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Electric Vehicles and Energy Communities: Vehicle-to-Grid Opportunities and a Sustainable Future

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Abstract: Renewable energy sources and energy independence are becoming increasingly important worldwide, and reducing emissions and optimizing energy use are high on the EU's agenda. In this context, electric and hybrid vehicles could not only be a means of transport but also an active part of the grid. This paper analyzes one year of empirical data of a hybrid vehicle using a linear programing method that allows the optimization of energy return under different settings. The aim of the study is to determine the contribution that vehicles can make to the stability of the grid and the functioning of energy communities. It also compares the distribution of energy sources used in the EU and presents the current range of V2G-capable vehicle models. The results show that hybrid vehicles can also be effective energy storage devices, especially at fleet level. V2G technology could influence the development of battery production and contribute to the expansion of secondary markets by enabling the recycling of degraded batteries for buildings or renewable energy systems. The article also summarizes the development opportunities and challenges for V2G technology, in particular its role in energy grids and sustainable transport.

Keywords: electric vehicles; energy communities; vehicle-to-grid; smart grid; renewable energy; energy management

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1. Introduction

In the 21st century, humanity faces numerous challenges and difficulties. One of the most pressing challenges today is the reduction of humanity's carbon footprint and the decrease or elimination of energy dependence, which has become even more critical due to the current geopolitical situation (2025). The countries of the European Community have taken significant steps to address both of these problems. Reducing emissions and optimizing energy consumption have become key priorities. Many manufacturers and service providers are striving to meet these emerging demands through innovative technical solutions.

Electromobility could be a key issue for energy security in Europe. For many countries dependent on oil imports, the uptake of electric vehicles will strengthen diversification of domestic energy production, which will have a positive impact on reducing greenhouse gas emissions and ensuring energy security. Such countries can rely on new primary energy sources such as wind, solar or hydropower. However, the spread of electric vehicles would place a heavy burden on the electricity grid. It is projected that 709 TWh of electricity will be needed by 2030 [1].

Differences between networks are a particular problem. It is predicted that by 2025, there will be around 3000 different locations in the Netherlands where 100 electric vehicles can be connected to the grid for charging at the same time. This is expected to mean that the local tram network will not be able to cope with simultaneous charging of vehicles [1,2]. Similarly, in California, grid upgrades are also needed to power the rapidly expanding electric vehicles. In addition to these problems, many HVAC systems, such as heating and air conditioning, have been electrified, resulting in a cumulative increase in electricity demand [1,3].

Despite the increased challenges, electric vehicles have potential as energy storage devices. The battery capacity of vehicles currently on the market and placed on the market by 2030 will reach 29 TWh, rising to 186 TWh by 2050 [1,4].

This increase in capacity can be used in a number of ways. One of the most common views is that the range of electric vehicles must be improved. Another idea is that vehicles should be tightly integrated into buildings, where renewable energy sources such as solar panels generate electricity and where the vehicle acts as an energy storage device. The increased battery capacity can then be used to store electricity. This technology exists with several modifications, such as vehicle-to-grid (V2G), vehicle-to-home (V2H) or vehicle-to-X (V2X) [5,6].

This study focuses on vehicle-to-grid technology, which is one of the most essential tools for enabling bidirectional energy flow between electric vehicles and the power grid, while also playing a crucial role in the development of sustainable energy communities. The article presents the V2G technology along with the concept of energy communities related to this technology in the European Union. The article also aims to look at the situation of current vehicle manufacturers, which models have V2G solutions and what the prospects are for the future. The main focus of the article is an analysis of data from a hybrid vehicle over the span of one year, which shows completely random usage without any charging or user strategy. The article seeks to answer whether and how much of the energy not consumed by the vehicle can be fed back into the grid or building, using mathematical methods. The article also presents the amount of electricity consumed by households in the EU Member States, against which the data of the vehicle under study are compared.

Overall, this article seeks to answer a complex question. By analyzing hybrid vehicle data and examining the relationship between energy storage and consumption, it aims to bridge the gap between the theoretical and practical aspects of V2G technology. The study combines one year of empirical data from a single vehicle with mathematical modeling to explore the potential of V2G systems. The study analyzes the data of a single vehicle over a full year. The user's habits are not controlled, as their daily routines and lives had to be carried out. The reason for this is to gain as many real-life results as possible. Vehicles of this type can be acquired at a rather high price; therefore, no fleet expansion and no further vehicle data were analyzed.

