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Photovoltaic electricity production of a grid-connected urban house in Serbia

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Abstract

A technically attractive solution for sustainable present and future is to integrate photovoltaic (PV) panels into building fabric of urban houses as an alternative to grid electricity, however, in Serbia this technology is rarely applied. To contribute to sustainability and create success conditions for renewable energy sources (RES) applications due its wish to join EU, Serbian government currently integrated RES into its new energy policy framework. In the near future in the separate law, the government will identify financial conditions to apply this policy and start RES use. To adequately inform this law, we calculated the electricity revenue during entire life of a two-floor house in Belgrade, Serbia and investment in PV panels (currently available on Serbian market) integrated in its entire envelope. It was discussed what are the current degree of economic viability of this solution and suggested level of state subventions needed to support the solar electricity production either by feed-in tariffs or other financial instruments.

Keywords: Solar electricity; Building; Photovoltaics

1. Introduction

As combustion during electricity production from non-renewable resources presents one of the main reasons for global and local pollution, sustainable electricity production by Photovoltaics (PVs) provokes great attention in European Union, Balkan region and worldwide (Tsoutsos et al., 2004; Patlitzianas et al., 2005; Reiche, 2004; Haas, 2003; Muneer et al., 2003 2005; Li et al, 2005; Nomura and Akai, 2004). As Serbia has political wish to join European Union in future, its crucial drive for renewable energy source (RES) development also comes from the conditions set by the EU such as the new EU-members targets for their RES development until 2010 given by the EU-Directive on the promotion of electricity produced from RES (Reiche and Bechberger, 2004).

In Serbia, electricity is not generated by using so-called ''new'' RES (biomass, geothermal, solar energy, wind, and mini-hydro power plants). In large power plants, 35% of Serbian electricity is produced by using water (which is ''traditional'' RES with high negative social and ecological externalities when erected) and additional 65% of electricity by using fossil fuel (mainly lignite) (MMERS, 2005a).

Having in mind such a RES situation in Serbia and its EU drive, the Serbian Government in 2004 rapidly becomes open towards idea to promote RES. For instance, the minister of Mining and Energy of Republic of Serbia officially stated that one of the priorities of Ministry of Mining and Energy of Republic of Serbia (MMERS) is enhancement of use of RES (MMERS, 2004a). In addition, the minister started up initiative for development of programs of RES and highlighted necessity that World Bank helps this initiative (MMERS, 2005b). Furthermore, director of National Program of Energy Efficiency also recognized the role of RES in this program and announced support for studies and projects in this field (Oka, 2004). The minister of Science and Environmental Protection of Republic of Serbia (MSEPRS) promised publicly that

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Nomenclature

LFE	Law on financial support for RES producers of electricity and heat
MMERS	Ministry of Mining and Energy of Republic of Serbia
MSEPRS	Ministry of Science and Environmental Protection of Republic of Serbia
MSTDRS	Ministry of Science, Technology and Development of Republic of Serbia
RES	Renewable energy source
PV	Photovoltaic

Serbia-Montenegro would sign and ratify the Kyoto Protocol on sustainable development by the end of year 2005 (IIS, 2005). To change current structure in its electricity production, the Serbian Government made several success-story conditions for RES application by two initiatives: (1) creation of the new policy framework regarding RES and (2) promotion of special research at universities and institutes to assess its RES potential and role of current and advanced technologies in using this potential. However, currently we do not have fully applicable framework for actual use of RES in electricity production.

To build new RES policy, MMERS and MSEPRS made significant efforts by preparing three documents in 2004. MMERS prepared one law and one special document: (1) new Energy Law that for the first time deals with electricity production from RES (MMERS, 2004b) and (2) Strategy for Development of Energy Industry of Republic of Serbia until 2015 that concretize application of the Energy Law in RES field (MMERS, 2005c). MSEPRS prepared one new law: Environmental Protection Law that also deals with RES (MSEPRS, 2004). The national assembly adopted these two new laws and will adopt the special document later this year. However, all adopted laws are only the basic regulations that control future use of RES with different set of measures, and national assembly must adopt other laws that concretize these measures such as the law on financial support for RES producers of electricity and heat (LFE).

