

sustainable transport; solar photovoltaic; low emission vehicles; electric vehicles; Slovenia

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SOLAR ENERGISED TRANSPORT SOLUTION AND CUSTOMER PREFERENCES AND OPINIONS ABOUT ALTERNATIVE FUEL VEHICLES – THE CASE OF SLOVENIA

Summary. Authorities in Slovenia and other EU member states are confronted with problems of city transportation. Fossil-fuel based transport poses two chief problems – local and global pollution, and dwindling supplies and ever increasing costs. An elegant solution is to gradually replace the present automobile fleet with low emission vehicles. This article first explores the economics and practical viability of the provision of solar electricity for the charging of electric vehicles by installation of economical available PV modules and secondly the customer preferences and opinions about alternative low emission vehicles. Present estimates indicate that for the prevailing solar climate of Celje – a medium-sized Slovenian town – the cost would be only 2.11€ cents/kWh of generated solar electricity. Other results have also revealed that the most relevant factor for purchasing low emission vehicle is total vehicle price.

ИСПОЛЬЗОВАНИЕ ТРАНСПОРТА НА СОЛНЕЧНОЙ ЭНЕРГИИ, ПРЕДПОЧТЕНИЯ КЛИЕНТОВ И МНЕНИЯ О СРЕДСТВАХ ТРАНСПОРТА НА АЛЬТЕРНАТИВНОМ ТОПЛИВЕ - ПРИМЕР СЛОВЕНИИ

Аннотация. Власти Словении и других стран-членов ЕС сталкиваются с проблемами городского транспорта. Транспорт работающий на основе ископаемых видов топлива представляет две главные проблемы - локальное и глобальное загрязнение, сокращающиеся поставки и постоянно растущие расходы. Хорошим решением является постепенная замена существующего автомобильного парка на транспортные средства с низким уровнем выбросов. Эта статья впервые исследует экономику и практическую жизнеспособность использования солнечной электроэнергии для зарядки электрических транспортных средств путем установки экономичных доступных PV модулей и, во-вторых, предпочтений заказчиков и мнений об альтернативных транспортных средствах с низким уровнем выбросов. Современные оценки показывают, что для имеющего в основном солнечный климат, Целье - среднего размера города Словении - цена будет только 2.11 евроцентов / кВт-ч выработанной солнечной электроэнергии. Другие результаты также показали, что наиболее важным фактором при покупке транспортного средства со сниженным уровнем вредных выбросов является его полная стоимость.

1. INTRODUCTION

Global climate changes call for an immediate global action through international cooperation of all countries. According to the European environment agency the transport sector is the fastest growing user of energy and hence the fastest growing producer of greenhouse gases in all EU states. Today,

city authorities in Slovenia and other EU member states are confronted with problems of city transportation in order to introduce the concept of green cities. These problems include an overpopulation of automobiles in city centres – leading to grid locks, pollution, smog, accidents etc. In order to reduce the damage, inflicted on city environments, transport change and change in the attitude of people and companies is needed. City authorities can influence the implementation of better management of transport in three ways (Portal, 2003; [9]):

- Regulations and taxes,
- Co-funded infrastructure development and environmentally-friendly vehicles and
- Change of transport regime

Michaelis [13] asserts that the level of CO₂ emissions in city transport can be reduced in three different ways: (1) by using more efficient, environmentally friendly transport technologies, (2) by altering peoples' travel habits and (3) to change transport policy of city authorities regarding city centre transport management.

Traffic jam in city centres is continuously increasing despite various measures due to rapidly increasing transport demands. The evolution and development of urban logistics in the past decade has only decreased the situation, partly also due to increased use of motor vehicles. In order to reduce negative impacts on the environment, different economic instruments have been implemented such as environmental taxes whereby the polluter pays. An important instrument is also the implementation of reducing payments or taxes or exemption from such taxes due to investments in environmental protection. Environmental technology or green technology is the power of environmental science, to protect nature and to reduce the impacts caused by mankind. In this article a clean energy solution has been proposed by means of propulsion of electric automobiles utilising solar energy.