The second chapter provides a brief overview of energy communities, helping to contextualize the findings and highlight their significance in both scientific research and practical applications.

2. Concept–Integration of Electric Vehicles into Vehicle-to-Grid System

The integration of V2G electric vehicles is a revolutionary concept that could transform the entire electricity system. This technology allows electricity from vehicle batteries to be fed back into the electricity grid or into buildings. This is called bidirectional charging. It allows vehicles to act as energy storage devices and compensate for imbalances in the grid. It is a way to store energy, reduce the carbon footprint and increase energy security [7]. For a comprehensive overview of grid balancing, see [8].

V2G integration opens up new opportunities. Vehicles will be part of the electric grid, which will include, in addition to energy storage, intelligent charge management systems that will ensure the flow of energy between producers, consumers and vehicles. This approach goes beyond compensating peak demand on grid [9,10].

The challenges involved in implementing V2G technology are an important element in the widespread uptake of electromobility and the spread of smart cities. As the number of electrically powered vehicles continues to grow, buildings and electrical networks need to be further developed. And as the vehicle population grows, the benefits of V2G technology and its development potential become evident [11,12].

3. Basic Concept—Energy Communities

The development of energy communities will bring energy management in the European Union to a new level. The communities will generate electricity from renewable energy sources and distribute it among their members. The energy produced is clean and community members can live and work in energy security. The European Union has drawn up a number of directives that its Member States must follow and implement. Such solutions enable a reduction in electricity consumption while simultaneously decreasing dependence on traditional grid systems [13,14].

The transition to sustainable energy sources places a huge burden on local communities. Buildings need to be equipped with renewable energy generation infrastructure, and aging electricity networks need to be upgraded. This will not only bring technical challenges (V2G technology, smart charging systems, etc.) but also generate financial, social and cultural changes. Tineke van der Schoor et al. provide a comprehensive overview of regional energy cooperation and its background [15].

Energy communities are local organizations with energy produced by and distributed among community members. This kind of approach necessitates the development of new business models. Reference [16] shows how the current regulatory and technological context allows for the development of an ECBM (energy community business model). These models are in the experimental and developmental stage. ECBM research should follow legislative changes. Thus, development is continuous and constant, as new methods must be developed to adapt in real time to the new legislative background; these regulations may differ from country to country, as pointed out by [17] (England) and [18] (Italy).

Electric vehicles act as flexible energy storage devices in the grid. V2G's bidirectional charging system enables this option. This technology does not currently exist in all vehicles [19,20]. To achieve a fully independent energy community, vehicles need to be charged by renewable energy sources. Such renewable energy sources are usually solar energy, but wind energy is also included [21,22]. In this way, vehicles can facilitate the connection of intermittent energy sources to the grid. However, the rapid expansion of vehicles is creating problems with aging electricity grids and also in places where the grid is modern but undersized for the increased number of electric vehicles. The problems that arise need to be addressed from both a policy and an energy community perspective to ensure that the increase in the number of electric vehicles has a minimal impact on the grid [23,24].

Users, vehicle manufacturers and energy suppliers are different stakeholders. Therefore, the development of charging infrastructure is a key task that needs to be carried out in coordination with urban planners. Not only will this make life easier for users, but also, if optimally located, vehicles can be integrated into energy communities [25,26].

The fourth chapter describes the composition of the current energy mix and the situation of each Member State in the energy sector, based on data provided by the European Union (EuroStat). The fourth chapter provides context for the mathematical analysis of the effectiveness of the calculated model.

4. Household Electricity Consumption and Renewable Energy in the EU

According to EuroStat data, household electricity consumption in the EU Member States in 2022 was 10.1 million terra joules, the lowest since 2016. In the year before 2022, the same value was 11 million terra joules, showing a difference of 7.7% between the two values [27,28].

Natural gas (30.9%), electricity (25.1%) and energy from renewable energy sources (22.6%) accounted for the largest share of EU energy consumption. Energy use was mainly concentrated on heating homes and buildings, accounting for 63.5%. Total energy use for heating buildings and water was 78.4%. Other electricity using appliances and lighting accounted for 13.9% of the total [27,28].