In 2002 to promote RES, Ministry of Science, Technology and Development of Republic of Serbia (MSTDRS) initiated National Program of Energy Efficiency that is active today. This program stipulated funds for universities and institutes in Serbia to work on National Research Programs in Energy Efficiency. One of these subprograms is ‘‘Use of alternative and renewable energy sources’’ (MSTDRS, 2003). This Serbian RES subprogram regulates activities of research, development and demonstration in the RES field. The Serbian RES subprogram contains only two topics of interest for solar electricity generation: (1) Development and investigation of hybrid solar surface collector for generation of heat and electricity and (2) Design, construction, monitoring and demonstration of PV system for supply of office building with electricity for lights.

As Serbian residences used 54.6% of electricity in Serbia in 2004 (MMERS, 2005a), a technically attractive solution is to integrate PVs into an envelope of urban buildings as an alternative to electricity grid, but this solution is not economically viable. An objective of this separate research (in direction of the Serbian RES subprogram) is to inform the future design of LFE of needed financial subsidies for the case of solar electricity generation. However, it is expected that in future the great shortages of non-renewable electricity may exist and the price of PV panels may drop because of their massive forthcoming production (Yoo and Lee, 2002; Bahaj, 2003; Compagnon, 2004; Yang et al., 2004).

To inform future design of LFE, for a conceptual urban grid-connected house in Belgrade-Serbia, electricity generation by PV panels integrated in all its walls and roofs is investigated. It is assumed that this building might consume electricity either from PV panels or from electricity grid. Several research issues of interest are investigated as follows: (1) the maximum amount of power of PV panels during electricity generation in this house; (2) the amount of electricity that can be generated yearly; (3) the best orientation of the house for the highest electricity generation; (4) degree of economic viability of PVs integrated into building architecture in Serbia (Belgrade region) today; (5) level of state financial support needed to produce electricity economically feasible.

2. Details of developed new energy policy framework for renewable electricity applications in Serbia

New energy policy framework for renewable energy applications in Serbia that is more sensitive to use of RES is given by three new documents: (1) ‘‘Energy Law’’, (2) ‘‘Environmental Protection Law’’ and (3) ‘‘Strategy for development of energy industry of Republic of Serbia until 2015’’. Details of these laws and document will be described below.

2.1. Energy law

To support use of RES for production of electricity, the law for the first time deals with several RES issues: (1) privileged electricity producers, (2) small RES power plants, and (3) agency for energy efficiency, (4) stipulation of RES use in document on energy policy and (5) stipulation of RES use in document on development of energy-industry strategy (MMERS, 2004b).

The privileged producers of electricity (defined by this law) in their electricity production must use RES and/or produce electricity in small RES power plants, all under conditions that they fulfill criteria of energy efficiency. These producers will have a right for subventions, tax and custom easements, and other simulative measures defined by a separate law. In addition, these producers will have some priority at the organized electricity market.

The small RES power plants are defined to have production power below or equal to 10 MW. The law states that they may be constructed and operated by private independent power producers and state producers, and they can use and sell the produced electricity through the existing electricity-distribution system.

The agency for energy efficiency would exist as a part of MMERS. The agency already operates and one of its missions is to enhance use of RES.

2.2. Strategy of development of energy industry of Republic of Serbia until 2015

This document prepared by MMERS defines elements how to achieve development strategy of energy sectors in Serbia until 2015 (MMERS, 2005c). This document is in an adoption procedure at National Assembly of Republic of Serbia. The part of this document explains how to stimulate investments in RES to achieve objectives of energy policy. To achieve this, this document suggests (as the third special priority) execution of two RES programs: first, of the program for selective intensive use of RES such as biomass, rest of hydro-potential, of geothermal sources, and of solar energy for decentralized heat production, and second, of the separate programs of new RES technologies that are energy efficient and environmentally acceptable such as new technologies for biomass combustion and new technologies of small and mini hydro power plants. For programs for selective use of RES, the document stipulates measures for financial stimulation of private investment and establishment of national fund for these programs. The selective intensive use and development of the new technologies for use of solar energy for electricity production are not part of this program probably because its authors believed that this application of solar energy is rather expensive for financial support of a country with low GDP as this is currently Serbia.