Early in 2002 Copenhagen started with the implementation of the so called City Goods Ordinance scheme in the medieval city centre regarding the use and the capacity of motor vehicles (DGET, 2002). The aim of this endeavour was reduce due to the impact of transport of goods has on the environment and to improve the accessibility of narrow medieval streets, by reducing the number of vans and all vehicles, which are driving into towns. The first half of the year concentrated on restricting the tours of vans and lorries to those with acquired certificates. The fine for those without such a certificate amounted to €68. According to the survey, the residents mostly approved of the scheme. Four larger Swedish cities introduced the so called environmental zones within city centres with the objective to improve air quality and reduce noise pollution [3]. This program refers to buses and lorries whose weight exceeds 3.5tonnes. The key requirement for entering the environmental zone was that no diesel vehicle be older than eight years. Older vehicles may enter the zone provided they have undergone emission tests or they can be entirely banned from entering the city centre. Following the Swedish example, Great Britain (Transport for London, 2008) implemented improvements regarding emission reduction by introducing the so called Low Emission Zone. It is a precisely defined area which may only be accessed with specific vehicles that meet the set requirements or standards. The main aim of this measure is to reduce traffic impact on the environment and hence increase air quality and encourage the use of cleaner or greener vehicles in city centres or areas with high level of pollution. Although it is not necessary that the number of vehicles in these areas will decrease as a result, and the number of cleaner vehicles with fewer emissions will increase.

Three German cities (PR Newswire Europe, 2008) have implemented a law which forbids those vehicles which pollute the environment, to enter certain parts of city centres. These areas are labelled environmental zones. In Berlin, Hannover and Cologne drivers must equip their vehicles with special stickers as proof that the vehicles comply with the new environmental standards.

The European Commission recently unveiled a "single European transport area" aimed at enforcing "a profound shift in transport patterns for passengers" by 2050. Top of the EU's list to cut climate change emissions is a target of "zero" for the number of petrol and diesel-driven cars and lorries in the EU's future cities. Siim Kallas, the EU transport commission, insisted that Brussels directives and new taxation of fuel would be used to force people out of their cars and onto "alternative" means of transport. "That actually means no more conventionally fuelled cars in our city centres" [31].

1.1. Electric vehicles – sustainable solution for city centres

The increasing concentration of population and wealth to cities is likely to continue-especially in the developing world [17]. With further global population increase and urbanisation on the horizon congestion will exacerbate the negative impact of the manner in which the automobiles will be driven and on the overall energy consumption. It will not be possible to tackle global automotive energy consumption and green-house gas emissions effectively without a radical change in thinking with respect to urban transport [15]. For over a century, the automobile has offered affordable freedom of movement within urban areas. Currently, however, a typical automobile is larger and heavier than it needs to be to provide personal urban transport. On an average it weighs 20 times as much as its driver, can travel over 450 km without refuelling, and can attain speeds of over 160 kph. The average vehicle occupies 10m² of road space for parking and is parked about 90% of the time [15]. Furthermore, the typical daily commuting distance in most European cities is less than 40km.

Worldwide, 18 million barrels of oil is consumed each day by the automobile sector. Annually the vehicles emit 2.7 billion tonnes of CO₂ (IEA, 2010) and claim 1.2 million lives via accidents (WHO, 2004). Within city centres the average vehicular speeds hardly ever exceed 16 kph [8].

One solution to tackle the problem of congestion and pollution within city centres around the world is to use electricity powered, two-wheelers or ultra-compact four-wheelers. The ultra-compact cars weigh less than 450 kg and occupy less than two-third length of a conventional compact car [17].

The first electric car was built sometime between 1832 and 1839 by Robert Anderson in Scotland (PBS, 2010). Breakthrough by Gaston Plante and Camille Faure increased battery energy storage capacity, which led to the commercialization of battery-electric cars in France and Great Britain in the 1880s. Battery-electric vehicles were quiet, clean, and simple to operate, but their batteries took a long time to recharge, were expensive to replace, and had limited range (US Department of Transport, 2010). Automobiles are quite inefficient with approximately 75% of the energy going into producing heat [11]. Research and development is being carried out into manufacturing affordable electric automobiles that offer an improved overall thermodynamic efficiency and in this respect the car manufacturer Nissan has announced plans to produce 50,000 Nissan “Leaf” electric cars in the UK starting in 2013 with a global production of 200,000 units per year. At the same time Chinese manufactured electric scooters are also increasingly making their entry in European cities with a typical scooter costing around €1,200. Such scooters emit around 33gCO₂/km if charged with fossil fuel electricity. The latter figure however drops to a significantly lower value of 1.3gCO₂/km if solar energy is deployed to charge the scooter’s lead acid batteries [18]. Within the UK market the ‘Charge’ scooter company has made available an ‘S1’ electric scooter that uses lithium-ion batteries and costs € 2,800. The 48-V, 40 Ah battery requires 4h to add an 80% charge and can deliver a 55km trip.

The main goal of this work is to review the energetic and environmental impact of the transportation sector in Slovenia, assess the propulsion energy requirement of automobiles for a small town’s fleet, determine the benefits of replacing a proportion of the conventional fleet with electric vehicles and identify the measures that would increase the people’s interest in purchasing LEVs.

