Assessment of the economic efficiency of energy-saving projects, methodology based on simple and compound methods

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Abstract
Among different engineering projects, there are ones intended to improve the energy-saving properties of buildings. Both new and much older buildings undergoing refurbishment can be involved. Broadly understood energy-saving projects increasingly often entail renewable energy installations. Every implementation of such an investment project needs to be preceded by an assessment of its economic efficiency. Although the literature provides examples of methods which can serve this purpose, a coherent methodological approach seems lacking. In this article, the author proposes methodology based on several simple and compound methods combined into a schematic assessment procedure. The methodology is presented as applied in a case of typical photovoltaic roof installation to generate electricity for a single-family house. The assessment procedure consists of a few steps leading from a preliminary to a more detailed appraisal. The first stage is an analysis of the projected cash flows, which in this case demonstrated that the payback would appear after 9 years. Next, a more precise evaluation showed that the payback period in this investment could be expected after 7.8 years. The following stages of calculations take into account the time value of money, having included a discount rate (discount rate 5%, the planned investment would be profitable). The next step, where the aim was to compute the internal rate of return, showed at what threshold value of the discount rate the investment would continue to yield profit (The IRR = 11.43%). It is extremely valuable information as it reveals the safety margin for the investment. The methodology discussed in this paper, which consists of a complex approach to an assessment of investments, especially in renewable energy sources, can yield much better outcomes than evaluations based on single methods, applied separately.

KEYWORDS
efficiency assessment, energy saving, methodology of assessment, static and dynamic methods
1 | INTRODUCTION

The idea of energy-saving investments and the broadly understood concept of saving energy in building emerged in the early 1970s, when the energy crisis and deteriorating condition of the natural environment became an increasingly acute problem in many countries across Europe and in the whole world. A need arose to find such solutions that would enable people to save energy and restrain the adverse impact of human activities on nature. Since then, the European Union has been passing regulations intended to reduce energy consumption and emission of greenhouse gases (Figure 1). The cost-effective and efficient use of energy is now promoted as a model of taking care of the environment in which we live. In the construction industry, it often entails the necessity to take measures in order to make energy savings in existing buildings and to plan new, energy-saving developments.1,2

To gain understanding of what energy-efficient investments are, we should first consider the definition of an investment itself. There are many terms defining the notion of investment. It is commonly understood that “an investment” consists of inputs into creating a new asset or expanding an existing one, which in the future will generate a greater stream of goods and services. Another sense of an investment is the allocation of economic means into an economic undertaking whose aim is to multiply the investor’s wealth by providing them with certain incomes. However, in the building industry, there is the term of “a building investment” which applies to steps taken in order to build a new or to re-build an old building. This meaning of an investment agrees with general definitions of the notion, as any investment in the building development is invariably connected with some expenditure and leads to an increase in the worth of tangible assets. The execution of projects whose aim is to improve the energy efficiency of buildings is an example of a building activity, and its consequences are clearly seen as the improved value of a building, lower maintenance costs or greater benefits obtained from its everyday use.3–5

There are various benefits gained from buildings meeting higher energy-efficiency standards, often beyond mere financial effects.4,6 It is worth remembering that improved energy efficiency minimizes the impact on the natural environment, limits the consumption of natural resources, reduces the harmful emissions to the ambient world and, last but not least, makes it possible to satisfy international obligations, which the European Union countries7 are obliged to comply with (Figure 1).

Energy efficiency also entails the use of renewable energy resources. The following RES are the most popular and accessible ones: solar power, wind and water energy, bio-mass. These energy sources should be taken into consideration when implementing development

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**The EU law**

**Primary sources of legislation** – the EU founding treaties, of Paris (1951), of Rome (1957)

**Secondary sources of legislation:**

- Regulations (apply to all EU members, legal regulations binding all member states),
- Directives (do not contain legal norms, do not apply to all but only to whom a directive is addressed)
- Decisions (issued in national legislation, according to administrative law, for every member state directly addressed to),
- Recommendations, opinions (expressing a statement in relations to a specific matter, suggesting a line of action, expressing expectations concerning the EU member states)

