Reduction of grid electricity demand of BEV's by applying integrated photovoltaics

- A modelling approach -

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ABSTRACT: In this paper we calculate the amount of energy that can be generated by applying vehicle integrated photovoltaics (VIPV). The amount of energy not only depends on the type of vehicle, availability of the area that can be used for integrated photovoltaics, but also in the driving profile, or the way the vehicle is used. For this reason first the typical driving profiles of the different vehicle types were defined and typical driving profiles were generated for the different vehicle types. Then the generated energy was calculated for two different locations, namely Amsterdam and Madrid and compared to the energy demand of the vehicle for that specific driving profile.

In total a series of 24 representative driving profile and vehicle combinations have been assessed through simulations using TNO's Energy Flow Model[(1)], which include passenger cars, small and large vans, buses and trucks.

The results were compared with other energy reduction options such as improved aerodynamics, lower rolling resistant tires, LED lighting etc. We show that the addition of PV to the vehicles can have significant impact on the overall energy consumption, especially when combined with other vehicle efficiency improvements.

KEY WORDS: vehicle integrated photovoltaics, renewable energy, battery electric vehicle

1. INTRODUCTION

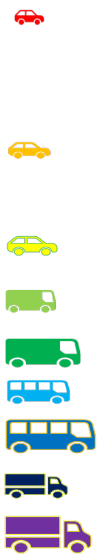
The electrification of the transport sector will result in an enormous increase in the electricity demand in all sections of the electricity grid as the charging will take place at home, on the street, in charging hubs, or along highways. This will require grid reinforcements and also a substantial increase in generated renewable energy to provide these charging stations with green energy. VIPV on the other hand will generate the electricity where it is needed and does not need electrical infrastructure to charge the vehicle. The model described here is able to determine the impact of the integration of PV on a large number of different but representative vehicles with different driving profiles and the results can then be used to create the energy demand of a typical fleet of vehicles for either a country or for a neighborhood. The model does not only calculate the generated energy, like most other models do, but takes into account the state of charge of the battery as well, and thus takes into account that not all generated energy can be used.

2. MODELS

2.1. Description of the models

To determine the energy consumption of the vehicles, the Multi-level Energy Optimisation MEO Model[(2,3)] and Energy Flow Model (EFM), both developed by TNO, were used. 24 archetypal vehicles and associated driving profiles have been assessed (see Fig. 1.) for 2 locations: Amsterdam and Madrid,. We compared the archetypes with and without VIPV, and for various charging strategies.

The driving profiles were fed into the MEO model and result in the required energy consumption per time step, including the energy needed for driving, as well as the auxiliary system. This is done for a whole year and fed into the EFM model. In the EFM model the energy consumption is used to calculate the state of charge of the battery and with that the moments at which the vehicle needs to charge are determined. With this the effect of VIPV on the energy consumption and charging moments was calculated as well as the CO_2 reduction.



Vehicle class and type	Use pattern
Small passenger car	'occasional use'
	'daily urban commute'
	'daily periurban commute'
	'long-distance highway travel'
	'car sharing'
Medium sized passenger car	'daily urban commute'
	'daily periurban commute'
	'long-distance highway travel'
SUV	'daily urban commute'
	'daily periurban commute'
	'long-distance highway travel'
Small van	'Local distribution'
	'Regional distribution'
Large van	'Local distribution'
	'Regional distribution'
Low-floor bus	'Urban public transport service'
	'Periurban public transport service'
High-floor coach	'Regional public transport'
	'Long-distance highway travel'
Rigid truck	'Urban distribution'
	'Regional distribution'
Tractor-trailer	'Regional distribution'
	'Long-haul freight transport'

Fig.1 Vehicle archetypes based on vehicle type and driving profile.

3. RESULTS

3.1. Energy Flow

Fig. 2 and Fig. 3 show the output of the energy flow model for a medium sized passenger car with daily semi-urban commute' with a 59kWh battery and an annual mileage of 10,548 km/year. Fig. 2 shows the situation without PV and Fig. 3 for PV on all surfaces for the Amsterdam location. The red circles indicate the charging moments. For this type of vehicle and driving pattern, daily peri-urban commute, the integration of PV on the top and sides reduces the number of charging moments from 41 to 28. An overview of the reduction in the number of charging moments for all the vehicle types is shown in Fig. 4 for passenger cars and vans and in Fig. 5 for buses and trucks. As can be seen, the number of charging moments drop substantially for the passenger cars and vans, but hardly for the trucks and buses. This is related to the fact that the trucks and buses travel large annual distances. Even if the PV contributes up to 5 % (as shown below), the overall solar kilometers will be on the order of 5000 km, or about 15 km a day, assuming 365 days of operation.