Further analysis of EuroStat data shows that between 2012 and 2022, residential electricity consumption in the European Union will decrease by 1.5%. It is important to note that in some EU Member States, consumption has increased, and in others it has decreased, with Malta showing an overall increase of 63.9% and Lithuania and Slovakia rising 24.5% over the period. However, it is important to note that some Member States recorded a decrease, such as Belgium (−17.7%) and Greece (−13%) [29,30].

EU Member States have taken important steps to meet their energy needs from renewable energy sources. The scale of these efforts and the potential of Member States vary widely. The integration of renewable energy sources has a significant impact on household electricity consumption patterns. While in 2022, renewable energy sources (including biofuels) accounted for 22.6% of total household energy consumption, in 2021 this figure was 21.2%, showing a modest increase [27,28].

The main sources of energy for households are natural gas (30.9%) and electricity (25.1%). Electricity from renewable sources accounted for 34.3% of net production in 2022. This suggests a shift towards the use of clean energy sources, while also, energy use is decreasing. This trend shows that the EU population is open to renewable energy sources and is changing their energy consumption patterns [27,28].

5. Electricity Consumption Methodology in Energy Communities

Energy communities are an EU concept that aims to create a new way of generating and redistributing electricity. It relies mainly on renewable energy sources.

Overall, energy communities are local initiatives in which citizens or community members collectively generate electricity and distribute it to community members. These communities can take different legal forms, such as cooperatives or non-profit organizations, which allow people to join clean energy projects [16,31].

Over the last twenty years, the range of energy models available to the public in the European Union and in many countries around the world has grown steadily, under different names. The EU created the Energy Communities model in 2019, and the new name and concept has been launched in the Member States with the Clean Energy for all Europeans Package (CEP). The Directive on the Internal Energy Market (IEMD) introduced the concept of Citizen Energy Communities (CECs) and the recast of the Renewable Energy Directive (RED II) introduced Renewable Energy Communities (RECs). The concept highlights the growing importance of community-owned projects. The characteristics of CECs and RECs are illustrated in Table 1 [32].

In practice, household electricity use is affected by the above schemes in a number of ways. One such aspect is increased on-site generation. This allows community members to generate their own electricity from renewable energy sources such as solar or wind power. This increased local production can reduce dependence on conventional energy suppliers and can lead to lower energy bills. By sharing electricity between members, energy communities can optimize consumption, resulting in more efficient use of the energy produced and less energy being drawn from the grid [31,32].

Table 1. CEC and REC description [32].

	Citizen Energy Communities (CEC)	**Renewable Energy Communities (REC)**
Section of CEP	Internal Electricity Market Directive	Renewable Energy Directive
Energy Type	No restrictions on energy technology	Only renewable energy sources and services
Members	Voluntary	Voluntary

These features make it possible to reduce so-called energy deficiencies. Energy communities often target households that need access to cheap and affordable energy [31,32].

To fully realize these potentials, it is essential to support legislators and to extend and implement legislation in all EU Member States.

In the European Union, the CEP has created the legal framework for energy communities, fostering their growth, facilitating energy sharing and opportunities to participate in markets. There are currently around 9252 energy communities in the EU, which vary considerably in the way they operate. Among EU Member States, Germany leads the way with almost half of the communities, while some countries have few or no energy communities [33–35].

EU lawmakers envisage that by 2050, a significant share of the EU's renewable energy will be produced by these local communities. This is in line with the vision of a decentralized energy system [31,33].

In conclusion, energy communities have considerable potential in the European Union. Local renewable energy production, consumption and distribution promise major benefits such as cost reduction, efficiency gains, the balancing of grid problems and more equal access to energy.

After presenting the used definitions and the current energy situation, the sixth chapter focuses on the products of vehicle manufacturers. This chapter tries to give a realistic picture of whether vehicle manufacturers have already put products on the market to make V2G technology truly implementable.

6. Short Overview of Vehicle Manufacturers (V2G)

Having described energy communities, it is easy to see that they are an unquestionable part of the future. As the previous chapter has shown, the energy produced must be effectively distributed among the members of the community. In practice, however, it is known that electricity use is not uniform. For both residential and business use, there are times of the day when there is no or minimal use and other times when the demand peaks. For households, the electricity generated by solar panels during the day needs to be stored in some way so that it can be reused by members of the community at a later date. Battery solutions or, going further, the use of existing electric vehicles as storage could be a good solution. In essence, the vehicle can act as a powerbank for the building or community, a technology called vehicle-to-grid [35]. This technology poses challenges for vehicle manufacturers. In the future, vehicles will not just be a means of transport but will become useful tools for buildings, smart cities and energy communities. These chapters aim to provide a comprehensive overview of current (2024) vehicle manufacturer solutions.

