Міністерство освіти і науки України

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У матеріалах збірника викладено результати досліджень у галузі технічних та економічних наук. Розглянуто шляхи підвищення ефективності промислових виробництв, автоматизації, контролю та керування технологічними процесами. Важливе місце займають питання енергозбереження, економіки, надійності охорони праці, техніки безпеки, захисту довкілля.

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VIABILITY OF VEHICLE-TO-GRID TECHNOLOGY AND RENEWABLES IN UKRAINE

Purpose. Assessment of economic feasibility of the ‘vehicle-to-grid’ technology (co-generation to the grid from the electric vehicle’s battery) for the car owner. Evaluation of financial indicators and estimation of conditions when this technology may become attractive for all the stakeholders of electric mobility market.

Methodology. Forecasts of the National Commission for Electric Energy Regulation of Ukraine, as well as analytical data and information from manufacturers of electric vehicles are used in the study. Analysis of daily charging/travelling schedule, ratings of power vs. capacities are used for the evaluation of financial expenditures and profits of the car owners.

Findings. The overview of renewables in Ukraine and electric mobility in particular are carried out, their feasibility is assessed. The tariffs on electricity from renewables are analyzed, the share of renewable energy sources in Ukraine in future is forecasted. Aspects of V2G technology are analyzed in detail – the use of vehicles’ batteries as intermediate energy storage, their charging during cheap night tariffs and co-generation during high demand in order to level electricity consumption on the grid level. It appears that the rated power of charging stations is a ‘bottle-neck’ – the main limiting factor. Besides. it is shown that reduction of batteries’ service life makes the V2G idea inexpedient for the car owner, unless the green tariff will rise.

Originality. It is proven that V2G technology would become feasible if the battery capacity increases, the power rating of charging/generation stations gets bigger and the special green tariff for co-generation from electric vehicles is introduced.

Practical value. Electricity tariff rates as well as other data necessary for calculations of V2G feasibility are given.

Keywords: renewables, green tariff, electric vehicles, co-generation, feasibility study

The problem and its relationship with scientific and practical objectives.

Renewables and electric vehicles (EVs) are widely discussed around the world. Both these technologies are often referred to as ‘green’, ‘clean’ or ‘environmentally friendly’. Reduction of CO2 emissions is also one of the incentives from international organizations like the United Nations Development Programme.

Meanwhile, it is admitted that the share of renewable energy sources in total energy generation is still small. Most countries provide themselves with energy by burning gas and coal, i.e. fossil fuels, in rare cases, like in France or Ukraine, the major energy resource is nuclear power. Electric vehicles are actually not ‘100% green’ – they are charged with electricity, derived from ‘non-green’ power stations. To make our environment really cleaner, renewable energy is to be deployed at far greater scale than it is now.

It is known that both technologies in question are very expensive yet. Wind turbines and photovoltaic (PV) panels can not compete with gas stations when it comes to price of kilowatt-hours of electricity. The price for electric cars rapidly declines, but their batteries are still a liming factor. They are expensive to buy, degrade with time quicker than other vehicle components and require recycling.

That is why many international foundations together with countries’ authorities provide financial incentives to promote renewable energy and electric mobility. Governments buy kilowatt-hours generated by renewables at a high price, and EV-manufacturing companies like Tesla or Nissan provide free-of-charge replacement of batteries [1].

The big question is whether renewables will still be feasible when government incentives will run out. Ukraine in this respect is an interesting case – PVs are being supported by the government, EVs are not, but both things rapidly grow. In our study, we tried to make a sober assessment of economic aspects of the technologies in question and look at the sheer feasibility of them.

Analysis of research and publications.

Regarding energy generation, Ukraine is in somewhat unique position. It inherited heavy industry and powerful generating facilities from the Soviet Union. After the collapse of the latter, as well as economic and political turmoil, the industry gradually declines [2].

Electric power stations meanwhile are still in place. There is a powerful river Dnipro in Ukraine with 9 hydropower plants, the capacity of the biggest one (the Zaporizhzhya Hydropower Plant) reaching 1.5 mln. kW. Besides, there are 4 nuclear power plants, including the biggest one in the City of Energodar which has 6 blocks of 1 mln. kW each – it covers some 25% of the country's energy demand. The diagram in Fig. 1 [3] shows the forecasted distribution of energy generation facilities up to 2035.

