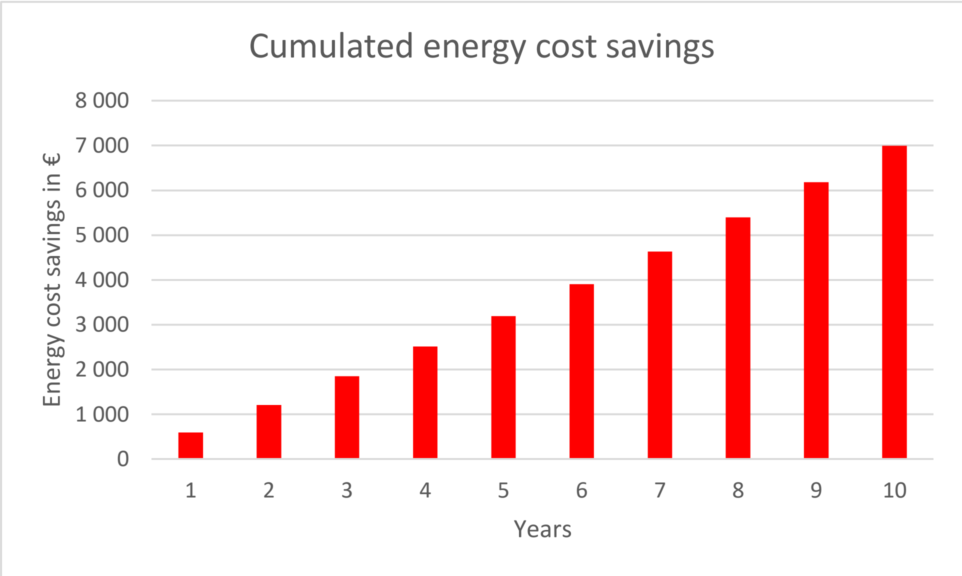


Figure 3: Cumulative energy cost savings over 10 years in €

Figure 3 shows the cumulative energy cost savings of dynamic PV surplus charging with the 'at home during the day' charging profile over 10 years.

Charging the electric vehicle dynamically with surplus PV energy during the day results in savings of up to €595 per year. This represents energy cost savings of 68% compared to charging without a PV system. Over the course of 10 years and taking a 3% price increase into account, savings of up to €6994 could be made.

Example 2:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: Dynamic PV surplus charging

Charging profile: '40 hour job'

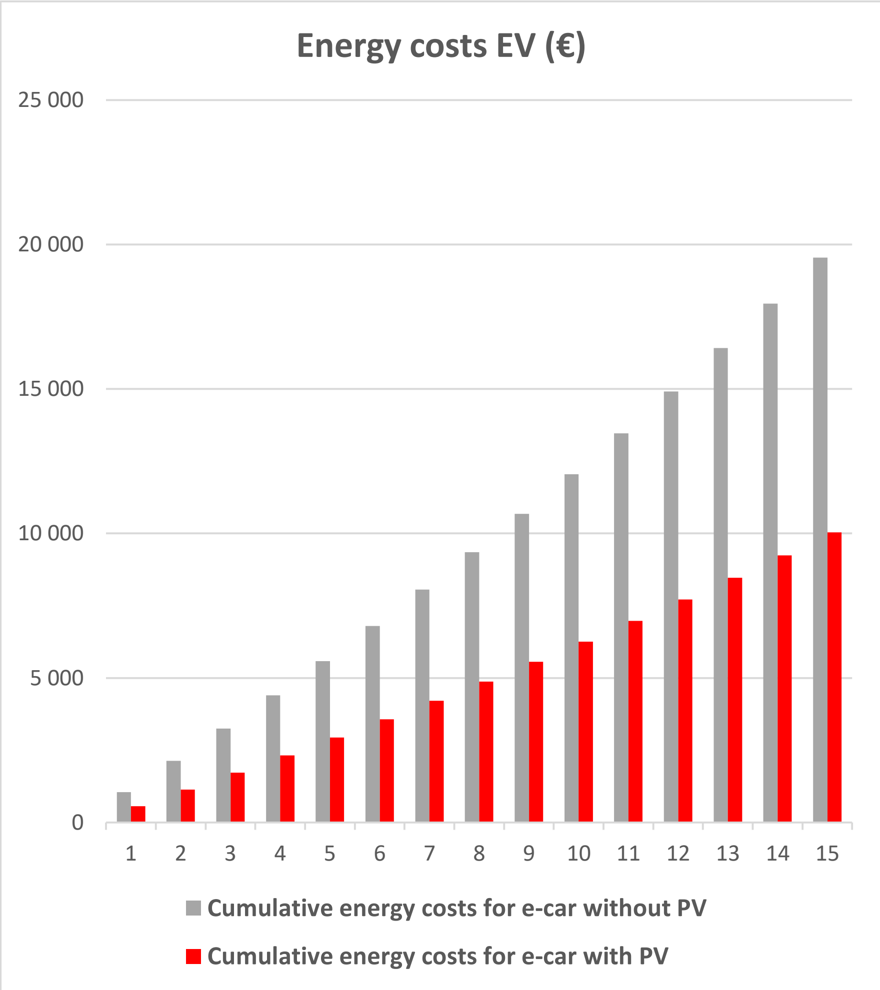


Figure 4: Cumulative energy costs for an electric car with and without PV system

Figure 4 shows the cumulative energy costs for an electric car with and without a photovoltaic system using dynamic PV surplus charging (charging profile '40 hour job').

Cumulative energy cost savings from dynamic PV surplus charging over 10 years (charging profile – 40 hour job):

Cost savings									
Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
€493	**€1003**	**€1532**	**€2079**	**€2646**	**€3233**	**€3840**	**€4469**	**€5119**	**€5792**

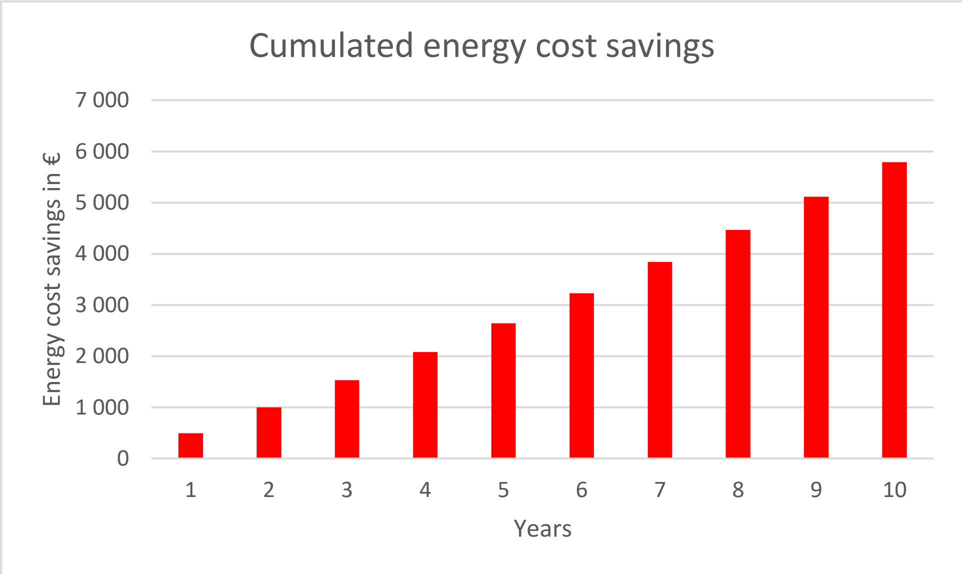


Figure 5: Cumulative energy cost savings over 10 years in €

Figure 5 shows the cumulative energy cost savings of dynamic PV surplus charging with the '40 hour job' charging profile over 10 years.

Charging an electric vehicle with surplus PV during the day is basically the most economical. Even if an electric vehicle is mainly only charged in the early hours of the morning and late afternoon/evening, dynamic PV surplus charging can significantly reduce energy costs. This is because the amount of energy required by the vehicle for the daily commute to work is typically no more than 8-12 kWh.
This amount of energy can often be provided by the PV system during the off-peak periods of energy production and used to charge the electric car.

