Politehnica University from Bucharest

Doctoral School of Electrical Engineering

Increasing the autonomy of electric cars using photovoltaic panels

PhD Thesis Summary

Author:

Ing. Alexandru ȚURCANU

Scientific coordinator

Prof. Dr. Ing. Aurelian CRĂCIUNESCU

BUCHAREST

2023

Contents

Chapter 1- Introduction

In this paper, a study is presented on the possibility of increasing the autonomy of electric cars by placing photovoltaic panels on their roof. The study is structured of a practical section and a theoretical section, with the role of validating the experiment.

In the practical section of the work, an experimental assembly was made with the help of a solar panel placed on the roof of a car traveling along an imposed route and then in the parking lot, in the city of Constanța, Romania. As a result of the experiment, the electric power and the electric energy obtained with the help of solar panels were determined. With the help of the energy results obtained with the solar panel, by extrapolating the capture surface to the surface of the roofs of 6 models of electric cars, the maximum electrical energy available through the use of solar panels was obtained. Subsequently, the 6 electric cars chosen for the study were subjected to EUDC and ECE-15 performance tests to determine the electrical energy consumed. By combining the values of the available electrical energy obtained with the help of the solar panels and the results of the electrical energy consumed during the performance tests, the distance that can be traveled by each electric car model, using only the solar panels, was determined. This distance represents the extended autonomy of electric cars by placing photovoltaic panels on their roof.

In the theoretical section of the paper, a series of simulations were carried out using the Matlab-Simulink language, in order to obtain electrical power and electrical energy, simulating the conditions during the practical experiment. By comparing the practical results with the theoretical ones, reasonable deviations were obtained, which validates the experiment.

At the end of the paper, a proposal business plan was created for the implementation of mobile charging stations for electric cars, in order to increase their autonomy, up to the first charging point.

Chapter 2 - The current state of electric cars

2.1 Introduction

In table 2.1, 6 models of electric cars from the Romanian market, from the top of the best-selling electric cars of the year 2022 will be presented, with their characteristics necessary for the the study of resistive forces.

Table 2.1- Resistive force parameters of electric cars proposed for study

Car model	Weight (kg)	Aerodynamic drag coef.	Frontal area (m^2)	Rolling resistance coeff.
Hyundai Ioniq 5	1830-2115	0.288	2.64	0.0125
Renault Megane E-Tech	1708 kg	0.29	2.67	0.0125
Volkswagen E-Up	1160 kg	0.31	2.47	0.0125
Opel Corsa E	1455 kg	0.29	2.13	0.0125
Hyundai Kona Electric 2021	1685 kg	0.29	2.8	0.0125
Mazda MX-30	1660 kg	0.33	2.81	0.0125

Chapter 3- Electrical energy obtained along the route

3.1 Introduction

This chapter will present a practical experiment of obtaining solar energy with the help of a solar panel placed on the roof of a vehicle traveling on a route in the city of Constanța, over a total distance of 11.6 km round trip (5.8 km one-way trip) , in an interval of 25 minutes.

3.2 The configuration used to obtain solar energy

The experimental setup is composed of a 15 Wpk photovoltaic panel, 12 V, 7 Ah gel-lead battery, SM206-SOLAR pyranometer for measuring global radiation, IR thermometer, solar controller, a smartphone with an Android application for measuring tilt of inclination of the solar panel, a device for measuring the electric voltage, electric current, electric power and the electric energy produced by the solar panel, called "battery meter".

The energy produced by the solar panel was stored in a 12V, 7Ah, Pb battery, through the solar-charge controller, located inside the car on the right side. The programmable charge regulator, or solar controller, has implemented the PWM (Pulse Width Modulation) algorithm, works up to a maximum current of 30 A, has an LCD display and has two USB ports.

3.3 Acquisition of experimental data

During the journey, for the acquisition of the instantaneous values of the electrical parameters on the "Battery meter" module and the instantaneous values of the global radiation, a video recording was made with the help of a mobile phone, and the data were subsequently processed, based on the video recording and entered in a table.

The theoretical power was obtained using the values recorded for solar radiation with the help of the solar energy meter during the round trip. The theoretical power was obtained using equation 3.1.

$$Pth = \frac{\eta_p \cdot Ir_{global}}{1000} \tag{3.1}$$

where Pth is the theoretical power at 25 ^{0}C, η_p is the efficiency of the solar panel, Ir global is the global solar radiation measured by the solar energy meter. The results of the analysis between the theoretical power and the power generated during the round trip are highlighted in Fig. 3.1.

The electrical energy obtained with the help of the solar panel, during the trip, was highlighted as a function of time, in fig. 3.2.

To calculate the difference between the recorded values of the theoretical power and the values of the power generated by the solar panel during the trip, using equation 3.2, the relative error in percentage is calculated.

$$E_{rel} = \left(\frac{P_{th} - P_{ex}}{P_{ex}}\right) \cdot 100 \tag{3.2}$$

where E_{rel} is relative error, Pex is the power generated by the solar panel during the trip.

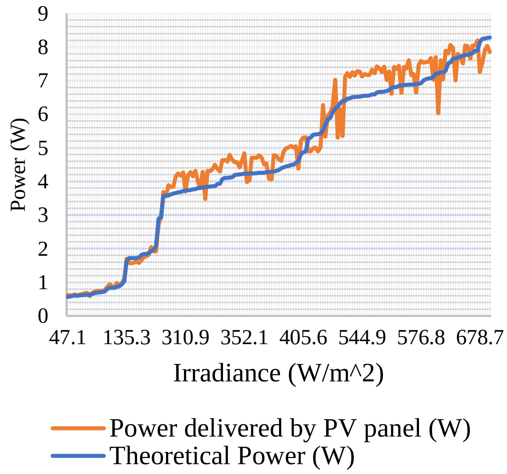

Fig. 3.1 – The power generated by the solar panel and the theoretical power as a function of solar radiation

