Figure 50: Graphic representation of measurement results.

EN_9. MODEL AND EVALUATION OF THE PANELS

EN_9.1. Dimensions of the model

The aim of the present chapter is to evaluate photovoltaic systems of different sizes and types. Our investigation is based on a two-dimensional model, which, on one hand operates by the application of panels of varying sizes and types and, on the other hand, also investigates a range of diverse application techniques. In the first dimension, we continued our work with the formerly described five panels and we distinguished two types of user categories.

- **solar home system users:** In this case, solar panels are installed on the roof structure of houses (mini home power plants), by which the complete photovoltaic system attains capacity of the order of 4 kW. In this category of users, regulations set forth the stipulation that only surplus generated over energy demand can be fed into the central network in Hungary[23].

- **energy investors**: This category involves big business enterprises which establish large-scale PV parks and feed electric energy produced by them into the central mains system. Power plants operated by such enterprises have an output of several hundred kilowatts, whereas, Hungarian regulations set forth 500 kW as maximum installed capacity. Since in Croatia the upper limit to solar power plant capacity is 300 kW[24], calculations for both countries were performed with 300 kW.

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[23]   In the case of Croatia we were calculation with overflow feed-in, however we also analysed the case of full selling situation.

[24]   http://files.hrote.hr/files/PDFen/Incentive%20prices/ENG_OIE_SE_2014_v1.pdf

Our objective is to enable the economically most appropriate technology to be selected from among possible alternatives along the two dimensions. This is the reason why we calculated net present value and carried out cost-benefit analysis to support choices of technology.

EN_9.2. Data, data sources

In order to perform cost-effectiveness calculations, we needed a considerable number of data that we listed into two categories: in view of both dimensions, we had to work with technical data and technical parameters and, on the other hand, we were also to consider the relevant prices in the process of our work. Our calculations were partly based on the measurement results and experience produced by the Croatian partner institution (capacity, life-cycle), and on the other, on the data (costs) provided by the business undertakings executing the construction of photovoltaic systems, as well as on the set of data supplied by energy authorities. The summary of the model's dataset, which is the result of a wide range of data collection, is presented by Table 15.

Table 15: Dataset of the Model

Denomination of data	Applied Source
Technical data, parameters	
Average annual energy production	Measurement results by the University of Osijek, ETFOS
PV panel capacity	Technical specifications
PV panel unit price	Price offers
Inverter unit price	Based on the Photon GmbH dataset
Panel life-cycle, capacity reduction	Based on the study by Jordan and Kurtz (2013)
Inverter lifetime	Based on technical parameters 12.5 years
System installation costs	Practical experience
Cost charged for central network connection	Price fixed in Croatia (1.400 EUR) while no such cost exists in Hungary
Internal system, cost of system construction	Experience-based determination (by business undertakings executing construction) of 20% of the cost incurred for the complete system
Annual maintenance costs	Experience-based determination (by business undertakings executing construction) of 20% of annual revenue
Price-type data	
Retail price of electricity	Electricity price trends, regulations
Electricity transmission rates	National legal regulations, directives
Other data	
Annual inflation rate	Complying with the European Union expectations: 3
Whole investigation period	According to long-term vision 25 years

Source: Own edition

Major performance data of systems with different panels

As has been pointed out in the previous chapter, in our present research we modelled cost-effectiveness with 5 panel types, more specifically, monocrystalline, polycrystalline, CIS and amorphous silicon panels as well as the black-frame monocrystalline panel. Depending on the type of panel, regarding individual panels, performance and efficiency reduction factors show larger and smaller deviations; therefore we have summarized such factors in Table 16.

