THE APPLICATION OF SOLAR ENERGY IN ROMANIA'S AUTOMOTIVE FIELD

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Rezumat. *Sectorul auto din România se confruntă cu o evoluție către transportul sustenabil cu un interes din ce în ce mai mare pentru încorporarea tehnologiei energiei solare în domeniul autovehiculelor. Acest articol examinează starea actuală a utilizării energiei solare în industria autovehiculelor din România, incluzând dificultățile, posibilitățile și perspectivele de viitor. Articolul analizează îmbunătățirile tehnologice, aplicațiile legislative, preferințele consumatorilor și amprenta de carbon a mașinilor alimentate cu energie solară din România.*

Abstract. *Romania's automotive sector is experiencing an evolution towards sustainable transport, with an increasing interest in incorporating solar power technology into vehicles. This article examines the present state of solar power use in Romania's automobile industry, including difficulties, possibilities, and prospects. The analysis looks at technology improvements, legislative applications, consumer preferences, and the carbon footprint of solar-powered cars in Romania.*

Keywords: Sustainability, renewable energy, solar power, automotive industry, management.

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1. Introduction

The automobile sector is rapidly turning to green energy solutions to minimize carbon footprints and promote sustainability. Environmental legislation, technical developments, and rising customer demand for eco-friendly automobiles all contribute to this transformation [1].

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There are a few major [2-10] areas where renewable energy is making a great impact in automotive industries:

1. Electric Vehicles (EVs) - Electric vehicles are leading the green energy transition in the automobile sector. They run on energy stored within power sources, which may be recharged using energy from natural sources including solar, wind, and hydro power.

The Romanian government provides large incentives to EV consumers [1]. The "Rabla Plus" initiative offers financial assistance for the purchase of new electric and hybrid vehicles, greatly lowering the cost to consumers [2].

The construction of electric vehicle charging facilities is ongoing, with an increasing percentage of charging stations in public places being added around the

Companies like as Renovatio, Enel X, and Kaufland are actively developing their charging network [3].

2. Hybrid Vehicles - Hybrid cars incorporate gasoline-powered engines with electric power. They are an intermediate technology that bridges the gap between conventional fossil-fueled automobiles and completely electrified ones. Hybrids provide higher fuel economy and less emissions than traditional automobiles.

Market dynamics, government legislation, infrastructure growth, customer needs, and environmental considerations have all had an impact on hybrid car uptake in Romania. While hybrid vehicles are becoming increasingly popular among Romanian customers, their market share is still limited in comparison to regular gasoline or diesel automobiles. The Romanian market offers a variety of hybrid car types to meet the diverse demands and tastes of its customers. However, the options may be restricted when compared to other European nations [4].

3. Hydrogen Fuel Cell Vehicles - Hydrogen fuel cell vehicles (FCVs) use hydrogen as a fuel to drive an electric motor. They produce just steam while heating air, making them an environmentally friendly substitute to fossil fuels.

Commercial fluctuations, government laws, building growth, scientific advances and economic considerations all have an impact on FCV adoption in Romania. While there is rising curiosity about FCVs among Romanian customers and stakeholders, market penetration remains low if compared to other areas with more advanced hydrogen economies [5].

4. Lightweight Materials - The addition of lightweight materials like fiberglass, aluminum, and strong steel may considerably enhance vehicle economy by reducing weight, resulting in decreased use of energy and emissions.

The use of lightweight materials in Romania fluctuates by industry, with certain sectors adopting novel materials and technologies faster than others [6]. While there are pockets of expertise and research activity dedicated to lightweight materials, their mainstream acceptance and application are still in the early stages.

5. Autonomous and Connected Vehicles - Autonomous and linked cars can improve driving patterns and minimize traffic congestion, resulting in fewer emissions and increased energy efficiency. These cars frequently connect with smart city infrastructures, improving overall sustainability.

Adoption of ACVs in Romania is in its early stages, with limited distribution and experimentation in certain locations [7]. Although there is rising interest and awareness, mainstream acceptance and commercialization have yet to occur. Pilot projects, research efforts, and cooperation with foreign partners are pushing Romania's investigation of ACV technology.

6. Circular Economy and Recycling - The automobile sector is embracing circular economy ideas, with an emphasis on material reuse and recycling. End-of-life cars are being deconstructed more effectively to recover precious elements for use in future vehicles or other purposes.

Romania has made strides towards advancing circular economy ideas and increasing recycling rates throughout recent years [8]. However, there are considerable hurdles to developing a truly circular and resource-efficient economy. While there are examples of outstanding performance and innovation, such as sustainable manufacturing techniques and recycling programs, more extensive and unified attempts are required to promote systemic change.

