Strojniški vestnik - Journal of Mechanical Engineering 56(2010)1, 3-17
UDC 620.92

Paper received: 06.12.2007
Paper accepted: 25.09.2009

Countrywide Positioning of Domestic Solar Water Heating Systems using Risk Analysis and Geographical Information System

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In this paper, choosing appropriate locations for household solar water heating systems within a country is based on assessing project feasibility by using solar irradiation integrated in a geographical information system (GIS) and investment risk analysis, based on uncertainties in project input variables. Current indicators and statistics of solar systems of EU and Croatia are given, followed by impacting factors on investments in domestic SWH. Investment risks are determined. GIS is constructed to assess solar irradiation potential on a countrywide scale.

A spreadsheet model for financial analysis using the Monte Carlo method for probabilistic simulation of uncertain project parameters is shown, which integrates GIS and determines a financial feasibility for two case studies. Financial indicators of net present value (NPV), internal rate of return (IRR) and simple payback time (SPB) are shown for three investment strategies, varying in financial resources according to profiled income categories of households in the country. A sensitivity analysis has been performed to determine the impact of individual risks on the financial outcome of the project. Financial flows are compared to determine the difference in feasibility for the same project on two different locations. Probability distributions for risks and financial indicators are shown

Keywords: solar systems, alternative energy sources, heating water, geographical information system, investment risk, analysis

0 INTRODUCTION

The economic value of a domestic SWH system is in the amount of electrical energy it saves and a certain degree of independence from conventional energy supply it creates. The same amount of electrical energy would otherwise be used to heat sanitary water, which is a cost that can be avoided by using solar resource for water heating. Saved energy depends on the size of the system, its operation by the consumer, solar radiation levels and, most significantly, the cost of displaced conventional energy. As conventional fuel prices are unstable and liberalized electricity markets sensitive to variations in fuel supply, reducing dependency on outside electricity sources can be considered a risk mitigation action. Environmental concerns have made household SWH systems a positive status symbol [1].

A solar thermal system has certain external benefits, like CO_2 and other air polluting emissions savings, reducing dependency on energy imports, reducing further external costs related to the use of fossil fuels or nuclear power and reducing peak electricity demand if solar thermal displaces electrical heating [2]. Benefits have to be balanced with costs of a solar thermal system, consisting of funds needed to buy and install the system, operation and maintenance costs, costs of repairs, costs of decommissioning and all other costs linked with the decision to invest.

Implementing domestic SWH, just like any other project, has its risks. Household owners as investors and financial institutions as loaners are naturally reluctant to accept risks that could create unexpected negative fluctuations in cash flows or value of a project. To ensure financing is feasible, there is a fundamental requirement to manage associated risks, in a way that minimizes the probability of occurrence that could give rise to a negative financial impact on the project.

Using risk analysis for investment planning of SWH is a domain not explored in the available literature. Since the model incorporates both, risk analysis which is traditionally a tool for financial institutions, together with GIS, the

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proposed model is considered to be a novelty in the area.

1 SOLAR WATER HEATING TECHNOLOGY APPLICATION STATUS

1.1 European Union

41.3% percent of the total end-energy consumption in the European Union (EU) is used in households – most common sector for implementing SWH systems. As listed in [3], space heating accounts for 69% of energy consumption per household in the EU, followed by 15% for water heating, 11% for electrical appliances and lightning and 5% for cooking.

Generally, an important part of the supplied electricity in the household sector is used to heat water for domestic appliances such as hot tap water, washing machines and dishwashers. In 2005, with 22.8% growth, the EU solar thermal market passed 2 million m^2 of solar collectors installed, corresponding to an installed capacity of approximately 1.450 MW [4]. The use of SWH in EU has significantly increased in 2006. The same applies for the sales of solar thermal systems, which grew by 35% up to 1.900 MW of ST power. The most dynamic markets are in France, in the United Kingdom and Germany, where growth rates are between 40% and 70%. This dynamic is heightened by the insight that solar thermal technology will play a much more important role in the fight against climate change and against the dependency on fossil fuel imports. It is considered that in the long run, 50% of the low temperature heating needs in Europe could be covered by solar thermal [5].

1.2 Croatia

According to IEA data [6], Croatia imports over 50% of its total primary energy supply. An analysis of energy consumption in Croatia as shown in [7] and [8] puts households as the biggest share in the final energy consumption of 32%, of which 55% is spent on low-temperature thermal energy needed for sanitary water and space heating [9].

During the 1980s, estimates were made on the quantity of installed solar collectors, ranging from 100.000 to 125.000 m^2. The lifetime of those systems was approximately 15 years. No data of significant sales of solar collectors is available from 1990s, resulting in the present estimates of only 12.000 - 15.000 m^2 [10]. Croatia's pending accession to the European Union indicates the adoption of new subsidy schemes for solar thermal systems in the future. Once subsidies are in place, the number of installed systems is expected to rise.

As shown in [11], it is possible for Croatian households to have a zero energy balance for space heating and hot water generation by 2030. This goal can be reached by building new houses using passive solar standards, installing additional insulation in old buildings, as well as an intensified use of RES, especially the generation of electricity through photovoltaics. Since this time frame is too long for a detailed assessment, the focus of this paper is on households which use their SWH systems only as a part of their energy supply, but remain connected to the grid.

2 THEORY

2.1 Financial Modelling of a SWH System

In order for project feasibility analysis to have its standpoint in reality, it must be done by examining both, the financial and technical side of the examined system. In order to evaluate project feasibility for a given set of parameters, benchmarking must be done by using a common set of performance indicators, usually based on economic value such as net present value (*NPV*), internal rate of return (*IRR*), and the return of investment (*ROI*).

Therefore, the system must be valorized by economic modeling, which in turn has to be based on the technical system. SWH systems are comprised of several components such as solar collectors, boiler, piping, etc. There are several types of SWH systems that can be implemented, and for this purpose we have included all the components that can be found in most complex domestic SWH systems.