Table 16: Principal performance parameters for particular panels

	performance of panel 1 (W)	Annual efficiency reduction (%)	Panel price (EUR)
Monocrystalline panel	250	0.23	200
Polycrystalline panel	250	0.59	207
CIS panel	150	0.02	142
Amorphous silicon panel	100	0.95	83
Black-frame monocrystalline panel	240	0.23	258

Source: Own edition

Regarding annual capacities, for an average family house, self-consumption from the energy generated is defined in 4.430 kWh[25], whereas, for energy investors, the whole amount of electricity produced is fed into the mains network.

Along with the above data, inverter price should also be taken into account, which we have defined on the basis of the public data provided by Photon GmbH and included in Figure 51 by applying the EUR/kW measurement unit, we calculated the average unit price for inverters produced by different manufacturers with a value of 262,21 EUR/kW for systems with a capacity of 4 kW, while we computed 143.7 EUR/kW for power plants having a capacity of 300 kW.
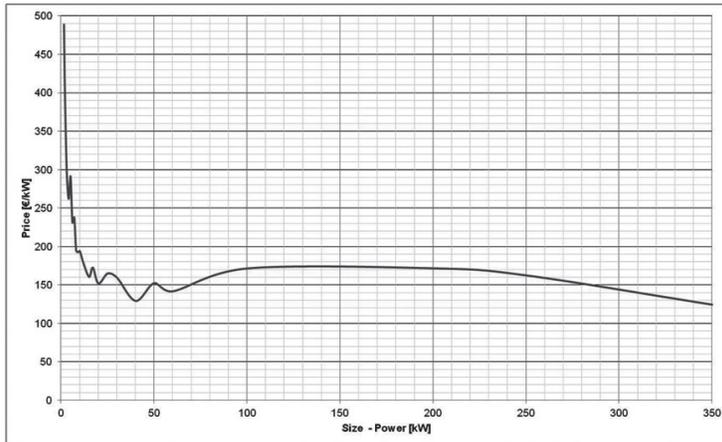
Figure 51: Trends in inverter prices in the light of the capacity of the whole photovoltaic system

Source: Danijel Topic, based on Photon GMBH, www.photon.info

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[25] http://www.energiapersely.hu/Haztartasi_eszkozok_energiafogyasztasa_Fogyasztasi_tablazat

In addition to statistics-based price-setting, we also considered the legal regulations of the two countries as well as the data provided by energy authorities. Thus, for solar home system users and energy investors, we determined Hungarian energy prices (subsequent to the reduction in overhead costs) in 13 and 15 euro cents/kWh respectively, while in Croatia the price is 14 euro cents in respect of both categories. In Hungary the costs of energy transmission into the mains network amount to 11 euro cents[26] in both user categories, while in Croatia, the relevant prices are 25 and 20 cents in the respective categories.

This is the point where there is a sharp boundary between the Croatian and the Hungarian relations. In Croatia solar electricity transmission prices are considerably higher than electricity consumer prices, consequently, it is more profitable to sell as much solar electricity as possible at the incentive prices – because in Croatia there is a possibility to sell all the produced energy. As opposed to this, in Hungary feed-in-tariff, which is lower than consumer price (85% of the latter), discourage investments, therefore, in terms of returns, the conditions created are worse than in Croatia, which provides incentive for the installation of hybrid systems or rather the construction of systems carrying out production for own use (otherwise, also legal regulations stipulate that only surplus remaining after the use of own consumption can be fed into the system). Preferably, it is worth installing these systems by using capacities with reasonable approximation to average energy consumption. Naturally, there is no guarantee that transmission prices for renewable energy kept high by the present, incentive systems will remain at the same high level; therefore, we made calculations considering other scenarios where the transmission price of generated energy decreases while the price of energy purchased from the mains electricity network increases.

Continuous technology development on the market may exert positive impact on the construction of domestic solar power stations while at the same time, such development gradually increases the efficiency of power plants, and on the other hand, results in falling investment costs (asset prices) attributed both to wider market participation and price competition.

EN_9.3. Evaluation methodology

In the interpretation of the described set of data, our model allows for the performance of several economic calculations, out of which hereby we use four indicators to enable us to evaluate the panel-choice alternatives for electricity producers.

