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DECARBONIZATION MANAGEMENT: DEVELOPMENT OF A SYNERGY MODEL OF ELECTROMOBILITY FOR CLIMATE CONSERVATION

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МЕНЕДЖМЕНТ ДЕКАРБОНИЗАЦИИ: РАЗВИТИЕ СИНЕРГЕТИЧЕСКОЙ МОДЕЛИ ЭЛЕКТРОМОБИЛЬНОСТИ ДЛЯ СОХРАНЕНИЯ КЛИМАТА

The work uses an integrated approach, methods of analysis and synthesis. The research is based on the official data of world economic statistics, the study of data from international news agencies and organizations.
The changes in the planet's climate under the influence of emissions of harmful substances into the atmosphere are shown. The analysis of the existing processes allows us to judge that the world community is already fully aware of the severity and possible consequences of climate change, but is not yet ready for taking radical effective measures to stabilize the situation. The need for systemic measures to preserve the climate was noted. It is pointed out that in the process of decarbonization management, the development of electromobility, which should be combined with environmentally-friendly methods of generating electrical energy, occupies the most important place. The synergistic effect of the proposed model for the development of electromobility is manifested in the fact that it can receive support not only from supporters of electromobility, but also from those who support the construction of private houses to ensure comfortable living for people.
The analysis of the calculated indicators of obtaining electrical energy for different conditions is carried out. It is shown that among many options for using the synergetic model, there are those that quite reliably provide electric vehicles and households with energy.
A synergetic model is proposed, which includes the management of a set of factors to ensure the process of balanced development of electric mobility, which has a number of advantages: ease of placement of electric vehicles; no air pollution; the possibility in some cases of fully charging electric vehicles with their own energy, meeting the needs of households, as well as the supply of excess energy to the external electricity grid; the ability to charge electric cars at home with your own charger, while such charging is not limited in time.
Such synergetic model of electric mobility development should contribute not only to the widespread use of electric vehicles, but also to the creation of comfortable living conditions for people, so it can be much more attractive for implementation.
The results of the work can be used in practice in the process of managing the development of real complexes of objects associated with the operation of environmentally-friendly transport.

У роботі використано комплексний підхід, методи аналізу та синтезу. Дослідження ґрунтується на офіційних відомостях світової економічної статистики, вивченні даних міжнародних інформаційних агенцій та організацій.
Показано зміни клімату планети під впливом викидів шкідливих речовин в атмосферу. Аналіз існуючих процесів дозволяє судити про те, що світова спільнота вже повною мірою усвідомлює гостроту та можливі наслідки кліматичних змін, але поки що не готова до радикальних дієвих заходів щодо стабілізації ситуації. Відзначено необхідність системних заходів щодо збереження клімату. Вказується, що у процесі менеджменту декарбонізації найважливіше місце займає розвиток електромобільності, яке слід поєднувати з екологічними способами отримання електричної енергії. Синергетичний ефект запропонованої моделі розвитку електромобільності виявляється в тому, що вона може отримати підтримку не лише прихильників електромобільності, а й тих, хто підтримує будівництво приватних будинків для забезпечення комфортного проживання людей.
Виконано аналіз розрахункових показників отримання електричної енергії для різних умов. Показано, що серед багатьох варіантів використання синергетичної моделі, існують такі, які цілком надійно забезпечують електромобілі та домогосподарства енергією.
Запропоновано синергетичну модель, що включає управління комплексом факторів забезпечення процесу збалансованого розвитку електромобільності, яка має низку переваг: зручність розміщення електромобілів; відсутність забруднення атмосфери; можливість у ряді випадків повної зарядки електромобілів власною енергією, задоволення потреб домогосподарств, а також постачання надлишкової енергії у зовнішню електричну

мережу; можливість заряджання електромобілів дома за допомогою власного зарядного пристрою, при цьому така зарядка не обмежується за часом.
Така синергетична модель розвитку електромобільності має сприяти як широкому поширенню електромобілів, а й створенню комфортних умов життя людей, отже може бути набагато привабливішою для реалізації. Результати роботи можна використовувати практично у процесі управління розвитком реальних комплексів об'єктів з експлуатацією екологічного транспорту.