Economic optimization at component level can be found in [12]. In this paper, each component is modeled using a layered approach. Starting from a technical system of physical components, the first level of abstraction is determining each component as a cost or profit center. In this middle layer, each component is seen as an object, which creates an expense (either only initial or periodical), and those which create income – generated heat which displaces electrical energy. The highest level of abstraction consists only of determining cash flows and final financial inputs and outputs of the project. The concept is illustrated in Fig. 1.

2.2 Risk and Risk Analysis

An appropriate definition of risk for a particular application to a large extent depends on the desired scope and purpose of the analysis. Risk is a result of uncertainty, and in some cases (i.e. portfolios in finance) it is defined as a measure of uncertainty. As such, it can be positive or negative. Risk is also defined as a combination of the probability of an event and its consequences [13]. Further definitions are that risk is the combination of the frequency, or probability, and the consequence of a specified hazardous event [14]. Mentioned definitions fail to provide a formal mathematical definition of or appropriate background information on the concepts, giving only a verbal description of the target safety measures. For the purposes of analysis in this paper, risk is best defined by (1):

$$R = E \cdot P \tag{1}$$

where R is the risk, E expected consequences and P probability of an event occurring.

Risk analysis is a part of a broader discipline of risk management, defined as the identification, evaluation and control of risk [15]. Thus, risk management consists of anticipating and altering conditions a system may reach in a desirable manner and reducing consequences to intended or economically tolerable levels [16]. Some form of risk management is done on every project, regardless of size or scope. Risks are an inevitable part of every project and it is impossible to disregard them, but in most cases, as is the case with SWH projects, risks are not handled in an organized manner. As shown in [17] and [18], risk management is usually composed of risk identification, risk analysis, risk response development, risk monitoring and risk reporting. This is not a definite list, and all parts can be further developed to a greater or lesser extent, depending on the quality of risk management and project needs. Hence, this paper covers only risk analysis from the process of risk management and other steps are not examined.

Risk analysis is divided into qualitative and quantitative risk analysis. Risks are identified using various techniques such as brainstorming, examination of experience with similar activities and projects, checklists, interviews and focus group discussions, scenario analyses, surveys and questionnaires and work breakdown structure analysis. Once risks are identified, qualitative risk analysis step assigns each risk a priority rating, taking into account existing activities,