1) **Real profit**: reveals the difference between total revenue and total expenses for a given year.

$$\Pi_t = TR_t - TC_t$$

Cumulated form: $T\Pi = \sum_{t=1}^{n} \Pi_t T\Pi = \sum_{t=1}^{n} \Pi_t$

where:

Π_t - total profit

TR_t - Total income for the year

TC_t - Total expenditure for the year

p – Acceptance price

Q_t – Generated electrical energy surplus, amount fed in the mains network

c_t – Annual energy demand

P - Consumer electricity price

t - Number of years (1-25)

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[26] The exact data: 11,4 euro cent at household consumers; 10,8 cent at energy producer investors.

The definition of the indicator's value may assist the evaluation of different alternatives in certain years but the problem posed by such evaluation method is that it assumes zero inflation in the event of long-term investigations.

2) **Inflation-adjusted profit:** It eliminates the drawback implied by the above indicator, more specifically, it is suitable for long-term investigations and its calculation allows for the comparison of not only specific years but also a period of several years.

$$\Pi_t^D = \frac{\Pi_t}{(1+i)^t} \Pi_t^D = \frac{\Pi_t}{(1+i)^t} \quad \text{Cumulated form: } T\Pi^D = \sum_{t=1}^{n} \Pi_t^D T\Pi^D = \sum_{t=1}^{n} \Pi_t^D$$

where:
i – inflation rate

3) **Net Present Values (NPV)**: It indicates the value of a given investment in year "t". We can talk about return on investment if it results in 0 NPV. This indicator extends the previous indicator by the mathematical operation of deducting the sum invested in year 0 from the inflation-adjusted profit.

$$NPV = PV_0 - C_0$$

$$NPV = \sum_{t=1}^{n} \frac{\Pi_t}{(1+r)^t} - C_0$$

where:
PV_0 – Present Value
C_0 – Investment value
r- Real interest rate

4) **Unit cost indicator** (IRENA, 2012): It indicates the ratio of total expenses and income/savings in a longer time period. Therefore, it can be interpreted as a type of cost-effectiveness, cost-benefit indicator.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + O_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t + S_t}{(1+r)^t}}$$

where:
LCOE – Levelised Cost of Electricity Generation
I_t – Investment cost
M_t – maintenance cost
O_t – Other costs
E_t – income from feed into network
S_t – Cost benefits generating from self-supply

EN_9.4. Evaluation of the basic model

Before adverting to the distinct analysis of the two user-categories, a piece of evidence, which resulted from the data applied, should be specified. The more serious and intense support measurably present on the Croatian side (i.e. feed-in tariff is bigger than consumer price), generates indicator results better on income side than those of the Hungarian counterpart.

However, the connection cost to the grid is higher in Croatia, therefore there is not as major difference in profit indicator as is in the cumulative indicator of cots and benefits.