The calculated savings for this situation are up to €493 per year. This represents energy cost savings of 56% compared to charging without a PV system. Therefore, up to €5792 could be saved over 10 years.

2.1.2 How it works

Energy from the PV system is used, regulated in individual ampere increments, to charge the electric vehicle with the aid of an intelligent charging solution, which communicates with the inverter and a Smart Meter. In this case, control based on individual ampere increments is specified by the type 2 charging standard. The minimum charging power when charging an electric car is 1.38 kW. When the surplus is above this amount, the car can then be charged in ampere increments. In the case of single-phase charging, this results in 230 Watt increments. If three-phase charging is being used, then the electric car is charged in 690 Watt increments. Certain intelligent charging solutions such as the Fronius Wattpilot can switch automatically between single-phase and three-phase charging.

The limitations of the type 2 charging standard mean that stepless control, i.e. control down to a precise watt, is not possible when charging electric cars.

Communication between the inverter and intelligent charging box is based on open interfaces (Solar API or Modbus RTU for example), which are implemented in all Fronius inverters. These interfaces enable optimum coordination between devices.

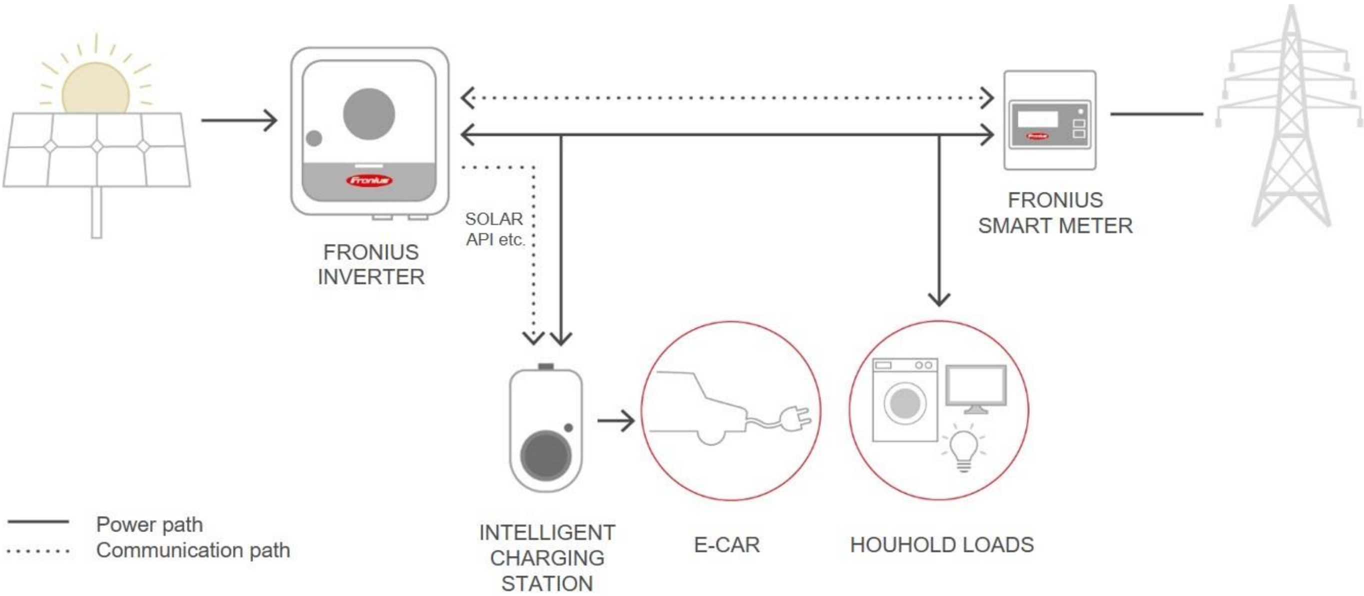


Figure 6: 'Dynamic PV surplus charging' configuration diagram

Figure 6 shows a configuration diagram for dynamic PV surplus charging. As already mentioned, the Fronius inverter communicates directly with the intelligent charging box via open interfaces. A Fronius Smart Meter is essential for dynamic PV surplus charging.

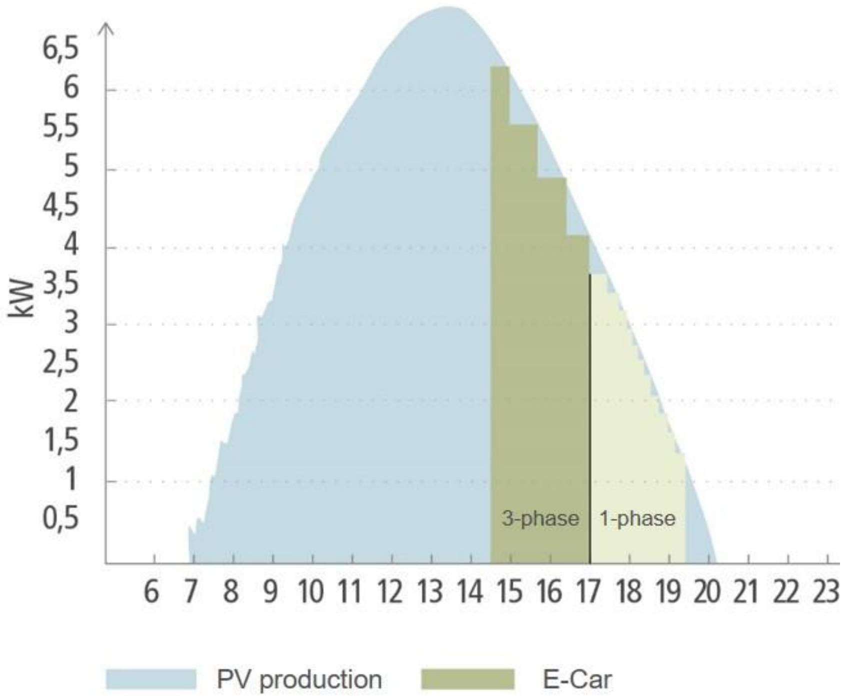


Figure 7: 'Dynamic PV surplus charging' functional principle

Figure 7 shows how dynamic surplus charging works. The customer starts charging their car at 14.30. As there is sufficient surplus PV available, three-phase charging begins. At 17.00, the charging box switches to single-phase charging. As already mentioned, only certain charging boxes, such as the Fronius Wattpilot, can switch between single and three-phase charging.

2.1.3 Overview of compatible charging solutions for dynamic PV surplus charging

The following table shows a selection of intelligent solutions for dynamic PV surplus charging, which are compatible with Fronius inverters (SnapINverter, GEN24 and GEN24 Plus).

	Fronius Wattpilot Go	Fronius Wattpilot Home	Hardy Barth cPH1	NRGkick	openWB series2
					
Surplus charging with 1/3-phase switchover	☑	☑	☒	☒	☑
Compatible with variable electricity tariffs	☑	☑	☒	☒	☑
RFID authentication	☑	☑	☑	☒	☑
Standalone app	☑	☑	☒	☑	☒
Automatic adapter detection	☑	☑	☒	☑	☒
Mobile solution	☑	☒	☒	☑	☒
PV surplus charging possible without	☑	☑	☒[1]	☒[2]	☑

additional hardware					

1) Only possible with associated eCB1 module
2) Only possible with associated NRGkick Connect

Surplus charging with 1/3-phase switchover: The charging box can automatically switch between single and three-phase surplus charging. This means that the entire power range of a PV system of 1.38 to 22 kW (depending on the output of the charging box) can be used.

Compatible with variable electricity tariffs: The charging box is compatible with variable electricity tariffs and can therefore also be used for low-cost charging at night when the cost of electricity is low, for example.

RFID authentication: RFID authentication enables personal access to the charging box with RFID cards or chips. The charged amounts of energy can thus be assigned to individual cards or chips.

Standalone app: The charging box can be commissioned, visualised and controlled using an associated app.

Automatic adapter detection: The charging box automatically detects when an adapter cable is plugged in (for example an adaptation of 16 A to an earthed (Schuko) plug).

Mobile solution: The charging box can be taken anywhere.