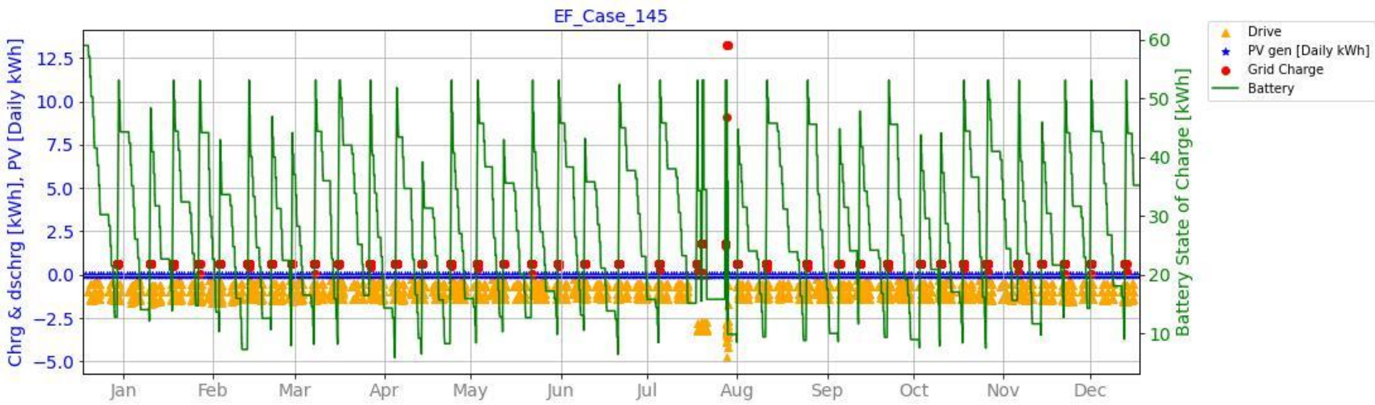


Fig. 2 The energy flow time series of the example, showing the 41 grid charging moments, red circles, required for the year.

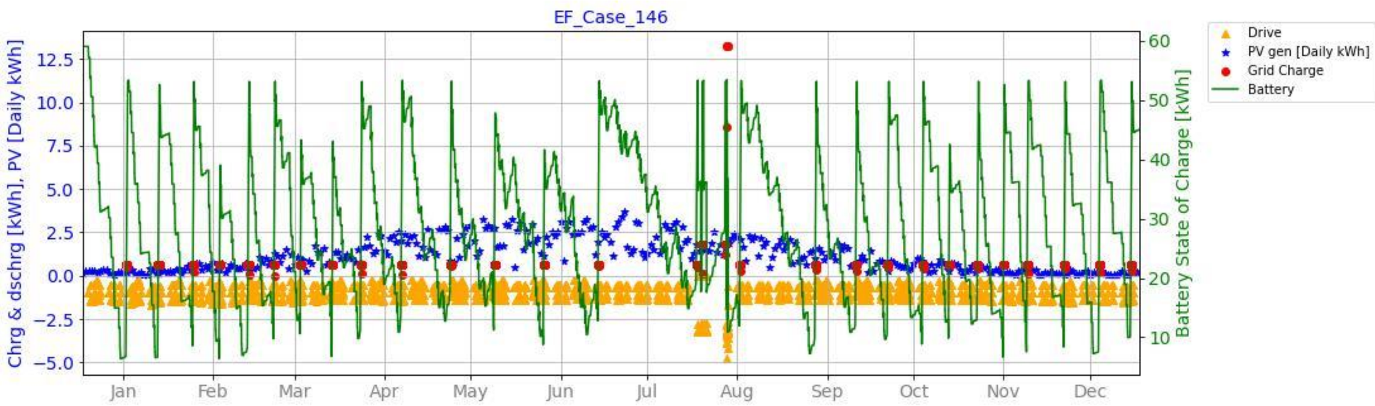


Fig. 3 The energy flow time series for the variant with PV on the top and sides, showing the reduced number of charging moments, 28 for the year.