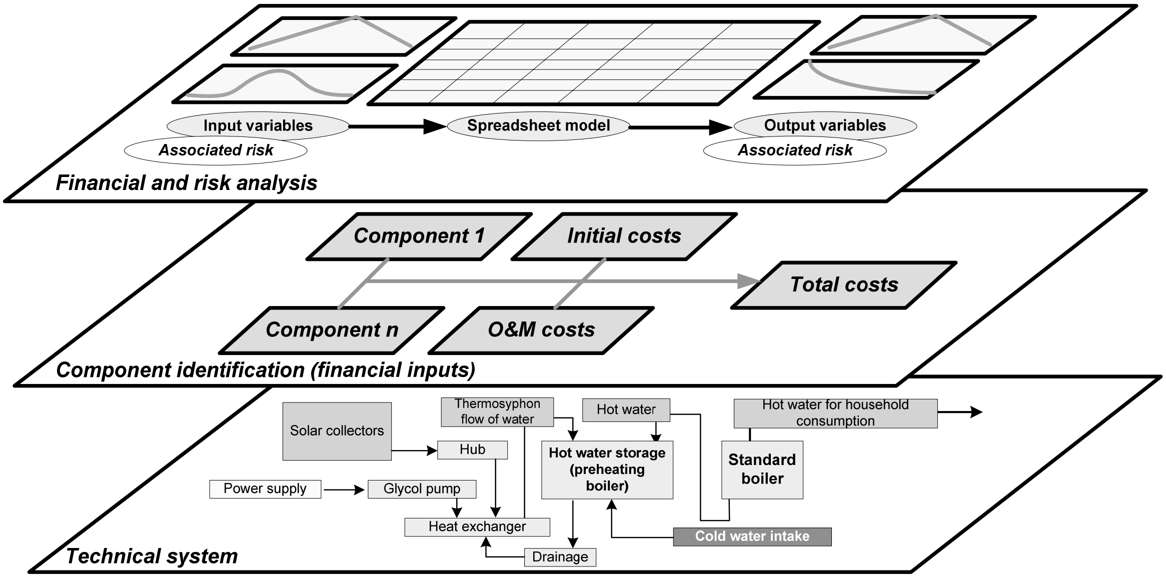


Fig. 1. *Layered modelling of SWH system for financial analysis*

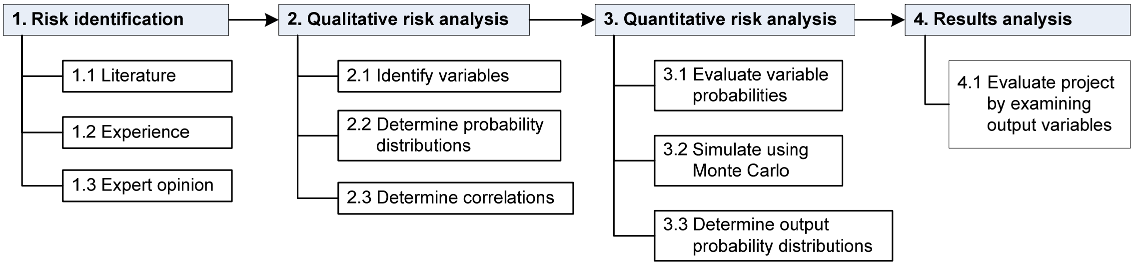


Fig. 2. *Chosen risk analysis process for household SWH systems*

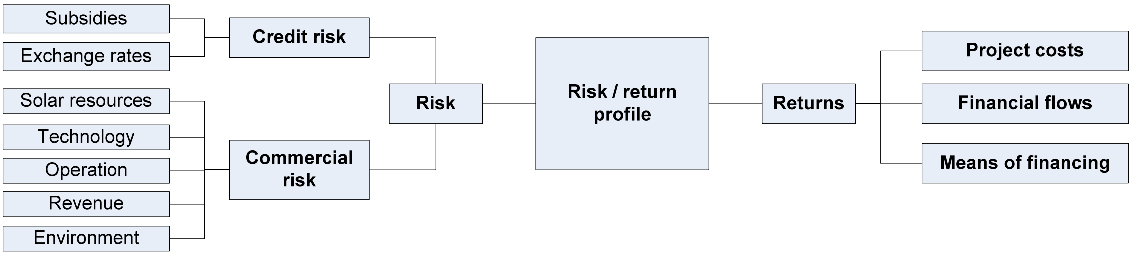


Fig. 3. *Risk / return profile parameters*

processes or plans that operate to reduce or control the risk [17]. This includes an evaluation of risk impact, likelihood of occurrence, but also risk tolerance and expenses. Qualitative risk analysis results produce a list of risks sorted by influence and likelihood of occurrence, grouping risks by categories, causes or possible reactions and a list of critical risks.

Quantitative risk analysis is done on a chosen set of risks selected from quantitative analysis. Risks are analyzed in detail and each risk is given a numerical value. Methods such as decision tree analysis and Monte Carlo are commonly used [19] and [20]. By using the probability theory, it is possible to assign a probability distribution to variables causing the risk. Correlations between variables can also be established and must also be taken into account should there exist a cause and effect relationship between input variables.

Most common risk analysis methods are stress testing, scenario testing, optimistic-pessimistic-most likely method and sensitivity analysis as simpler forms of risk analysis. Value at Risk (VaR) method, AS/NZS 4630 (Australia and New Zealand) and PMBOK method are more complex methods, [19] and [21]. Combinations of methods are possible. For purposes of this paper, the following process steps have been selected (Fig.2), 1-3 being qualitative analysis; 4 and 5 quantitative and 6 final analyses:

1. Identifying input, output and other variables, and assessing their impact on the project.
2. Determining probability distributions for relevant variables.
3. Examining correlations between variables.
4. Evaluate probability distributions for all input variables that influence output variables.
5. Calculate probability distribution of the output variables using the Monte Carlo method.
6. Evaluating the project using the information contained in the probability distribution of the criterion variable.

As a result of financial modeling, project input and output variables at this point represent project income and costs, and technical parameters outside the boundary of the technical system such as the number of persons in a household or an amount of hot water needed per person, are taken into account in the model as fixed variables.

2.3 SWH Project Risk Identification

Household owners make energy investment decisions based on their estimation of both, the risks and returns of a project. In considering a project, an owner should assess all the parameters of a risk/return profile, as shown in Fig. 3. Each risk should be assessed to determine ways of reducing its potential impact on the project. Evaluating returns involves verifying the cost and revenue projections and then comparing the financials of the project with the cost of financing to be used.

Risks can be categorized in wide ranges by dividing them into project risks, political/institutional risks and market risks. Project risks include:

- Lead time risks - associated with estimating the time and costs involved in the planning stage. The topic has been covered in depth in [22].
- Construction risks - associated with the construction phase and risks that may impact the project not being completed and operating on schedule.
- Performance risk – the possibility that the project does not perform or operate as expected. Elements include the operational risk like machinery breakdown and property damage; the resource risk like a lack of sunlight; the technology risk like the quality of solar collectors and natural hazard risks.

Political and institutional risks include a wide range of risks relating to the political, regulatory or institutional environment in which the project is operating. In case of household SWH systems these risks are secondary and will not be discussed. Broadly, they include legislative and political changes, administrative risks, risks associated with participating in Kyoto markets and any possible ownership problems.

Market risks include:

- Financial risk – relating to the capital structure of the project and its ability to generate cash flows sufficient to fund a planned investment, operations and maintenance expenditures, service debt, and providing reasonable returns to the owner.
- Economic risk – relating to interest rates, exchange rates and product prices risk.
- Subsidy risk – in Croatia, risk of not getting subsidized from the Fund for Environmental Protection and Energy Efficiency (FZOEU), and the risk of payment delays.

A qualitative analysis of risks identified as relevant for considering solar thermal systems in Croatia has been performed. Results are shown in Table 1.

Risk list differs from the mentioned categories since some risks have been completely eliminated. For example, no permits are needed in Croatia to install a solar thermal system in buildings which are not registered as historically important, and the focus is on households which do not belong in this category. In addition, no direct legislation defining the status of solar thermal systems exists. Consequently, variables to which risks could be associated are not defined by the legislator.

Household SWH systems are generally small-scale projects, so most usual risks associated with renewable energy sources are considered irrelevant, such as roadwork, land ownership or public opinion (project being done on private property of the owner).

2.4 Project Input and Output Variables

Project income is equal to displaced energy that would otherwise be used to heat sanitary water. Savings can be well above 60% as has been demonstrated in [23]. The most common way of heating water in Croatia is by using electrical energy, therefore, the project income is considered to be equal to the amount of saved electrical energy priced according to current tariff systems [24].

Project costs for SWH systems can generally be divided into:

- solar collector costs,
- storage tank costs,
- other equipment costs (piping, etc.),
- consultation costs,
- installation costs.