The introduction of V2G technology in vehicles is of paramount importance. Vehicle manufacturers have started to address these developments. The table shows that, unfortunately, European manufacturers are lagging behind. Vehicle manufacturers have recognized that in the future, vehicles will have to be treated as parts of buildings and smart cities. Vehicles offer the potential to increase the stability of the network and provide economic benefits to vehicle owners.

As you can see, the strength of V2G technology lies in its ability to create synergy between energy communities and contribute to sustainable energy management. Vehicles equipped with V2G technology are able to store excess energy from renewable energy during periods of low demand and share or recycle this energy during peak periods.

However, Table 2 reflects the fact that some manufacturers do not currently offer models that can adequately use V2G technology. This is particularly true for European manufacturers.

Table 2. Brands, models and overview of V2G.

Brand	Model	Overview	Ref.
Nissan	Nissan Leaf, e-NV200	More than 500 vehicles have been integrated into V2X (Vehicle to Everything) projects. Ambition 2030 project	[36–38]
Mitsubishi	Outlander PHEV, iMiEV	Mitsubishi has been involved in V2X development for many years. The company is a member of the Renault-Nissan consortium, which has access to the technology.	[39–41]
Honda	Honda e	This Honda model is capable of two-way charging. The company is involved in pilot projects in Switzerland (2022).	[42]
Hyundai	Ioniq 5, Ioniq 6	V2X capability was a criterion in the design of the Ioniq 5. The model has a V2X feature that can be used.	[43,44]
Renault	Renault Zoe, upcoming Renault 5	The Renault Zoe has already been involved in various trials, and the forthcoming Renault 5 will have bi-directional charging capability.	[45,46]
Ford	F-150 Lightning	With F-150 Lightning, designed for two-way charging to support network stability.	[47]
Volvo	Volvo EX90, Polestar 3	Both Volvo and Polestar models have V2G capabilities (Scalable Platform Architecture (SPA2) models)	[48,49]
Stellantis Group	Peugeot iOn, Citroën CZero	Stellantis has tested the V2G feature on several brands within its portfolio and models such as the Peugeot iOn have already been equipped with bidirectional charging.	[50]
Volkswagen Group	Various models using MEB platform	Volkswagen is working to introduce V2G capabilities across its brands, including Audi and Porsche, using the Modular Electric Drive Matrix (MEB) architecture.	[51,52]
BMW	BMW i models, New class models	BMW has started development with the i3 models, and the Neu Klasse models that will be launched in 2025 will be capable of V2G technology.	[53]
TESLA	Tesla Cybertruck, Tesla Model 3 (2025), Model Y (2025)	The Cybertruck model is equipped with a "Powershare" solution to provide 120 V and 240 V. Model 3 and Model Y models will have this solution from 2025.	[54]
BYD	BYD Dolphin, BYD Atto 3, BYD Seal, BYD Bus	V2G technology is available in all models.	[55,56]
Mercedes-Benz	EQS models	Mercedes will make V2G technology available in its new generation EQS models.	[57]
KIA	Niro, EV6. ev9	Technology is available	[58]

7. Tested Vehicle and Data

As discussed in the previous chapter, European manufacturers are at a competitive disadvantage. This article examines data from a BMW 225XE vehicle (BMW AG, Germany Leipzig Plant) to see whether and how much energy can be stored and recharged using a theoretical/retrofit solution based on one year's user data. The vehicle data is shown in Table 3.

Table 3. The hybrid car data [59].

Engine model	B38B15
Engine displacement	1499 cm^3
Number of cylinders	3
Engine power	136 Hp/220 Nm
Gross battery capacity	7.6 kWh
Net (usable) battery capacity	6.1 kWh
Battery technology	Li-Ion
All Electric range	41–45 km
Performance	88 Hp/165 Nm

The vehicle is built around a 1499 cm^3 3-cylinder petrol engine with a hybrid system fitted with a 7.6 kWh battery. According to the vehicle's catalog, in electric mode the vehicle can cover 41–45 km on a single charge.