***Key words**: management; decarbonization; synergistic model; development of electromobility; climate change of the planet; World Meteorological Organization; emissions.*

***Ключові слова:** менеджмент; декарбонізація; синергетична модель; розвиток електромобільності; зміни клімату планети; Всесвітня метеорологічна організація; викиди.*

Introduction. The increasingly visible changes in the planet's climate require urgent measures to curb this process. The development of specific steps in this direction should be accompanied by a study of decarbonization management issues, so that the measures taken are supported by the society and implemented.

Analysis of recent research and publications. The problems of management, innovative development of enterprises, the creation of effective mechanisms for the functioning of companies are touched upon, in particular, in works [1-7], such authors as V.V. Prokhorova, O.V. Bozhanova, YU. Appelo, O.V. Dykan′, S.M. Illyashenko, N.I. Chukhray, O.P. Prosovych, V.M. Protsenko, V.I. Chobitok, V.M. Heyets′, V.P. Semynozhenko.

At the same time, there is a significant number of issues of managing the course of the decarbonization process, in the context of the maturation of the planet's climate, which has not yet received a detailed study and needs further research.

The **arm** of the article is to develop a synergistic model, which includes the management of a set of factors to ensure the process of balanced development of electromobility.

Results. In recent years, more and more attention has been paid to the study of climate problems on the planet. One of the most authoritative international organizations is the World Meteorological Organization, which is an agency of the United Nations. [8].

Analysis of the Greenhouse Gas Bulletin [9] of the World Meteorological Organization showed the following:

- the temperature of the planet’s atmosphere will continue to increase due to the impossibility of not only reducing the existing level of carbon dioxide emissions, but also maintaining the current level;
- the defining forecast can only be the growth of carbon dioxide emissions;
- it is indicated that even a very intense reduction in CO_2 emissions “to a net zero level” will not lead to a decrease in global temperature, which is due to the duration of the existence of carbon dioxide molecules;
- the inertia of maintaining the temperature on the planet, as suggested by the World Meteorological Organization, even in the absence of an increase in carbon dioxide emissions, will be calculated for many decades;
- CO_2 emissions lead not only to an increase in global temperature, but to natural disasters, hurricanes, floods, destruction of housing and industrial facilities, landslides and changes in relief;
- adverse climatic events lead to very large economic damage;
- the melting of ice in the oceans, mountain glaciers is characterized by dimensions unknown to the history of mankind;
- the concern that the ability of terrestrial ecosystems and oceans to act as sinks may become less effective in the future, which will reduce their ability to absorb CO_2 and act as a buffer against larger increases in temperature;
- the rise in temperature on the planet will be even more intense, not only under the influence of the growing economic activity of man, but also due to the destruction of the protective mechanism of nature, which functioned earlier and is dangerously lost today.

Secretary General of the World Meteorological Organization Professor Petteri Taalas noted: “The Greenhouse Gas Bulletin contains a stark, scientific message for climate change negotiators at COP26. At the current rate of increase in greenhouse gas concentrations, we will see a temperature increase by the end of this century far in excess of the Paris Agreement targets of 1.5 to 2 degrees Celsius above pre-industrial levels. We are way off track.” [9].

The opinion of the Secretary-General of the World Meteorological Organization is shared by the UN Secretary-General António Guterres, who at the summit of world leaders within the framework of the UN climate conference (COP26, Glasgow, autumn 2021), in particular, pointed out: “Six years after the Paris Climate Agreement became the hottest years in history. Our planet is changing before our eyes - from ocean depths to mountain peaks; from melting glaciers to unforgiving extreme weather events.” António Guterres commented on the efforts of various countries to reduce the destruction of nature and commitments for the future: “And even if the recent promises were clear and credible - and some of them raise serious questions - we are still heading for a climate disaster. Even in the best case, the temperature will rise significantly above two degrees ... ”[10].

It can be stated that climate change is an acute concern, and the current prevailing trends and the possible state of the planet in the future seem extremely alarming. This requires urgent, energetic action by the world community, thoughtful and effective action.