2.3. Law for Environmental Protection

To support environmental protection through use of RES, the Law for Environmental Protection, for the first time, deals with two issues: (1) environmental protection fund and (2) financial support (MSEPRS, 2004).

The fund for environmental protection may be used to finance program and project development for RES and to support actual use of RES according to 10-year "National program of environmental protection".

Financing support is given to companies and individuals that use RES (solar radiation, wind, biogas etc.). These subventions, tax and custom easement, and other simulative measures are obtained, under conditions and method determined by separate law.

3. Conceptual building with integrated-photovoltaic panels

Table 1 lists characteristics of the investigated building and Fig. 1 shows its appearance of its envelope from north and south. The building is located in Belgrade region in Serbia with latitude of 44.82°. It has two stories with one flat in each story. It has seven envelope surfaces with distinct orientation designated as the north wall, east wall, south wall, west wall, north roof, south roof, and upper roof. These surfaces are entirely covered by PV panels, while surfaces of windows and doors are not. Fig. 1 also shows the location of the north of the house relative to the building walls. The location is defined by angle θ as an angle between the true north and the house north. The angle is useful to express the orientation of the house when the house is rotated for simulation purposes.

The size of each PV surface (wall or roof) of the building is shown in Fig. 2. The greatest size have PV surfaces located at the south and north wall. The characteristics of used PV panels (and cells) used in PV surfaces are given in Table 2. The PV cells are of mono-crystalline type.

4. Energy plus and photovoltaic building

To model the PV-house as well as to calculate its produced electricity and developed power, we used software *EnergyPlus* produced by Lawrence Berkley laboratory in USA (Crawley et al, 2001).

Table 1
Building characteristics

Located in	Belgrade, Serbia
Latitude	44.82°
Longitude	20.28°
Time zone	+1 h
Elevation	99 m
Building	Urban house
Number of flats	Two
Number of stories	Two stories
Roof slope	44.82°