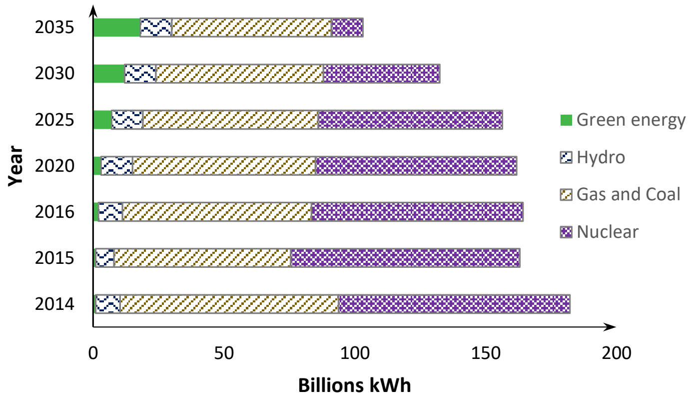


Fig. 1. Forecast of energy generation by types in Ukraine

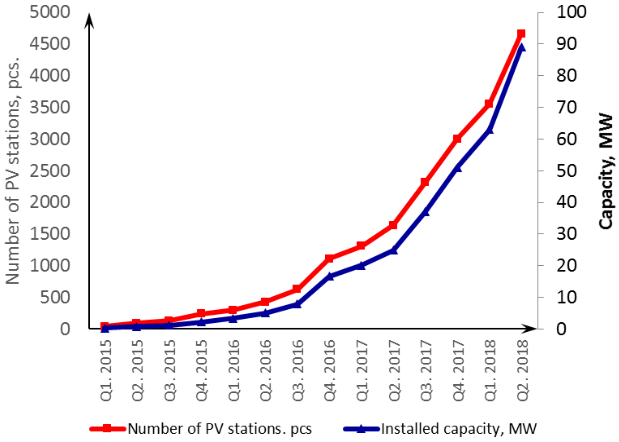
That is why, electricity in Ukraine is one of the cheapest in the world, the price of one kWh is roughly 0.06 euro [4]. France, having biggest share of nuclear power in the world, enjoys low electricity price, too, but it is way higher than in Ukraine –0.1462 euro per kWh, which is nevertheless 26.5% cheaper than the EU average (20.02 euro cents per kWh) [5].

Without a doubt, renewables can not compete with conventional energy in Ukraine. Apart from some remote areas far from centralized grid, it has been completely inexpedient, moneywise, to install wind turbines or PV panels. Ukrainian government has proclaimed its course towards green energy and developed financial mechanisms promoting their wider use. For certain reasons, they have become truly effective only recently and it sparked a rapid growth of installation of PV stations in Ukraine, as it is shown in Fig. 2 [3, 6].

Currently, small PV station of 10 kW costs roughly EUR 15 000, the payback period is around 4-5 years.

From Fig. 2, the growth rate of PV stations in Ukraine looks very promising, but the situation is not that optimistic. Green tariff, which is the main reason for this development, will go down. The idea was to improve the technology of renewables by its practical use, and hopefully reduce the prices for solar and wind stations by promoting wider manufacturing. Nevertheless, it should be understood that such policy is actually a financial burden for the governments' budgets. In Germany, for example, the idea did not play out as it was expected – the country heavily invested in the development of PV technology, but 1) PV stations did not generate as much energy as it was anticipated, because Germany is a cloudy country, and 2) Chineese manufacturers captured technological achievements and entered the market with way lower prices [7].

Therefore, eventually governments will stop supporting renewables with green tariffs. Initially, the ratio of green tariff and price on conventional kWh was 10:1, currently it is about 3:1. Supposedly, at certain point the cost (not price) of 'renewable kWh' will be competitive, if not equal to the price of the kWh derived from fossil fuel. The National Energy and Utilities Regulatory Commission of Ukraine [4] forecasts that it will happen in 2030. The green tariff will decline, while the price on conventional kilowatt-hour will, of course, keep growing as it is depicted in Fig. 3 [3].