This has hardly an effect on the number of charging moments. But overall, 5000 km per truck or bus means a substantial cost saving and CO2 emission reduction.

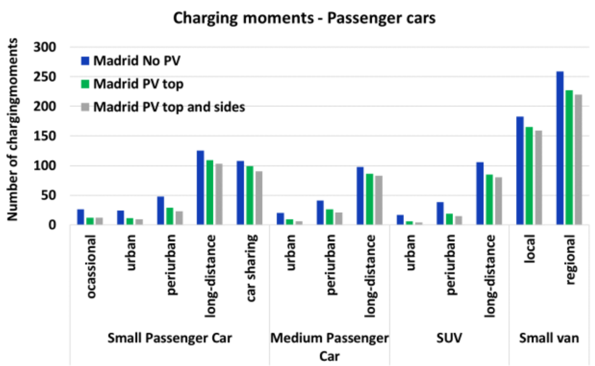


Fig. 4 Number of charging moment of Passenger Cars for the Madrid location.

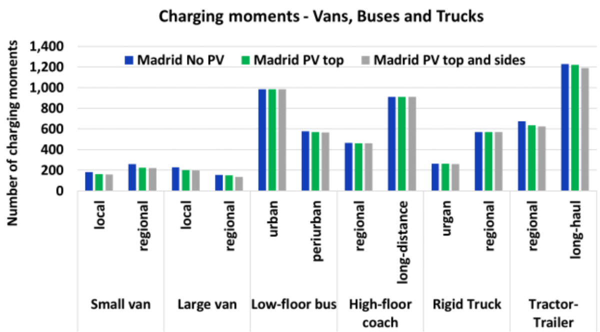


Fig. 5 Number of charging moment of Vans, Buses and Trucks for the Madrid location.

3.1. Energy efficiency improvements

The results show that VIPV can play a role in reducing the energy consumption on vehicles, but the automotive industry is also working on other energy improvement options, like improving the aerodynamics, reducing weight and rolling resistance of tires. For all the archetypes, viable energy improvement options have been identified for 2025 and 2030, see Table I, and the effect on the energy requirement of the vehicles has been calculated and compare with the effect of adding VIPV.

The results are given in Fig. 6 for the trucks and compared with the VIPV energy reduction option. This shows that VIPV can give a similar or even higher contribution as the other energy reduction options. The relative effect scales with the annual driving distance. For shorter annual driving distances, the rigid truck local distribution archetype (HT11), the VIPV is more efficient, whereas for the larger driving distances, the tractor-trailer for long-haul distribution (HT22), they become comparable.

Table I Energy reduction options.

Option	Description
TYRES1/2	Low rolling resistance tyres on truck/tractor
TYRES3/4	Tyre pressure monitoring system (TPMS) on truck/trailer
TYRES7	Wide base single tyres
AERO2	Side and underbody panel at truck chassis
AERO3	Aerodynamic mud flaps
AERO5	Redesign, longer and rounded vehicle front
AERO6	Side and underbody panels at trailer chassis
AERO7	Boat tail short, additional
AERO8	Retrofittable roof and rear recess flaps 400 mm
MASS1	5% Mass reduction (truck/tractor)
AUX1	Electric hydraulic power steering
AUX2	LED lighting
AUX3	Air compressor
AUX4	Cooling fan

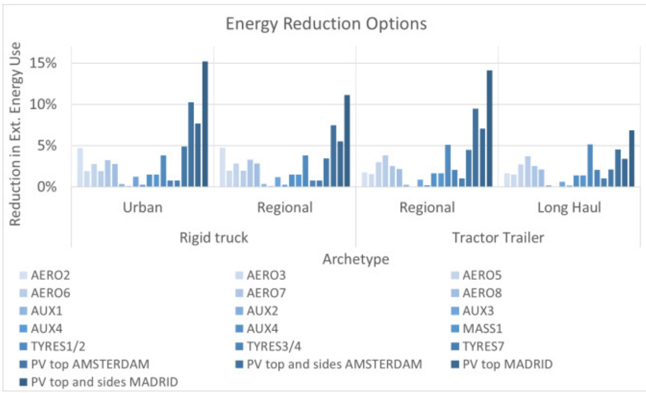


Fig. 6 Comparison of the effect of different energy reduction options for trucks, and tractor-trailer.