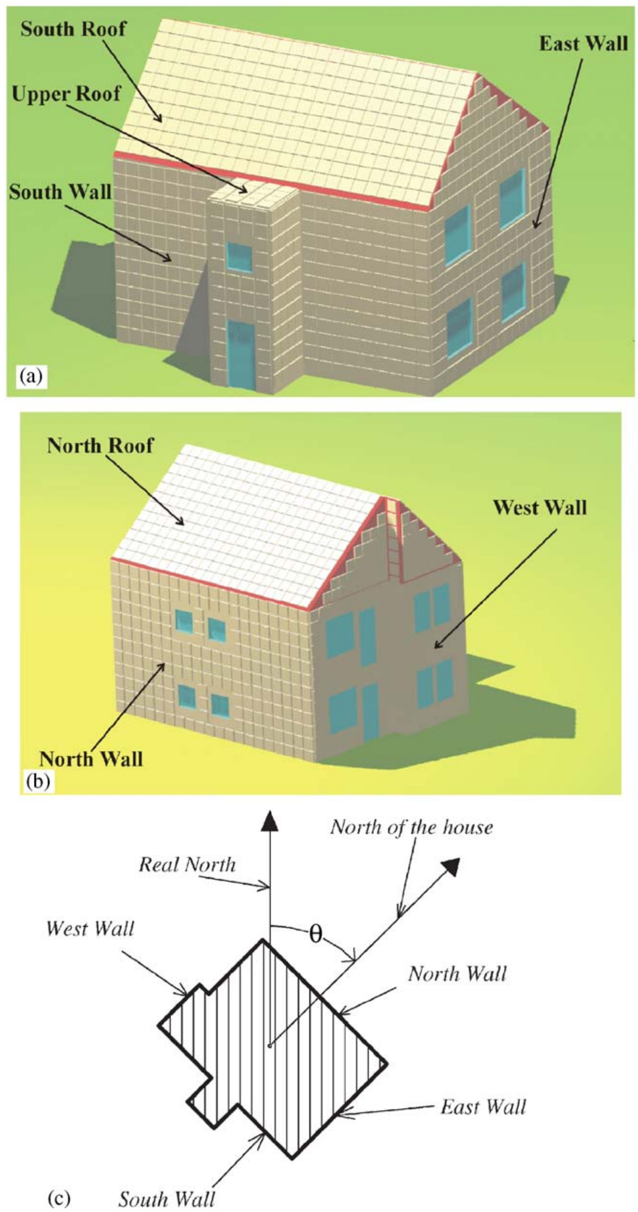

Fig. 1. (a) Appearance of southern part of building; (b) appearance of northern part of building; (c) plan of building.

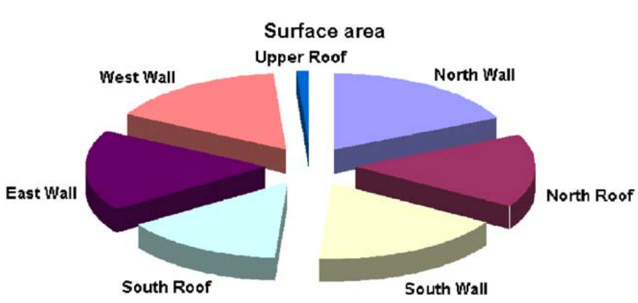

Fig. 2. Size of PV surfaces of the PV building.

Table 2
PV characteristics

Array type	Mono-crystalline
Number of cells in series	36
Shunt resistance	1,000,000 (Ω)
Short circuit current at reference conditions	6.5 (A/K)
Open circuit voltage at reference conditions	21.6 (V/K)
Temperature at reference conditions	25 (°C)
Radiation at reference conditions	1000 (W/m^2)
Current at max power	5.9 (A)
Voltage at max power	17(V)
Temperature coefficient of short circuit current	0.002(A/K)
Temperature coefficient of open circuit voltage	−0.079 (V/K)
Ambient temperature at NOCT	20 (°C)
Cell temperature at NOCT	40(°C)
Radiation at NOCT	800 (W/m^2)

In this software, model of PV panel is equivalent electricity circuit with one diode that will be explained in the separate section. Program enables integration of single panels in wall and roof surfaces of the house to describe their orientation and use results of solar-radiation calculation (University of Illinois and University of California, 2004).

In this modeling, there are the following assumptions:

(1) Produced electricity by the PV arrays is always put to good use, as in an ideal, grid-tied system. Currently, EnergyPlus does not include separate models for supplementary equipment for a PV array such as batteries, charge controllers, power-point trackers, and inverters.
(2) Modules are assumed to operate at maximum power point. For a variety of reasons, actual installations of PVs are often exhibit system-level problems that significantly reduce electricity production. Therefore, this modeling should be considered as method of bracketing the upper end of electricity production rather than an accurate prediction of what the panels will produce.
(3) The model predictions are closely related to the solar radiation data of TMY2 origin in the EnergyPlus weather file. These solar data are usually from a model rather than direct measurements. The data encountered by a real installation in a given year are likely to differ from the TMY2 data.

5. Mathematical model of photovoltaic panel

The model of PV panel (the equivalent electricity circuit with one diode) predicts its electrical performance. The model is also known as the "TRNSYS PV" model. The model was developed by Duffie and

Beckman (1991) and first incorporated into a component for the TRNSYS simulation package by Eckstein (1990). This model employs the Eckstein model for crystalline PV modules, using it whenever the short-circuit IV slope is set to zero or a positive value as modified by Ulleberg (2000). Mathematically speaking, the EnergyPlus PV model employs equations for an empirical equivalent circuit model to predict the current–voltage characteristics of a single module. This circuit consists of a DC current source, diode, and either one or two resistors. The strength of the current source depends on solar radiation and the IV characteristics of the diode depend on temperature. The results for a single module equivalent circuit are extrapolated to predict the performance of a multi-module array.