The preservation of the planet's climate can be facilitated by the widest use of energy that does not harm the environment. It is of interest to what extent the possibilities of generating such types of energy are real.

Analysis of data from the US Energy Information Administration [11] for the period 2011-2020 showed (Table 1) that only one time there was a value of the installed capacity factor of wind power generators less than 32% (31.8% in 2012), three times - value over 32%, five times over 34%. In general, over 10 years there has been an increase in this indicator, which reached 35.3% in 2020. Analysis of the monthly data array of the US Energy Information Administration [11] showed that the lowest value was 22.9%, the highest reached 44%, while in general there is a tendency to increase the installed capacity factor of wind power generators, which can be explained as an increase in the number of windy days per year, and technical improvement of wind turbines.

According to the US Energy Information Administration (Table 1), only once was the installed capacity factor of solar power generators less than 20% (19% in 2011), with the greatest value taking place in 2014 and 2017 (25.6%) [11]. It is noteworthy that the value of the installed power factor of solar power generators is more stable, but its value is significantly less than that of wind power generators. At the same time, the analysis shows that in the case of solar power generators, there are very noticeable fluctuations in the installed capacity factor in different months throughout the year, while in the summer it is highest [11].

Comparison of wind and solar power generators with some other types of primary sources of electricity for the analyzed period in terms of the installed capacity factor showed the following:

- hydroelectric power plants had an ICUM from 35.7 to 45.8%, which is noticeably more solar power, but in some years it can be comparable to wind power plants, although in general the latter are still steadily inferior to hydroelectric power plants;
- nuclear power generators were distinguished by the highest capacity factor, surpassing solar ones by 4-4.5 times, wind ones by about 2.5-3 times, their consistently high performance in combination with the high power of nuclear power plants and the absence of carbon dioxide emissions makes them currently the most important source of electricity, which is likely to be relevant for the next several decades;
- gas power generators had a capacity factor of about 54-67%, which is significantly higher than solar and wind ones, somewhat more hydroelectric generators, but they are inferior in terms of capacity factor to nuclear power plants, while gas power plants are the only ones we have considered that still emit carbon dioxide and other harmful emissions, although and in much smaller quantities than, for example, thermal, using bituminous or brown coal, fuel oil.

Table 1

Dynamics of installed capacity factors of electric generators, according to the Energy Information Administration (EIA) USA [11]

Type of power generators	Years									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Solar photovoltaic,%	19	20,4	24,5	25,6	25,5	25	25,6	25,1	24,3	24,2
Wind,%	32,1	31,8	32,4	34	32,2	34,5	34,6	34,6	34,4	35,3
Hydroelectric power plants,%	45,8	39,6	38,8	37,2	35,7	38,2	43	41,9	41,2	40,7
Atomic,%	89,1	86,6	90,8	91,7	92,3	92,3	92,3	92,5	93,4	92,4
Gas,%	54,1	59,6	55,9	54	60,8	64,8	62,8	65,4	67,4	64,6

Taking into account the possibility of use, the stability of work depending on the weather, the presence of wind, the possibility of generating large amounts of electricity, the strategic need for decarbonization, it is advisable to use various types of power plants in combination:

- coal-fired thermal power plants, which are today the most important element of the world energy, must be gradually, but with a steady consistency, decommissioned, which is likely to occur in the world extremely unevenly, in some countries, for example, Germany, for one and a half to two decades, in many others, for at least three to four decades;
- nuclear power plants, which have many important advantages, will obviously retain their influence in most countries (except, for example, Germany) for several decades, and in a number of countries, such as France, they will be dominant or close to this value;
- wind and solar power plants with the most important perspective will actively develop, increasing many times, gradually occupying leading positions, while wind power plants will be transferred to the coastal waters of the World Ocean, in varying quantities will be located in urbanized areas, solar power plants, located on the roofs of buildings and buildings in cities, will additionally extend to many deserts of the planet, economic activities in which are currently extremely limited and which cannot be used for other purposes;
- gas power plants will retain their importance and receive a new impetus for development during the transition period, until the energy of renewable energy sources allows them to almost disappear;
- for several decades, the electric power industry requires the existence of different types of power plants, in which the advantages of some types of energy production will compensate for the disadvantages of others, with the general mainstream development of global decarbonization.