Category of solar home system users

As has been previously shown, discrepancies between profit indicators are constituted only by inflation-adjusted corrections, consequently, hereby we present merely inflation-adjusted calculations.
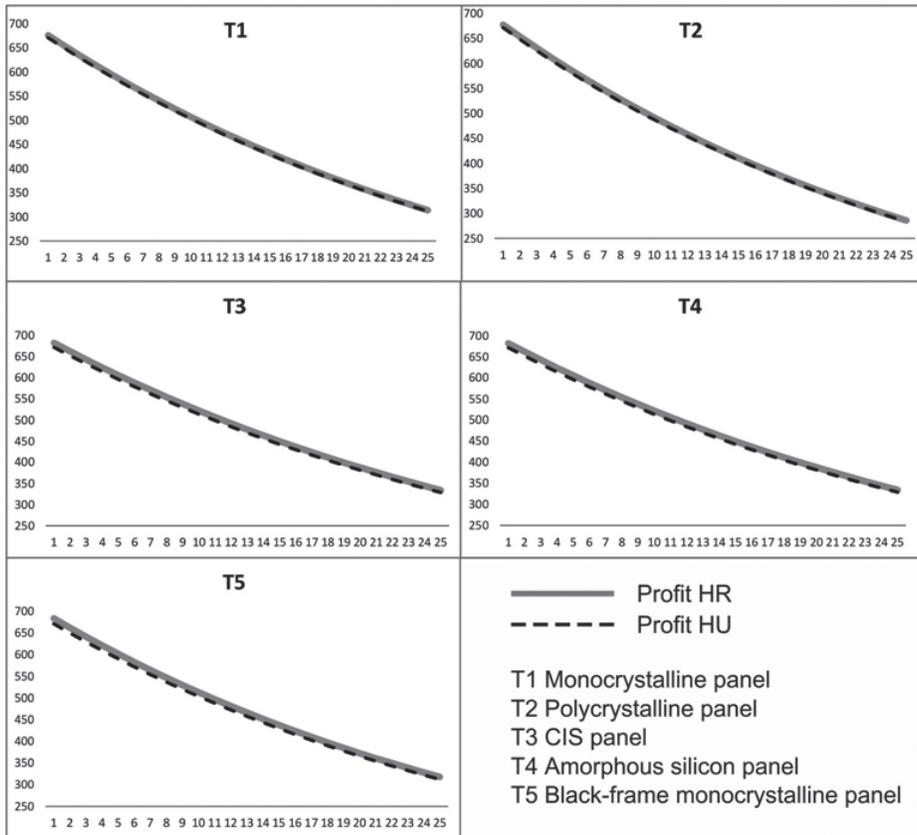
Figure 52: The development of annual inflation-adjusted profit in the context of the five technologies with regard to solar home system users

Source: Own edition

Figure 52 reveals that at the end of the 25-year period the highest value of the yearly profit is attributed to the CIS panel. This is not surprising if we consider that the level of annual efficiency reduction for this type is as low as 0.02%. As has been indicated earlier, relying simply on annual profit data in terms investments does not seem to be an appropriate approach mainly because the type producing the best profit results is considered to be one of the most expensive investments.

Therefore, if, we look at the net present value and the rate of return at the point of intersection on the horizontal axis included in Figure 53, we will certainly come to a different conclusion.
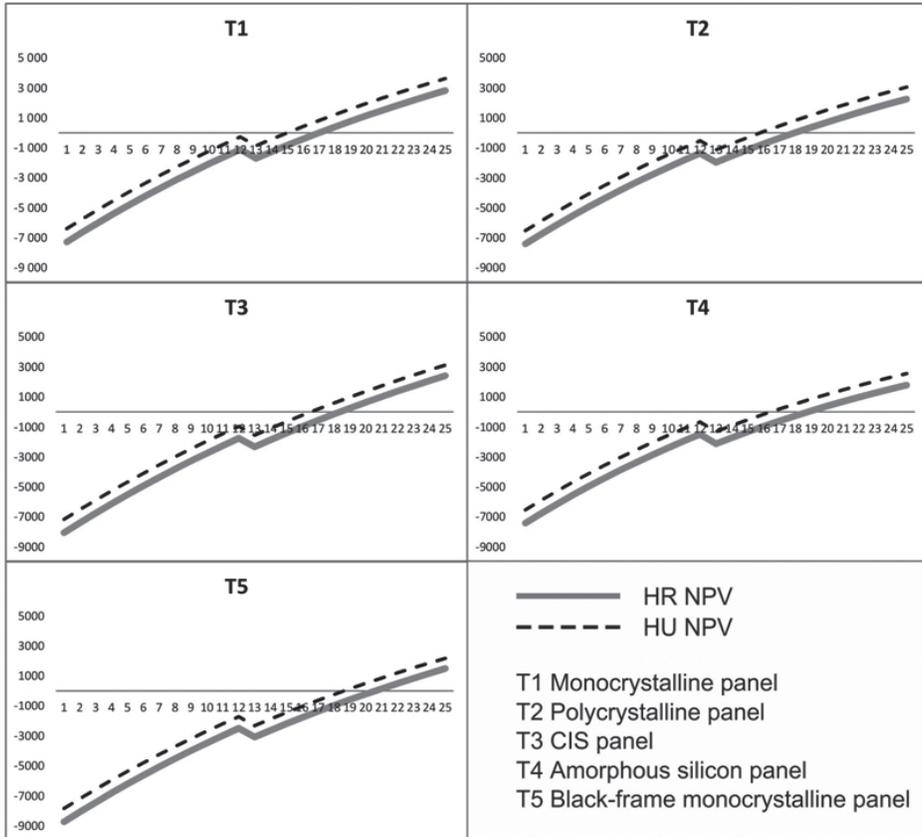