Only system components available in Croatia are used in the assessment. The manufacturing price of solar collectors and other equipment are dependent on the prices of European manufacturers since there are no factories producing solar equipment in Croatia. This creates a certain uncertainty over prices, especially taking into account that the projected domestic SWH systems are planned to be built in the near future when different prices might apply. Stainless steel storage tanks with efficient insulation and spiral heat exchangers, including outside measurement devices are not a large investment in the EU countries, which is contrary to Croatia due to import policies and taxation. Summed with the prices of collectors, this is another issue that lowers competitiveness for domestic SWH in Croatia. Other equipment includes automation devices, heat exchangers, pumps, expansion tank, security devices, valves, pipes, pipe insulation, temperature sensors and mounting gear. Customizing systems according to the owner's needs brings costs to a minimum, however, the final price cannot be set until the system is operational, hence it can be concluded there is an amount of uncertainty when assessing total system cost. The price of capital is also an issue since no special loans for household renewable energy projects yet exist in the country. Operation and maintenance costs are minimal for SWH systems and are usually only comprised of regular check-ups during annual or bi-annual maintenance.

All uncertain input variables are associated with risks and will have an impact on the project in the future. Risks are converted into monetary units so that their influence can be illustrated by changes of project financial indicators. A probability distribution is applied to every input risk variable.

Table 1. *Qualitative risk analysis for SWH systems in Croatia*

Risk	Cause of Risk	Likelihood of Occurence	Impact on Project
a) PROJECT			
risk of incorrect evaluation of project duration	administrative procedures	medium	large
risk of underproduction	inefficient system and/or bad weather	medium	large
capital financing (risk of failure to make financial arrangements)	financial risk as perceived from financial institutions	large	large
financial dependence of the project	risk of changes in the financial market (inflation, etc.)	small	medium
b) MARKET			
risk of variable component prices	different vendor prices, market price fluctuations, demand and supply	small	medium
risk of lack of sunlight (resource)	no risk of resource cost change, but possible that there can be less sunny days in a year as anticipated	small – medium (assuming quality measurements)	very large
risks regarding subsidizing the project	risk of not getting subsidized	medium (falls with rise of popularity of technology)	small (since subsidies are not big, projects don't depend on them)
	risk of late payment once subsidy is given	large (payment mostly late)	
c) TECHNICAL			
low quality measurements of sun resource	necessary measurements have not yet been done in Croatia	medium	very large
risk of equipment failure	unreliable information on possibilities of failure, lack of experience of system assemblers	medium	medium – large
d) POLITICAL			
risk of a change in the political trend of opinion (withdrawing subsidies)	dependant on subsidy system, reflected in purchase prices	medium	small (subsidies are not critical)
e) ADMINISTRATION			
unclear procedures	clear procedures have not been defined	medium (compensated by contracts)	medium
unpredictable duration of procedures	parties involved	medium	medium

The model is constructed for a family house with an electrical water heater with its own storage tank installed. It is possible to extend the calculation to systems for water heating with natural gas, but this case will not be discussed in this paper. The chosen input variables are:

- System parameters (persons in household – the fixed number of 4 for this model, the amount of hot water (60 °C) needed per person - given as 50 l for this model and the length of needed piping – given as 3 m horizontal and 2 floors 2.7 m high between collector and storage tank).
- Initial costs (development and consulting, solar collector price, storage tank price, solar loop piping materials, construction equipment price, additional equipment price of pumps and automation electronics and installation costs).
- Periodic and annual costs (the cost of operation and maintenance every 2 years and the cost of repairs every 5 years).
- Annual production (solar radiation to horizontal surface and system efficiency).
- Annual savings (the price of electrical energy).

All input variables have been simulated according to probability distributions given in Fig. 4.

Selected output variables are the total cost of SWH system, electricity savings, payback time, net present value (*NPV*) and internal rate of return (*IRR*).

The total cost of the SWH system is the sum of individual expense categories. Electricity savings are the product of electricity price and produced energy from the SWH system. The produced energy is the product of total annual solar irradiation to all collectors and overall system efficiency.

NPV is calculated using (2):

$$NPV\left(C,t,d\right)=\sum_{i=0}^{N}\frac{C_i}{\left(1+d\right)^t}. \qquad (2)$$

where C_i is the i^{th} cash flow, d is the assumed discount rate, t_i is the time between the first cash flow and the i^{th}.

IRR is the discount rate which sets the *NPV* of the given cash flows made at the given times to zero and is defined by (3),

$$NPV\left(C,t,IRR\right)=0. \qquad (3)$$

In the model, *NPV* and *IRR* are calculated using Excel's internal functions npv and irr, based on cash flow during 25 years, which is the systems assumed lifetime. SWH systems' typical lifetime is 30 years, so this can be considered a conservative estimate. *IRR* is calculated by an iterative method, repeated until variance is under 0.00001%, which is accurate enough for the designed model. Payback time is calculated using lookup function to determine where cumulative cash flow becomes positive. The model is scalable and allows determining any variable an output variable.

3 INTEGRATED PLANNING MODEL

The basic purpose of the developed system is to be used as a financial analysis tool for SWH projects, enabling a flexible project feasibility assessment testing for any location within the country. The tool is intended to be used both, for individual project feasibility analysis and for a countrywide analysis of locations, should parameters of price and/or other variable parameters linked to a geographic location be entered in the model. The model is constructed to allow both, changing present variables as well as adding new ones.

Geomedia Professional 6.0 is used as the GIS platform [26]. Spreadsheet model is built in MS Excel 2007, and for Monte Carlo simulation and risk analysis Crystal Ball 7.3.1 [27] was used. This choice is made based on the features, the list of reference users, wide availability of the software and a short learning curve for basic use. A general structure of the model is shown in Fig. 4.

3.1 Geographic Information System

Managing data on daily, monthly and annual solar irradiation is essential for predicting future productivity of a SWH system. The first step in the constructed GIS is either entering geographical coordinates of the planned location or choosing a place on the map using the cursor. On location entry, a database query is formed to retrieve monthly solar radiation data on the nearby measurement stations, correlated with basic country geometry. The result is forwarded in the financial model. Data has been validated by a comparison with international databases of solar irradiation by NASA [28] and PVGIS [29]. No relevant differences were found.