8. Mathematical Solutions About Vehicle-to-Grid Applications

Vehicle-to-grid solutions introduce a completely new approach to energy management. Vehicles use, store and transmit electricity at the same time. The results of V2G technology highlight the potential of grid load stability. Ref. [60] shows what happens to the electricity grid when a thousand electric vehicles are integrated into the grid. The study shows that unplanned charging exacerbated peak load and demand, a structured V2G program significantly reduced peak load and increased grid stability. The study calls attention to the design of planned V2G programs and their optimization.

To optimize V2G systems we can use a combination of genetic algorithms, Gated Recurrent Units and Reinforcement Learning methods. These methods can be used to develop new charging strategies to minimize peak loads and predict costs [61,62]. Multi-Objective Optimization helps to reduce network load through optimized charging and discharging schedules. Ref. [63] points out that individual user habits need to be taken into account for V2G optimization. Without proper incentives for the population and a compensation and maintenance scheme for battery degradation and replacement users may be reluctant to actively connect their vehicles to the community's energy network. The socialization of V2G technology is important [64].

It is clear from the above that technology is a key issue, yet there are still many challenges to full implementation. The complexity of calculations and monitoring of various factors is critical. Accurate optimization methods often require significant computational resources, making them difficult or impossible to apply in real-time applications. The dynamic nature of power systems makes it worthwhile to use agile methods such as heuristic algorithms. Refs. [65,66] V2G systems involve not only technological but also economic challenges. Charging schemes could compensate users for the degradation of batteries that vehicles suffer during their participation in a V2G system. Optimizing charging strategies could lead to significant cost savings for both users and network operators [67–69].

There is a large literature on integer linear and non-linear programing as a possible optimization method for several reasons. LP methods facilitate efficient allocation of resources and easily integrate dynamic usage patterns into LP formulas, thus improving the accuracy of models [70–73].

This chapter provides a brief overview of current optimization issues. Vehicle-to-grid technology does not only address problems related to vehicles and the integration of renewable energy sources. These problems are multi-level. Integrating vehicles into an optimized system and developing an appropriate charging and discharging strategy is costly, and integrating vehicles into real-time applications is difficult due to the large computational capacity. Incentive programs and/or public support schemes for the degradation of vehicle batteries need to be developed. Based on the research conducted so far, linear programing and its complement via machine learning methods may show a solution that can be used to balance the charging strategy and the electrical grid by taking into account user behavior.

Linear programing was used to optimize charging and discharging strategies. Several battery-preserving factors were incorporated into the calculations to ensure long battery life. At the same time, it was important to be able to theoretically achieve the highest possible level of energy feedback into the grid.

Factors considered in the model:

- Monthly energy consumption;
- Average charge level, when the charger is connected;
- Battery safety factor.

In the analysis, there are some assumptions and constraints:

- User habits;
- Infrastructure availability;
- Other external factors (e.g., temperature, humidity, etc.).

In this research, I focused only on the capabilities officially specified by the vehicle manufacturer and the data recorded by the vehicle's charging.

9. Data Analyses and Visualization

9.1. Introduction and Mathematical Background

As the previous chapters have shown, the provision of V2G technology for electric vehicles is critical for future cities and an indispensable prerequisite for the integration of renewable energy sources.

This research used annual charging data from a vehicle where the user did not follow any strategy or regularity. His habits, i.e., the charging times for the vehicle, were dictated by a random sequence of real-life events.

The vehicle under study did not have V2G technology, but this shortcoming does not prevent the research from drawing conclusions about the theoretical amount of electricity that could be recovered from a hybrid vehicle by linear programing, taking into account user behavior.

Linear programing (LP) was used for data analysis. It is a mathematical method that can be used to solve various optimization problems. The aim of the method is to find the most optimal solution through either maximization or minimization of a given objective function while taking into account the constraints imposed [74–76].

In LP applications, the objective function to be optimized is first defined. Simultaneously, a set of constraints is set, which must be considered by the solutions. These constraints can be equations or even inequalities. During the optimization process, the so-called decision variables represent the elements to be optimized. Typically, LP models involve multiple decision variables [74–76].

LP is a widely used method [74–76]:

- Engineering;

- Economy;
- Logistic.