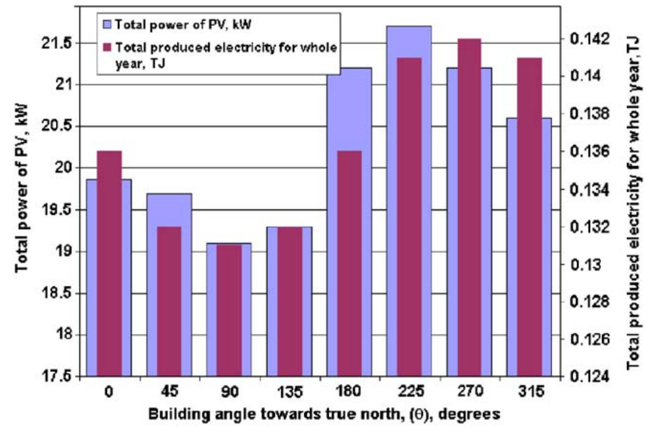

Fig. 3. Yearly power at integrated PVs and yearly electricity produced by integrated PVs vs. the building orientation.

6. Electricity power and production

To describe electricity generation by the PV house, we calculate its maximum electricity power (D) and its produced amount of electricity (Q) on the yearly basis.

Higher value of D of the PV house would mean its higher production of electricity in unit time. Then, the environmental performance of the PV house should be regarded as better as higher production of electricity may globally reduce CO_2 production.

We evaluate D as a yearly maximum of the sum of the values of the predicted hourly powers of all PV surfaces as

$$D = \sum_{J=1}^{N} Q_{\max,J} \tag{1}$$

Here, $Q_{\max,J} = \max\,(Q_{I,J})$, where $Q_{I,J}$ stands for the electrical energy (an output of EnergyPlus) produced by PV surface J during hourly time interval I where $I = 1, \ldots, 8760$ and $J = 1, \ldots, N$. Next, N stands for the total number of distinct PV-surfaces. Fig. 3 shows D for different orientations of the PV house. When $\theta = 225^\circ$, the PV house has the maximum value of D at 21.7 kW. This value is 12% greater than the minimum value of D obtained when $\theta = 90^\circ$.

We calculate Q as

$$Q = \sum_{I=1}^{8640} \sum_{J=1}^{N} Q_{I,J}. \tag{2}$$

Fig. 3 shows Q for different orientations of the PV house. When $\theta = 270^\circ$, the value of Q has its maximum value of 0.142 TJ (this is the best orientation of the PV house). This value is 8% higher than the minimum value of Q obtained when $\theta = 90^\circ$.

7. Economics and policy development

To find what is the degree of economic viability of PVs integrated into building architecture in Serbia (Belgrade region) today, and what is the needed level of state subventions for the economically feasible production of electricity, we perform economic calculations. For each PV surface (designated by J) of the PV house, we calculate its investment cost (IP_J) and electricity revenue (CQ_J).

We calculate IP_J as

$$IP_J = A_J\, TP_J, \tag{3}$$

where A_J represents size of PV surface of the PV house designated by J and TP_J represents cost of m^2 PV surface "J" in present value €. In this analyses of investment in PVs, we only took into consideration only the price of PV-surfaces and did not take into consideration the price of additional electro equipment (battery, battery controller, and inverter). For all PV surfaces, value for TP_J would be the same. The value for TP_J will be different for present and future scenario.

We calculate CQ_J during entire house life (n years) in money units of the first investment year (present value €) by using the following equation:

$$CQ_J = Q_J\, TQ \frac{(1+e)}{(d-e)} \left[1 - \left(\frac{(1+e)}{1+d}\right)^n\right]. \tag{4}$$

Here, $Q_J = \sum_{I=1}^{8640}\sum_{J=1}^{N} Q_{I,J}$ represents electricity produced by PV surface "J", TQ represents electricity price of kW h of electricity in present value €, d stands for the discount rate, e stands for the escalation rate of electricity price, and n stands for the expected life of PV surface. In addition for these analyses, we took current values of $d = 0.1226$, $e = 0.1$, and $n = 50$ years. Values of d and e are taken here to be constant during entire useful life of a house, however, due to current fluent economic situation in Serbia, these values may be variable. The value for TQ will be different for present and future scenario.