1.2. The energy budget of Slovenia

According to energy statistics for 2010, the production of primary energy in Slovenia increased by 2% compared to the previous years. The increase was mostly influenced by an 8% increase in renewable energy sources production out of which the production of biogas increased the most, namely by 80%. Total energy primary supply, which besides primary energy production includes also import and export of energy increased by 3%. The increase was influenced mostly by the increase in supply of renewable energy sources by 10% and supply of natural gas by 4% (SURS, 2011a). Supply with petroleum products also decreased in 2010, compared with the previous year by 2%. Energy dependency of Slovenia in 2010 was 50%. In 2010 the gross production of electricity was 16,433GWh. Most electricity was produced in thermal power plants (37%), followed by the nuclear-(34%) and hydro power plants (29%).

Table 1

SWOT analysis for Electric Vehicles

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> • Eco friendly • Silent • Low cost of Ownership • Cheaper to run • Energy savings – achievable from regenerative braking system • Simpler mechanism 	<ul style="list-style-type: none"> • Needs time to recharge • Lack of recharging infrastructure • Batteries change is expensive
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> • Governments subsidy for ownership • No congestion charge • Lower taxes • Increasing fossil fuel costs 	<ul style="list-style-type: none"> • Competition in form of electric hybrids, alternative fuel, hydrogen-powered cars • Rise in cost of electricity

2. RESEARCH METHODOLOGY

This study is divided into five sections. First we calculate the average mileage of Slovene cars and energy consumption of EVs, and then the CO₂ emissions of passenger cars in Celje are presented. The third and fourth sections respectively present calculation of solar energy availability and the required recharging capacities for proposed EV fleet. At the end, some results of the survey, which was carried out in Slovenia in connection with the opinion of the customers regarding LEVs, are presented.

In 2010 Celje had registered 32,214 road vehicles (SURS, 2010b and SURS, 2011b). Fig. 1 shows the very significant increase in the automobile population, primarily resulting from the membership of Slovenia in EU.

2.1. Calculating the mileage and energy consumption of EVs in Slovenia

In the first step, we calculate the mileage of all vehicles. At the end of 2010, Slovenia had 1,061,646 registered passenger cars, or 518 vehicles per 1000 inhabitants (SURS, 2011b). The total vehicle mileage (MGE) was thus obtained as,

$$MGE = N \times D = 23,356,212,000 \text{ vehicle-km/year} \quad (1)$$

Q is the amount of gasoline consumption in liters and FC is average fuel consumption of European cars, which is around 6.5l/100km (GCC, 2004). For the purposes of transport, Slovenia spent 651,690,000kg of gasoline in year 2008 (leaded and unleaded) (MOP, 2009). For calculation purposes we have taken into account the petrol density of gasoline, which is 760g/m³ and thus get Q in liters, which in our case is 857,486,842 liters of gasoline. We can also calculate the average mileage of each car which comes out as 47km/day-vehicle.

According to the study prepared by MIT Electric Vehicle Team [14], electric vehicle (EV) consume 200-300Wh for a mile on average. In this study a figure of 200Wh/km was used, i.e. if all of the above cars in Slovenia were converted to EVs they would consume 3,654GWh/year. The energy consumed by one electric car would approximately be 3.4MWh/year, or 9.3kWh/day.

2.2. CO₂ emissions associated with passenger cars in Celje

CO₂ emissions of new vehicles registered respectively in the years 2008, 2009 and 2010 have shown a decreasing trend of 159, 156 and 145 g/km. For calculation purposes, we considered the number of cars within Celje, amounting to 32,000 and the average value of CO₂ emissions of cars as 153.3 g/km. This translated to a figure of 84,060 tonnes of CO₂ per annum or 230 tonnes/day.