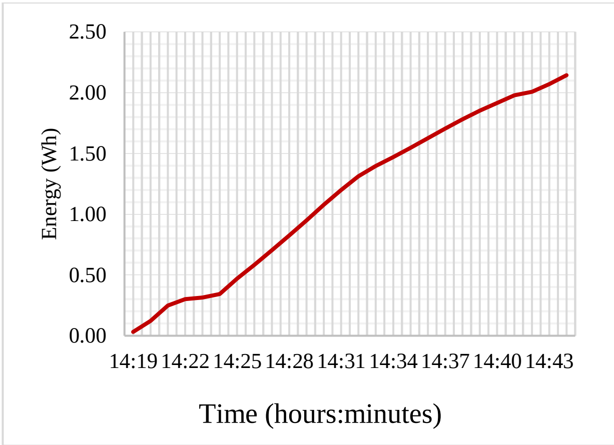

Fig. 3.2 – The amount of energy obtained on the route

3.4 The study of increasing the solar surface capacity of solar panels

When carrying out the current study to estimate the available surface for obtaining solar energy, two cases were chosen. In the first case, the surface available for capture is represented by the roof surface A_1 on which photovoltaic panels glued to the roof can actually be mounted, and is highlighted by formulas 3.7, 3.8, 3.9:

$$A1 = L \cdot w_1 \tag{3.7}$$

$$A1 = 1671\ mm \cdot 1024\ mm \tag{3.8}$$

$$A1{\sim}1.7\ m^2 \tag{3.9}$$

In the second case, the surface available for capturing A2 is represented by the surface of the roof on which a "trunk" type support can be mounted on which photovoltaic panels can be fixed, and is highlighted by equations 3.10, 3.11, 3.12:

$$A2 = L \cdot w_2 \tag{3.10}$$

$$A2 = 1671\ mm \cdot 1197mm \tag{3.11}$$

$$A2{\sim}2\ m^2 \tag{3.12}$$

In order to obtain the energy obtained by extension 1 and 2, E_{1d} , E_{2d}, equation 3.13, 3.14 were applied:

$$E_{1d} = \frac{A_1\ \cdot E_d}{A_{PV1}} \tag{3.13}$$

$$E_{2d} = \frac{A_2\ \cdot E_d}{A_{PV1}} \tag{3.14}$$

Applying equation 3.13 and 3.14, based on the energy obtained during the travel, the values for the energy through extension no.1 and no.2 were obtained, values that were entered in table 3.3.

Table 3.3- Extended energy obtained using solar panel

Total energy obtained (Wh)	**Energy obtained Ed (Wh)**	**Energy obtained by extension no. 1 E_{1d} (Wh)**	**Energy obtained by extension no. 2**
	2.14	36.44	42.84

For the energy obtained through extension no. 1, E_1, was obtained 36.44 Wh and for the energy through extension no. 2, E_2 was obtained 42.84 Wh. These values indicates the special energy potential represented by the placement of photovoltaic panels on the roof of the car during its movement.

Chapter 4 – Energy obtained by simulation along the route

4.1 Introduction

In this chapter, the values of the electric power obtained through simulation will be presented, in order to make a comparison with the electric power values practically obtained along the route, by the photovoltaic panel mounted on the roof of the car.

4.2 Simulation scheme

To create the simulation scheme, figure 4.1, the MATLAB/Simulink language was chosen, starting from the equivalent scheme for an assembly of photovoltaic cells, figure 4.2.

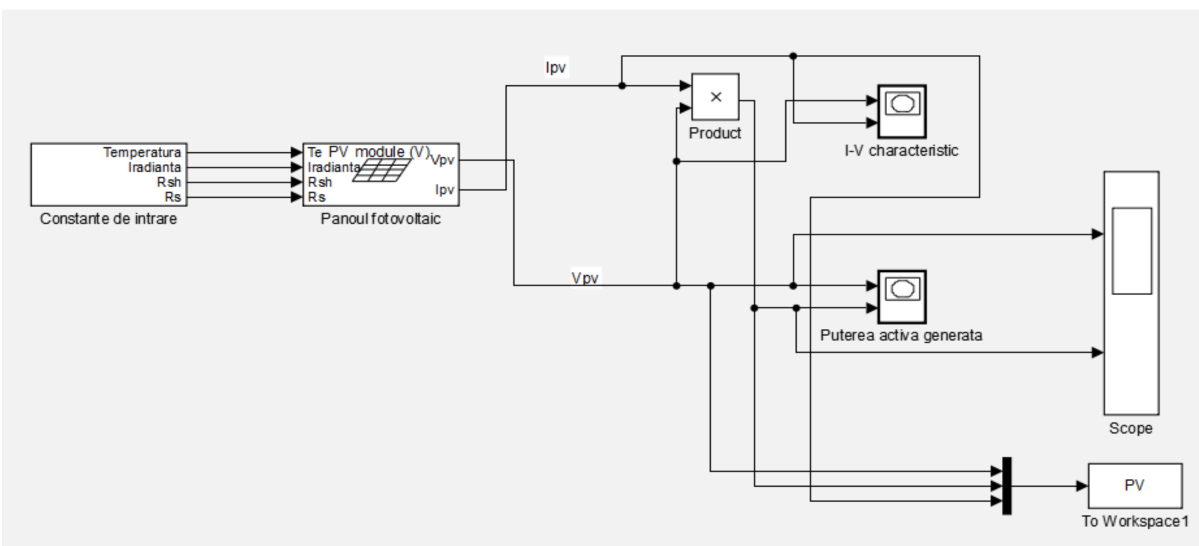

Fig. 4.1- General simulation scheme in Matlab-Simulink

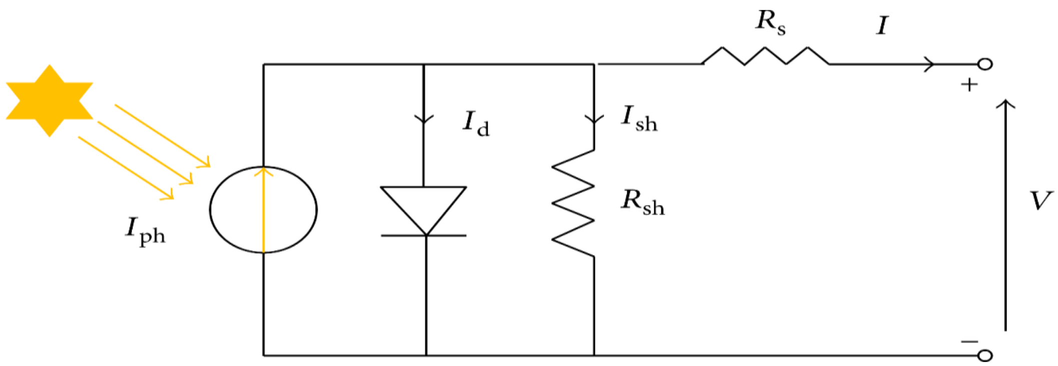

Fig. 4.2 – Equivalent circuit diagram of photovoltaic cell

Applying Kirchhoff's current law, we can write current as in equation bellow:

$$I = I_{ph} - I_d - I_{sh} \tag{4.1}$$

Using equation 4.1, the diode current I_d can be written as a function of the saturation current, I_s and obtain:

$$I = I_{ph} - I_S \left[exp\left(\frac{q(V + R_s I)}{KTN_s} \right) - 1 \right] - I_{sh} \tag{4.2}$$