PV surplus charging possible without additional hardware: The additional hardware required for surplus charging is built into the charging box. No additional components are needed.

Other charging solutions which can be used for dynamic PV surplus charging with Fronius inverters are also available on the market. However these need to be combined with an external energy management system:

Charging solution	External energy management
Keba P20/P30 b-series	Loxone / BayWa sonniQ
Keba P20/P30 c/x-series	Loxone / BayWa sonniQ
Mennekes AMTRON Xtra / Premium	BayWa sonniQ
Heidelberg Wallbox Energy Control	BayWa sonniQ

2.2 Charging using the integrated energy management function of the Fronius inverter

Charging using the inverter-integrated energy management function from Fronius is another option for charging an electric car with surplus PV. There are two ways of doing this:

- Control of a charging box with surplus PV
- Control of a charging socket with surplus PV

One of the main advantages of charging using the energy management function of the Fronius inverter is that a charging socket can be used for charging. Thus it is not essential to invest in an additional charging box.

2.2.1 Monetary effect of charging using inverter-integrated energy management

The following examples again illustrate the monetary effects of PV surplus charging with inverter-integrated energy management. All assumptions used in the calculations can be found in the appendix.

Example 3:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: Charging with inverter-integrated energy management

Charging profile: 'At home during the day'

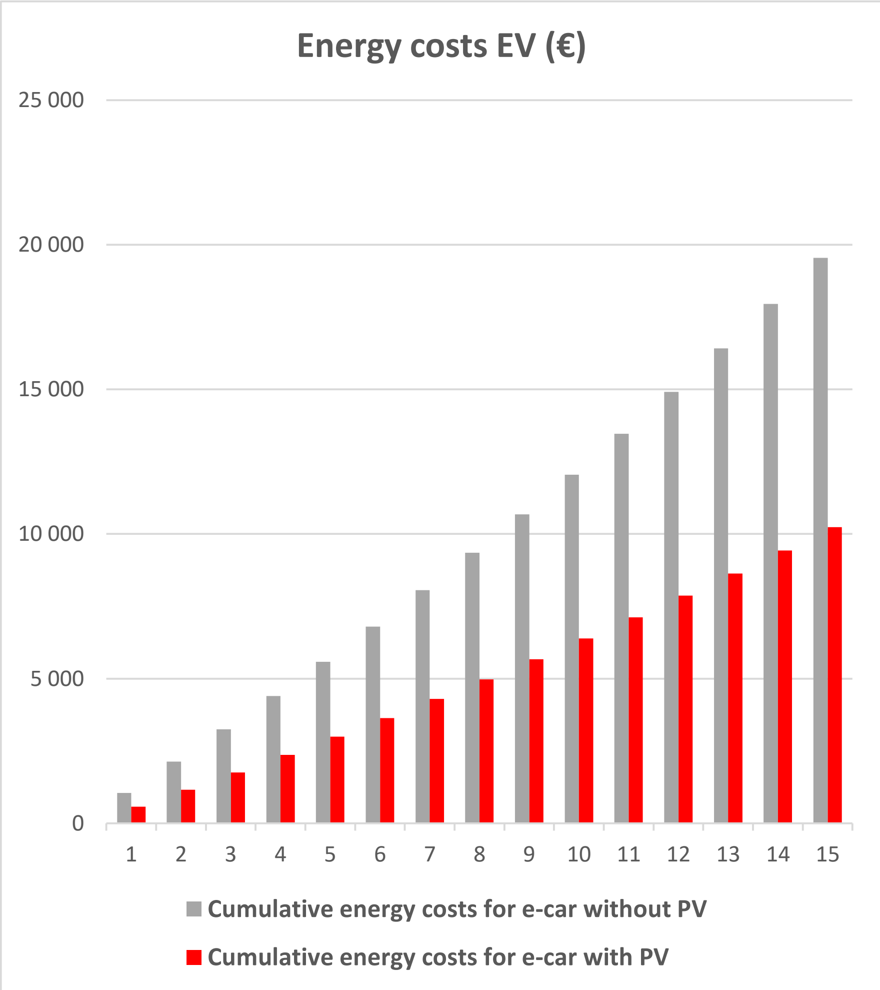


Figure 8: Cumulative energy costs for an electric car with and without PV system

Figure 8 shows a comparison of the cumulative energy costs for an electric car with and without a photovoltaic system using PV surplus charging with inverter-integrated energy management (charging profile 'at home during the day').

Cumulative energy cost savings from charging with inverter-integrated energy management over 10 years (charging profile – during the day):

Cost savings									
Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
€482	€981	€1498	€2034	€2588	€3162	€3756	€4371	€5007	€5666

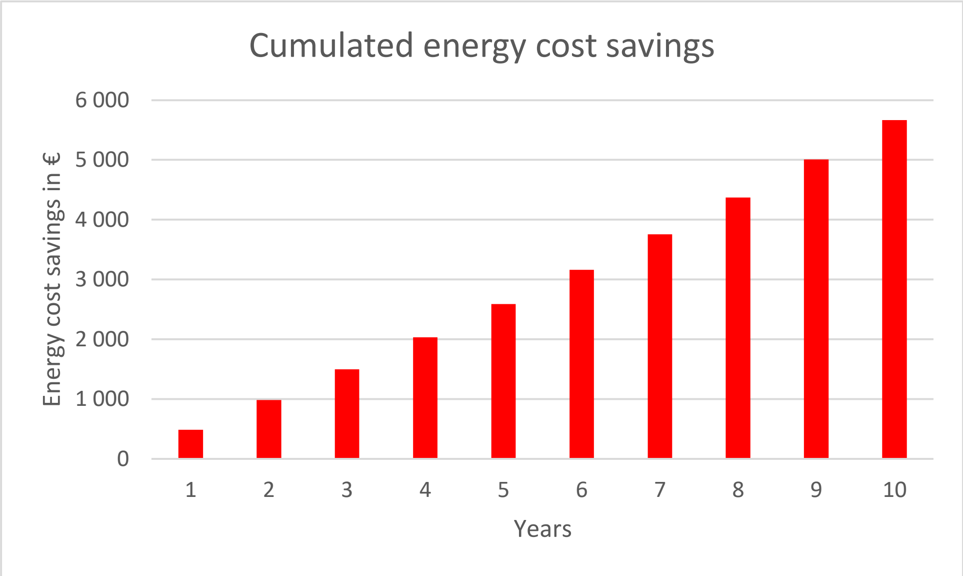


Figure 9: Cumulative energy cost savings over 10 years in €

Figure 9 shows the cumulative energy cost savings of dynamic PV surplus charging with the 'at home during the day' charging profile over 10 years.

Annual savings of up to €482 can also be achieved with the PV surplus charging (during the day) with inverter-integrated energy management. This represents energy cost savings of 55% compared to charging without a PV system. Thus, up to €5666 can be saved over 10 years.

Example 4:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: Charging with inverter-integrated energy management

Charging profile: '40 hour job'