The economically viable energy reduction options have been used in combination with the European battery electric fleet projection to determine the overall effect on the electricity grid.

The fleet projection has been made for 2025 and 2030, based on the historical and projected development of the EV fleet in the Netherlands. Figure 7 shows the potential electricity consumption reduction if all EVs from 1/1/2024 onwards would be equipped with the economically viable energy efficiency options and VIPV for 2025 and 2030. The numbers shown are expressed as GWh per year. As shown, the overall grid reduction would add up to 25 TWh per year in 2030 if all options would be implemented.

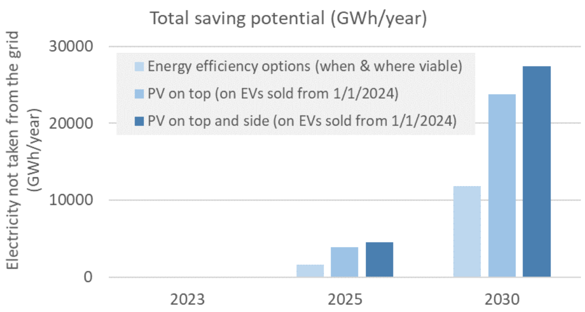


Fig. 7 Potentially avoided grid electricity consumption resulting from reduced energy consumption options and VIPV, for the projected EV fleet. Baseline=2023 vehicle efficiency & no VIPV. Additional fleet only = only newly sold vehicles from 1/1/2024 onwards.

The distribution over the different vehicle types is given in Figure 8 for 2030.

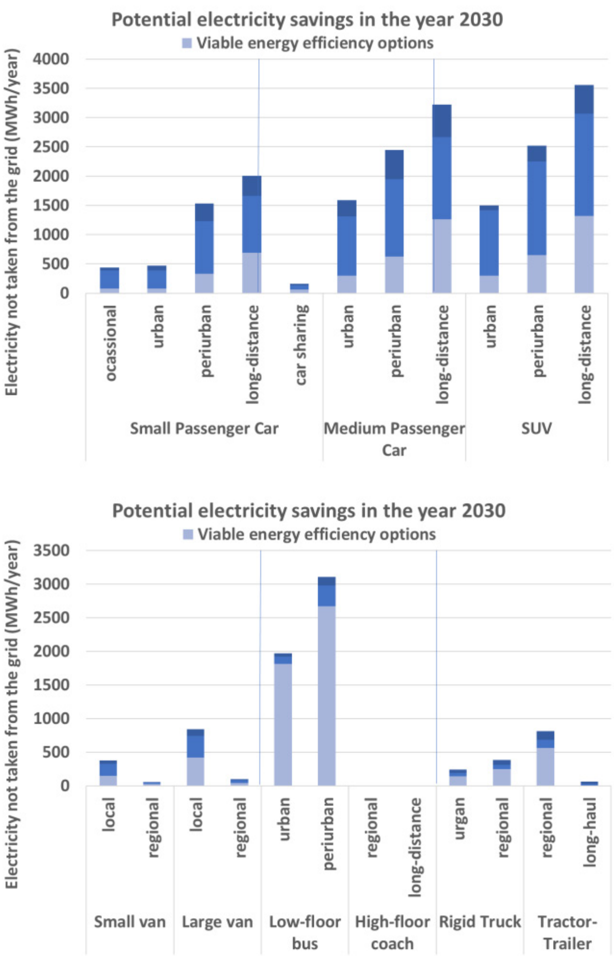


Fig. 8: Contribution of the different vehicle archetypes to the potential electricity savings in 2030 for the vehicle archetypes. Top passenger cars, bottom vans, busses and truck/tractor-trailer.

4. CONCLUSIONS

In this paper we have shown the effect of VIPV on the reduction of the grid energy consumption of various vehicles types with different driving patterns, ranging from passenger cars and vans up to buses and trucks. The amount of reduction depends strongly on the vehicle type and use pattern. Small cars that drive large annual distances, with a small area available for PV benefit less that larger cars, especially if those do not drive large annual distances. But in all cases, the VIPV can contribute substantially to the energy reduction and thus reduce the number of charging moments, costs and CO2 emissions.

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