7.1. Current degree of economic viability

To answer what is current degree of economic viability of PVs integrated into the PV house, we construct Fig. 4 for the present situation in Serbia that shows the electricity revenue and investment in PVs for each PV surface when $\theta = 0°$ when $TP = 588$ present value €/m^2 and $TQ = 0.05$ present value €/kW h. Fig. 5 shows that the highest investment costs are for PVs installed on the north wall of around 51,000 Present Value Euros and the lowest are for the south roof of around 40,000 Present Value Euros (if the upper roof is not taken into account). However, the highest electricity revenue is obtained from the south roof PVs of order of 16,000 Present Value Euros and the significantly lower electricity revenue is obtained from the north wall. The electricity revenue from the south roof is around 49% lower than the value of investment. It can be concluded that when the main electricity is available at power grid, generation of electrical energy by PVs is currently not economically viable for Serbia (Belgrade). To spread use of solar energy for generation of electricity in Serbia, it would be necessary to subsidy this kind of energy production. To answer what is level of state subventions needed in order the electricity production to be economically feasible, two subsidized scenarios were analysed.

7.2. First subsidized scenario—higher feed-in tariff for PV electricity

In the first scenario, government would subsidy PV eletricity production by higher feed-in tariff for produced PV eletricity. In this analysis, the feed-in tariff was taken $TQ = 0.13$ present value €/kW h that was 157% higher than the grid electricity tariff. The price of PVs $TP = 588$ present value €/m^2 was the same as that at today Serbian PV-panel market. The electricity revenue and investment in PVs were calculated when $\theta = 0°$ and the results were shown in Fig. 5. In this figure, IP_J and CQ_J had the same value for the south roof meaning that the electricity production by PVs at the south roof would be economically viable. For other PV-surfaces, this feed-in tariff would be lot higher. To conclude, in order PV panels located at the south roof produce electricity economically, the necessary feed-in tariff for PV electricity would currently be around 160% higher than the tariff for grid electricity.

7.3. Second subsidized scenario—financial support for PV-panel procurement

In the second scenario, government would subsidy PV electricity production by financial support to PV-panel procurement. In this analysis, the price of PV panels is taken $TP = 299$ present value €/m^2 that is 49% lower than that at today PV-panel Serbian market. The feed-in tariff for produced PV electricity is $TQ = 0.05$ present value €/kW h that is the same value as the value of the