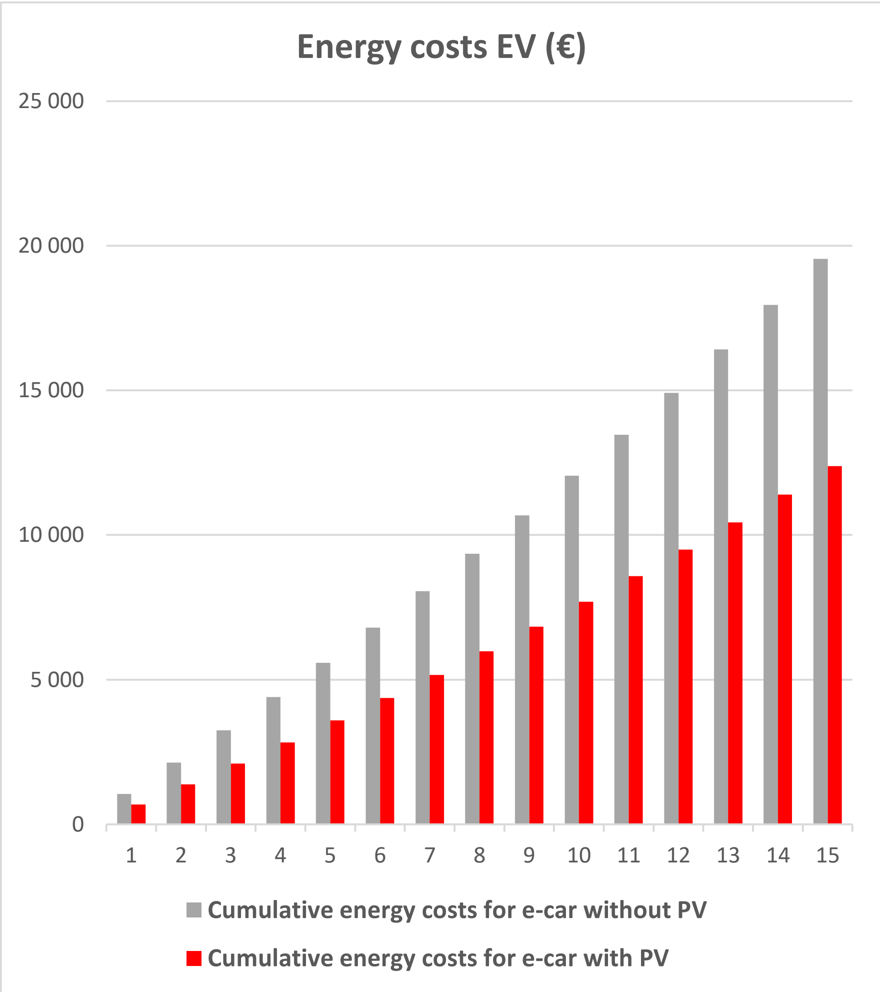


Figure 10: Cumulative energy costs for an electric car with and without PV system

Figure 10 shows a comparison of the cumulative energy costs for an electric car with and without a photovoltaic system using PV surplus charging with inverter-integrated energy management (charging profile '40 hour job').

Cumulative energy cost savings from charging with inverter-integrated energy management over 10 years (charging profile – 40 hour job):

Cost savings									
Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
€371	€755	€1153	€1565	€1992	€2434	€2891	€3364	€3854	€4360

Inverter-integrated energy management also enables up to €371 per year to be saved with the charging profile of a person in full-time employment. This represents energy cost savings of 42% compared to charging without a PV system. Thus, up to €4360 can be saved over 10 years.

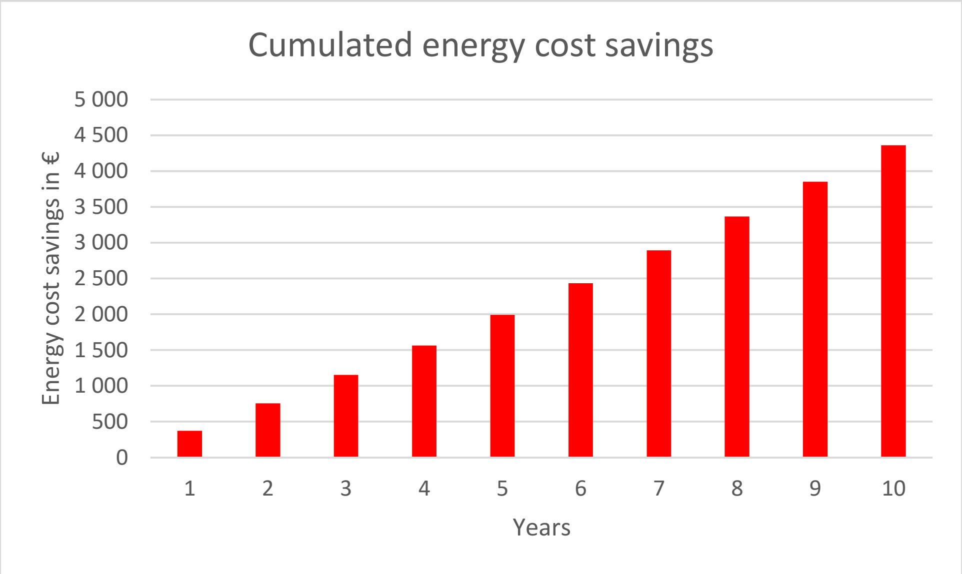


Figure 11: Cumulative energy cost savings over 10 years in €

Figure 11 shows the cumulative energy cost savings of dynamic PV surplus charging with the '40 hour job' charging profile over 10 years.

2.2.2 How it works

When charging with inverter-integrated energy management, the inverter's digital output activates a socket or charging box and begins charging when a pre-set PV power or PV surplus threshold value is reached. Unlike dynamic PV surplus charging, the charging power cannot be dynamically controlled. The charging process can be activated or deactivated based on the available surplus PV. The charging power is fixed and cannot be changed during the charging process. You can find details on how to implement this solution in the whitepaper E-Mobility Solutions at www.fronius.com.

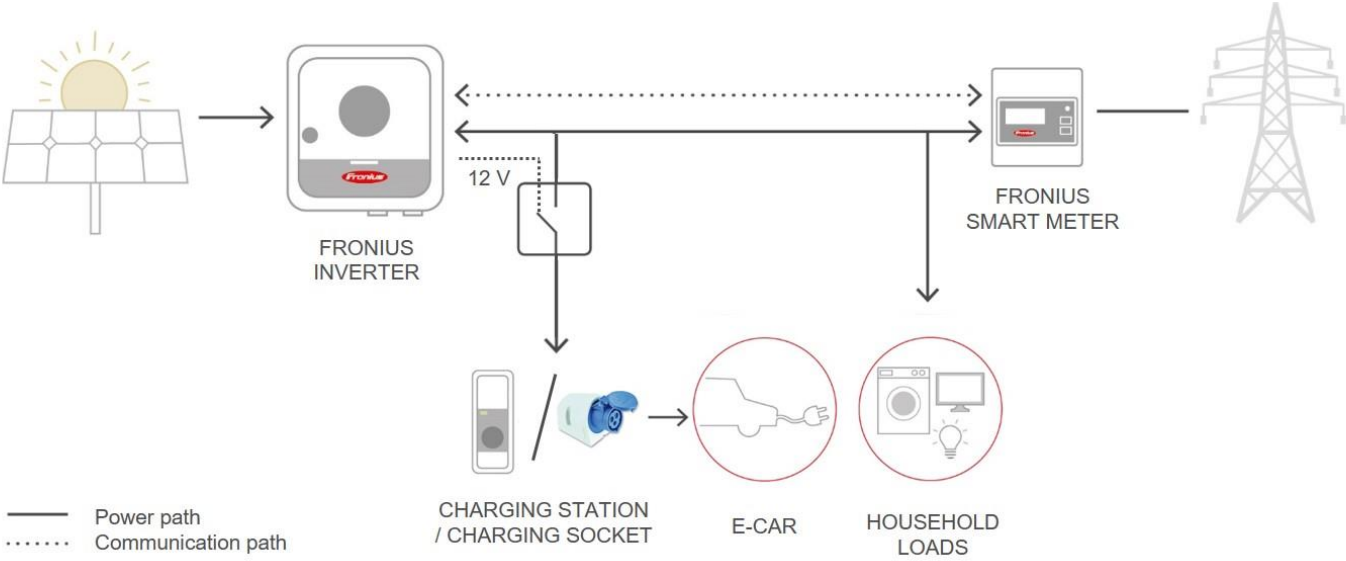


Figure 12: Configuration diagram 'Charging with inverter-integrated energy management from Fronius'

Figure 12 shows the configuration diagram for the charging solution 'Charging with inverter-integrated energy management'. The charging box or the charging socket is activated via a 12 Volt DC signal from the inverter, as soon as the required threshold value is reached. A Fronius Smart Meter is also essential for this solution.