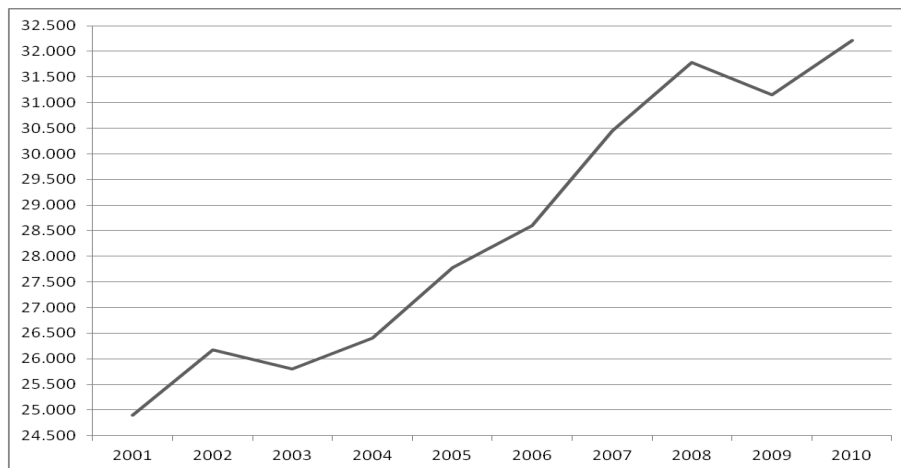


Fig. 1. Number of vehicles registered in Celje from 2001 to 2010

Рис. 1. Количество транспортных средств зарегистрированных в Целье с 2001 по 2010

2.3. Solar recharging

The two factors that will bring about a significant change in the present day unsustainable aspect of transport sector are market inducements for the introduction of electric vehicles and a sustainable supply of electricity for charging them. In this respect a brief review of the policy of the Slovenian government is presented. Firstly, the introduction of electric vehicles is being encouraged by a subsidy offer of €5,000.

Secondly, the relevant legislation affecting RES-E (Renewable Energy Sources) in Slovenia makes it incumbent on the energy network operators to purchase electricity from “qualified producers” either for fixed feed-in or premium feed-in tariffs. The network operator and the qualified producer sign a Purchase Agreement covering the purchase of electricity from the qualified producer for a period of 10 years.

Slovenia measures only 20,256 square kilometres, but in spite of this we can divide its territory into three climate types: sub Mediterranean, temperate-continental, and mountainous [19]. However, the quantity of energy received due to solar radiation is influenced more by various relief positions than by the different climate types. Average solar radiation in Slovenia is more than 1,000kWh/m²-annum. The ten-year average of the measured (1993-2003) annual global radiation was between 1053 and 1389 kWh/m² (Fig. 4). Half of Slovenia receives between 1153 and 1261 kWh/m².

The construction of solar power plants in Slovenia has shown an extremely rapid growth. In a few years Slovenia has installed more than 1,390 plants that were connected to the grid. Total power plants at the end of 2011 were more than 90 MW. In 2012, Slovenia’s electricity generation was more than 130MWh from solar energy.

The efficiency of solar modules that are available on the market ranges between 8 and 20%. In our study, electric characteristics of monocrystalline silicon photovoltaic modules produced by Bisol Company of Slovenia were used. An average module efficiency of 14% was used.

3. ECONOMICS OF SOLAR RECHARGING FOR EV'S IN CELJE

One of the options to reduce CO₂ emissions is the integration of electric vehicles (EV) as far as possible, but only if the EV’s would be charged from environmentally friendly sources of energy.

Distribution of electricity in Celje is carried by Elektro Celje Company. Electricity production is still dominated by conventional sources (63%) and 37% from renewable energy sources (Elektro Celje, 2011). The present Carbon footprint for Slovenian electricity is 0.44-0.66 kgCO₂/kWh [12].