Vectorized data was constructed using raster maps from the available literature and measurement data on entire country territory. Raster data has been converted to vector data, and then merged with the measurements database. Attributes appended to geometry within Geomedia are comprised of minimum and maximum solar irradiation of a polygon over the course of the entire year. For proposes of later modeling, normal distribution can be fit between described limits, to cover 90% of the interval.

3.2 Spreadsheet Model

Model is contained within a workbook and consists of three sheets, as shown in Fig 5. Model is scalable and allows simple adding or deleting of additional variables.

The first sheet is the energy model, which is used for basic input parameter calculations such as collector area and storage tank capacity, the needed length of piping materials, and per unit prices of individual components. Solar irradiation data and electricity price are also included. The second sheet contains loan parameters, and is used for cash flow analysis and converting all technical data from the first sheet into monetary units. Income and expenses are summed up and cash flow and cumulative cash flow calculated. The third sheet contains the output variables. An auxiliary sheet is provided (not shown) in order to calculate the needed storage tank capacity. A detailed explanation of calculations in the model is outside the scope of this paper, but can be found in [30].

3.3 Input Variable Probability Distributions

All input probability distributions are graphically shown in Fig. 6. Development / Consulting has been assumed as a triangular distribution with minimum value of 68,4 EUR, likeliest 68,4 EUR and maximum 137 EUR. Solar collector price has been assumed as a triangular distribution with minimum value of 246,57 EUR, likeliest 273,97 EUR and maximum 301,37 EUR.

Storage tank price was assumed as a triangular distribution with the minimum value of 753,42 EUR, likeliest 794,52 EUR and maximum

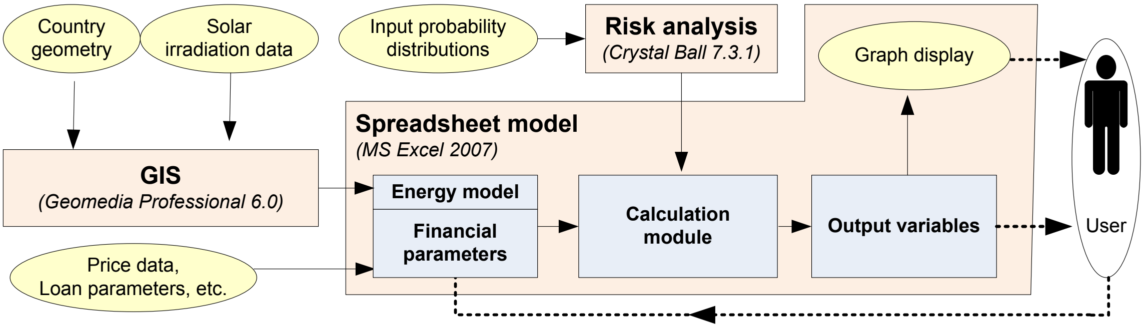


Fig. 4. *Integrated planning model*

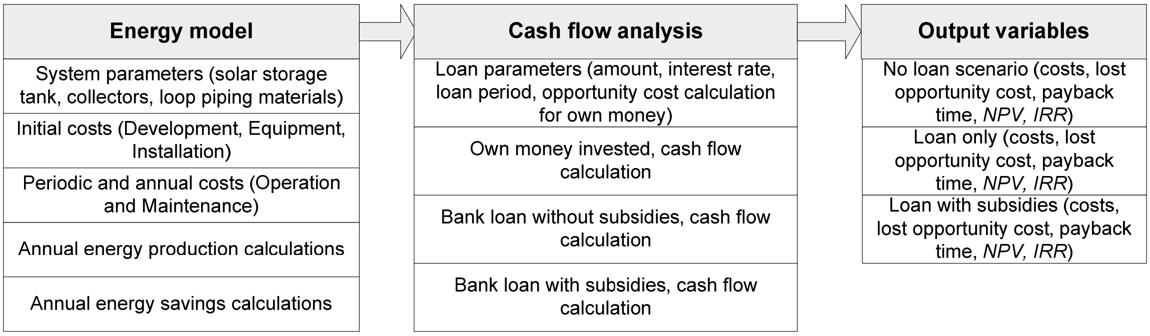


Fig. 5. *Spreadsheet model for analyzing financial parameters*

Table 2. *Results of deterministic analysis*

	Zagreb	Split
S1 – no loan		
Total initial costs (EUR)	2.155,07	
Opportunity cost (EUR)	1.311,23	
Total investment (EUR)	3.466,30	
Simple payback period (years)	11	9
Net present value (EUR)	459,32	1.197,40
Internal rate of return (%)	13	19
S2 – loan without subsidy		
Total initial costs (EUR)	3.056,44	
Simple payback period (years)	10	8
Net present value (EUR)	865,62	1.503,56
Internal rate of return (%)	22	41
S3 – loan wih subsidy		
Total initial costs (EUR)	2.869,59	
Simple payback period (years)	9	8
Net present value (EUR)	1.222,60	2.034,53
Internal rate of return (%)	22	52

835,62 EUR. Solar loop piping materials price was assumed as a triangular distribution with the minimum value of 6,83 EUR, likeliest 7,52 EUR and maximum 9,57 EUR. Construction equipment price was assumed as a triangular distribution with the minimum value of 116,43 EUR, likeliest 136,98 EUR and maximum 205,48 EUR. Additional equipment (pumps, automation) total price was assumed as a triangular distribution with the minimum value of 136,98 EUR, likeliest 164,38 EUR and maximum 191,78 EUR. Installation costs were assumed as a uniform distribution with minimum value of 109,59 EUR and maximum 164,38 EUR.

Costs of operation and maintenance were assumed as a triangular distribution with the minimum value of 13,69 EUR, likeliest 20,54 EUR and maximum 47,94 EUR. The cost of repairs was assumed as a triangular distribution with the minimum value of 34,27 EUR, likeliest 54,79 EUR and maximum 82,19 EUR.