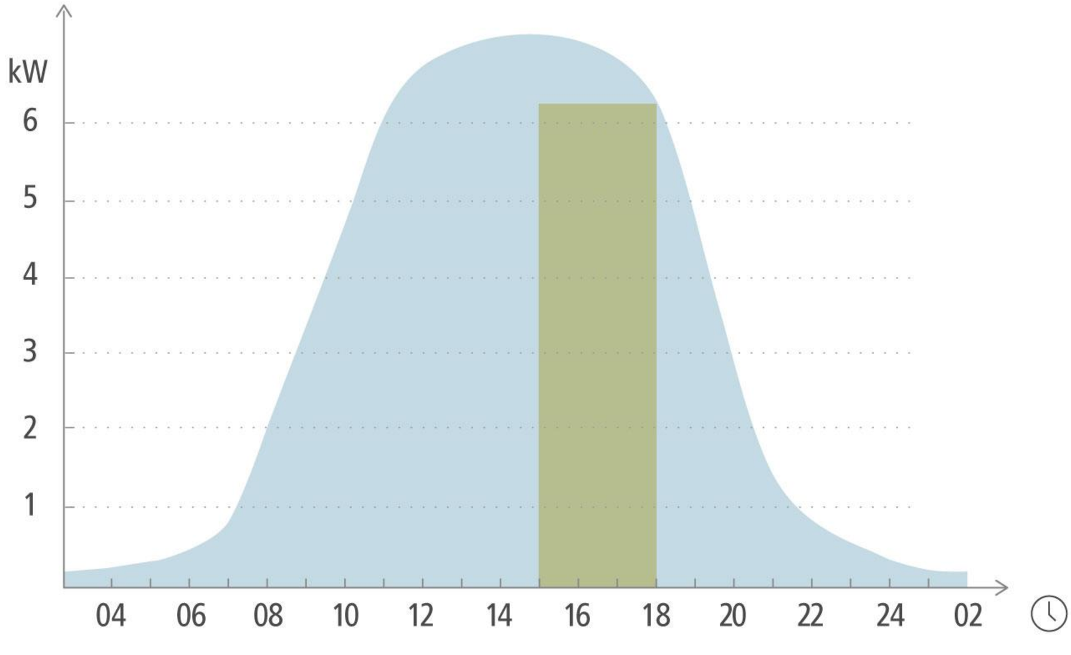


Figure 13: Functional principle of charging using inverter-integrated energy management

Figure 13 shows how charging using inverter-integrated energy management from Fronius works. Once the pre-set amount of surplus PV energy is available, the inverter activates the charging process for the electric car.

2.2.3 Overview of compatible solutions for charging with inverter-integrated energy management

PV surplus charging using Fronius energy management uses a 12 V control signal. Certain charging solutions already have an integrated release contact with 12 V. However, the majority of solutions require an additional 12 V relay to be connected upstream. The requirements for this relay are given in the energy management solution sheet.

The following table shows a selection of solutions for PV surplus charging with Fronius energy management, which are compatible with Fronius inverters (SnapINverter, GEN24 and GEN24 Plus).

	Enomics Wallbox Fronius optimized	Keba P20/P30 b/c/x-series	Mennekes AMTRON Compact/Xtra/Premium	Schneider Electric Schneider EV Link G3+
				
Surplus charging with 1/3-phase switchover	☒	☒	☒	☒
Compatible with variable electricity tariffs	☒	☒	☒	☒
RFID authentication	☒	☑	☑	☒

Standalone app	☒	☒	☑	☒
Mobile solution	☒	☒	☒	☒
12 V release contact – no additional relay needed	☑	☒	☒	☒

12 V release contact: These charging boxes already include a release contact integrated in the box. There is no need to install an additional relay.

2.3 Manual charging with PV energy

Charging solutions without intelligent control can also be operated in conjunction with a Fronius inverter. In this case, the charging box's charging power should always be adapted to the PV system's specifications. Many charging solutions allow the charging current to be set. This should correlate with the PV system's power to prevent load peaks when charging an electric car.

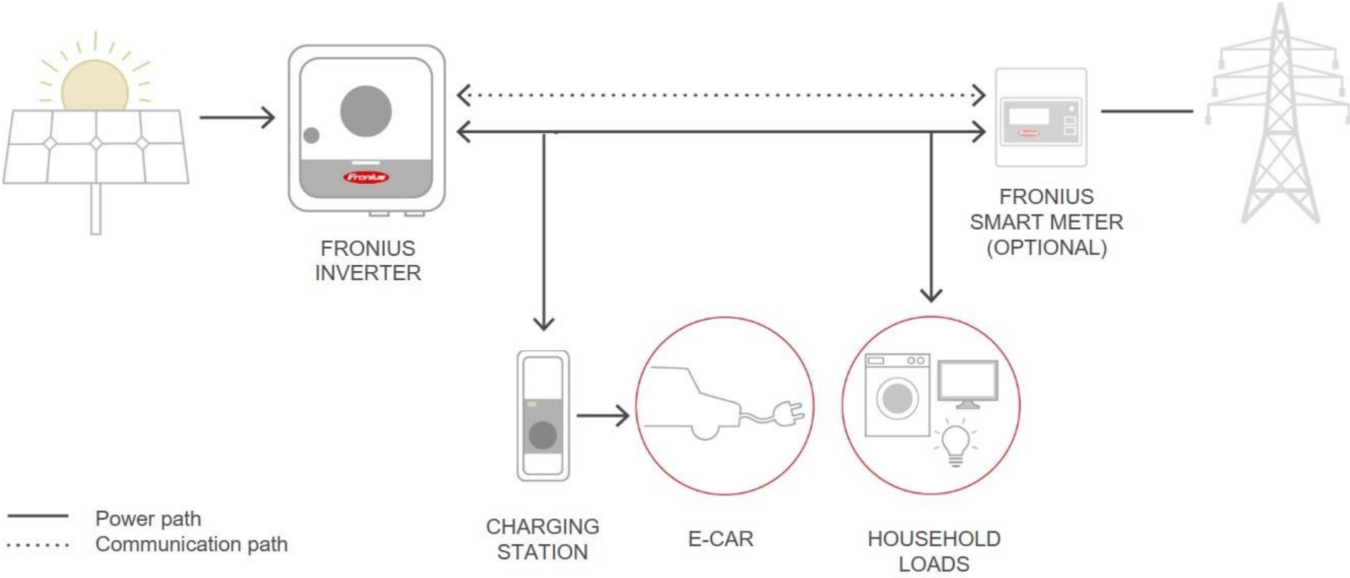


Figure 14: Configuration diagram 'manual charging with PV energy'

Figure 14 shows a configuration diagram for manual charging with PV energy. There is no communication between the inverter and charging box. Charging must be activated manually. A Fronius Smart Meter is optional with this charging solution.

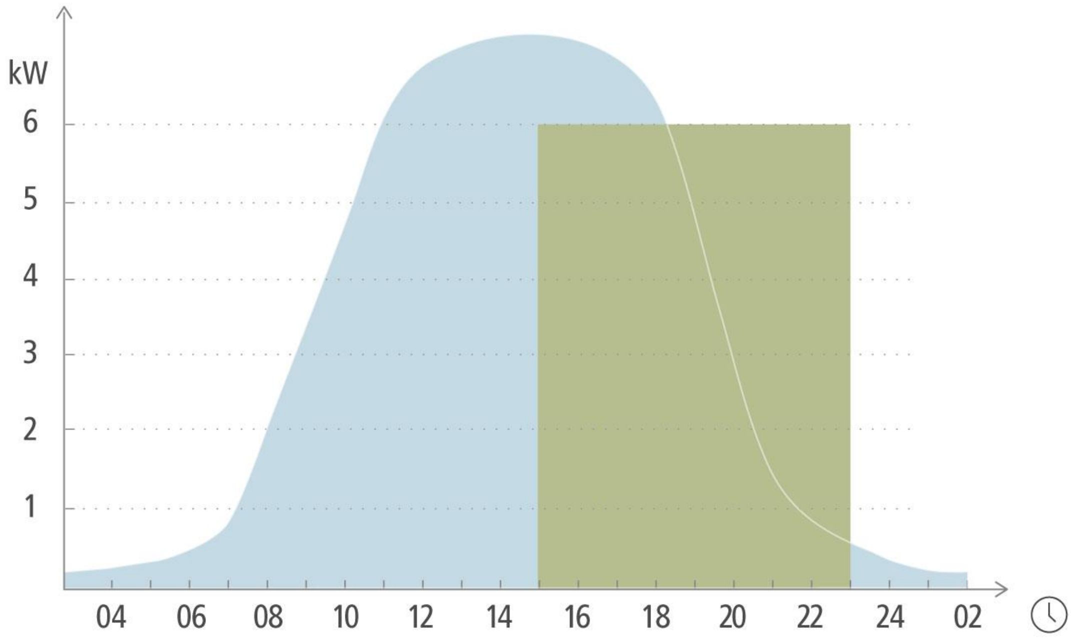


Figure 15: Functional principle of manual charging with PV energy

Figure 15 shows how manual charging with PV energy works. Customers have to activate and end charging of their electric cars manually.