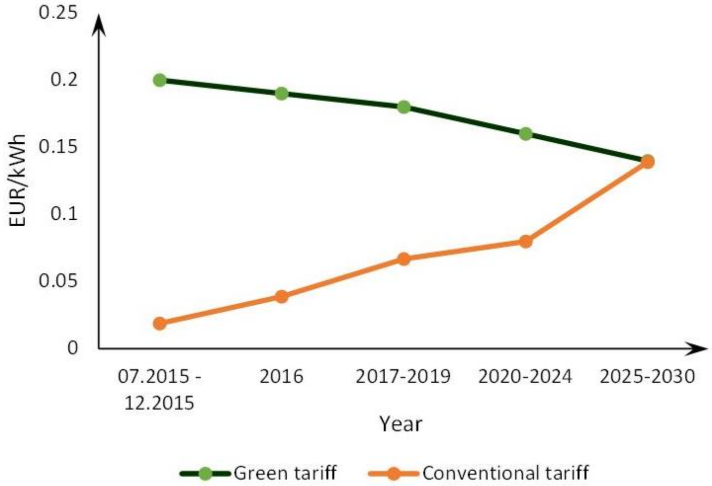


Fig. 2. Growth of PV stations in Ukraine

Fig. 3. Green tariff and price for conventional electricity in Ukraine up to 2030

Thus, time is running out. In ten years, we will have between 5% and 8% of renewables in total energy generation of Ukraine. Together with hydropower, that will constitute up to 18% of 'green' energy in Ukraine, and this is the clean energy to rely on.

Research objectives.

Considering the trends of technology and tarrifs, we will try to evaluate the economic attractiveness of renewables in Ukraine. Electric vehicles, being a part of global trends, should be assessed separately. They are energy consumers on the one hand, and can be used as enegy storages on the other. Both these usages are stimulated by the tarrifs on electricity, thus, we will estimate whether it will be expedient for the car owner to engage in V2G technology and what are the tarrifs which could make it attractive.

Material presentation and results.

Simply speaking, driving on electricity is extremely cheap in Ukraine. It is because 1 liter of gasoline costs about 1 EUR, roughly equal to the fuel price in Europe, while 1 kWh of electric energy costs about 1/6th of its European price.

An average sedan-size car needs about 16 kWh for 100 km, which means that driving 100 km on electricity costs less than 1 EUR, while driving this distance on gasoline is 6-8 EUR in the urban driving cycle. Even taking into account additional costs for EV battery maintenance, this makes a striking difference. That is why Ukraine demonstrates such a rapid growth of EV sales - +402 % in 2017 (Europe - +78%, China - +175%) [8]. The sales of conventional cars meanwhile has dropped by 68%, partly due to ongoing economic recession, but mainly, for the obvious benefits of EVs.

The lion's share of EV market belongs to Nissan Leaf – one of the cheapest electric vehicles. The share of used Leafes accounts 76% of all the EVs in Ukraine, though this number tends to decrease (in 2016 it was 87%).

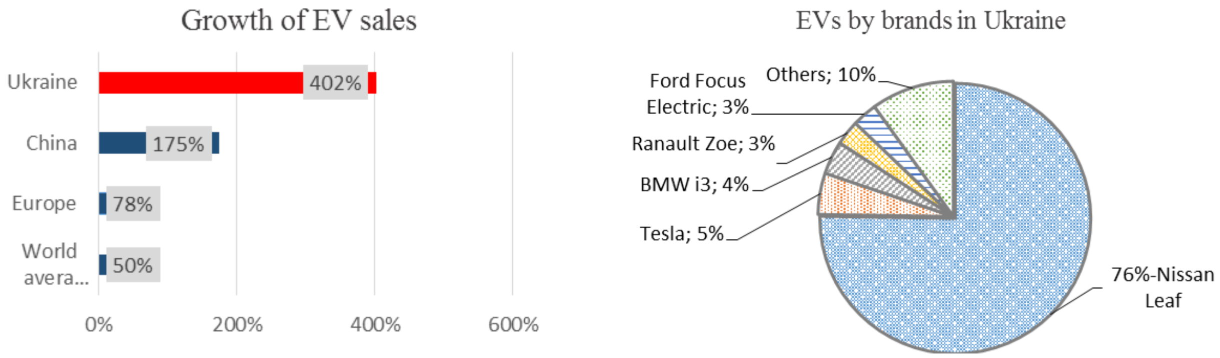


Fig. 4. EV sales and in Ukraine in 2018

Take into account that the charging infrastructure in Ukraine merely exists. There are only several fast charging stations in big cities and some quantity of slow-charging stations. Moreover, the government provides no viable financial support to promote electric mobility in the country. All this shows that having EV in Ukraine is de-facto very feasibly in itself.