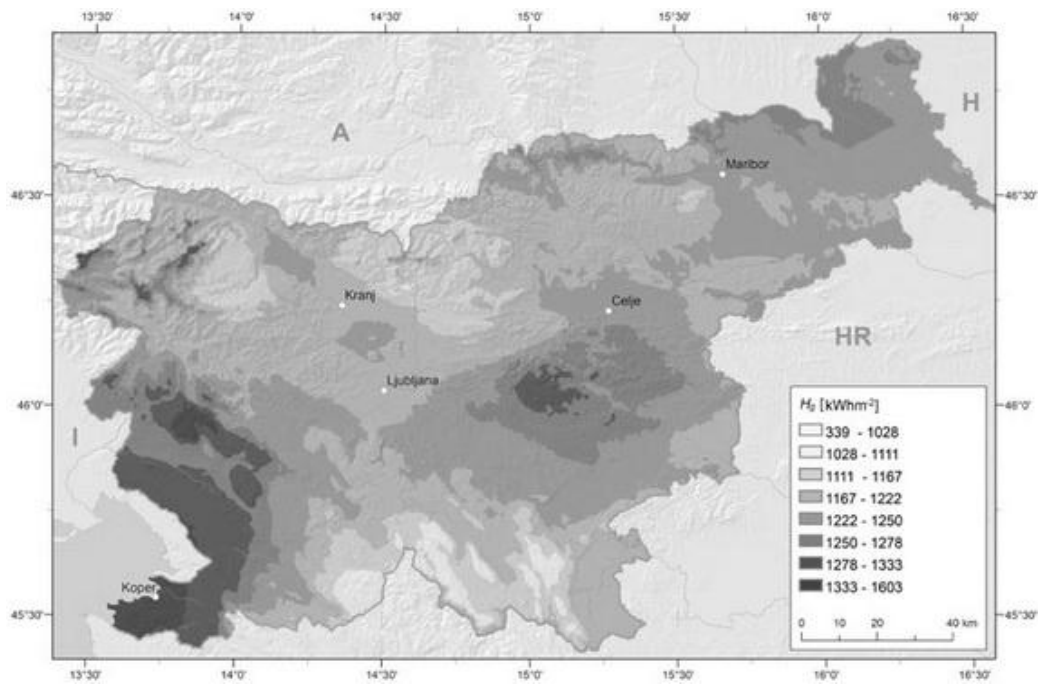
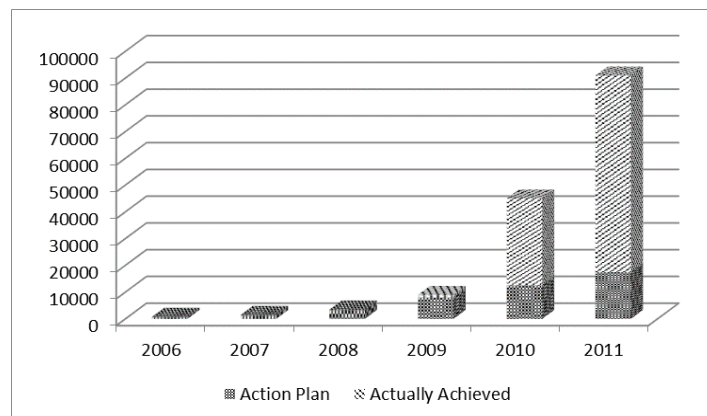
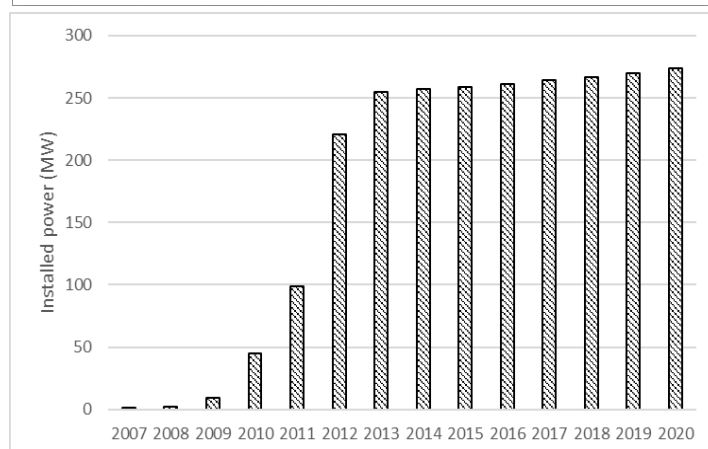


Fig. 2. Annual global solar radiation on a horizontal surface for Slovenia

Рис. 2. Общая годовая солнечная радиация на горизонтальной поверхности для Словении



a



b

Fig. 3. Slovenian constructions of solar power plants, (a) and the forecast for 2020 at 10-15% annual growth, (b)

Рис. 3. Строительство солнечных электростанция, (a) и прогноз до 2020 с учетом 10-15% годового роста, (b)

As alleged by a study conducted by Purgar [23], EVs can reach a market share of 10% by 2020. The required electricity that needs to be produced from PV panels to empower the 3,200 EVs for Celje's roads by 2020 is shown in Table 2.

Table 2

Electrical energy needed for propulsion of EVs

Energy demand, MWh	Per day	Per month	Per year
	29.80	907	10,800

Figures 4 show the historical price drop of PV module costs and the total system cost. In Celje there are about 9,000 residential buildings and if just one half of them could be suitable for PV modules installations, it means that at least 3kW systems could be installed on 4,500 homes. This could mean the sum of about 112,000 m² of PV modules would generate 14MW peak power which may be used for charging the battery bank for two- or four-wheel electric vehicles.