2.3.1 Monetary effects of manual charging with PV energy

The advantage of this charging variant is that basically any charging solution can be used. As the charging process is activated manually, device communication/control via relay or release contact is not needed. However, the charging process must be started manually.

The following examples illustrate the monetary effects of manual charging with PV energy. All assumptions used in the calculations can be found in the appendix.

Example 5:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: 'Manual charging with PV energy'

Charging profile: 'At home during the day'

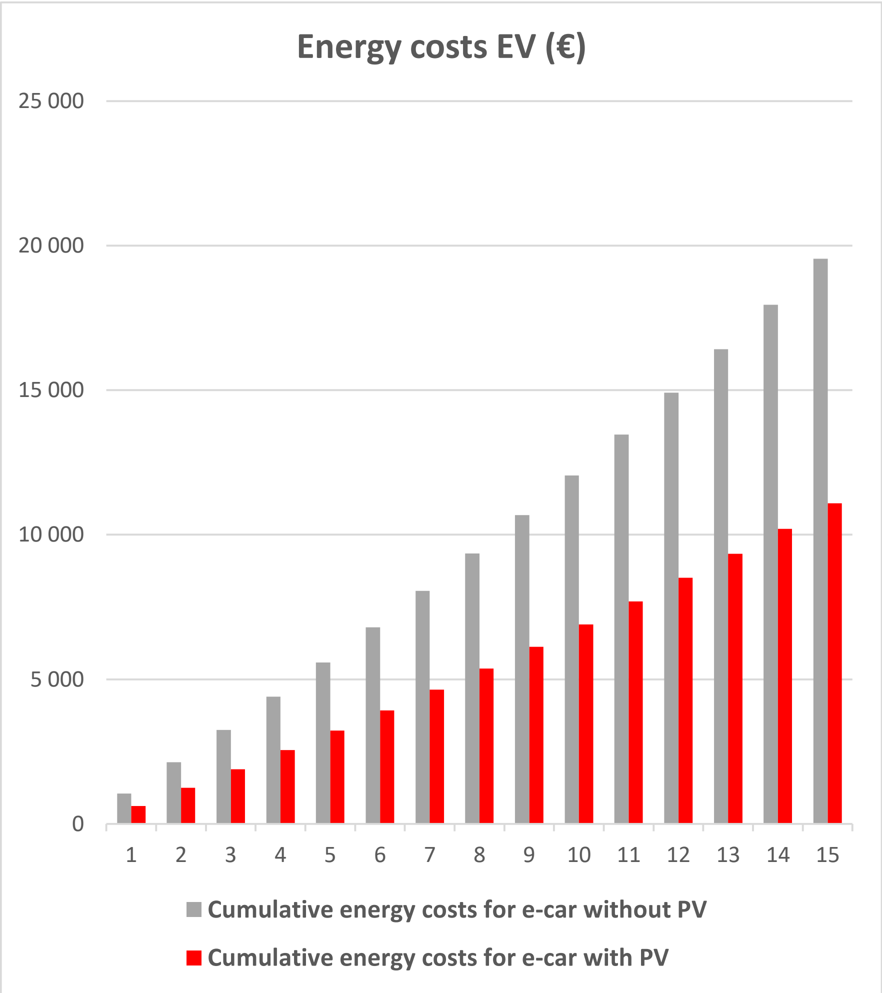


Figure 16: Cumulative energy costs for an electric car with and without PV system

Figure 16 shows a comparison of the cumulative energy costs for an electric car with and without a photovoltaic system using manual charging with PV energy (charging profile 'at home during the day').

Cumulative energy cost savings from manual charging with PV energy over 10 years (charging profile – during the day):

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
€438	€892	€1362	€1849	€2353	€2875	€3415	€3974	€4552	€5150

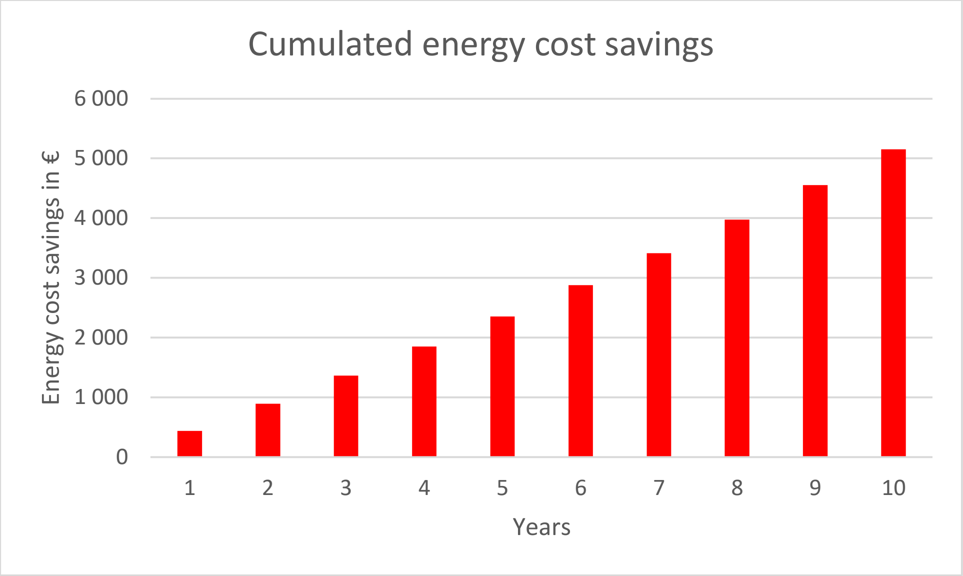


Figure 17: Cumulative energy cost savings over 10 years in €

Figure 17 shows the cumulative energy cost savings of manual charging with PV energy with the 'at home during the day' charging profile over 10 years.

Manual charging with PV energy can also result in a significant reduction in costs for the required energy. Energy cost savings of up to €438 per year can be achieved when charging during the day. This is an energy cost saving of 50% compared to charging without a PV system. Over the course of 10 years, savings of up to €5150 can be made.

Example 6:

Customer with an electric car travels around 20,000 km per year/60 km per day

Charging mode: 'Manual charging with PV energy'

Charging profile: '40 hour job'