4.3 Functional blocks

The simulation scheme, figure 4.1, is made up of the functional blocks: the "Input Constants" block, the "Photovoltaic Panel" block, the "Product" block, the "I-V characteristic" blocks, the "Electric Power Generated" block, the "Scope" block and the "PV-To Workspace". The "Photovoltaic panel" functional block, figure 4.4, was made based on formulas 4.1, 4.2, 4.3, 4.4, 4.5, 4.6 formulas that describe the equivalent circuit for solar cells.

$$I_{ph} = \left(I_{SC} + K_i(T - 298.15)\right) \frac{G}{1000} \tag{4.3}$$

$$I_S = I_{rs} \left(\frac{T}{T_n}\right)^3 exp\left[\frac{qE_g \left(\frac{1}{T_n} - \frac{1}{T}\right)}{nK} \right] \tag{4.4}$$

$$I_{sh} = \frac{(V + IR_s)}{R_{sh}} \tag{4.5}$$

$$I_{rs} = \frac{I_{SC}}{exp\left(\frac{qV_{OC}}{nN_s KT}\right) - 1} \tag{4.6}$$

To calculate Id, the function block Id was created, where Id is written as a function of the saturation current Is, using equation 4.7:

$$I_d = I_S \left[exp\left(\frac{q\left(V_{pv} + R_s I\right)}{nKTN_s} \right) - 1 \right] \qquad 4.7$$

4.4 Experimental results

By using the constants from table 4.1, the solar radiation variables and the measured temperature into the simulation scheme fig. 4.1 , the results from Table 4.3 were determined for the practically obtained electrical power, the simulated electrical power, and the relative error,

$$E_r = \frac{P_{sim} - P_{pr}}{P_{sim}} \cdot 100 \qquad (4.8)$$

Table 4.1 – Constants used in the simulation scheme

Constant	Description	Numeric value
V_{OC}	Open circuit voltage	13.5 V
I_{SC}	Short circuit current	1.1 A
K	Boltzmann's constant	$1.38\cdot10^{-23}$
N_S	Number of cells in series	24
N_P	Number of cells in parallel	12
G	Current solar radiation	638 W/m^2
1000	Reference solar radiation	W/m^2
K_i	Current/temperature coefficient	0.0017%/^{0}C
T	Temperature	298.15 ^{0}K
298.15	Reference temperature	298 ^{0}K
q	The charge of the electron	$1.6 \cdot10^{-19}$ C
E_g	The band gap of the semiconductor	1.1 eV
n	Coefficient associated with load carriers	1.3
R_S	Series resistance	24 mΩ
R_P	Parallel resistance	6 kΩ

Table 4.3 – Summary of results obtained along the route vs. simulation

	Solar radiation W/m^2	**Power practically obtained (W)**	**Power obtained by simulation (W)**	**Relative error %**
AVERAGE	388.09	4.85	4.42	10.37
MAXIM	690.9	8.2	7.87	12.17
MINIM	47.1	0.59	0.53	-10.16

Chapter 5 - Energy obtained in the parking lot

5.1 Choosing the conditions for the experiment

The place of coordinates 44°12'14.9"N, 28°37'07.2"E, was chosen for the experiment. The car was parked with the front side facing SW. The experiment took place on October 21, 2022, between 09:00 and 17:00, for 8 hours. Weather conditions were good with clear sky and light wind. The photovoltaic panel was placed on the roof of the car, on a metal frame adjustable in height, at

2 inclinations, of 45^0 and 0^0 respectively, in order to be able to compare the values obtained for the 2 angles.

5.2 Description of the experiment

For the experiment, was chosen the photovoltaic panel "Breckner 100 Wp", monocrystalline, with an efficiency of 22%, calculated using the generated power vs. panel surface at reference solar radiation (1000 W/m2).

The experimental assembly, fig. 5.1-a,b consists of: gel-lead battery 12 V, 7 Ah, for storing energy from the solar panel, pyranometer for measuring solar radiation, type "Solar meter" SM 206-SOLAR, Solar Controller , of PWM type, to maintain the constant voltage and regulate the current to control the charging process of the 12 V battery, a measuring equipment generically called "battery meter" capable of measuring and displaying parameters such as: electric voltage, electric current, electric power, electric power, internal resistance, an infrared thermometer to determine the temperature of the solar panel, a 12V/55W car light bulb as a consumer, a smartphone to measure the tilt angle of the photovoltaic panel, with an Android app installed to facilitate inclination measurement. The amount of energy produced by the solar panel was recorded by the "battery meter" measuring device, for the tilt angle of 0^0 and 45^0 and displayed as a function of time in Fig.5.4. By plotting the power generated by the solar panel during parking, Fig.5.2, the difference between the power generated at a tilt angle of 0^0 and a tilt angle of 45^0 was highlighted. The amount of energy produced by the solar panel was recorded by the "battery meter" measuring device, for the tilt angle of the solar panel of 0^0 and 45^0 and displayed as a function of time in Fig.5.3.

Fig.5.1 (a) – Structure of the experimental assembly

Fig. 5.1 (b) – Structure of the experimental assembly

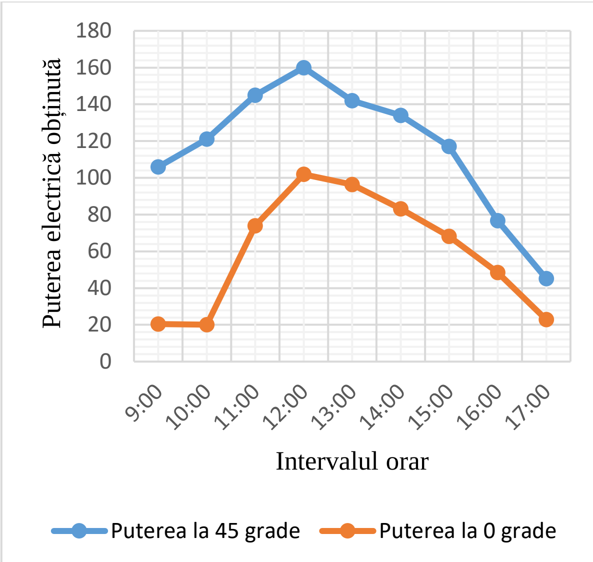

Fig. 5.2 – The electrical power obtained with the solar panel tilted at 0 and 45 degrees