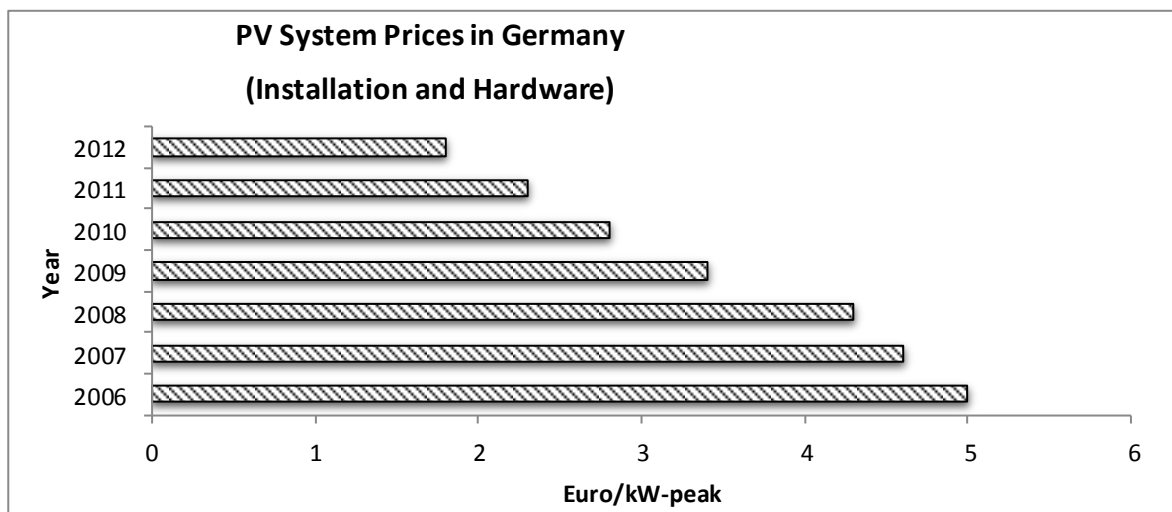
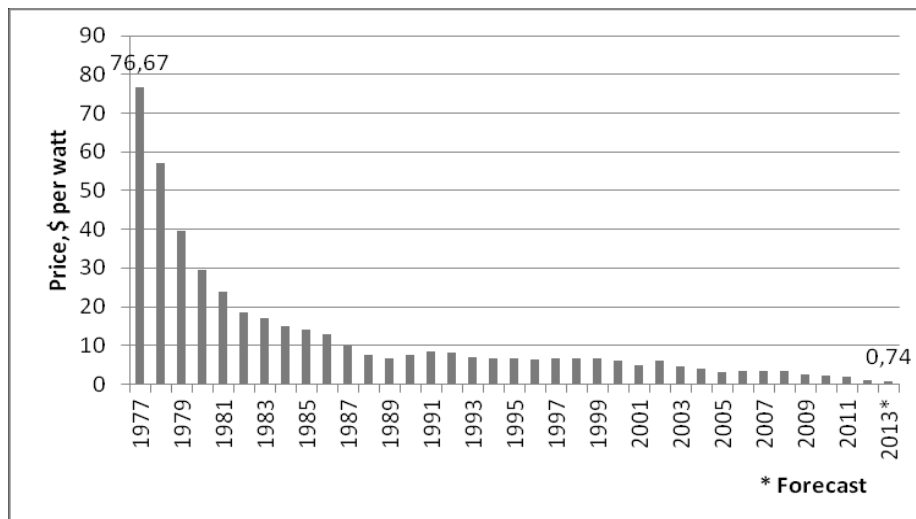


Fig. 4. The decreasing cost of (a) crystalline silicon photovoltaic cells [28], (b) complete PV electricity systems
Рис. 4. Снижение стоимости (а) фотоэлементов на кристаллическом кремнии [28], (б) в целом для PV электрических систем

The price of the electricity generated by a solar PV system (C_{PV} , €/kWh) is the ratio between annual payment to offset PV installation financing loan and the total annual amount of energy produced (E_{an}). Capital costs can be decomposed in investment: panels (I_p), inverter (I_i), installation (I_l), and annual maintenance, M . Note that the replacement costs of the inverter, which has a shorter lifetime than the panels, have to be taken into account. We thus have the basic set of equations that lead to financing costs.

Annual payment to offset PV installation financing loan,

$$A = P \cdot F_i (1 + F_i)^n / [(1 + F_i)^n - 1] \quad (2)$$

P = Capital costs associated with erection and life-time maintenance of the PV plant and n is the payback period, assumed to be 25 years for the present study (life of PV modules).