Meanwhile, the impact of EVs on environment is a contradictory issue. The technology of internal combustion engines is very mature. The so-called 'well-to-wheel' efficiency and 'well-to-wheel' CO_2 emissions, i.e. energy and emissions calculated taking into account all the stages of energy production and conversion, is roughly equal for conventional and electric cars [9].

Perhaps, gasoline cars are even environmentally 'cleaner' – the on-board catalytic converters and other measures to reduce the harmful substances in modern cars often work better than filtering devices at coal power stations. Nevertheless, electric vehicles have one fundamental advantage, which is electric braking. When vehicle decelerates, some part of its kinetic energy can be captured and put back to the battery, which is impossible in case of gasoline cars. That is why, EVs will always need less equivalent kilowatt-hours than conventional vehicles. Inevitably, conventional cars will cease to exist.

Vehicle-to-Grid Concept

The idea of V2G is to use the batteries of electric vehicles as a temporary storage of electric energy in order to level the loads in electric grids [10]. EVs parking time, as well as most conventional private vehicles, is 85% [11]. Their batteries could be charged during the nighttime, when the load onto the network is low (and electricity is cheap, and then discharged back to the grid during the hours of peak demand. The timing suits fine both utilities and EV-owners. Utilities could benefit from smoothed demand curve, and EV owners can earn money on the difference between the charging/discharging tariffs.

Actually, projects like Tesla Powerwall and Tesla Powerpack serve the same purpose. Such big investments should demonstrate the viability of the V2G concept, too; the thing is that the increase of charging cycles reduces the battery service life. The question is whether it will be feasible for EV-owners to earn extra money with the help of their electric cars, but have a need to replace it sooner. We will try to evaluate that in the next section.

Case Study: Private PV-Station and Co-Generating Electric Vehicle

To assess the user-side economics, let us take typical middle-class household in Ukraine. In winter people often use electric heating in addition to gas/coal or wood pellet furnaces, and, besides, spend more energy on illumination as the daylight hours are shorter. In summer, air conditioning is one of the major consumers. The average latitude in Ukraine is 48° and the intensity of solar irradiation is about 1380 kW/m^2 [12]. The chart in Fig. 5 illustrates the daily consumption versus generation for a typical household with 10 kW PV station.

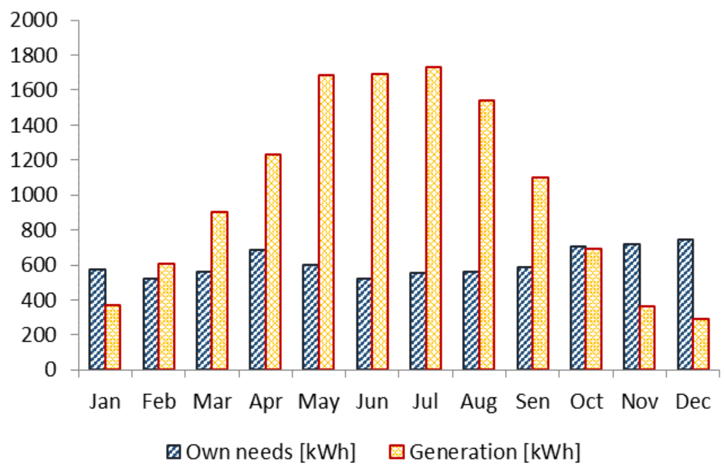


Fig. 5. Average daily consumption of the typical household and PV generation (10 kW station)

Table 1.

Provides indicative financial figures for three PV stations of 10 kW, 20 kW and 30 kW capacities respectively [4].

Indicator	PV capacity [kW]		
	10	20	30
PV station cost (with installation) [EUR]	14489	24155	32500
Annual generation [kWh]	14747	26269	36657
Average daily generation [kWh]	72.2	144.4	216.6
Average daily consumption for own needs* [kWh]	12.1		
Average gross daily income [EUR]	9.6	21.2	32.7
Gross annual income [EUR]	3509.8	7726.3	11942.8
Payback [years]	4.1	3.1	2.7

*Only the daylight hours are counted

The data show that PV station is a good investment with payback period of 3-4 years. The bigger the rating of the station, the more daily income is, given that the consumption is constant. That is why, despite the bigger capital investment, the payback for more powerful station is shorter.