Many studies use linear programing to analyze V2G systems. Ref. [77] examines the state of energy trading in scenarios where users experience stochastic energy supply. The study calls for the coordination of energy trading and V2G network services. Ref. [78] investigates the availability of plug-in hybrid vehicles, focusing on the statistical likelihood of vehicles being available for charging or discharging, using an LP-based approach. Refs. [79,80] use LP to investigate the allocation of charging stations and the integration of V2G and V2B (vehicle-to-building) solutions.

The mathematical method and the literature reviewed show that LP is suitable for addressing vehicle-to-grid challenges. The following chapters present and analyze one year of data from a hybrid vehicle. Then, conclusions are drawn to place the results on a map of the energy consumption of a country.

9.2. Mathematical Analyses

Such research could even lay the foundations for the development of a 'retrofit' solution for older vehicles. The data in the tables was provided by the vehicle's own software (My BMW). The objective function is as follows:

$$Max\sum_{i=1}^{12} R_i, \tag{1}$$

where

- R_i is amount of energy that can be recharged in the i-th month

The limits are as follows:

The amount of energy that can be recharged must not exceed the amount of energy consumed and the capacity of the battery.

$$R_i \leq E_i \leq E_{battery\_max}, \tag{2}$$

The energy that can be recharged depends on the charge level and the battery conservation factor:

$$R_i \leq C \times T_i \times E_i, \tag{3}$$

where:

- C—battery conservation factor,
- T_i—Average charge when connected (%),
- E_i—Average monthly electricity consumption (kWh).

For the purposes of the study, it was appropriate to calculate monthly average quantities and to present the results on a monthly basis. Several battery conservation factors were introduced in the study and are listed in Table 4. The conservation factors were chosen to set a moderate limit to protect the battery. A value of 0.5 means that only 50% of the battery is allowed to be recharged to the grid or building. The more permissive we are, the higher the value we need to set this factor to.

Table 4. Mitigation factors.

C_1	C_2	C_3	C_4
0.5	0.6	0.7	0.8

In addition to the factors described in the table, we observe that the amount of energy that can be recycled increases. Table 5 illustrates the basic data on a monthly basis. It is important to note that in very few cases the vehicle battery was almost fully discharged, so that the battery had some amount of current almost constantly, as illustrated in the first column of the table for monthly aggregation. In the second column of the table, the amount of current drawn during the charging process in a given month is shown, and in the last column, the amount of current stored for the whole month is shown. The last row of the table shows the total annual electricity stored depending on the user's habits.

Table 5. Monthly test loads and rechargeable energy.

	Amount of Electricity in the Battery During the Month (kWh)	Amount of Electricity Consumed During the Month (kWh)	Total Monthly Electricity Stored in the Month (kWh)
January	72.43	59	131.43
February	79	86	165
March	104	113	217
April	108	107	215
May	77	125	202
June	65	83	148
July	60	84	144
August	83	134	217
September	38	54	92
October	56	91	147
November	110	123	233
December	85	87	172
			2083.43 kWh

The first column of Table 6 shows the average percentage of charge for the month when the vehicle was connected to the charger, the second column shows the same value but in kWh. The third column shows the average amount of electricity charged per month.

Table 6. Monthly averaged data.

	Average–Load at Connection (%)	Average–Amount of Current in Battery When Charging (kWh)	Average–Amount of Electricity Consumed per Charge (kWh)	Average–Sum Monthly Amount of Electricity (kWh)
January	56	4.26	3	7.26
February	47	3.59	4	7.59
March	47	3.6	4	7.6
April	49	3.71	4	7.71
May	35	2.66	4	6.66
June	40	3	4	7
July	37	2.85	4	6.85
August	35	2.68	4	6.68
September	38	2.89	4	6.89
October	37	2.79	5	7.79
November	45	3.43	4	7.43
December	46	3.52	4	7.52

Table 7 illustrates the results under different battery conservation factors. It can be clearly seen that for different conservation factors, the amount of energy that can be recharged varies, and the more permissive we are, the more electricity can be recharged.

Table 7. Re-feedable quantities for different C_x values.