For a unit square metre of PV module area that has a nominal efficiency of η expressed as a fraction),

$$P, \text{ €} = 1000\eta (I_p + I_i + [L_p / L_i] \cdot I_l + n \cdot M) \quad (3)$$

Note that Tables 3 and 4 respectively provide a further explanation for above-used symbols and the present cost of fossil-nuclear powered electricity. The estimation of the annual-averaged energy generated per square metre of PV module area, E_{an} ought to include the decline of cell efficiency with time (d) and the energy generated per peak Watt installed capacity of the PV modules per year, i.e. kWh/kWp-year. It may easily be shown that,

$$E_{an} = 0.5\eta [F_0 + F_{25}] G_\beta \quad (4)$$

G_β is the annual-averaged global irradiation (kWh/m²) in the plane of (inclined) PV modules. F_0 and F_{25} in Eq. 3c are usually provided by module manufacturers and a typical set of values indicate a 97% performance (F_0) for new modules that literally drops to a figure of 80.2% (F_{25}) after a 25-year use.

The cost equation thus becomes,

$$C_{PV}, \text{ €/kWh} = A / E_{an} \quad (5)$$

Using data of Table 3 and using above equations, 3a through to 3d, we thus obtain for one square metre of PV module area: $P = 364.8$, $A = 23.35$, $E_{an} = 168.34$ and $C_{pv} = 0.139$. Note that in the above calculations a value of solar irradiation of 1,250kWh/m²-year for Celje and an efficiency of 15.2% for monocrystalline PV modules was used.

The above estimate of solar electricity (13.9€ cents/kWh) may be compared to the present cost of 14.74€ cents/kWh for fossil-nuclear fuel electricity that is available in Celje.

4. PREFERENCES AND OPINIONS ABOUT ALTERNATIVE FUEL VEHICLES

Our main goal of this part of the study was to identify the measures that would increase the people's interest in purchasing LEVs. The results reveal new perspective of purchasers, and indicate which factors are the most important for the purchase of a LEV.

Two non-financial factors are crucial when deciding on a car purchase – 1: “overall condition and mileage of vehicle (when buying a used car)”, and – 2: “safety features”. Other very important factors are: vehicle size (exterior), style/appearance/colour, body shape (e.g. hatchback, coupe ...) and fuel type. Divided results for men and women are presented on Figures below.

5. CONCLUSIONS

The present study encompassed the following five tasks:

- Estimate the average mileage of Slovene cars.
- Obtain the corresponding CO2 emissions of passenger cars in Celje, a medium-sized town.
- Compute the energy requirements of electric vehicles (EVs).
- Calculate the available solar energy and the required recharging economics for the proposed EVs.
- Present the factors that influence the purchase decision regarding LEV.

It was shown that within Slovenia there is a strong and robust uptake of solar PV plants with actual installations exceeding the planned capacities by a factor of six. Furthermore, it was noted that the price of PV modules within the past 36 years has dropped by a factor of 104. The present analysis indicates that price of solar electricity that is presently obtainable is 13.9€ cents/kWh. This compares quite favourably with the present cost of 14.74€ cents/kWh for fossil-nuclear fuel electricity that is available in Celje.

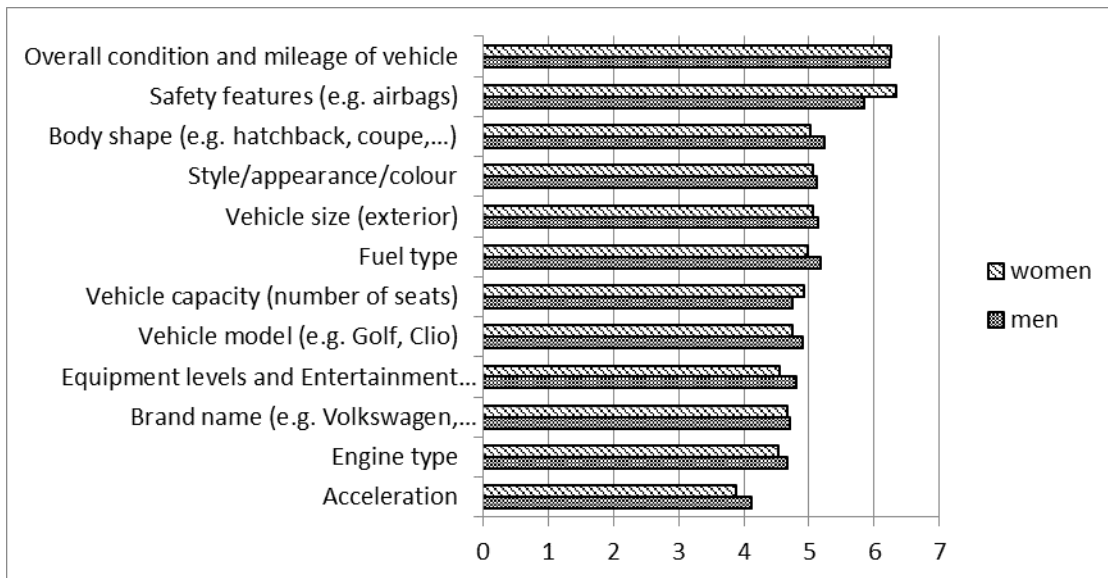


Fig. 5. Important vehicle performance factors (On a scale from 1 to 7 where 1 means NOT IMPORTANT and 7 means VERY IMPORTANT) [10]