**Organs shaping the EU legislation:**

- European Council (defines strategic EU development goals, sets obligations and assigned them to appropriate organs),
- European Parliament (the opinion and advice-making body for the European Council)
- Council of the European Union (a body of the European Community, implements the provisions of the Treaty of Maastricht)
- European Commission (supervises the enforcement of law, implements the EC decisions and regulations, is responsible for the EU’s policy and coordinates its actions).
- Court of Justice of the European Union (interprets law, creates new laws, not authorised to pass decisions)

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**FIGURE 1** Schematic presentation of the EU regulations pertaining to protection of the natural environment, organs shaping the law (source: own preparation based on7,8)
investments, both small, private ones, and large projects, like industrial facilities or public buildings and amenities. Each time, an investment into energy-saving solutions is considered, what needs to be taken into account is the long service life and the fact that benefits will appear for many years to come after the solution is implemented.8,9

The building sector is this branch of economy that scores the highest energy-consumption index. The construction industry is responsible for about 40% of total energy consumption in the European Union,10,11 which is one of the most powerful arguments in favor of implementing energy-efficient solutions in civil engineering. The high energy consumption rate is also significantly affected by the demand for energy when completed buildings are used (21.7%). Hence, the most important issue in the building sector in recent years has been how to achieve the highest possible energy efficiency. With new laws and the EU directives, certain modifications to legal regulations are made, which force the implementation of more eco-friendly solutions, in addition to which energy efficiency is now a top priority of contemporary energy policy. Beside the legal regulations imposing energy-saving solutions, common sense of investors and users of buildings and building structures are increasingly often voiced. Any analysis of costs incurred by the demand for energy to be supplied to buildings clearly shows that modern energy-saving technological solutions are the only way to decrease the costs during the useful life of a building.6,12

Thus, rather than an obligation to comply with legal regulations, a greater interest in energy efficiency is more often stimulated by economic calculations, which allow us to assess buildings and consider possible pro-environmental solutions. Reduction of energy consumption and consequently lower CO₂ emissions are achieved through the implementation of different measures. Because there are many buildings constructed in different time periods in the past failing to meet the current standards, it is necessary to develop different methods to improve this situation without having to demolish such buildings. Approximately 50% of residential houses in Europe were built before 1980, which means that they are over 40 years old.13 This group comprises around 20% of buildings raised before 1945. Most houses dating back to that time are in the UK, where as many as 37.8% of homes in detached, terraced or multi-flat houses were built before 1945. Other notable countries in this regard are Belgium, with 31.7% of all flats found in houses built before 1945, Denmark (34.1%), France (28.7%), and Switzerland (26.6%). 59.1% of the flats in Romania were built between 1946 and 1980, compared to 55.4% in Bulgaria, 52.6% in Slovakia, 51.4% in Italy, and 49.6% in Lithuania (www.locja.pl). These are huge stocks of residential housing that do not meet the current standards on energy saving. There are several ways to improve energy efficiency of buildings. First and foremost, the expected outcome is achieved through renovation and thermal modernization of existing buildings.13 A building project including the improvement of energy balance is also frequently connected with the installation of devices which allow the user to obtain energy from renewable energy resources, eg, solar panels or heat pumps. Such solutions are gaining popularity in Europe,14 as depicted in Figure 2. The diagram shows a distinct increase in the production of nuclear, wind and photovoltaic power, and both wind and solar power can be obtained by individual energy users.

Energy-saving measures often incur high costs, which can discourage investors.15 However, the costs of such investments can be paid off quickly. Lower bills for heating or electricity, many options to claim co-funding, as well as a higher market value and attractiveness of a given real property mean that the mentioned investment can turn out to be profitable; yet, the profitability of any investment project needs to be properly assessed.

In view of the fact that individual energy users take advantage of renewable energy sources and problems arise as to how to best assess the economic efficiency of RES, it appears necessary to develop a method that would facilitate such evaluation. This article contains a suggestion to employ a stepwise procedure method, where it is proposed to make an assessment in a series of steps employing a few methods. The proposed method is developed by the author and is a new approach to this type of analysis.