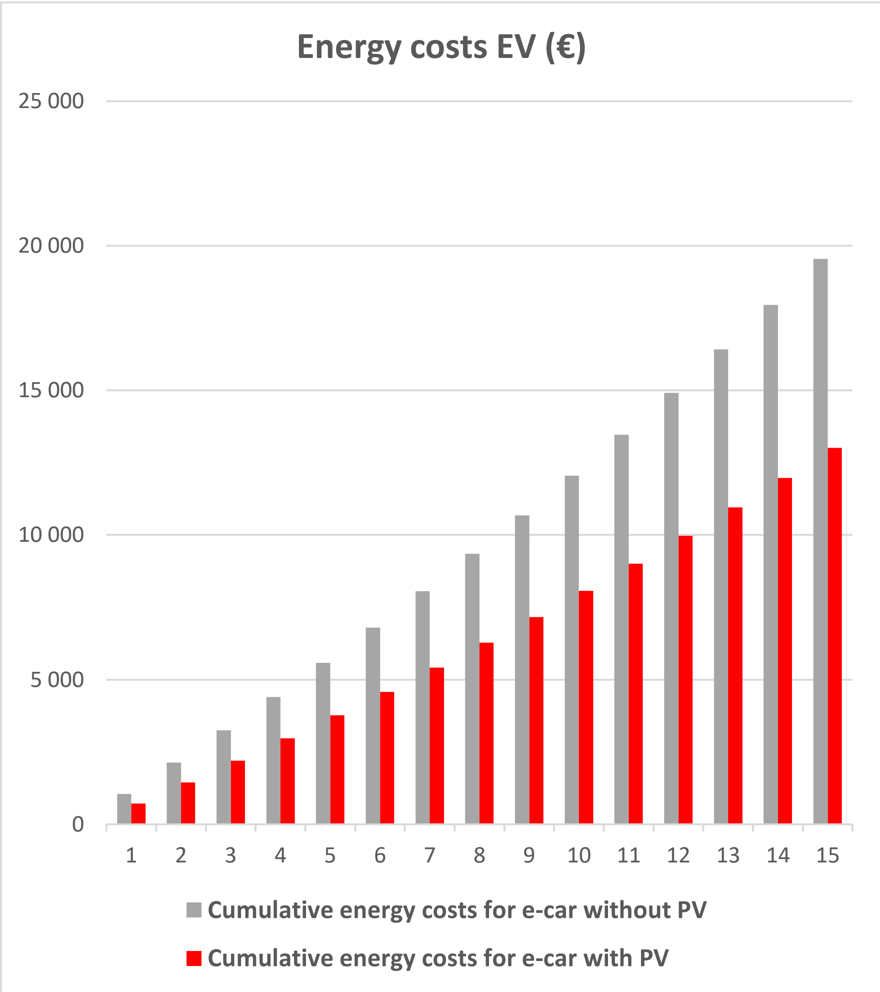


Figure 18: Cumulative energy costs for an electric car with and without PV system

Figure 18 shows a comparison of the cumulative energy costs for an electric car with and without a photovoltaic system using manual charging with PV energy (charging profile '40 hour job).

Cumulative energy cost savings from manual charging with PV energy over 10 years (charging profile – 40 hour job):

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
€338	€689	€1052	€1428	€1818	€2221	€2638	€3070	€3517	€3979

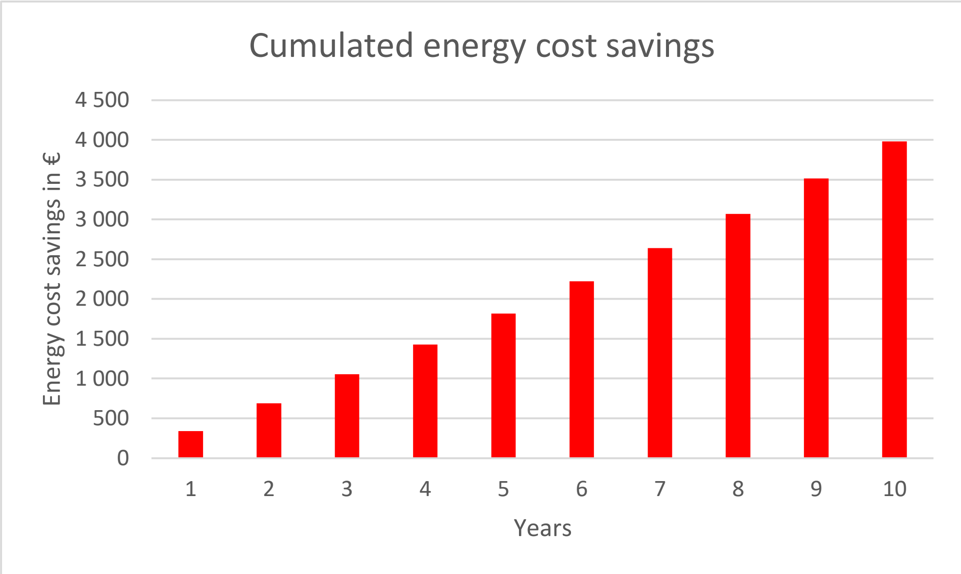


Figure 19: Cumulative energy cost savings over 10 years in €

Figure 19 shows the cumulative energy cost savings of manual charging with PV energy with the '40 hour job' charging profile over 10 years.

Manual charging with PV energy also enables up to €338 to be saved per year with the charging profile of a person in full-time employment. This represents energy cost savings of 39% compared to charging without a PV system. Thus, up to €3979 can be saved over 10 years.

2.3.2 Overview of compatible solutions for manual charging with PV energy

This category includes all charging solutions available on the market. There are no special technical requirements. Several charging solutions for manual PV surplus charging are listed below:

- ABL eMH series
- Alfen EVE Pro
- Hardy Barth cPµ1
- Heidelberg Wallbox Energy Control
- Innogy eBox series
- Webasto Live
- Wallbe Eco
- Juice Booster 2
- ESL Walli Light pro

3 BATTERY STORAGE SYSTEM COMBINED WITH ELECTRIC CAR

The assumption that a battery home storage system is not particularly suitable for charging an electric car is often based on the grounds that the capacity of a home storage system is several times smaller than that of the vehicle. However, if you take the typical amount of kilometres driven daily and the associated low amount of energy, it does make sense to use a home storage system for charging an electric car.

To increase the PV self-consumption rate even further, battery home storage systems can also be integrated into the PV system. A home storage system makes the most sense for people who charge their electric vehicles when PV generation has already begun to fall. Cars can thus be charged overnight using one's own solar power directly from the home storage system.

The hybrid inverters from Fronius (e.g. Symo GEN24 Plus) can be used to highly efficiently charge and discharge the home storage system with a power of up to 9 kW (depending on the battery connected). Thus, short periods of sunshine on a day with less insolation can be used to maximum effect. It also makes complete sense not to fully charge the electric vehicle, but instead to only supply it with the energy that will be needed the following day. When travelling an average of 40 km per day and consuming 17 kWh/100 km, the resulting energy required is around 7 kWh per day. As can be seen in the figure 20, the electric vehicle can also be charged directly with this amount via the home storage system without sourcing additional energy from the grid.

Another advantage of having a home storage system in the system is that the battery can cushion short periods of bad weather. If the PV generation, for example, is interrupted by cloudy weather while the electric car is charging, then the home storage system can take over. This avoids having to draw energy from the grid.

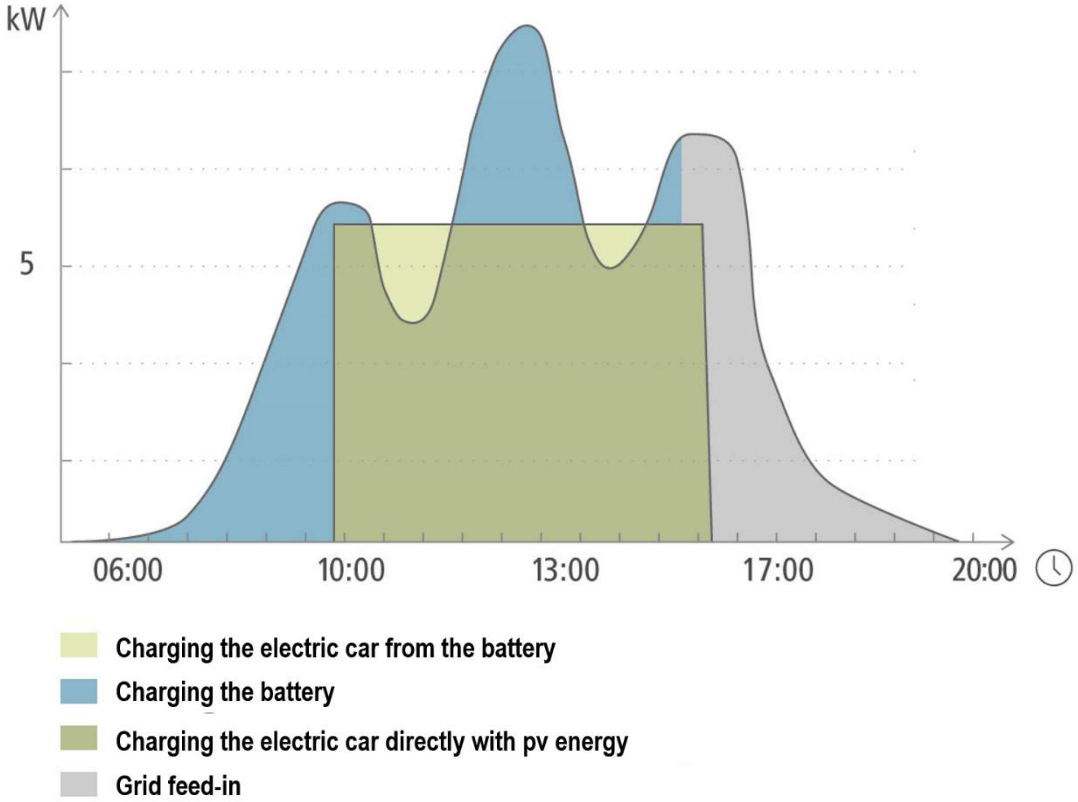


Figure 20: Charging the electric car from a battery storage

4 CONCLUSION

To summarise, there are many advantages to be had from combining photovoltaics and e-mobility. One of the most important aspects is the cost-effectiveness of the electric car/PV system. Combining e-mobility and photovoltaics reduces both the payback time of the PV system and the electric vehicle, as it raises the PV self-consumption rate and means the electric car can be charged with very cheap solar power. This lowers the operating costs, creating a win-win situation.