Figure 53: The development of net present value with regard to solar home system users

Source: Own edition

The shortest payback time can be attributed to monocrystalline panels (Figure 53) where the net present value measured after 25 years is 3 582 Euros in Croatia and this value is 3 297 Euros in Hungary. In Hungary the smallest net present value is ascribed to black-frame monocrystalline panels (1 880 Euros), whereas in Croatia the smallest net present value is attributed to amorphous silicon panels (2 349 Euros).

In terms of the unit cost indicator, it is also the first technology that is considered to be the most appropriate investment in both countries. On the Croatian side, in a timeframe of 25 years, all the cost factors related to this technology account for 68,7% of the income, while, due to lower-level revenue opportunities, this percentage value reaches 65,7% in Hungary. In contrast, black-frame panels (T5) amount to as much as 77,2% of revenues and have cost factors constituting 78.0% of the income. In relation to polycrystalline and amorphous silicon

panels, the order of priorities also shows a discrepancy between the two countries. In Croatia the first type and in Hungary the latter one was ranked the second place (Table 17).

Table 17: The development of unit price indicators regarding solar home system users

LCOE $_{T1,HR}$	0.687	1	*LCOE* $_{T1,HU}$	0.657	1
LCOE $_{T2,HR}$	0.696	2	LCOE $_{T2,HU}$	0.668	3
LCOE $_{T3,HR}$	0.737	4	LCOE $_{T3,HU}$	0.718	4
LCOE $_{T4,HR}$	0.697	3	LCOE $_{T4,HU}$	0.669	2
LCOE $_{T5,HR}$	0.780	5	**LCOE** $_{T5,HU}$	0.772	5