The first step is to make an action plan and, based on the design assumptions, prepare a set of basic data about the planned investment. It is also recommended to prepare an analysis of cash flows over the time period submitted to analysis as this will be useful in further analyses. In the subsequent steps, by using a few assessment methods, it is possible to achieve an effective assessment of the investment. The purpose of this article is to present the method for an assessment of economic efficiency designed by the author and intended to be used by private investors and institutions which provide financial support for such investments. The method can also be a source of inspiration for scholars and researchers involved in this field. Assessments based on simple and compound methods will be reviewed in the following parts of this article, and the methodology proposed by the author will be also visualized in a graphic diagram.

2 MATERIALS AND METHODS

A rational decision to proceed with a planned investment should be based on an evaluation of the profitability thereof, including an analysis of costs and benefits. An approach to making such an assessment can vary, to a large extent
depending on which stage of a project the assessment is performed at, the accessibility of data, and the purpose for which we make the analysis. Consequently, many methods have been developed to support economic efficiency assessment of investments. They can be divided into two groups:

- **Static methods** – often referred to as simple ones, most often applied in early stages of project assessment. Their advantages are the simplicity of calculations and easy interpretation of the results.

- **Dynamic methods** – they are discounting methods, also known as compound ones. Unlike static methods, they take into account the whole duration of an investment and changes in the time value of money.

### 2.1 Static, simple methods

Static methods of economic efficiency appraisal include the payback evaluation (Payback), average rate of return (ARR) and simple payback time (SPBT) methods. They are all examples of a simplified approach, which allow the user to drop the least profitable solutions at the early stage of an investment.

#### 2.1.1 Simple payback time

The most popular method for making an economic efficiency appraisal of an investment is to calculate the period of time needed to recover the initial outlays spent on making that investment, which is what the SPBT index demonstrates. The simple payback period is calculated from the moment the investment is commenced to when the cumulative gross profits earned from the investment balance the outlays.

When annual gross inflows are constant, the SPBT can be calculated from the formula (1):

$$ SPBT = \frac{I}{Zi} $$

where SPBT – the period after which the outlays will be paid back, expressed in years, $I$ – value of planned outlays, $Zi$ – annual savings.

The SPBT yields a simplified description of the profitability of an investment as it does not take into account the influence of time on the undertaking. This method is suitable for making preliminary economic efficiency assessments of considered investments, mainly at the inception stage.

#### 2.1.2 Simple return rate (SRR)

The simple return rate is the return, expressed as a percentage, earned from a given investment in a year relative to the cost of this investment. The computed rate of return is only an estimate and often differs from the actually obtained return. The simple rate of return, known as the SRR, is calculated as a ratio of net inflows from a given investment in a specified time period, most often a year, relative to the invested capital (2):
\[ R = \left( \frac{KN}{I} \right) \times 100\% \]  \hspace{1cm} (2)

where \( R \) – rate of return, \( KN \) – net profit, \( I \) – investment capital (outlays).

The algorithm allows the user to achieve a result in two forms, one of which takes into account both own and borrowed capital, which are together called total investment outlays (ROI – Return on Investment) (3), while the other one only considers own capital (ROE) (4).

\[ ROI = \left( \frac{\text{gain after tax}}{\text{total outlays}} \right) \times 100\% \]  \hspace{1cm} (3)

\[ ROE = \left( \frac{\text{net gain}}{\text{investment outlays from own capital}} \right) \times 100\% \]  \hspace{1cm} (4)

2.1.3 | Average rate of return (ARR)

Another simple profitability appraisal method is that of an average accounting rate of return (ARR), also known as the average accounting return (AAR). The goal of this approach is the same as in the previously mentioned methods, but it determines the ratio between net gains obtainable by the assessed investment to the outlays incurred by the execution of this investment.23,24 Unlike the ROE and ROI, this method employs average values rather than annual ones, determined for each period separately (5):

\[ ARR = \frac{K_{av}}{I_{av}} \]  \hspace{1cm} (5)

where \( K_{av} \) – average accounting net gain, \( I_{av} \) – average accounting value of investment outlays

Investment projects approved to be executed are ones where the accounting rate of return is higher than or equal to the subjective threshold value set by the investor.