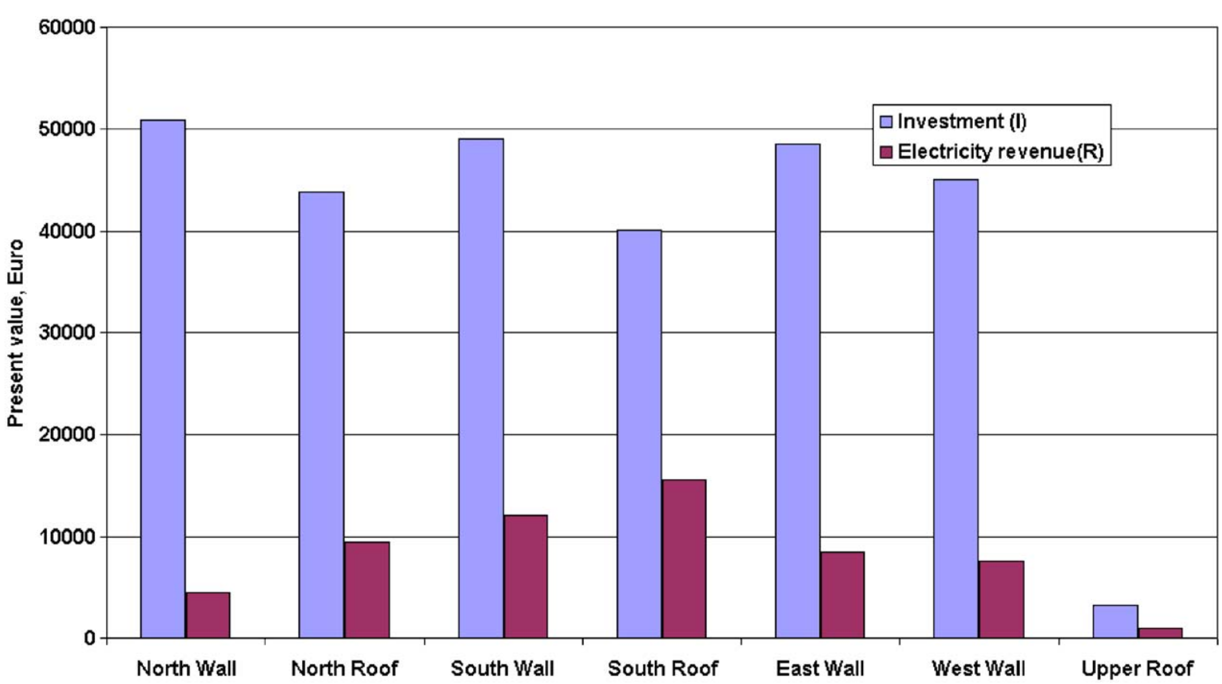

Fig. 4. Electricity revenue and investment in PVs when $\theta = 0°$ for the curent situation.

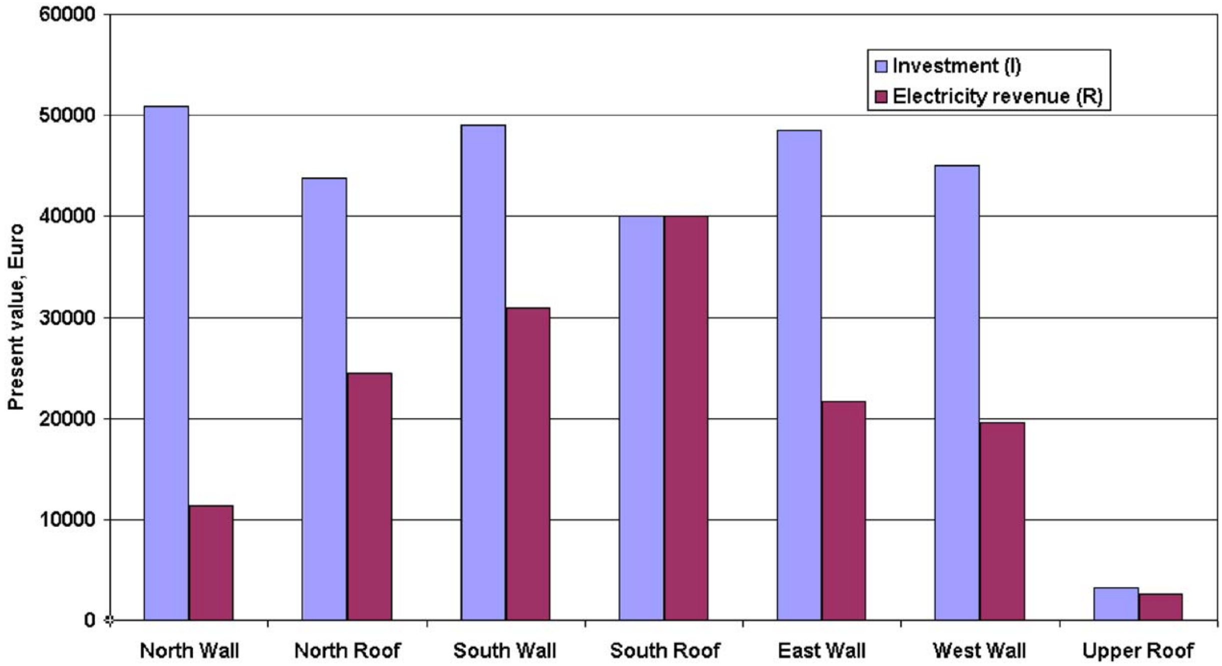

Fig. 5. Electricity revenue and investment in PVs when $\theta = 0^{\circ}$ for two subsidized scenarios.

grid electricity tariff. The electricity revenue and investment in PVs are calculated when $\theta = 0^{\circ}$ and the results are the same as for the first scenario and shown in Fig. 5. In this figure, IP_J and CQ_J have the same value for the south roof meaning that the electricity production by PVs at the south roof will be economically viable. For other PV-surfaces, financial support for PV-panel procurement should be lot higher. To conclude, in order for the PV panels located at the south roof to produce electricity economically, the necessary financial support for their procurement should currently be about 50%.