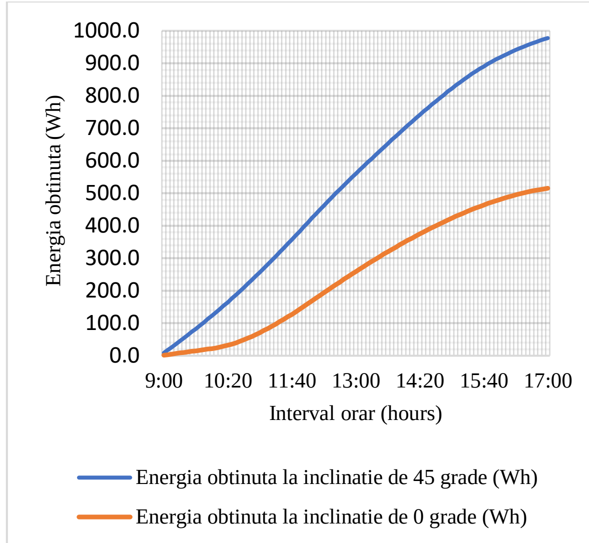

Fig. 5.3 – The electrical energy obtained with the solar panel at tilt angle of 0 and 45 degree inclination in the parking lot

5.3 The study of expanding the capture capacity of solar panels

In order to create an overview of the energetic potential offered by the placement of photovoltaic panels on the roof of the cars, the energy obtained through the solar panel will be extrapollated according to the roof surface of the car. For this purpose, based on the energy obtained in the parking lot, Ep, will be calculated the energy value in extenso Ep_1 and Ep_2.

The calculation of these energy values is based on the area of the Breckner 100 W panel used to capture energy in the parking lot, in the amount of 0.486 m^2. The calculation of the solar energy potential based on the roof area, formulas 5.1 and 5.2, lead to the formation of a complete picture of the solar potential on the roof of the car, obtaining the values of the energy in the parking lot. It should be noted that the chosen day is a sunny one, and the energy potential must be treated differently depending on the atmospheric conditions and the season.

$$E_{p1} = \frac{A_1 \cdot E_p}{A_{PV1}} \quad (5.1) \qquad E_{p2} = \frac{A_2 \cdot E_p}{A_{PV1}} \quad (5.2)$$

where Ep_1 and Ep_2 is the energy obtained by expanding the capture surface, Ep is the energy obtained with the solar panel in the parking lot, A_1 and A_2 are the extended surfaces no. 1 and 2 of the solar panels. For the obtained parking lot energy values Ep, in the time interval 09:00-17:00, the extended energy values Ep_1 and Ep_2 were obtained with the panel inclination at 180^0 and 45^0, table 5.1.

Table 5.1 – Electrical energy obtained in the parking lot by extending the capture surface

Solar panel energy at tilt angle of 45^0 Ep (Wh)	Solar panel energy at tilt angle of 180^0 Ep (Wh)	Solar panel energy at tilt angle of 45^0 Ep_1 (Wh)	Solar panel energy at tilt angle of 180^0 Ep_1 (Wh)	Solar panel energy at tilt angle of 45^0 Ep_2 (Wh)	Solar panel energy at tilt angle of 180^0 Ep_2 (Wh)
977.6	515.5	3419.6	1803.1	4023.0	2121.3

Knowing the values of energy obtained in parking lot and together with the values of energy obtained during travel, a total value of energy obtained, parking + travel can be estimated, a value that can be used later in the calculations to estimate the extension of autonomy. The values of the energyy obtained were listed in Table 5.2.

Tabelul 5.2 –Total elctric energy obtained through the roof's area extension

Solar panel energy at tilt of 45^0 Ep+Ed (Wh)	Solar panel energy at tilt of 180^0 Ep+Ed (Wh)	Solar panel energy at tilt of 45^0 Ep1+Ed1 (Wh)	Solar panel energy at tilt of 180^0 Ep1+Ed1 (Wh)	Solar panel energy at tilt of 45^0 Ep2+Ed2 (Wh)	Solar panel energy at tilt of 180^0 Ep2+Ed2 (Wh)
979.74	517.64	3456.04	1839.54	4065.84	2164.14

The obtained value of the total energy in extenso, Ep_2+Ed_2, in the amount of 4065.84 Wh, represents a promising result for charging the car's batteries sufficiently to extend its autonomy by the distance required to cover the road from home to work and vice versa on a sunny day , as the day when practical experiment has been hold.

Chapter 6- Electrical energy obtained by simulation in the parking lot

6.1 Introduction

In chapter 6, the solar radiation and temperatures values obtained practically from chapter 5 were compiled with the help of the Matlab-Simulink language according to the simulation scheme in figure 6.1, in order to be able to make a comparison between the values obtained practically and through simulation.

6.2 Simulation scheme

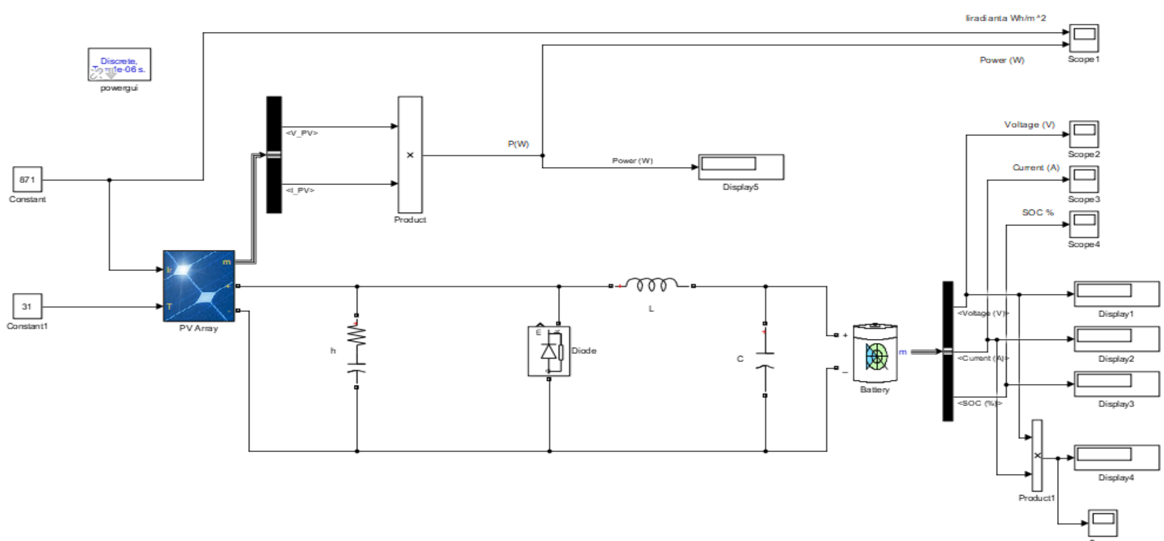

Fig.6.1 Simulation scheme for the solar panel placed on the roof of the parked car