The worldwide automobile industry is shifting to green energy resources to decrease environmental impact and dependency on fossil fuels. Romania, a developing market in the automobile sector, is also adopting sustainable methods.

Romania's support for renewable energy is reflected in its national energy policy, which intends to increase the proportion of green energy in the energy mix. With an annual average of 210 bright days each year, the country has a lot of solar energy potential [9]. This establishes a solid framework for incorporating solar technology into a variety of industries, including automotive.

Romania has achieved significant advances in renewable energy, notably wind and hydropower. However, solar energy remains underused, accounting for just a tiny portion of overall energy generation [10]. Recent funding and government support have fueled excitement over solar projects, paving the way for more widespread uses.

2. Solar Energy in the Automotive Industry

2.1.Solar-Powered Vehicles

Solar-powered automobiles are a new technology that uses photovoltaic cells to transform sunshine into electricity. Although fully solar-powered automobiles are currently in the experimental stage, hybrid versions that use solar panels for auxiliary services like battery charging and operating onboard electronics are gaining popularity [11].

Solar-powered automobiles are a new and ecologically sustainable alternative to typical fossil-fuel vehicles. They collect solar energy using photovoltaic (PV) panels, which convert sunlight straight into electricity. Here is an outline of the main features of solar-powered automobiles, Table 1:

1. Solar Cars: These are usually experimental, or prototype cars created specifically for solar racing events including the World Solar Challenge. They use high-efficiency solar panels and flexible components to enhance performance.
2. Solar Bicycles and motorbikes: Solar panels may be installed on smaller vehicles such as bicycles and motorbikes. These are frequently utilized for private use and can be very useful in sunny climates.
3. Solar boats use PV panels on the surfaces to charge batteries, which power electric motors. They are very effective at lowering emissions in maritime areas.
4. Solar-Powered Airplanes: While still in the experimental stage, solar-powered planes have been created to illustrate the possibilities of solar power in aviation.

Table 1. Key aspects of solar powered vehicles

Key components	*Description*	*Advantages*	*Challenges*
Solar Panels	The most important component of these panels are photovoltaic cells, which catch daylight and transform it into power.	Reduces Greenhouse Gas Emissions Reduces Reliance on Fossil Fuels Longevity	Seasonal Variability Large Area Needed Conversion Efficiency
Battery Pack	Stores the power produced by the photovoltaic panels when sunlight is unavailable, such as at night or on a cloudy day, the battery pack powers the system.	Consistent Power Supply Increased Self-Consumption Reduced Carbon Footprint	Expensive Technology Thermal Runaway Toxic Materials
Electric Motor	Transforms the electricity from a battery into physical energy to power the vehicle.	Low Energy Loss Zero Emissions Energy Recovery	Charging Infrastructure Temperature Sensitivity Battery Disposal
Power Management System	Regulates the flow of power between solar power plants, battery, and motor, resulting in more efficient energy consumption.	Maximized Energy Output Efficient Storage Utilization Reduced Energy Costs	Compatibility Issues Vulnerability to Attacks Variable Solar Generation

Source: Authors' own research

The use of solar-powered automobiles in Romania is still in the very beginning stages. Automotive manufacturers and academic organizations have launched several concept projects and pilot studies. These efforts seek to examine the feasibility and effectiveness of solar-powered cars in Romanian climate conditions [12].

Fig. 1. highlights the different levels of renewable energy adoption in Europe's transportation sector, as well as the collective goal of reaching 30% by 2030. It emphasizes the key players in this shift while also emphasizing the issues encountered by countries who are falling behind. This lays out a clear roadmap for policymakers and stakeholders to push renewable energy investments and technologies to meet these lofty goals.

Sweden is a huge outlier, with the greatest proportion, much outpacing the other countries. The Netherlands, Finland, and Austria follow with far higher percentages, demonstrating widespread use of renewable energy in their transportation sectors.

Countries such as Denmark, Portugal, and Germany have modest amounts of green energy in transportation, falling between the leaders and the countries with lower percentages.

Countries with low renewable energy shares in transportation include Romania, Poland, and Greece, showing possibilities for development and expansion.

Norway differentiates out among non-EU nations for its high percentage of electricity from renewable sources in transportation, which is equivalent to top EU countries.