Besides the monetary benefits, charging with PV energy can also have a positive effect on the electric car's battery life, as detailed in section 1.1.2.

In terms of specific charging variants combined with Fronius inverters, dynamic PV surplus charging has a particularly positive effect on cost-effectiveness. Thanks to the communication between the charging solution and the inverter, this variant enables the electric car to be charged with the maximum amount of PV energy. Users can therefore avoid drawing energy from the grid or keep it to a minimum. PV surplus charging with inverter-integrated energy management and manual charging with PV power also result in significant savings compared to charging with energy from the public grid.

In summary, all charging boxes can be integrated into a system with a Fronius inverter. Individual charging solutions, however, vary in terms of technology and cost.

To conclude, a comparison is made between an electric car and a car with a combustion engine over a period of 10 years.

The following assumptions were made:

- 20,000 km travelled per year
- 10 years of being driven
- Electric car consumption: 16 kWh/100 km
- Combustion engine consumption: 7l/100 km
- Average price per litre of fuel for the combustion engine: €1.3 (as of 2021 – Germany)
- All other assumptions for the electric car (cost of electricity from the grid, increase in electricity prices/year, etc.) can be found in the table in the appendix

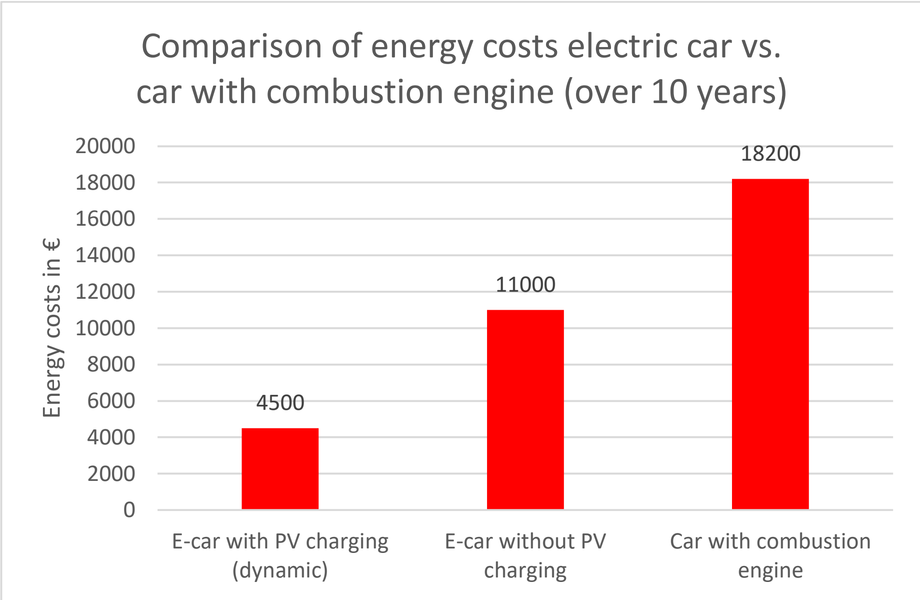


Figure 21: Cost comparison – electric car vs. car with combustion engine

As can be seen in Figure 21, the costs for charging an electric car in combination with PV energy are only around €4500 over 10 years. Charging an electric car without PV energy is approx. €11,000. Of course, this type of charging is heavily dependent on the cost of electricity. The car with combustion engine comes out worst. The costs for the fuel alone are approx. €18,200 over 10 years. The higher service and maintenance costs for cars with combustion engines and the possible price increase for diesel and petrol are not taken into account in this calculation.

It can therefore be concluded that a combination of photovoltaics and e-mobility represents the most cost-effective way of charging an electric vehicle.

5 APPENDIX

5.1 Assumptions for the calculations

Assumptions for the calculations in section 2	
Average distance travelled per day	60 km
Electric car consumption 100 km	16 kWh
Tariff for drawing electricity from the grid	€0.300
Feed-in tariff	€0.050
Increase in energy prices per year	3.0%
Size of the PV system	10 kWp
Cost of the PV system	€12,000
Self-consumption rate without electric car	30%
Household energy consumption without electric car over a year	5000 kWh
PV generation per year and kWp	1000 kWh/kWp/a
PV system generation per year	10,000 kWh
Charging solution connection: dynamic PV surplus charging	Switching over between 1 and 3-phase (Use of surplus PV from 1.38 kW - 22 kW)
Charging solution connection: inverter-integrated energy management	1-phase (charging is activated when the surplus reaches 3.6 kW)
Charging solution connection: manual charging	1-phase (car is charged with 3.6 kW as soon as it is plugged in)

5.2 Description of the charging profile

The energy generated by a 10 kWp PV system is simulated for both charging profiles in a 15 minute interval.

Charging profile 'At home during the day':

The electric car is mainly charged throughout the whole day (45 charges/year) / in the afternoon (300 charges/year). To make this scenario as realistic as possible, a few evening charges (20 charges/year) are also included.

Charging profile '40 hour job':

The electric car is mainly charged in the evening (176 charges/year). To make this scenario as realistic as possible, several charges are carried out throughout the whole day (93 charges/year) / in the afternoon (96 charges/year). This represents the charges carried out at the weekend, when the customer is not at work.

5.3 Overview of all compatible charging solutions

<table>
<tr><th colspan="2">Dynamic PV surplus charging</th><th>Charging using the integrated energy management function of the Fronius inverter</th><th>Manual charging with PV energy</th></tr>
<tr><td colspan="2">Fronius Wattpilot Go / Home</td><td>Enomics Wallbox Fronius optimized</td><td>ABL eMH-Serie</td></tr>
<tr><td colspan="2">Hardy Barth cPH1</td><td>Keba P20/P30 b/c/x-Serie</td><td>Alfen EVE Pro</td></tr>
<tr><td colspan="2">NRGkick</td><td>Mennekes AMTRON Compact/Xtra/Premium</td><td>Hardy Barth cPµ1</td></tr>
<tr><td colspan="2">openWB series2</td><td>Schneider Electric Schneider EV Link G3+</td><td>Heidelberg Wallbox Energy Control</td></tr>
<tr><th colspan="2">Compatible solutions with external energy management</th><td></td><td>Innogy eBox Serie</td></tr>
<tr><th>Charging Solution</th><th>Energy Manager</th><td></td><td>Webasto Live</td></tr>
<tr><td>Keba P20/P30 b-Serie</td><td>Loxone / BayWa sonniQ</td><td></td><td>Wallbe Eco</td></tr>
<tr><td>Keba P20/P30 c/x-Serie</td><td>Loxone / BayWa sonniQ</td><td></td><td>Juice Booster 2</td></tr>
<tr><td>Mennekes AMTRON Xtra / Premium</td><td>BayWa sonniQ</td><td></td><td>ESL Walli Light pro</td></tr>
<tr><td>Heidelberg Wallbox Energy Control</td><td>BayWa sonniQ</td><td></td><td>And other charging solutions</td></tr>
</table>