The simulation scheme, fig.6.1 is composed of two constant blocks, solar radiation and temperature, the functional block "Battery" representing the battery, the functional block "PV

Array", representing solar panel, the RLC circuit, resistor and capacitor in parallel with the current source , the coil in series protection diode in parallel with the solar panel, and a filter capacitor.

6.3 The results obtained by simulation

After entering the constants and variables into the simulation scheme, the simulation scheme was compiled. The obtained values of electric power for each value of solar radiation and temperature of the solar panel measured with the pyranometer and IR thermometer, at panel inclinations of 0^0 and 45^0, were exported to an Excel table.

The electrical energy, expressed in Wh, was calculated using equation 6.1, considering the constant electrical power during the 5 minutes of the electrical power values sampling interval.

$$E_s = \int_0^t P_s(t) \cdot dt \tag{6.1}$$

where Es represents the energy obtained by simulation, Ps is the electric power generated by the Breckner 100 Wpk solar panel, and *dt* is the time interval when the integration of the electrical power was performed.

Figures 6.2 - 6.3 represents the values from table 6.1, creating the possibility for a comparison between the practically obtained values vs. simulation obtained values.

From figure 6.2, the accuracy of the results obtained experimentally can be noted in comparison with those obtained by simulation, the two curves of the electric powers running parallel at certain time intervals and at other time intervals the results of the simulation vs. practically being almost equal.

Figure 6.3 shows the electricity obtained by simulation at the inclinations of the Breckner 100 Wpk panel, of 0^0 and 45^0 , as a function of time, in the time interval 9:00 - 17:00. Note a value of the obtained energy of about 950 Wh with the solar panel tilted at 45^0 and an approximate value of 500 Wh for the energy obtained with the solar panel at the inclination of 0^0.

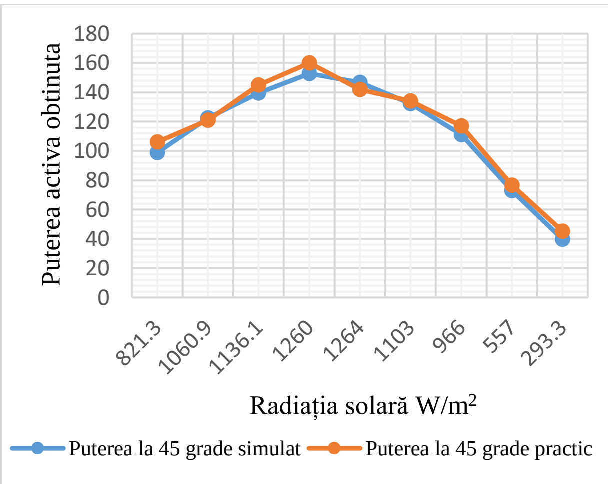

Fig. 6.2- The electrical power generated at the tilt angle of 45^0 simulation vs. practically

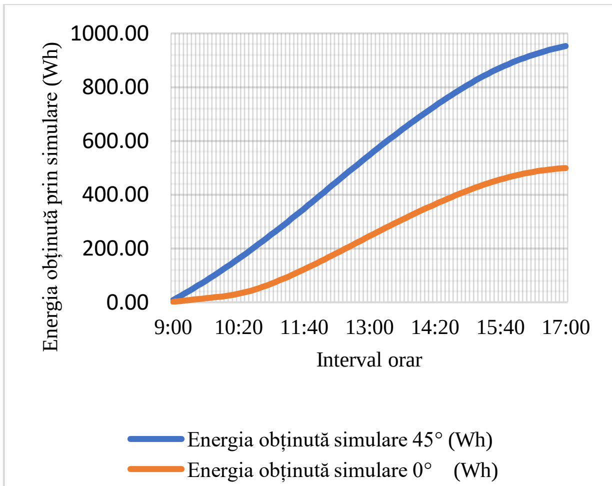

Fig. 6.3- Electrical energy obtained by simulation at the inclination of 45^0 vs. 0^0

Chapter 7 - Extending the autonomy of electric cars by placing photovoltaic panels on their roofs

7.1 Introduction

Chapter 7 has the final aim of presenting the results obtained regarding the extension of the autonomy of 6 electric cars by placing photovoltaic panels on their roof.

7.2 Selecting the electric cars for study

In order to choose the electric cars for the study, a market consultation was carried out in order to identify the best-selling electric cars from the year 2022 in Romania, and that they belong to different car manufacturers and are from different classes. The following cars were selected for the study: Hyundai Ioniq 5, Renault Megane E-Tech, Volkswagen E-Up, Opel Corsa E, Hyundai Kona Electric 2021, Mazda MX-30.

7.3 Available area of the roof of electric cars vs. available solar energy

In order to identify how much solar energy can be obtained from the roof of the sixth models of electric cars used for the study, the initial values for electrical energy from Table 7.1 were used.

To obtain the values from table 7.1, an experiment was carried out with a solar panel placed on the roof of a personal car. The personal car was parked in the residential parking lot. The photovoltaic panel was mounted on a mobile frame, with the possibility for set-up at 2 angles: 0^0 and 45^0.

The experiment was carried out in the city of Constanța, Romania, on a day of October 21, 2022, with a clear sky, in the time interval 09:00-17:00, in the place with the coordinates 44°12'14.9"N, 28° 37'07 ,2"E.

The experimental device consisted of the following component parts: an adjustable frame for the possibility setting the tilt angle of the solar panel, a gel-lead battery 12 V, 7 Ah for storing the energy obtained by the solar panel, solar energy meter SM 206-SOLAR for measuring solar radiation global, "battery meter" representing a measuring device capable of displaying electrical voltage, electrical current, electrical power, electrical energy, internal resistance and time, IR thermometer for measuring solar panel temperature, solar controller for maintaining constant voltage and regulating current from the solar panel to control the charging process of the 12 V battery, a smartphone with an Android application installed to measure the tilt angle of the solar panel to adjust it to the desired angle.