Solar radiation to horizontal surface was assumed as a normal distribution with mean value of 1,22 ± 0,02 $\mathrm{MWh/m^2}$ annually [31]. Future developments will include GIS for calculating solar irradiation. System efficiency was assumed as a normal distribution with mean value of 60% and standard deviation of 1%.

Having in mind negotiations to join the EU and the foreseeable end of that process in the next 5 years, the future price of electricity in Croatia is expected to rise from present values and was assumed for this model as a Weibull distribution with location at 0,09589 EUR/kWh, scale 0,01 and shape factor 1. The initial price was assumed from observing the EU electricity price trends for small users in western countries as shown in [32].

4 RESULTS

Three investment scenarios were calculated:

- S1: Household owner does not use a loan to pay for the investment
- S2: Project receives a cash loan, annual interest 11%, period 7 years, without a period of grace [33]
- S3: Project receives a subsidy [34] which is a cash loan with an interest rate lowered by 2% compared to initial loan conditions, final credit parameters in this case being 9% interest rate, period 7 years, without a period of grace.

Two cases were considered – a familiy house in the country's capital Zagreb, and the second largest city of Split. Houses have four occupants, and the only differing factor is the solar potential of the location. No other parameters, including input probability distributions for other variables were changed for the purposes of establishing a baseline for comparison.

The expenses are separated to three components:

- Total initial investment or credit payment (depending on investment scenario).
- Maintenance (once in 2 years).
- Repairs (as needed or once in 5 years).

In case the investor does not use a loan, the opportunity cost is calculated as if the owner put the same amount of money in the bank, with an average 2,5% annual increase due to profit from low risk investment funds, which is realistic for current market conditions.

Deterministic modeling (without using risk analysis) produced results shown in Table II.

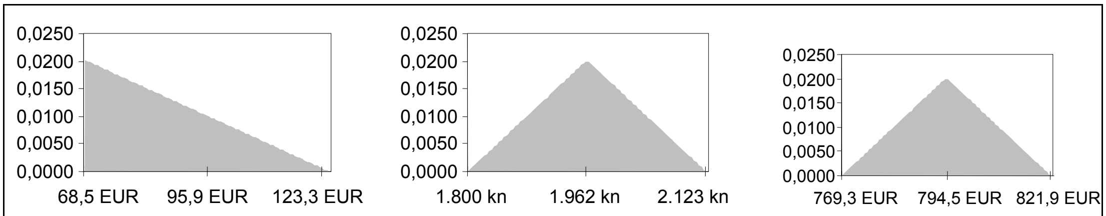
Risk modeling has been done according to previous chapters. Using Monte Carlo method implemented through an Excel add-in [25], 10.000 iterations have been simulated and the following probability distributions of output variables have been created. Larger numbers of iterations have minor impact on final results and could only be helpful to make output variable probability distributions appear graphically smoother. Border values of the 80% reliability range are determined from numerical analysis of data from simulation which is not presented here due to its volume.

To determine which assumptions have the greatest influence in output variable forecasts, positive or negative, sensitivity analysis was performed. The results are presented to the right of output variable probability distribution charts.

Due to the similarity in results and constraints on the amount of material for purposes of this publication, only the results for case study in Zagreb are shown, and Split is shown in later comparison.

The entire *NPV* range for the three scenarios is shown in Fig. 11 The entire *IRR* range for three scenarios is shown in Fig. 13.

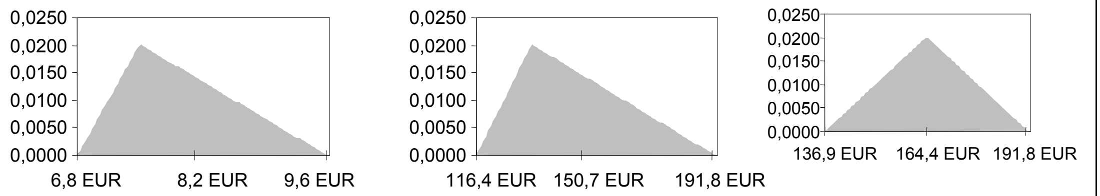
A cash flow comparison between two locations were done by extracting values of financial flows into a separate data table, and can be integrated with graphical display in the model. This kind of visualization is used to verify output parameters of the risk analysis, primary *IRR* since



Development and consulting

Solar collector price

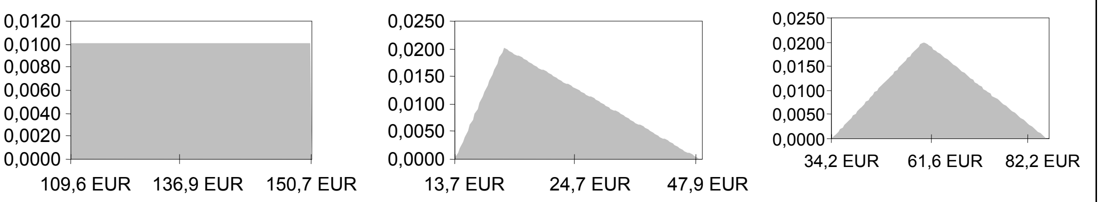
Storage tank price



Solar loop piping materials (per m)

Construction equipment price

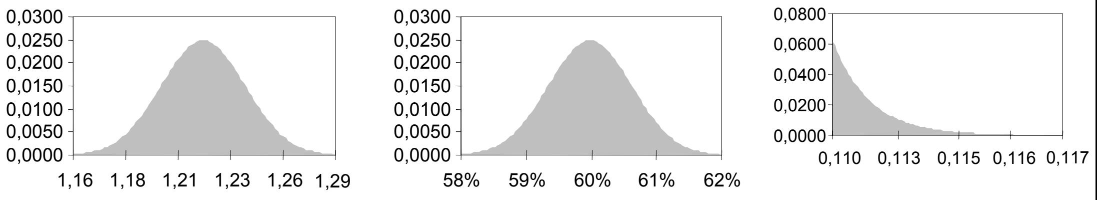
Additional equipment price (pumps and automation electronics)



Installation costs (manual labor)

Cost of operation and maintenance (every 2 years)

Cost of repairs (every 5 years)



Solar radiation to horizontal surface (MWh/m^2, annually)

System efficiency

Price of electrical energy (EUR / kWh)

Fig. 6. *Probability distributions of input variables (y axis represents probability of occurrence)*

it is dependent on several factors, the main one being the existence of a negative and a positive cash flow (hence change of cash flow graph slope) and only one extreme in the cash flow function. Mean values from risk analysis were used for visualization. Differentiation between S1, S2 and S3 for both cities was omitted since they are very similar and only differ in the end amount, which is the largest for S3 scenario.