	C_1—Average Amount of Electricity That Can Be Recycled (kWh)	**C_2—Average Amount of Electricity That Can Be Recycled (kWh)**	**C_3—Average Amount of Electricity That Can Be Recycled (kWh)**	**C_4—Average Amount of Electricity That Can Be Recycled (kWh)**
January	2.0328	2.43936	2.84592	3.25248
February	1.78365	2.14038	2.49711	2.85384
March	1.786	2.1432	2.5004	2.8576
April	1.88895	2.26674	2.64453	3.02232
May	1.1655	1.3986	1.6317	1.8648
June	1.4	1.68	1.96	2.24
July	1.26725	1.5207	1.77415	2.0276
August	1.169	1.4028	1.6366	1.8704
September	1.3091	1.57092	1.83274	2.09456
October	1.44115	1.72938	2.01761	2.30584
November	1.67175	2.0061	2.34045	2.6748
December	1.7296	2.07552	2.42144	2.76736
	18.64475	22.3737	26.10265	29.8316

The trend is clear from the data. The question is whether the amount of electricity that can be recycled in one year (last row of Table 7) for the hybrid vehicle under study is enough for practical applications.

Figure 1 illustrates Table 7 in graphical form.

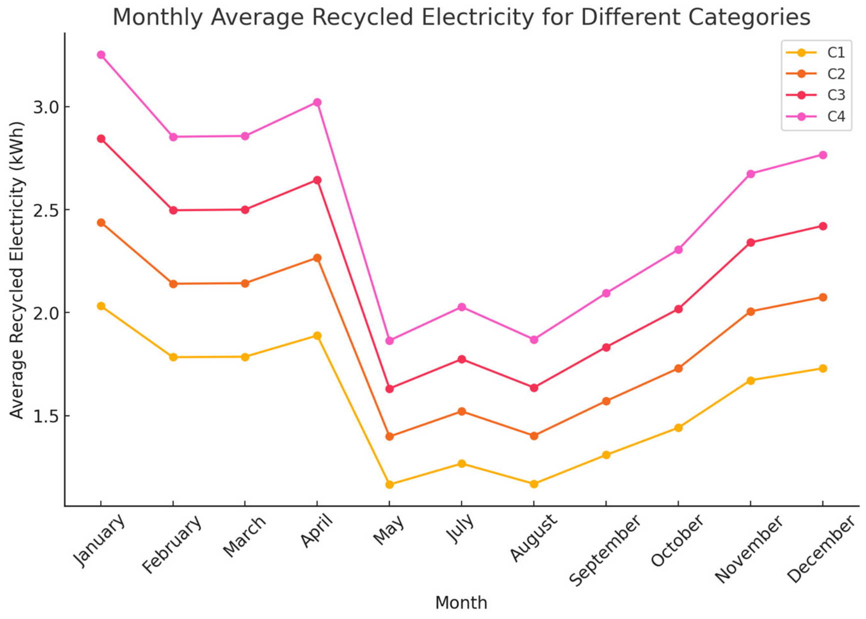

Figure 1. Re-feedable quantities for different Cx values.

The results show that not only full electric vehicles but also hybrid vehicles can be part of an energy community and contribute to the stability of the electricity network. The amount of electricity that can be recharged ranges from 18.6 to 29.8 kWh, depending on the configuration. These values represent the total energy contribution over the course of a year.

10. Critics and Future Work

Using the method described in the previous chapter, it is possible to statistically demonstrate that it is possible to recycle electrical energy from the battery of a hybrid vehicle, even with a smaller capacity. A further question is: what could the annual energy recycled from such a vehicle be enough for?

As can be seen from [30], electricity consumption in the European Union varies widely between Member States. The average electricity consumption for households in the EU was 1.584 kWh (approx. 1.6 MWh) in 2022. The data show striking differences, for example, in Romania and Poland, consumption is below 1 MWh per hour, and there are Scandinavian countries (Finland (4.1 MWh) or Sweden (3.9 MWh)) where consumption is close to or above 4 MWh per capita. Table 8 illustrates the consumption of some European countries [30,81].

Table 8. Re-feeding and percentage distribution [30,81].

	Annual Consumption—kWh	Reuseable Electricity—kWh	
EU average	1.584	18.6447	1.177%
		22.3737	1.4124%
		26.1026	1.6478%
		29.8316	1.8833%
Romania	800	18.6447	2.3305%
		22.3737	2.7967%
		26.1026	3.2628%
		29.8316	3.7289%
Sweden	3.900	18.6447	0.478%
		22.3737	0.5786%
		26.1026	0.6692%
		29.8316	0.7649%

A comparison of the values obtained in the analysis of the vehicle under consideration is shown in Table 8 for the EU average, Romania (least consumer) and Sweden (most consumer).