Table 7.1. Initial data obtained during the experiment using the solar panel

Tilt angle of solar panel	Solar panel area A_{PV} (m^2)	Total energy obtained with the 100 Wp solar panel E_{PV} (Wh)	Total power generated by the solar panel 100Wp Ppeak (W)
45^0	0.486	977.6 Wh	160 W
0^0		515.5 Wh	101.87 W

7.4 Average electricity consumption according to WLTP vs. available solar energy – extended autonomy 1.

A simple method of estimating the number of kilometers that the electric car can travel with the energy captured from the sun, is to make a calculation based on the average consumption of electricity declared by the manufacturers of electric cars, from table 7.3. Knowing the available energy from the roof, Eroof, and the average energy consumption, Ec, one can estimate the distance that can be traveled using only solar energy, Dpv1, easily calculated by equation (7.1) and shown in table 7.2.

$$D_{pv1} = \frac{E_{roof} \cdot 100}{E_c} \cdot \frac{1}{1000} \tag{7.1}$$

Table 7.2. Available energy for the surface of electric cars

Type of electric car for study	Basic dimensions (L·B·H) (mm)	The car's roof area A_{roof} (m^2)	Available energy E_{roof} (Wh)
Hyundai Ioniq 5.58 kWh	4636x1890x1605	1.692	3403.496
Renault Meganne E-Tech	4199x 1768x1505	2.135	4294.601
Volkswagen E-Up	3600x1645x1492	1.688	3395.45
Opel Corsa E	4060x1765x1435	1.76	3540.28
Hyundai Kona Electric 2021	4205x1800x1565	1.738	3496.026
Mazda MX-30	4395x1848x1555	1.873	3767.582

Table 7.3. The average energy consumption of the solar car

EV model	Average energy consumption according to the test (WLTP) E_c (Wh)	Available energy E_{roof} (Wh)	Extended energy 1 D_{pv1} (km)
Hyundai Ioniq 5	16.7 kWh/100 km	3403.496	20.38
Renault Meganne E-Tech	19 kWh/100 km	4294.601	22.60
Volkswagen E-Up	12.7-12.9 kWh/100 km	3395.45	26.32 - 26.74
Opel Corsa E	15.6-17.1 kWh/100 km	3540.28	20.70 - 22.69
Hyundai Kona Electric 2021	14.1 kWh/100 km[1] / 14.3 kWh/100 km[2]	3496.026	24.791, 24.452
Mazda MX-30	19 kWh/100 km	3767.582	19.83

7.5 Energy consumption of electric cars subjected to ECE and EUDC tests vs. available electricity - extended autonomy 2**.**

7.5.1 Resistive forces

To obtain the energy consumption of electric cars, the following equations were used to create the simulation scheme:

Moving resistance forces:

$$Fri = Fr + Faero + Fp + Fa \qquad (7.6)$$

Rolling resistance force Fr: $Fr = f \cdot m \cdot g$ (7.7)

Aerodinamic drag force F_{aero} [16]: $F_{aero} = \frac{\rho}{2} \cdot C_d \cdot A \cdot (v + v_0)^2$ (7.8)

Climbing resistance force Fp: $F_p = m \cdot g \cdot \sin\theta$ (7.9)

Inertial force Fa: $F_a = m \cdot a$ (7.10)

Power on wheels P_W: $P_W = F_t \cdot v$ (7.11)

Energy consumption E_c (t): $Ec(t) = \int_0^t P_w \cdot dt$ (7.12)

Acceleration a: $a = \frac{F_t - (F_{aero} + F_p + F_r)}{m}$ (7.13)

Speed $v(t)$: $v(t) = \int_0^t a \cdot dt$ (7.14)

Distance $D(t)$: $D(t) = \int_0^t v \cdot dt$ (7.15)

Torque T from the equation of traction force Ft:

$$Ft = \frac{T \cdot \eta \cdot i}{Rw} \qquad (7.16)$$

7.5.2 Tests ECE și EUDC

In this section, the speed values were imported from the UNECE R101 register and used to simulate an urban and extra-urban cycle, for 6 electric cars selected for this study.

Table 7.4 – ECE and EUDC tests characteristics

	Unit of measure	**ECE 15 test**	**EUDC test**
Distance	km	1.013	6.955
Time	s	195	400
Average speed	km/h	18.7 (cu opriri)	62.6
Maxim speed	km/h	50	120

The proposed simulation scheme provides facilities for changing certain constant parameters such as vehicle mass, slope inclination, rolling friction coefficient, car’s frontal area, wind speed.

7.5.3 MATLAB-Simulink simulation of ECE and EUDC cycles

To obtain the values of the equations for the energy balance of the electric vehicle, the MATLAB-Simulink language was used as a simulation environment. The language allows the input of function blocks, which simulate the equations of drag forces such as: aerodynamic drag force, inertial force, rolling resistance force, traction force, climb force. With the help of the simulation scheme, Fig.7.1, the values of the energy consumed during the EUDC test, Fig.7.2, the energy consumed during the ECE cycle, Fig.7.3, and the power required at the wheels in the EUDC cycle, Fig.7.4 were obtained and in the ECE cycle, Fig. 7.5.