An important tool for preserving the planet's climate is the use of clean energy and electric vehicles in the complex. To supply electric vehicles with very interesting, it seems, can be proposed, in cases where it is possible, a synergistic model for the development of electromobility (Fig. 1), the essence of which is the widespread development of private households for people to live, on whose territory there will be capacities for the production of solar, wind energy, individually or in combination, chargers, energy storage devices, garages for electric vehicles, while these objects can both be connected to the mains and be autonomous.

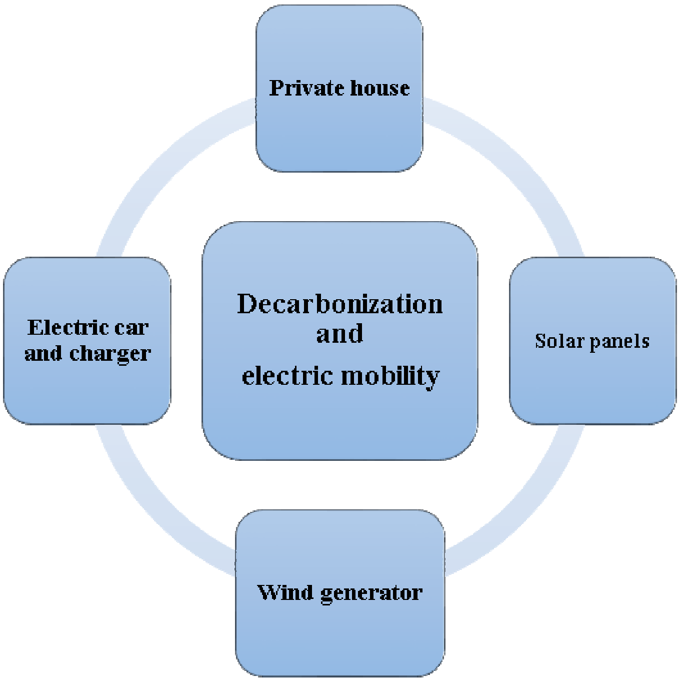

Figure 1. Synergistic model for the development of electromobility

This synergistic model has a number of advantages (Fig. 2):

- convenience of placing electric vehicles, no need for external garages, no time spent on the road to them and back, which is especially significant in bad weather conditions;
- no air pollution;
- the possibility, in some cases, of fully charging electric vehicles with their own energy, meeting the needs of households, including for heating in winter, as well as supplying excess energy to the mains;
- the ability to charge electric vehicles on site using their own charger, while such charging is not limited in time.

Such a synergistic model for the development of electromobility should contribute not only to the widespread use of electric vehicles, but also to the creation of comfortable living conditions for people, which means it can be much more attractive for implementation. It can be part of national and international decarbonization and electromobility programs in the framework of global climate preservation.

Research into the use of private household power generators for provision is considered subject to the following conditions:

- land plots on which a private residential building, outbuildings, garages for electric vehicles are located, etc. there must be a sufficiently large area that allows the use of solar panels and wind generators, individually or in combination, while various capacity options for these energy sources are possible, requiring different areas;
- in the options under consideration, the wind intensity will be sufficient to maintain the operation of wind turbines with a large number of windy days per year;
- the intensity of solar energy and the duration of the effective operation of solar generators are quite large, while there is a relatively large number of sunny days during the year;
- an external electrical network may or may not be present, in the latter case, sufficient capacity of storage batteries is required to save electricity;
- availability of chargers, the power and quantity of which meet the needs;
- with a lack of its own energy generated by wind, solar generators or their combination, it is required to supply electricity from the mains, in the absence of it, the possibility of using electric vehicles will be limited by the amount of its own energy.