2.2 | Compound discounted methods

Compound methods, or more precisely the compound methods applied to identify the profitability of an investment, are dynamic methods that take into account the entire life of a given investment.25 Owing to the discounting technique, it is possible to consider the outlays and inflows over different periods of time, at a specific discount rate, which makes it possible to include the time value of all amounts of money in the whole period considered.26,27 There are a number of discounted methods available, for example, the net present value (NPV), internal rate of return (IRR), the annuity method, profitability index (PI), discounted payback period (DPP), net present value rate (NPVR), modified internal rate of return (MIRR), or modified payback index (MPI). Let us have a closer look at the most popular ones.

2.2.1 | Net present value NPV

The most popular discounted method is based on the net present value NPV, which is the difference between the present value of inflows and the present value of outflows arising from the considered investment and the updated, the current value of gains from the projected investment.28,29 The NPV can be presented as the sum of net flows discounted separately for each year over the time period for which the calculations are made, at a fixed discount rate (7) or at a variable discount rate (7):

\[ NPV = \sum_{t=0}^{n} \left( \frac{NCF_t}{(1+r)^t} \right) \]  \hspace{1cm} (6)

where \( NCF_t \) – sum of cash inflows in year \( t \), \( r \) – discount rate, \( t = (from \ 1 \ to \ n) \) – subsequent years in the investment’s useful life, \( t \) – time period covered by the analysis.

A value of the NPV < 0 means that the planned investment should be discarded because the gain will be lower than the outlays or there will be no gain at all; if the NPV = 0, the discount rate equals the minimum threshold rate and the savings obtained by implementing the investment will only cover the expenses incurred by its implementation; finally, when the NPV > 0, the execution of the projected investment is profitable.

2.2.2 | Internal rate of return IRR

The IRR index is the interest rate at which the present value of net inflows expected from a given investment is equal to the value of outlays (ie, NPV = 0). The procedure for calculating the IRR is the same as for computing the NPV. The internal rate of return is the value of the discount rate “\( i \)” at which the present value of gains is equal to the present value of inputs, and it reflects the direct profitability rate of the assessed investment. An investment can be approved by the investor if the IRR value
is higher than the threshold value being the lowest acceptable rate of return in the considered case. In other words, each discount rate higher than the IRR yields a negative NPV. 30–32

The value of the IRR does not depend directly on the discount rate, which means that the IRR can be applied in an efficiency assessment even when the discount rate is unknown. Below, we present an approach to calculating the IRR through successive approximations, where the first step is to determine the value of net cash flows for the entire period of the investment project being implemented and then used. Next, we assume a probable level of the discount rate for which the NPV = 0 and after that, using the method of successive approximations, we determine two levels of the discount rate \( r_a \) and \( r_b \) for which the NPV\(_a\) is close to 0 but positive, while the NPV\(_b\) is close to 0 but negative:

\[
IRR = r_a + \left[ \frac{NPV_a (r_b - r_a)}{NPV_a + i^\text{NPV}_b i} \right] \quad (8)
\]

### 2.2.3 The annuity method

The annuity method, also known as the method of equal annuities, is used in the practice of making an assessment of the profitability of an investment. 33,34 Some building investments are characterized by varied investment and maintenance outlays, thus in order to compare realistically their economic efficiency, the costs are determined with the help of the present value of all cash flows, that is the value obtained by depreciating cash flows over the whole life of the asset. The annuity method makes it possible to calculate values of present cash flows from the formula (9):

\[
CF = PV \times A_n
\]

where \( PV \) – the present value of all cash flows in the life of an asset (investment inputs and maintenance costs), \( A_n \) – total discount factor for \( n \) years of use, calculated from the formula:

\[
A_n = i \times (1+r)^n / (1+r)^n - 1 \quad (10)
\]

where \( r \) – the discount rate.