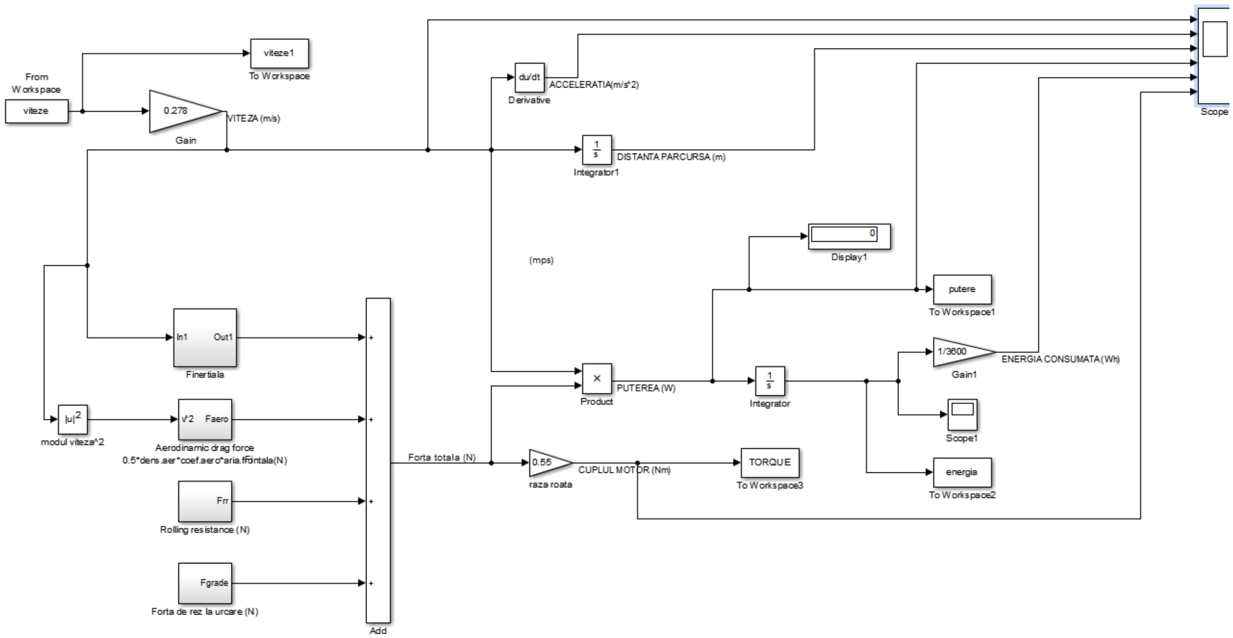

Fig. 7.1 - Simulation scheme in Matlab-Simulink

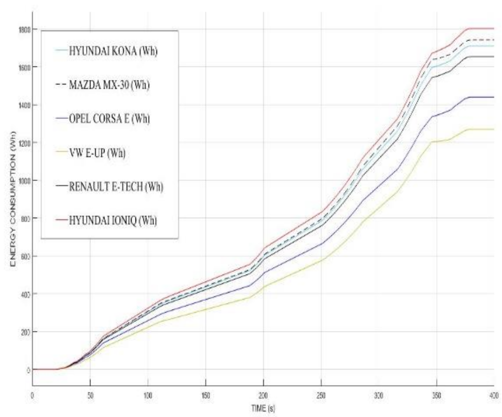

Fig. 7.2 - Simulation graph "Energy consumed as a function of time" in the EUDC scenario

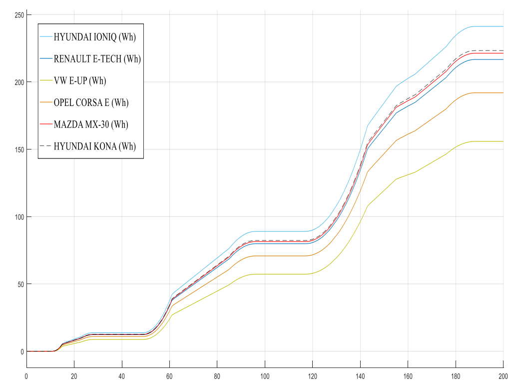

Fig. 7.3- Simulation graph for the ECE-15 test: "Energy consumed as a function of time”

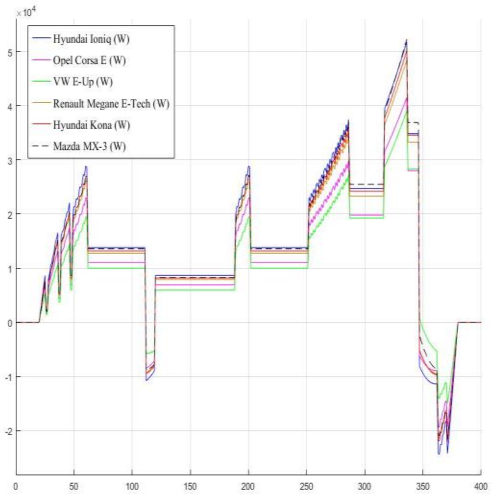

Fig. 7.4 - Simulation graph "Electrical power required at the wheels (W)" in the EUDC scenario

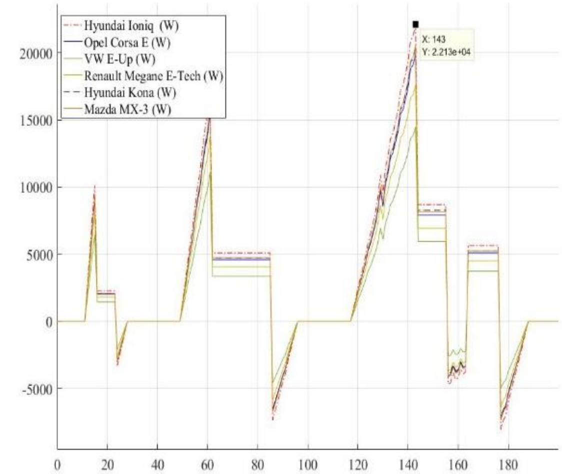

Fig. 7.5 - Simulation graph "Electrical power required at the wheels (W)" in the ECE scenario

7.5.4 Analysis of available solar energy from the roof of automobiles and energy consumption

To determine the distance covered by the EUDC and ECE-15 cycles of electric cars, using the energy obtained from the sun, a comparative analysis is required between the energy produced by the photovoltaic panel and the energy consumed by the electric car. To determine the total distance traveled as a function of the available energy, Dpv2,3, equation (7.17) was used**.**

$$D_{pv2,3} = \frac{E_{roof} \cdot D_{eudc}, D_{ece}}{E_{c1}, E_{c2}} \quad (7.17)$$

To show the relationship between the available solar energy and the energy consumed during the EUDC and ECE-15 cycles, table 7.5 was created.