5 DISCUSSION AND CONCLUSION

Evaluation criteria for *NPV* requires that it is positive, indicating the project is financially feasible. This is satisfied for entire ranges of S1, S2 and S3, with the previously established input variable distributions. The results show that all scenarios would create the added value to the household, and that the project of installing a SWH is financially feasible. From this indicator, it can be concluded that the project should be done, and the household owner can concentrate on the ways of financing the project.

All scenarios show positive values in full range of values, and are in similar correlation as *NPVs* of individual scenarios. Scenarios satisfy the positive evaluation criteria for *IRR*, set to require *IRR* is equal or greater then the value of the interest rate of the more expensive loan, which in this case is 11%. This condition is satisfied within the entire range of *IRR* output variable.

The most sensitive part of the model is determining the assumptions for input variables. In this paper this is done by using the best available experience and financial parameters of SWH system components and bundles available within the country.

The household SWH project in this paper is profitable regardless of the way it is financed, although with moderate financial indicators regarding payback time. Differences in projected financial performances between scenarios should be in the investor’s focus.

As expected, output variables show that a subsidized loan, if approved, is the best financing option, which creates the least financial strain on the household, making this the best selection for most households.

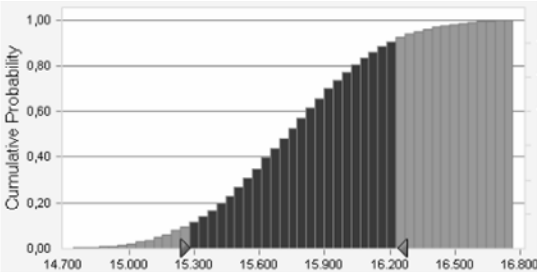


Fig. 7. *Cumulative probability distribution for Initial system price with 80% certainty range*

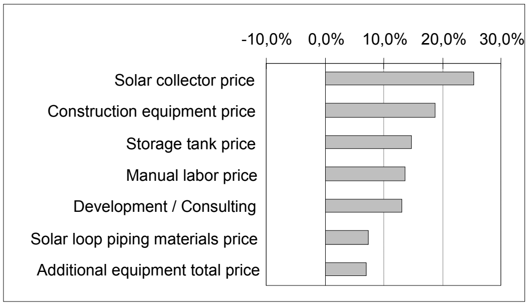


Fig. 8. *Sensitivity analysis for Initial system price*

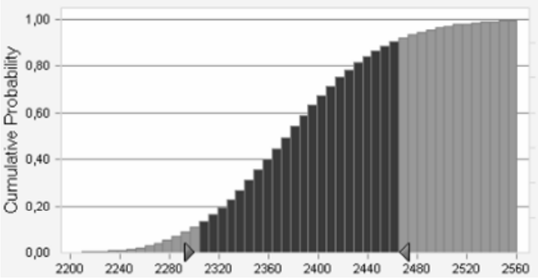


Fig. 9. *Cumulative probability distribution for annual electricity savings with 80% certainty range*