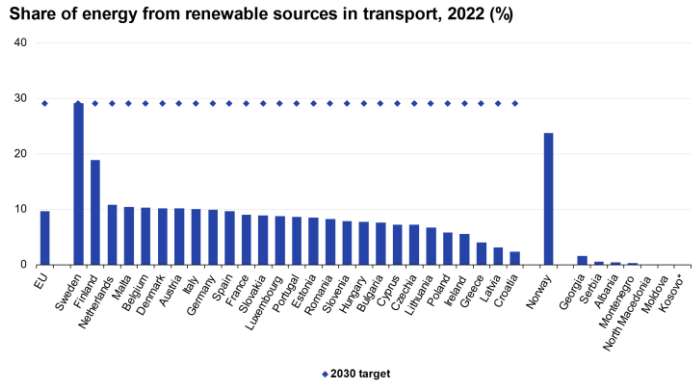

Fig. 1. Share of energy from renewable sources in transport [13]

2.2.Solar Charging Stations

Solar-powered automobiles are a new technology that uses photovoltaic cells to transform sunshine into electricity. Although fully solar-powered automobiles are currently in the experimental stage, hybrid versions that use solar panels for

auxiliary services like rechargeable batteries and generating onboard electronics are gaining popularity [14]. Various Romanian universities are currently working to investigate and produce solar-powered cars. These initiatives frequently entail developing models to assess and show the feasibility of harnessing solar power for transportation. Examples include technical university teams competing in international solar vehicle contests.

Dozens of students representing Romanian technological universities created solar-powered car prototypes. These cars are generally developed for competitions and educational uses, demonstrating the use of solar energy in mobility. The Romanian administration has established objectives for increasing the proportion of green energy in the national power mix, including solar power. However, direct assistance for solar-powered automobiles is minimal.

3. Carbon footprint of solar-powered cars in Romania

The transportation industry contributes significantly to global emission levels of carbon, accounting for a large share of Romania's total greenhouse gas production. Even if Romania is one of the countries with the lowest level of emitted greenhouse gases as shown in Fig. 2., there is still room for improvement.

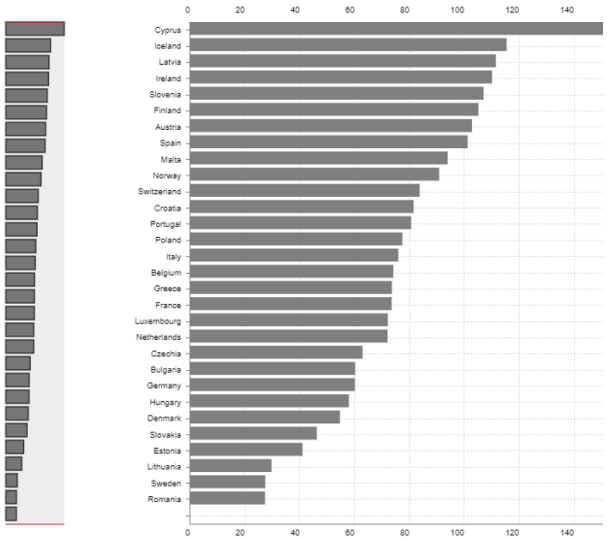

Fig. 2. Net greenhouse gas emissions (Source: National Institute of Romania)

Solar-powered automobiles are gaining popularity in response to worries about climate change and the demand for better transportation choices [15]. Solar-powered cars use solar energy to create electricity, providing the possibility of zero-emission transportation. However, the environmental advantages of these

cars are contingent on a variety of variables, like the carbon intensity of energy production, production methods, and operational efficiency.

The energy mix utilized to generate electricity is a key factor in determining the greenhouse gas emissions of solar-powered automobiles in Romania. Romania's energy mix includes a variety of resources like fossil fuels, nuclear power, and green energy. Measuring the carbon level of energy production is critical for determining the carbon dioxide emissions related to charging solar-powered vehicles. While Romania has made tremendous progress in boosting its renewable energy potential, especially photovoltaic solar panel installations, fossil fuels remain the primary source of power generation.

The manufacturing techniques used to produce solar power systems and electric automobiles add to their greenhouse gas emissions [16]. Assessing the emissions related to raw material mining, manufacture, logistics, and assembly is critical for undertaking a thorough lifecycle study. Factors such as industrial energy sources, transportation distances, or manufacturing practices all have an impact on the environment. Lifecycle evaluations give information about the captured emissions of solar-powered vehicles, which informs decision-making processes for their acceptance and deployment.

The energy output of solar energy systems and electrical systems has a considerable impact on solar-powered vehicles' operational emissions. Higher efficiency means reduced use of energy per mile traveled, which reduces overall emissions of carbon dioxide. Vehicle weight, aerodynamics, and driving behaviors may all have an impact on economy and performance. Optimizing vehicle design and supporting eco-driving techniques can help to increase the environmental advantages of solar-powered transportation.