Source: Own edition

We can say that in the case of household users, taking into account the costs and benefits in a 25 year timeline, the suggested technology is the monocrystallin based technology.
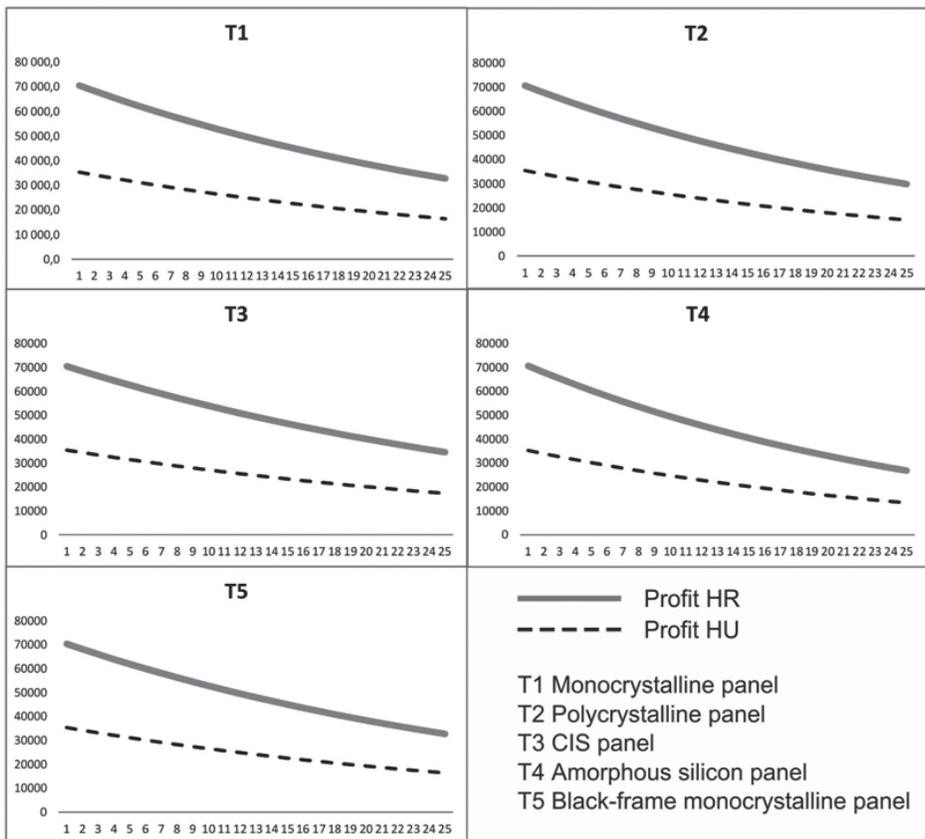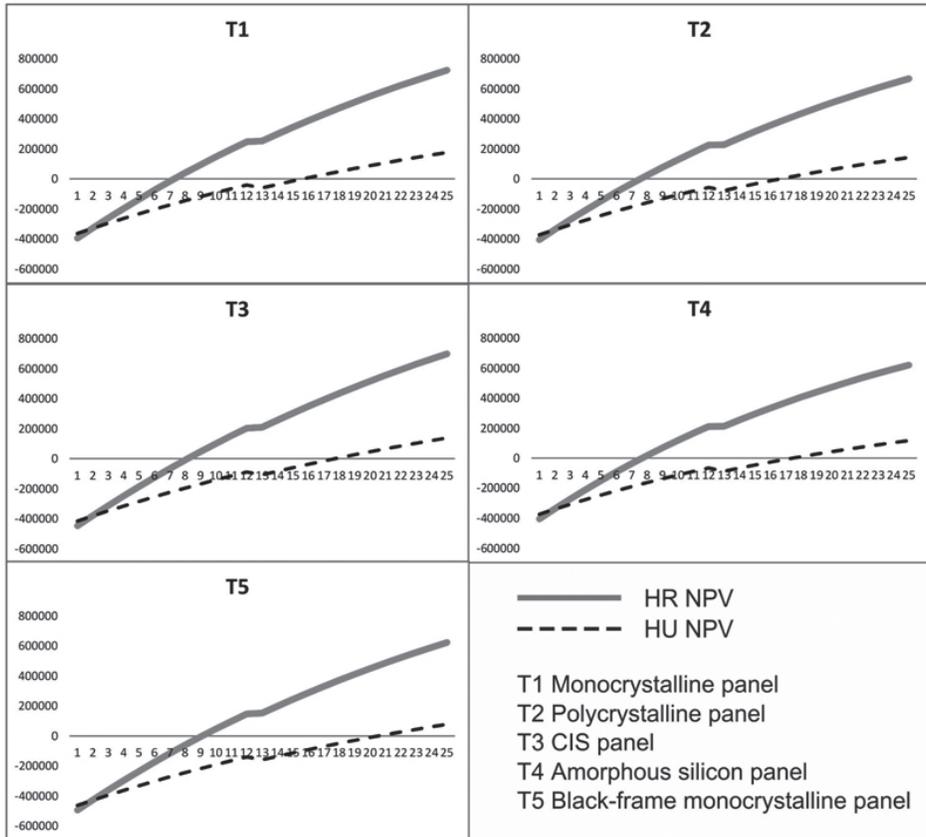

Source: Own edition

Energy producer investors

In the case of energy producer investors profit indicators – although with significant differences – show the same ranking, namely CIS panels with the highest costs and with the lowest amortisation are the most favourable, and the amorphous one is the least profitable (Figure 54).