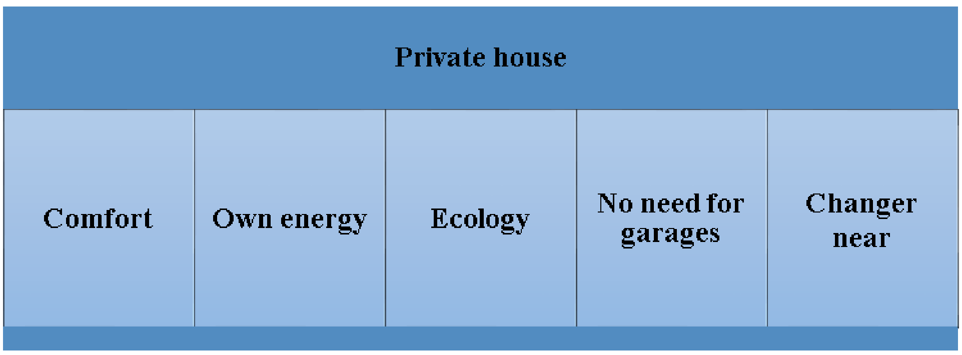

Figure 2. Benefits of the synergistic model

Let us consider various design options for the production and charging of electric vehicles using the synergistic model we are considering (Table 2).

Table 2

The ability to manufacture and charge electric vehicles

№ option	Type of electric generator	Capacity of electric generator, kW	Electricity generation, kWh per day	Charging level, % at electric vehicle battery capacity, kWh	
				48	82
1	solar	1	5	10,4	6,1
2		3	15	31,2	18,3
3		5	25	52	30,5
4		10	50	104	61
5		20	100	208	122
6	wind	1	8	16,7	9,8
7		3	24	50	29,3
8		5	40	83,3	48,8
9		10	80	166,7	97,6
10		20	160	333,3	195
11	combination solar / wind	1 / 1	13	27,1	15,9
12		3 / 3	39	81,3	47,6
13		5 / 5	65	135,4	79,3
14		10 / 10	130	270,8	158,5
15		20 / 20	260	541,7	317

Option 1 (Table 2) of using "green" energy to supply electric vehicles provides for the use of a 1 kW solar power plant, which generates 5 kW / year of electricity per day. This is capable of charging a battery with a capacity of 48 kW · year by 10.4%, and a significantly larger battery with a capacity of 82 kWyear only by 6.1%. In both cases, the energy produced is very insufficient and the mains will be required to charge the electric vehicle. The transition to a solar station of greater and then substantially greater capacity will allow the generation of energy, which, even if it does not fully charge the battery of an electric vehicle, at least greatly contributes to this.

For a car battery with a capacity of 48 kW · year, full charge will be provided with a solar power plant of about 10 kW, while the state of charge of a battery with a capacity of 82 kWyear will be only 61%. To fully charge such a battery, you will need a solar station power of about 17 kW.

The use of wind power generators allows generating, in the presence of wind, electricity not only during the day, but also at night, all year round with a higher installed power factor than solar stations. Option 11 (Table 2) of using "green" energy to supply electric vehicles provides for the use of a 1 kW wind farm, which generates 8 kW · year of electricity per day, which is capable of charging a 48 kW · year battery by 16.7%, and battery with a capacity of 82 kW · year - by 9.8%.

For a vehicle battery with a capacity of 48 kW · year, a full charge will be ensured at a wind farm capacity of just under 7 kW. To fully charge a car battery with a capacity of 82 kW · year, you will need a wind power plant of about 11-12 kW.

The use of a combined source of electricity as part of a solar and wind power plant makes it possible to provide, under favorable conditions, a noticeably larger amount of it. So, for example, even with a solar and wind power plant of 5 kW each, each energy will be quite enough to charge a battery with a capacity of 48 kW · year, but still not enough to charge a battery with a capacity of 82 kW year. The large capacity of electric generators will allow not only to provide charging of an electric vehicle, but also to use electricity to supply a household or send energy to the electric grid.