Table 8 relates the EU average and the two extremes. The table shows that Sweden's reintroduction values are below 1% of 1-year consumption, while Romania's can be above 3.5% per household.

This value may seem very small, but readers should not just look at the data for one household and one vehicle and should look instead at the data for an established energy community. In such a community, where users store and share energy across multiple devices and appliances, an electric or hybrid vehicle with a small battery capacity can play a six-fold greater role. One can even think of safety aspects, where small-capacity batteries can be used to run some equipment for longer periods of time, such as for hospital or medical equipment, refrigerators, freezers, etc.

As the chapter explains, such a vehicle can store and recharge relatively little energy. It is important to look beyond this limitation. Vehicles need to be understood at the fleet level, where the cumulative effect of stored and returned energy needs to be investigated in further research. We should not forget the rapid development of battery technology, which could further enhance the role of vehicles in achieving energy independence. V2G solutions could encourage battery manufacturers to produce batteries with longer battery life. Longer lifetime, greater charging and discharging flexibility will be key issues in the future.

In addition, the so-called secondary market for batteries is of paramount importance. This means that degraded batteries can be reused simply as storage batteries for buildings or renewable energy sources. V2G technology can therefore extend the life cycle of batteries and create new business opportunities in the energy storage market.

There are several open questions in the study that require further research. These include charging and infrastructure development, integration of the technology and grid connection of larger capacity batteries within the energy community.

Challenges and Practical Implications

This research highlights a number of implications and technical challenges. These perspectives will help us to position hybrid vehicles appropriately within the energy supply chain.

- Energy Communities: It is essential for energy communities to see that hybrid vehicles provide only short-term energy security. It is important to note that even these small energy reserves contribute to the stability of the electricity grid.
- Policy: The creation of public subsidies is essential for the widespread adoption of this technology and for mitigating costs associated with battery degradation in vehicles.
- Manufacturers: Retrofitting older hybrid vehicles could further expand the V2G market.
- Infrastructure: Replacing aging electricity networks is essential. Additionally, it is important to take into account the geological characteristics of settlements, e.g., holiday resorts with a high number of visitors at certain times of the year, remote or hard-to-reach areas, etc.
- Users: Financial incentives play an important role in encouraging the spread of technology, a point linked to policy making.

If this technology becomes widely adopted and the regulatory environment becomes optimal, fossil fuel use in urban environments could be greatly reduced and vehicles could provide energy to buildings and/or hospitals in the event of a disaster. In the long run, communities could also save money on energy costs.

With these points, the article sets out a broad set of challenges and opportunities, which should be explored in the future.

11. Summary

Today, reducing our carbon footprint and energy exposure is essential. Hybrid—and in the future, all-electric vehicles—will be a big help in solving these problems.

These vehicles are not only changing the way we travel, but they are also shaping new urban and energy goals, such as smart cities or energy communities. In the future, vehicles will no longer be stand-alone devices but will become part of cities and buildings. A new area of advancement for this is vehicle-to-grid and V2X technologies in general. Many regulatory problems are still to be discovered for this technology, but not all vehicle manufacturers are integrating the technology into their vehicles, so its take-up is slow. In the European Union, the emergence of energy communities has given an impetus to manufacturers and electricity suppliers to be open to the new technology.

As shown in this article, hybrid vehicles have significant potential despite their smaller battery capacity. The findings highlight the competitive disadvantage of European car manufacturers and the importance of integrating electric and hybrid vehicles into smart cities and renewable energy systems.

Identifying three major areas for future development is key:

- Scalability of V2X technologies: Investigate V2G for the largest possible energy communities. That is, what is the maximum size of the energy community where the technology can be used? What are the new challenges?

- Integrating AI for energy management and grind balancing: Which artificial intelligence and machine learning methods can be integrated into a flexible energy community?
- Standards, rules: What standardized guidelines can be developed? This could include regulations for energy sharing, battery swapping, business models, etc.

By using real vehicle data and relevant literature, the article provides a solid research basis for future studies on V2G technology and related regulatory and standardization research.

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