Considering net present values, no significant difference between user dimensions can be demonstrated (Figure 55). Similarly, for solar energy production-based power stations, the shortest payback time and the highest net present value are ascribed to monocrystalline panels. However, in view of this indicator, rankings are exactly the same in both countries; which appears in the sequence of T1, T3, T2, T4, T5.

Figure 55: The development of net present values for energy investors

Source: Own edition

Unit cost calculations produced relatively more interesting results since the order of rankings show (Table 18) differences both in terms of countries and in user dimensions. In Croatia, regarding energy generating and investment-focused installations, the smallest unit

cost is ascribed to monocrystalline panels (56.8%), whereas in Hungary the smallest unit cost (75.4%) is attached to amorphous silicon panels. However, in Hungary the order of rankings is blurred inasmuch as the difference between the best and the worst values does not reach 0.5%.

Table 18: Unit cost indicators

LCOE $_{T1,HR}$	56.7968%	1	**LCOE $_{T1,HU}$**	75.9220%	5
LCOE $_{T2,HR}$	57.3892%	2	LCOE $_{T2,HU}$	75.4203%	2
LCOE $_{T3,HR}$	59.9494%	4	LCOE $_{T3,HU}$	75.4251%	3
LCOE $_{T4,HR}$	57.4281%	3	*LCOE $_{T4,HU}$*	75.4199%	1
LCOE $_{T5,HR}$	62.7225%	5	LCOE $_{T5,HU}$	75.4302%	4

Source: Own edition

On the basis of all the above, for energy investors in Croatia it is the installation of monocrystalline panels that proves to be the best alternative, as a contrast, in this respect such unambiguous statement cannot be made in Hungary.

EN_9.5. Possibilities of Model Modifications – Scenarios

As has been indicated before, within the framework of the model we investigated an array of possibilities for reasonable economic and efficiency modifications to be made, through which the rating of systems deemed most applicable could be changed.

Cateris paribus we examined the increase in the consumer prices of energy, the decrease in transmission prices and the impact of technological development. Taking into consideration the trends of the past years, we defined a 5% increase in energy prices while, based on the modifications occurring in the assistance schemes, we calculated with a 15% decrease in transmission prices. The impact of technological development can be gauged by the fact that maintenance costs and other yearly expenses are declining relative to the volume of investments and, on the other hand and that solar panels display signs of downturn in annual power output.

Our investigations demonstrated that in the order of rankings outlined above in relation to the basic model, no changes can be observed in any of the scenarios. As a contrast, trends in payback time show considerable changes. Technological development and the increase in consumer prices exert positive influence by making payback time decrease since technological progress results in the reduction of annual costs and the increase in consumer prices entails savings generated from self-consumption (Table 19). As opposed to this, the decline in transmission prices induces lower levels of annual revenues, i.e. it results in prolonged payback time.

Table 19: Impact of different variables on returns (year)

Panel type	Croatia		Hungary	
	Home system production	Low-scale power plant	Home system production	Low-scale power plant
Increase in consumer price (+5%)				
T1	-1.0	0	-1.8	0
T2	-1.0	0	-1.2	0
T3	-0.8	0	-2.0	0
T4	-1.0	0	-3.0	0
T5	-1.1	0	-2.5	0
Transmission price reduction (-15%)				
T1	0.7	1.9	2.4	4.3
T2	0.9	2.2	2.7	5.2
T3	0.8	3.3	2.7	4.3
T4	1.0	4.1	3.2	5.5
T5	0.8	3.7	2.4	4.2
Technological development				
T1	-0.5	-1.2	-1.7	-2.4
T2	-0.6	-1.3	-2.0	-2.9
T3	-0.6	-1.2	-1.8	-3.4
T4	-0.6	-1.0	-2.3	-3.5
T5	-0.7	-1.4	-2.2	-2.7