The need to use an electric vehicle does not necessarily imply full battery charging every day. In many cases, a significantly lower battery charge, corresponding to a certain daily mileage of an electric vehicle, will be sufficient. Let us consider the degree of charging of electric vehicles according to the variants of conditions (Table 2), taking for 100% the charge that corresponds to the mileage of an electric vehicle of 150 km with an electricity consumption of 13.5 kW · h/100 km. According to the calculated data (Fig. 3), in the first variant of the conditions, the daily production of electricity provides only 25% of the daily mileage of an electric vehicle and an external energy source is required to meet the demand. The possibility of fully satisfying the daily needs of an electric vehicle with its own solar energy appeared only in the third variant of conditions (generator power 5 kW). In the case when the power of the generator is 10 and 20 kW, energy is generated that provides 250 and 500% of the demand, respectively.

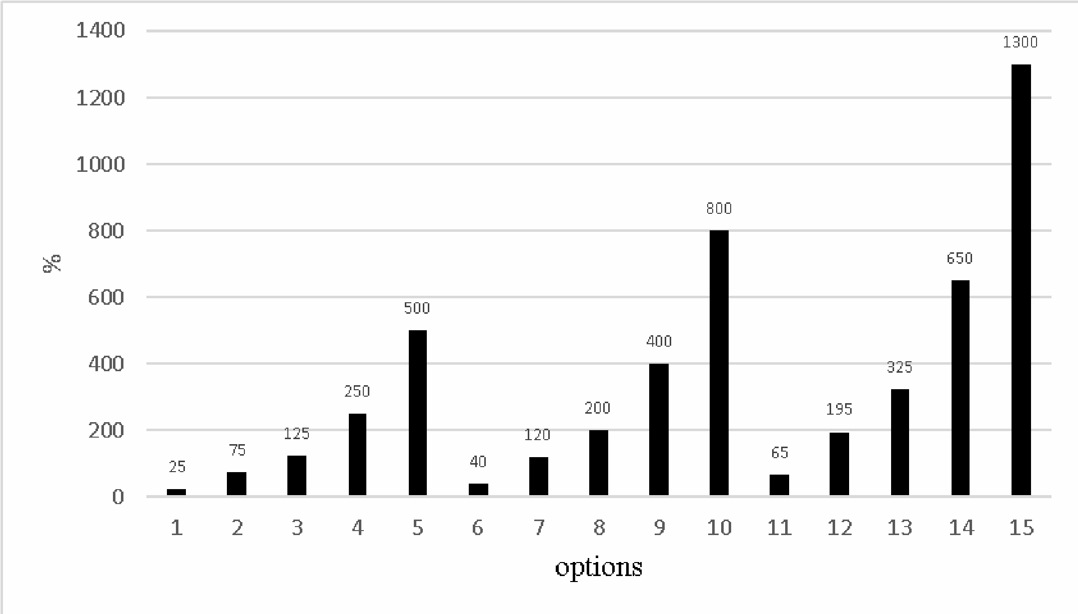

Figure 3. The state of charge of the batteries by options

When using wind energy, the possibility of generating energy to meet the daily mileage requirement are the following: for example, already with a generator power of 3 kW, there is enough energy for 120% of the needs, with a power of 10 and 20 kW, respectively, for 400 and 800% of the needs.

With the combined use of solar and wind generators (Fig. 3), even with the power of these devices of 3 kW, each (option 12) provides 195% of the daily mileage of an electric vehicle. In the case of options 14 and 15, energy will be generated for 650 and 1300% of the demand, respectively.

Calculations show that among the range of options for using a synergistic model of energy production for electric vehicles using solar, wind generators or their combination, there are those that quite reliably provide electric vehicles and households with energy and make such a model quite workable.

Conclusions. Thus, we can state the following: under the influence of already noticeable environmental changes and numerous natural disasters, the problem of climate preservation is gradually becoming one of the most important problems of mankind. The world community is already fully aware of the severity and possible consequences of climate change, but is not yet ready for radical effective measures to stabilize the situation. In the context of the management of the decarbonization of the economy, it seems quite appropriate to use a synergistic model for the development of electromobility, which provides for a combination of comfortable living for people in private households with the production of solar and wind electricity used for the functioning of such a model.

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