The environmental impact of solar-powered automobiles in Romania is determined by several factors that span the vehicle's full lifespan. While solar energy is a renewable and sustainable energy source, the environmental advantages of solar-powered mobility are dependent on the carbon footprint of producing electricity, manufacturing processes, and operating efficiency [12]. Addressing these issues through legislative incentives, technology breakthroughs, and sustainable behaviors is critical for optimizing the environmental benefits of solar-powered vehicles and moving to a low-carbon mobility future in Romania.

Table 2. Carbon footprint of solar-powered cars in Romania

Aspects	*Description*
Energy Source	Solar power
CO2 Emissions during Manufacturing	Low
CO2 Emissions during Operation	Negligible (if solely powered by solar energy)
Total CO2 Emissions over Lifecycle	Minimal

Environmental Impact	Low
Economic Benefit	Reduced dependence on fossil fuels, potential cost savings over time

Source: Authors' own research

The figures shown above are approximate figures and may vary based on factors like the individual manufacturing process, solar panel efficiency, and vehicle usage habits. Furthermore, the environmental and economic benefits of solar-powered automobiles go beyond CO_2 emissions, including improved air quality, energy independence, and possible job development in the renewable energy sector.

In Romania, the EV market has been expanding with increasing sales of fully electric vehicles. The most common models include the Dacia Spring, the Renault Zoe, and the Tesla Model 3 [19].

In Table 3, we can see a few of the EV brands found on Romania. The best car to be driven by CO_2 emissions point of view if the Renault Zoe with only 75g of emissions per kg but from the range point of view is on the third place among the analyzed cars. While not having the biggest amount of CO_2 emissions, the Romanian produced Dacia Spring has the worst range with only 165 km.

Based on the information found in Table 3, we used regression analysis to assess whether changes in the independent variable (predictor), in our case Range (km) causes changes in the dependent variable (outcome), in our case Useable battery.

Table 3. CO_2 emissions by car brands driven in Romania [17], [18]

Brand	*Useable battery*	*Range (km)*	*Efficiency*	*CO_2 emissions per km*
Renault Zoe ZE50 R110	52.0 KWh	315	165 Wh/km	75 g
Volkswagen I.D.3	58.0 KWh	350	166 Wh/km	76 g
Dacia Spring	25.0 KWh	165	152 Wh/km	78 g
Mercedes EQC 400 4MATIC	80.0 KWh	370	216 Wh/km	81 g

Multiple R (0.937): Indicates a strong positive correlation between the Range (X Variable 1) and Useable battery.

The regression model explains a high proportion of the variance in the dependent variable, Useable battery, (R Square = 0.878), indicating a good fit.

Adjusted R Square (0.817): This value is adjusted for the number of predictors in the model and the number of observations. It is slightly lower than R Square, indicating a very good fit but considering the small sample size.

Table 4. Regression statistics

Regression Statistics	
Multiple R	0.936888736
R Square	0.877760503
Adjusted R Square	0.816640754
Standard Error	9.691531029
Observations	4

As seen in Table 5, F Statistics (14.361) indicates that the model is statistically significant. However, with a Significance F value of 0.063, which is slightly above the typical alpha level of 0.05, the result is marginally non-significant.

Table 5. ANOVA

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1348.8984	1348.8984	14.3613	0.06311
Residual	2	187.8515	93.9257		
Total	3	1536.75			

The coefficient for X Variable 1 is positive and shows a strong relationship, but its significance is marginal at the 0.063 level, Table 6.

Table 6. Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-14.7799	18.7215	-0.7894	0.5125	-95.3322	65.7722	-95.3322	65.7722
X Variable 1	0.2284	0.0602	3.7896	0.0631	-0.03092	0.4877	-0.03092	0.4877

Overall, while the model shows a strong relationship between the predictor and outcome variables, the small sample size (4 observations) and the marginal p-values suggest cautious interpretation of the results. Further data collection and analysis would be beneficial to confirm these findings.

Table 7. ANOVA: Single Factor

Groups	*Count*	*Sum*	*Average*	*Variance*
Range (km)	4	1200	300	8616.666667

Efficiency (Wh/km)	4	699	174.75	796.9166667
CO_2 emissions per km (g)	4	310	77.5	7

Table 8. Source of variation

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	99535.1666	2	49767.5833	15.8485	0.0011	4.2564
Within Groups	28261.75	9	3140.1944			
Total	127796.9167	11				

The ANOVA results indicate that there are significant differences between the means of the three groups: Range (km), Efficiency (Wh/km), and CO_2 emissions per km (g). The very small p-value (0.001125) and the high F-value (15.849) compared to the critical value (4.256) strongly suggest that at least one of the group means is significantly different from the others.