Source: Own edition

It appears from the data that the model is sensitive to each of the three changes investigated. The increase in consumer prices does not affect the production of power plants since in this case the entire production output is transferred to the mains system, thus it produces no savings. The decrease in transmission prices has significant implications for power plants due to the relatively lower prices inherent to them. Technological progress provides for greater savings, as a consequence of which, returns relative to those of home system production decrease more significantly.

In relation to modifications, the issue of rates should be addressed at three points, provided we are strict about the 25-year investigation period. This is because in Hungary the investment is unlikely to be realized in this period of time if home systems are equipped with Panasonic-type panels or if in small-scale power plants amorphous silicon panels or Panasonic panels are installed. In this case, the transmission price reduction acceptable for home systems is 10.5% (viz. a minimum of 10.2 cents/kW). The investment will bring returns in the last year of the investigated period (25 years) provided in power plant installations

amorphous silicon panels – 9.4 cents (13.4% reduction) – and Panasonic panels – 10.16 cents (6.2% reduction) – are applied.

Since the return on investment and price regulation (with special regard to Hungary) encourages capacity installations aimed primarily at satisfying energy needed for self-consumption, we performed calculations also for bit higher capacity (5 kW) home system investments (which, naturally, entail smaller investment costs but also result in smaller revenues). According to our calculations, all this does not affect the selected and/or recommended technology in view of profit, net present value or specific cost indicators. Although real profit analysis ranks T3 (CIS) panels the first place in both countries, payback time, net present value and the LCOE indicator constitute a clear argument for the installation of monocrystalline panels. At the same time, with regard to all the technologies applied, calculating with 10 kW (which is quite common in Croatia as it is the up limit of the highest incentives) in Hungary the installation of a relatively small capacity causes a decrease in average payback period whereas such installation in Croatia entails an increase in average payback period, viz. the gap depicted by figure 3 is narrowing. In Croatia, due to a uniform tariff of 1.400 EUR charged for network connection, the unit cost will become higher than it is in Hungary. Naturally, tariff levels are dependent on the location relative to the geographical and network infrastructure of the energy producer but on average, we can use this value as the basis for our calculations. Given a capacity of 10 kW, the expected average payback period of 10-12 years increases to 14-16 years obtained by halving capacity, whereas in Hungary the installation of a relatively large capacity results in an expected average payback period of 18-23 years, a period which, if 5 kW capacity is applied, is expected to decrease to 16-19 years. In Croatia, installed capacities being halved drives down unit costs which, in the case of monocrystalline systems representing the most widely recommended technology, produce a cost ratio of 61%.

EN_10. SOCIAL IMPACTS

When considering the impacts of solar energy utilization, it becomes inevitable to also pay substantive attention to the assessment of its social impacts. More particularly, it is essential to examine investments in renewable or solar energy, to assess how their communication affects a given social group and in what ways such communication affects renewable/solar energy-related decisions made by that given group[27].

As has been formulated by Csizmadia (2008), "The existence, lack, number, composition, applicability and value of social relationships exert a fundamental influence on the every-day life of an individual or that of a community" (Csizmadia 2008, p.27), by which these factors have important implications for the spread of environmentally conscious patterns including also the advance of renewable/solar energy investments (in addition to the economic and other framework conditions (Varjú (szerk.) 2014). Consequently, where there are intense social relationships (e.g. typically the interaction between small groups or between small communities), solar energy investments by individual actors more significantly affect other actors' decisions.

Change in the intensity of social publicity can be brought in parallel with the expansion of public infrastructure as well as with the professionalisation of and structural change in such

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[27] Social framework conditions for solar energy investments have been delineated in an earlier piece of work (Varjú (szerk.) 2014