Of course, there are far more factors than simple capital cost versus daily generation, the cost of land, for example. But these factors lie beyond the scope of this study, we just want to illustrate the feasibility of PVs and give indicative dependencies.

To assess the attractiveness of V2G for a typical EV owner, we assume that he or she commutes daily to and back from work, the average daily travelling range is 68.5 km [11]. Thus, 11 kWh for actual driving is needed. Out of 40 kWh battery of Nissan Leaf, the EV owner has 29 kWh in his disposal that can be charged during the night at cheap tariff and sell to the grid when the vehicle is parked (given that there is a charging station that allows recuperation to the grid). Since there is no special tariff, we assume that the owner will be paid at current green tariff rates. Table 2 summarizes calculations of time, energy and money on the user-side. Note that 11 kWh needed for commuting are not taken into account, as this energy the owner would use to travel anyway.

We have taken discharge power at 3 kW, equal to charging in the ‘slow’ mode.

The typical mid-class worker arrives to work at 8:00 and leaves at 18:00. That gives ten hours of parking time, or 30 kWh to generate to the grid. But he cannot afford that, because he needs charge to drive back home (not to mention that no one will agree to deplete the battery completely). That is why, actual generation time is less than time allows.

Table 2.

Calculation of V2G indicators

Time		Power and Energy		Money	
Daily commuting [h]	2	Battery capacity [kWh]	40	Charging tariff [EUR/kWh]	0.03
Available parking time [h]	10	Energy expenditures for travelling [kWh]	11	Green tariff [EUR/kWh]	0.18
Available night charging time [h]	12	Available energy for generation [kWh]	29	Daily expenditures for charging* [EUR]	0.87
Actual generation time [h]	7	Charge/discharge power [kW]	3	Daily profit from generation [EUR]	5.22
Actual night charging time [h]	11	Actual generation [kWh]	29	Gross annual income [EUR]	1131

*Energy needed for commuting is not taken into account

Thus, the calculations show that battery capacity is a main limiting factor. If a vehicle had a battery of bigger capacity and rated power were higher, it would use all the available time windows and the owner would profit more.

However, more important is that the gross annual income is not that big to make this idea attractive for the owner. First, very important aspect to be considered is the reduction of battery service life because of the increase of annual charge/discharge cycles. The dependence is nonlinear, the deeper the discharge, the faster degrades the battery. Safe estimate is 300 charging cycles reduce battery capacity by 20% [13-15]. Assume that the owner will be compelled to replace the EV battery when its capacity drops down to 80% (which is a rather realistic assumption). When commuting only, the battery service life is 4.2 years. When using the battery for V2G, it has to be fully charged and completely depleted daily, the service life will not exceed 1.5 years. Given the high price for battery (roughly EUR 5000 for Nissan Leaf's 40 kWh), the user will earn nothing – all the accumulated profit will be spent to buy new battery.

It is to be taken into account that EV owners will unlikely tend to deplete their batteries completely, always preferring to keep some level of charge in their EVs' batteries.

Of course, this is a very rough calculation. We have taken many assumptions, the charging tariff extremely cheap, and generation (green) tariff very lucrative and still it shows that this idea is not viable now.

In future, when there will be far more EVs in European cities which will be able to provide essential support for the utilities for the load levelling, and when the charging/co-generation infrastructure is in place, and batteries are cheap – then, the V2G option will be viable

Conclusions and futher research.

The viability of PV generation worldwide and in Ukraine in particular depends exclusively on government support. As the green tariff declines, so will be the number of newly installed PV stations. Eventually, they'll occupy some small niche in the country's power generation and will keep growing slowly with the advancements in technology;

electric vehicles are viable and expedient for end users even without governments support. No matter how gas/electricity prices vary in future, regenerative braking will always make a decisive advantage of EVs. All the trends in technology play in favor of electric mobility;

The viability of V2G concept remains doubtful. Particularly, in Ukraine it doesn't likely to play out due to the lack of infrastructure and government incentives. When the infrastructure will be deployed at sufficient scale, the green tariff will be already too low to make it feasible for EV-owners. To make it feasible, the following tendencies are to take place:

a) Increase of battery capacity;
b) Improvement of fast charging technology;
c) Reduction of batteries' vulnerability to the number of charging cycles;
d) Increase of the difference of night and peak tariffs, or special 'EV tariff' from electric utilities.