To identify which specific groups have significant differences, a post-hoc test (such as Tukey's HSD) would be necessary. This analysis would provide a more detailed comparison between the groups and determine which pairs of groups are significantly different from each other.

4. Legislative applications of solar energy in Romania's automotive sector

The use of solar energy in the automobile industry promises a possible path toward sustainable mobility and lower carbon emissions. Legislative frameworks play a significant role in accelerating this transition by offering incentives, rules, and support mechanisms to encourage the use of solar-powered devices. Legislative uses of solar power in the automobile sector are gaining traction in Romania as the nation strives to line with European Union (EU) renewable energy goals and minimize its carbon impact.

Renewable energy legislation in Romania is critical to increasing the use of solar power in the automobile sector. The Renewable Energy Law (Law No. 220/2008) and its revisions provide a framework for promoting renewable energy production, such as solar energy production for electric vehicle (EV) charging systems [20]. Feed-in taxes, ecological certificates, and financing opportunities help to establish powered by solar panels charging stations and stimulate funding for solar energy plans for mobility.

Legislative regulations and certification criteria guarantee reliability, efficiency, and conformity of solar-powered cars in Romania. The Romanian

Road Traffic Regulations (Law No. 455/2001) and European Union guidelines specify vehicle safety, emissions, and technical parameters for electric and solar-powered cars. Certification techniques evaluate the integrity as well as performance of photovoltaic systems installed into automobiles, fostering customer trust and commercial adoption [21].

Government-funded R&D activities promote innovation and technological improvements in solar power for automotive applications. Projects like the National Research, Development, and Innovation Strategy (2014-2020) provide support for collaborative R&D initiatives centered on solar-powered vehicle technology [22]. Research institutes, colleges and universities, and private sector partners work together to create novel solar energy integration solutions such as solar energy systems, storage solutions for energy, and vehicle-to-grid (V2G) technology.

Legislative support for infrastructural development is critical to the broad adoption of solar-powered cars in Romania. The National Energy Regulatory Authority (ANRE) and the Ministry of Transport develop legislation and standards for installing and operating solar charging stations. Grid connection rules, authorization techniques, and technical specifications facilitate the safe and effective installation of solar-powered charging facilities, increasing the availability and dependability of solar energy for mobility [23], [24].

Tax breaks and financial assistance mechanisms encourage the use of solar-powered cars and infrastructure in Romania. The Green Certificate Scheme offers financial incentives to renewable energy providers, including solar charging station owners. Furthermore, tax credits, funding, and subsidies are accessible to firms and people that invest in solar power systems for transportation, lowering financial obstacles to adoption and encouraging market demand [25].

Environmental rules and environmental goals are driving the move to solar-powered vehicles in Romania. The National Energy and Climate Plan (NECP) establishes goals for lowering greenhouse gas emissions, encouraging renewable energy, and increasing the proportion of electric and solar-powered cars in the transportation sector. Emissions requirements, air quality laws, and vehicle electrification schemes all help to decarbonize transportation while also mitigating environmental concerns.

Global collaboration is needed to help Romania develop its attempts to integrate solar energy into the automobile sector [26], [27], [28]. Participation in EU-funded research projects, engagement with worldwide agencies for instance the International Renewable Energy Agency (IRENA), and efforts to share knowledge all contribute to innovation transfer, policy uniformity, and best practice exchange. Romania's position as a pioneer in environmentally friendly transport and energy efficiency innovation is strengthened through international alliances [29].

Conclusions

The prospects of solar-powered automobiles in Romania rests on technology improvements, governmental backing, and market acceptance. As solar power continues to grow and become affordable, its incorporation into the car sector might become more frequent, connecting with Romania's policy of sustainable development.

Solar energy provides a sustainable and cost-effective alternative for Romania's automobile sector. Romania can lower its carbon footprint, boost innovation, and improve its energy security by capitalizing on its solar potential. Collaborative efforts from multiple sectors will be critical in achieving the full capacity of solar energy in the automobile industry.

The use of solar electricity into the automobile sector provides great potential for Romania to move to sustainable transportation solutions. Despite hurdles, continuous research and legislative initiatives are opening the path for a more environmentally conscious and sustainable automotive industry in Romania.

Notations and/or **Abbreviations**

ACVs – Autonomous and connected vehicles
EV – Electric Vehicles
FCVs – Hydrogen fuel cell vehicles
PV – Photovoltaic panels
V2G – Vehicle-to-grid

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