8. Conclusion

So far in Serbia, so-called "new" RES are not used for electricity production because there was not any systematic support for this production. However, as Serbia wants to join EU, the Serbian Government rapidly opens towards the utilization and promotion of RES. In this direction, Serbian government made good RES policy foundation by (1) adopting two separate laws and one document, and by (2) promoting of special RES research at universities. However, fully applicable framework for actual use of RES in electricity production still does not exist. The missing links are a set of laws that will concretize RES policies in the adopted laws where of the paramount importance is LFE.

We should stress that new Serbian energy law defined (1) privileged RES electricity producers (that will have a right for subventions, and tax and custom easements), (2) small RES power plants (that may be constructed and operated by private independent power producers and may use and sell the produced electricity through the existing electricity-distribution system), and (3) agency for energy efficiency dealing with RES. For the first time, the law requires that use of RES is a part of two separate documents: (1) on energy policy and (2) on development strategy of energy industry. The part of the second document deals how to stimulate investments in RES until 2015. This document suggests execution of two RES programs, however these programs do not deal with use of solar energy for electricity production probably because its authors believed that this application is rather expensive for financial support of a country with low GDP as this is currently Serbia. However, it is expected that this program would deal in future with this application as the great shortages of non-renewable electricity may exist and the price of PV panels may drop because of their massive forthcoming production.

The new Law for Environmental Protection, for the first time, proposed existence: (1) of environmental protection fund that may support RES use and (2) financial easement for RES use regulated by separate law. On the other hand, National Program of Energy Efficiency funds research in RES subprogram "Use of alternative and renewable energy sources" with solar-electricity topics.

A technically attractive solution for future in Serbia may be to integrate PVs into envelope of urban buildings as an alternative to electricity from grid, but this solution is not currently economically viable. An objective of this research (in direction of the Serbian RES research subprogram) is to inform future design of LFE of needed financial subsidies for this case.

In order to inform future design of this separate law, for a conceptual urban grid-connected house in Belgrade, Serbia, electricity generation by PV panels integrated in all its walls and roofs is investigated. This research revealed that economical PV electricity production requires adequate technical approach and huge financial support from government by adequate financial policies. Adequate technical approach means that for the highest generation of electricity, the house should be oriented adequately (the building angle toward true north should be 270 °C) and solar panels should be put only on the one surface of the house (the south roof of the house). Adequate financial policy, if this electricity is sold to the grid, may enable either (a) 157% higher feed-in tariffs for PV electricity or (b) 49% subsidies for procurement of PVs.

This research should be repeated every 2 years for several reasons: (1) price of PV panels may change (drop), (2) price of electricity may change (increase), (3) the PV market in Serbia may obtain new market players and (4) the PV market may offer new types of PV panels. Then, electricity production by solar PV panels would require smaller subsidies and/or smaller feed-in tariffs. New results should be fed into LFE and "Development Strategy of Energy Industry" for promotion of solar electricity under new conditions.

Further research may be organized also (1) for different architectural shapes of buildings, (2) for the buildings exposed to shading in city core, (3) for rural buildings and (4) for buildings in different parts of Serbia. On the other hand this assessment may be done with more complex model that is sensitive to (1) application of different eletricity consumers and parts of eletricity installation, (2) application of different eletricity use schedules, (3) application of different heat use schedules, (4) application of different temperature settings inside houses, (5) application of the envelope with better or worse thermal performances, (6) use of measured meterological data. The obtained results can be verified against measured data obtained at the demonstration PV application that would be built in future.

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