Рис. 5. Важность различных факторов для автомобилей (в границах от 1 до 7, где 1 означает НЕ ВАЖНО и 7 означает ОЧЕНЬ ВАЖНО) [10]

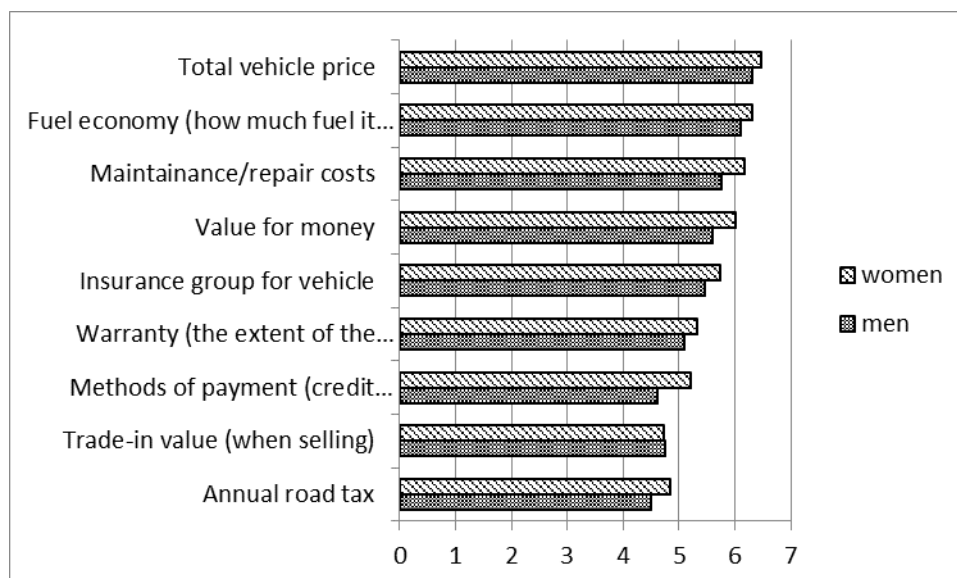


Fig. 6. Important financial considerations (on a scale from 1 to 7 where 1 means NOT IMPORTANT and 7 means VERY IMPORTANT) [10]

Рис. 6. Важность финансовых оценок (в границах от 1 до 7, где 1 означает НЕ ВАЖНО и 7 означает ОЧЕНЬ ВАЖНО) [10]

One of the important finding of this study also involves the strength of the relationships between gender and willingness to consider green products. Different studies, as well as the results of this study, reveal that there is no single measure that would dramatically increase the demand for LEVs. The solution is to combine different measures or strategies like top-down and bottom-up, where both government and car industry should come across.

It is clear that Slovenian government must be aware that single measures do not exist and that they are not effective. If the government wants to increase interest in purchasing LEVs, it should adjust and adopt a variety of different measures, combining both pull and push factors. The most important pull factor is development of special incentives for LEVs. Other relevant measures are VAT based on carbon emissions (buyers with lower emission vehicles would pay less VAT), vehicle registration fee based on carbon emissions of vehicles (buyers of lower emission vehicles pay less), motor insurance premiums partly based on carbon emissions (i.e. drivers of higher emission vehicles pay more), and a road user charging scheme based on carbon emissions (i.e. drivers of higher emission vehicles pay more).

Table 3

Parameters used for the cost equation

Investment cost for PV panels	I_p	0.6 €/Wp
Investment cost for inverter	I_i	0.2 €/Wp
Investment cost for installation	I_l	0.8 €/Wp
Lifetime for PV panels	L_p	25 years
Inverter lifetime	L_i	10 years
Maintenance costs	M	0.02€/Wp/year
Interest rate	F_i	4%/year

Table 4

Electricity prices for households (EUR/100 kWh),
Slovenia, second half of 2011

Consumer group (annual consumption band)	Price, all taxes included
DA (< 1 000 kWh)	22.52
DB (1 000 < 2 500 kWh)	17.02
DC (2 500 < 5 000 kWh)	14.92
DD (5 000 < 15 000 kWh)	13.61
DE (>= 15 000 kWh)	12.49
SLOVENIA, average	14.74

Source: SURS, 2011a.

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