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Блок информации

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ТЕХНІКО-ЕКОНОМІЧНЕ ОБҐРУНТУВАННЯ ТЕХНОЛОГІЇ КОГЕНЕРАЦІЇ ІЗ ВИКОРИСТАННЯМ ЕЛЕКТРОМОБІЛІВ

Мета роботи. Оцінити економічну привабливість альтернативної енергетики, і, зокрема технології «Vehicle-to-grid» (V2G), тобто використання батареї електромобіля для когенерації в мережу. Визначити економічні показники та умови, за якими ця технологія стане привабливою для власників електромобілів.

Методи дослідження. Для розрахунку економічних показників використані прогнози Національної комісії регулювання електроенергетики України, дані аналітики та виробників електромобілів.

Отримані результати. Виконаний огляд тенденцій в галузі альтернативної енергетики в Україні і, зокрема, електричної мобільності в контексті їх економічної доцільності. Проведено аналіз тарифів на електроенергію, отриману від відновлених джерел і зроблений прогноз щодо частки альтернативної енергетики України в майбутньому. Розглянуті аспекти технології V2G – використання батареї електромобілів як проміжного накопичувача енергії, заряджання їх під час низького нічного тарифу на електроенергію і віддачі в енергомережу для часткового покриття пікового навантаження. Показано, що скорочення терміну служби батарей через збільшення циклів заряду-розряду робить цю ідею непрацездатною за сучасним рівнем тарифу на когенерацію.

Наукова новизна. Доведено, що для забезпечення привабливості технології V2G для власника електромобіля необхідне збільшення ємності акумуляторів електромобілів, підвищення потужності пристроїв заряджання і розряджання та підвищення рівня «зеленого» тарифу або встановлення спеціального тарифу для когенерації від електромобілів.

Практична цінність. Надані числові значення тарифів на електроенергію та параметри заряду-розряду батарей електромобілів, необхідні для техніко-економічного обґрунтування технології когенерації з батарей електромобілів в енергомережу. Визначені межі тарифів та параметри системи, за якими технологія V2G стане самоокупною.

Ключові слова: відновлювана енергетика; зелений тариф; електромобілі; когенерація; тех-ніко-економічне обґрунтування.

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ТЕХНИКО-ЭКОНОМИЧЕСКОЕ ОБОСНОВАНИЕ ТЕХНОЛОГИИ КОГЕНЕРАЦИИ С ИСПОЛЬЗОВАНИЕМ ЭЛЕКТРИЧЕСКИХ ТРАНСПОРТНЫХ СРЕДСТВ

Цель работы. Оценить экономическую привлекательность альтернативной энергетики и, в частности технологии «Vehicle-to-grid» (V2G), то есть использование батареи электромобиля для когенерации в сеть. Определить экономические показатели и условия, по которым эта технология станет привлекательной для владельцев электромобилей.

Методы исследования. Для расчета экономических показателей использованы прогнозы Национальной комиссии регулирования электроэнергетики Украины, данные аналитики и производителей электромобилей.

Полученные результаты. Выполнен обзор тенденций в области альтернативной энергетики в Украине и, в частности, электрической мобильности в контексте их экономической целесообразности. Сделан анализ тарифов на электроэнергию, полученную от возобновляемых источников энергии и сделан прогноз касательно доли альтернативной энергетики в энергогенерации Украины в будущем. Рассмотрены аспекты технологии V2G - использование батареи электромобилей в качестве промежуточного накопителя энергии, зарядка их во время низкого ночного тарифа на электроэнергию и отдачи в энергосеть для частичного покрытия пиковой нагрузки. Показано, что сокращение срока службы батарей из-за увеличения циклов заряда-разряда делает эту идею несостоятельной при текущих уровнях тарифов на электроэнергию.

Научная новизна. Доказано, что для обеспечения привлекательности технологии V2G для владельца электромобиля необходимо увеличение емкости аккумуляторов электромобилей, повышение мощности заряда и разряда и уровня «зеленого» тарифа или введение специального тарифа для когенерации от электромобилей.

Практическая ценность. Даны числовые значения тарифов на электроэнергию и параметры заряда-разряда батарей электромобилей, необходимые для технико-экономического обоснования технологии когенерации от батарей электромобилей в энергосеть. Определены граничные значения тарифов и параметры системы, при которых технология V2G может стать экономически оправданной.

Ключевые слова: возобновляемая энергетика; зеленый тариф; электромобили; когенерация; технико-экономическое обоснование.