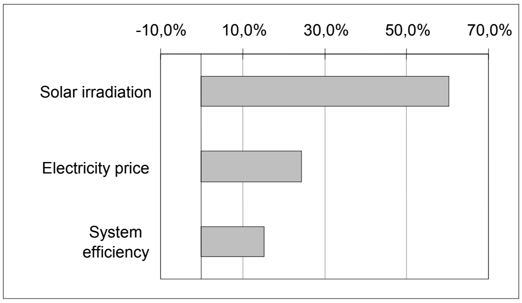


Fig. 10. *Sensitivity analysis for Electricity savings*

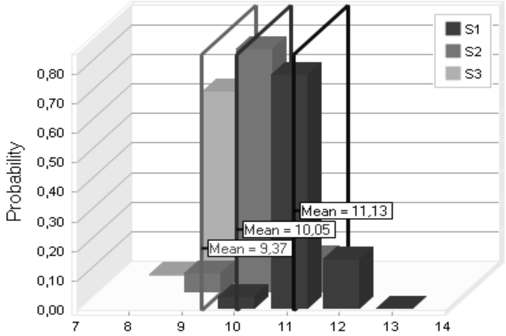


Fig. 11. *Probability distribution for payback time, all scenarios*

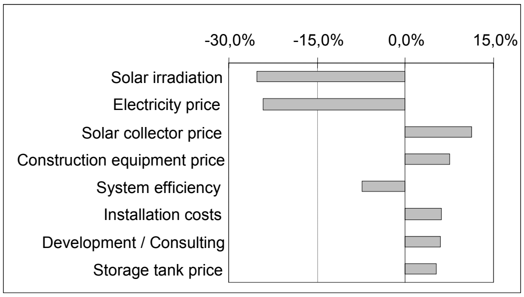


Fig. 12. *Sensitivity analysis for Payback time, all scenarios*

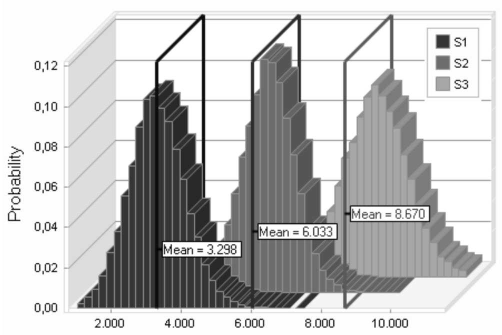


Fig. 13. *Probability distribution for NPV, all scenarios*

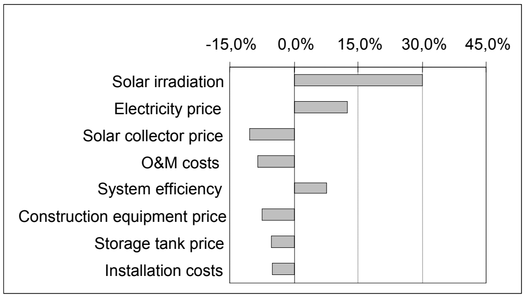


Fig. 14. *Sensitivity analysis for Net present value, all scenarios*

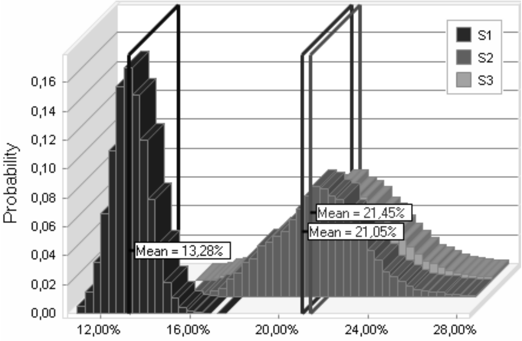


Fig. 15. *Probability distribution for IRR, all scenarios*

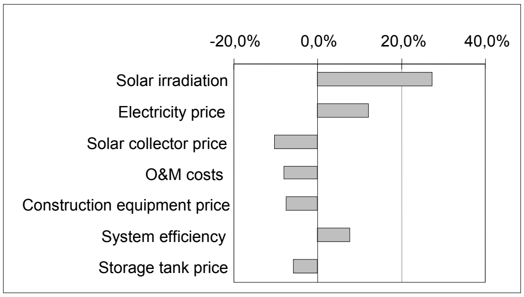


Fig. 16. *Sensitivity analysis for IRR, all scenarios*

Sensitivity analysis shows that most influential risks are linked to available solar irradiation, overall system efficiency and displaced electricity price in the process of transforming solar energy to heating energy for water. Risks related to price differences can be reduced by narrowing input variable ranges just before the project is about to start.

The inevitable question of influencing input data to get a more positive financial image of the project arises. Since the model in its core is deterministic (only input variables are probabilistic, not the model itself), by changing

Table 3. *Results of risk analysis*

	Zagreb, 80% certainty range			Split, 80% certainty range		
	Min	Mean	Max	Min	Mean	Max
S1 – no loan						
Simple payback period (years)	10	11,14	13	8	9,3	10
Net present value (EUR)	310,96	450,27	591,23	967,95	1.117,81	1.270,96
Internal rate of return (%)	12,2	13,3	14,3	16,8	18,1	19,4
S2 – loan without subsidy						
Simple payback period (years)	9	10,06	11	7	8,32	10
Net present value (EUR)	414,25	824,79	954,25	1.297,95	1.442,19	1.583,70
Internal rate of return (%)	18,3	21,0	23,5	31,2	38,4	45,3
S3 – loan wih subsidy						
Simple payback period (years)	9	9,44	10	7	7,99	9
Net present value (EUR)	1.022,19	1.185,75	1.345,62	1.780,96	1.956,71	2.130,96
Internal rate of return (%)	18,4	21,4	24,3	33,4	46,4	59,8

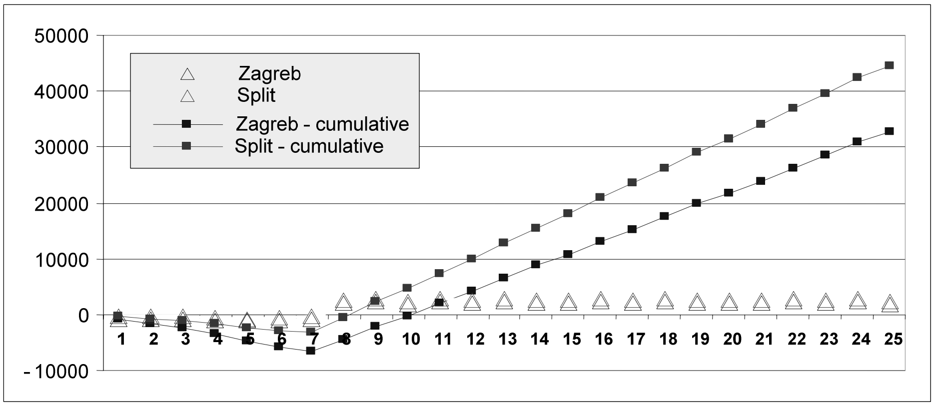


Fig. 17. *Comparation of cash flows for SWH systems in Zagreb and Split*

the input parameters by following sensitivity analysis is possible. This can also be used to balance the model once new variables are implemented or some of the existing ones removed. Western countries, on a case by case basis, publicly determine certain variable parameters, so that all financial analysis, in part, use the same input data. There are still no discussions about this in Croatia and, therefore, this part of the discussion is for academic purposes only.

Investing in household SWH is a comparatively small and short project. However, it is still a substantial investment compared to the country's average household income. To enhance investment safety for the owner, a rapid and proficient system of analyzing investment risks for a project is needed. Institutions extending loans for SWH projects perform their own risk analysis so quality preparation can signify the difference between the loan being approved or not.

Although the reference case is for a SWH system in Croatia, it can easily be extended to include passive solar water and space heating methods and active solar space heating, and can be adjusted for any market. The model is scalable as it allows changes in input probability distributions and the possibility of adding new variables. It is possible to apply the model to projects of other RES with adjustments to embrace the specifics of individual sources. Since the model is based on numerical risk analysis, it can be used for most investment projects.

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