Table 7.5 - Available energy vs. the energy consumed for different types of electric cars

Model EV	**Available energy E_{roof} (Wh)**	**Energy consumed (Wh)**	
		EUDC test E_{c1} (Wh)	**ECE-15 test E_{c2} (Wh)**
Hyundai Ioniq 5	3403.5	1802.8	241.2
Renault Megane E-Tech	4294.6	1654.1	216.6
Volkswagen E-Up	3395.5	1269.1	155.8
Opel Corsa E	3540.3	1439.3	191.9
Hyundai Kona Electric 2021	3496	1710.1	223.3
Mazda MX-30	3767.6	1741.8	221.3

Table 7.6 - Extended range for different types of electric cars

EV model	**Extended autonomy 2 for the cycle EUDC D_{pv2} (m)**	**Number of EUDC cycles completed**	**Extended autonomy 2 for the cycle ECE D_{pv3} (m)**	**Number of ECE-15 cycles completed**
Hyundai Ioniq 5	18057.5	2.6	20085.1	19.8
Renault Megane E-Tech	18608.2	2.7	22077.3	21.8
Volkswagen E-Up	17107.5	2.5	18688.5	18.4
Opel Corsa E	14218.3	2.0	15859.6	15.7
Hyundai Kona Electric 2021	15044.0	2.2	17246.2	17.0
Mazda MX-30	18057.5	2.6	20085.1	19.8

The extended range results for the studied electric cars, EUDC and ECE cycles, were shown in table 7.6.

Chapter 8 - Business Plan - Mobile Charging Stations for Electric Cars

Within the A-SUCCES project, in the last chapter of the doctoral thesis, it was necessary to create a business plan, in order to complete the scientific work with an economic component, in order to implement the entrepreneurial skills acquired during the implementation of the entrepreneurial skills development project.

8.1. General data

Full name of the company: Green Mobility

Company details - Registered office: Bd. Tomis no. 300, Bl. 10b, Sc. A, ground floor, Municipality of Constanța.

Working points: A2, Tronson Constanța-Cernavoda, Cernavoda-Drajna, Drajna-Bucuresti.

Legal form of incorporation: S.R.L

Date of establishment/Trade Register number: 01.10.2020

The main activity of the company and the related CAEN code: CAEN Code 3514 - Trading of electricity.

The value of the share capital: 200 RON.

8.2 Vision, strategy

The business plan contains concrete measures aimed at social innovation, sustainable development through products, technologies or services and supporting the transition to a low-CO_2 and resource-efficient economy. The creation of mobile charging stations for electric vehicles is a form of innovation for the development of the electric vehicle market, with zero CO_2 emissions.

8.3 Projected turnover and number of employees

Table 8.1 - Projected turnover and number of employees

Objectives (target indcators)	UM	2021	2022	2023
Fiscal value:	LEI	182 500	365 000	657 000
Profit:	LEI	417	107 687	326 252
Number of employees	Number of persons	3	3	3
Objectives (target indicators)	UM	2021	2022	2023

8.4 The financing structure of the investment project

Table 8.2 - Financing structure of the investment project

Source of funding	VAT free	
	RON	%
Bank credits	115 000	24
AFN (Non-Reimbursable Financial Allowance)	245 000	50
Other sources	130 000	26
TOTAL invest value	490 000	100%

8.5 Investment realization chart

Table 8.3 –Gantt's graph

Intended activity	Time of execution	Implementing duration											
		L l	L 2	L 3	L 4	L 5	L 6	L 7	L 8	L 9	L 10	L 11	L 12
Research+consultance	1 month												
Establishment+fitting	2 month												
Acquisition of equipments	3 month												
Assembly + testing	2 month												
Authorizations+Advertising	3 month												
Selling	1 month												

Table 8.4 - Value implementation schedule – without VAT

Intended activity	Total without VAT	Implementing duration											
		L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L 11	L l2
Research+consultance	10 000												
Establishment+fitting	10 000												
Acquisition of equipments	140 000												
Assembly + testing	20 000												
Authorizations+Advertising	50 000												
Total value	**230 000**												

8.6 Business risks

8.6.1 Major risks identified: Market risks, Financial risks, Legislative risks.

8.6.2 Ways to minimize the first three major risks

Table 8.5 - Ways to minimize the first three major risks

Nr. crt.	Risk name	Mitigation actions
1.	Vehicle failure	Purchase a vehicle as a back-up solution.
2.	Emergence of competitors	Creation of customer retention solutions: -Granting bonuses to loyal customers: price reductions for a certain number of loads; - Consulting service.
3.	Energy price increase	- Increasing the price of energy from battery charging .

Original Contributions

1. Obtaining electricity by placing a photovoltaic panel on the roof of a car traveling on an imposed route, from the municipality of Constanța, and recording the values of the electricity obtained, the electrical power generated and the global radiation, along the route.

2. Designing a basic mechanical device, easy to use and low manufacturing cost to ensure the inclination of the photovoltaic panel at different angles in order to capture the maximum energy from the sun while the car is parked in the parking lot.

3. Obtaining electrical energy by carrying out a practical experiment with a photovoltaic panel placed on the roof of a car, at different inclinations, in conditions of the car being stationary in the parking lot, and recording the values of the electrical energy obtained, the electrical power generated and the global radiation with the car in the parking lot .

4. Obtaining the energy consumed and the required power at the wheels by simulating the ECE-15 and EUDC scenarios for 6 electric car models.

5. Extending the autonomy of 6 models of electric cars by placing photovoltaic panels on their roofs.

6. Realization of a business plan for the implementation of mobile electric car charging stations for recharging electric car batteries.

List of the author's publications

A. Journal Articles

[1]. **Alexandru Țurcanu** și Leonard Călin Valentin, „Dimensionarea sistemului de propulsie al unui vehicul electric. Studiu de caz”, APME, vol. 16, nr. 1, pp. 31–44, ian. 2020.

[2] **Alexandru Țurcanu** și Leonard Călin Valentin, „Modelarea în Matlab/Simulink a funcționării unui vehicul electric în diferite cicluri de acționare”, APME, vol. 16, nr. 1, pp. 18–30, ian. 2020.

B. Articles presented at international conferences

[1] **Alexandru Țurcanu,** ”Experimental Determination of the Energy Provided by the Photovoltaic Panels Placed on the Roof of a Vehicle with an Imposed Route”, The 13th International Symposium On Advanced Topics In Electrical Engineering, (ATEE), March 23-25, 2023, Bucharest, Romania, pp. 1-8, doi: 10.1109/ATEE58038.2023.10108293.

[2] **Alexandru Țurcanu,** “Increasing the autonomy of electric cars using the energy provided by own photovoltaic panels”, 2023 Fifth International Conference on Electrical, Computer and Communication Technologies (ICECCT 2023), February 22-24, 2023, Erode, Tamil Nadu, India, pp. 1-8, doi: 10.1109/ICECCT56650.2023.10179793 .

[3] **Alexandru Țurcanu**, Aurelian Crăciunescu și Leonard Călin Dobre, “Floating photovoltaic power plants”, 2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE), Bucharest, Romania, pp. 1-4, doi: 10.1109/ATEE52255.2021.9425257.