The CF value thus obtained corresponds to constant, annual expenses relative to the needs over the entire life of an asset, such as a building. The lower the CF value, the more profitable the analyzed variant.

Methods for an economic assessment of efficiency are broadly applied in different branches of economy, including the construction and building sector, in different regions of the world. The literature provides numerous examples of these methods being used in practice, for example, these methods have been applied in Latin America to evaluate the possibilities of an economic development of a country based on renewable energy sources; in Asian countries, they served to measure the economic efficiency of high-income economy, 35,36 while a techno-economic assessment of solar photovoltaic integration into national grids has been made in South Africa. 37 Economic efficiency analyses are often used to evaluate the profitability of investing in renewable energy sources. 37–39

### 2.3 Proposed assessment methodology

There are numerous methods for making an analysis and assessment of investments, which can be applied in different situations. From simple methods, easy to use but lacking in precision, to compound ones, which require a large amount of data but which provide answers to many questions concerning the profitability of an investment—all are useful and it would be incorrect to claim that some are better than others. In order to make a reliable appraisal of an investment, same as in other analytical settings, it is recommended to apply a few methods so that the final decision is then based on an analysis of results obtained in several ways. This article proposes a stepwise procedure methodology, where it is suggested to make an assessment supported by a few methods at every step (Figure 3).

This diagram illustrates the proposed procedure. The first step consists of planning the investment and, depending on the design, collating the basic information about the envisaged development. It would also be helpful in further analyses to prepare the specification of cash flows in the time period submitted to the assessment.

In the second step, in order to gain preliminary insight, it has been suggested to employ one of the simple assessment methods. The aim is to find out quickly whether the planned investment can be profitable. An approximate result can resolve the dilemma if it is reasonable to be further interested in the investment, and to plan and carry out the next steps in the appraisal procedure. If the answer is affirmative, we can proceed to the third step, where the proposed method is the net present value NPV approach.

The proposed method has many advantages, for example, it includes the current money value and the whole duration of an investment’s implantation and useful life. It connects the project with the long-term financial output. A downside of this method is the required skill of handling discounted cash flows, bearing in mind that an inadequately set discount rate strongly impacts the results obtained with this method. In view of the difficulty
determining a correct discount rate, it is proposed that the next step should include the calculation of the internal rate of return IRR. When calculating the IRR, we are searching for such a discount rate at which the present net value of cash flows (obtained during the implementation of an investment and life of the developed asset) would reach the value zero. A single development project will pay off if its internal rate of return is higher than (in an extreme case, equal to) the threshold value of profitability acceptable by the investor.

The procedure is finalized by making an analysis where all the results achieved before are summarized,

| No. | Authors | Title | Journal |
|-----|---------|-------|---------|
| 1   | Abdeen Mustafa Omer | Energy, environment and sustainable development | Renewable and Sustainable Energy Reviews |
| 2   | Haibin Han, Xiaoyu Zhang | Static and dynamic cultivated land use efficiency in China: A minimum distance to strong efficient frontier approach | Journal of Cleaner Production |
| 3   | Rafael Alvarado, María Iníguez, Pablo Poncea | Foreign direct investment and economic growth in Latin America | Economic Analysis and Policy |
| 4   | Ching-Cheng Lu, Xiang Chen, Chia-Leng Hsieh, Kuo-Wei Chou | Dynamic energy efficiency of slack-based measure in high-income economies | Energy Science and Engineering |
| 5   | Rodrigo Cortés-Severino, Carlos Cárdenas-Bravo, Rodrigo Barraza, Antonio Sánchez-Squella, Patricio Valdivia Lefort, Federico Castillo-Burns | Optimal design and experimental test of a solar simulator for solar photovoltaic modules | Energy Science and Engineering |
| 6   | Bachir Ismael Ouedraogo, Daniel Yamegueu | Techno-economic assessment of solar photovoltaic integration into national grids: A case study of Burkina Faso | Energy Science and Engineering |
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| 9   | Pablo Ponce, Syed Abdul Rehman Khan | A causal link between renewable energy, energy efficiency, property rights, and CO₂ emissions in developed countries: A road map for environmental sustainability | Environmental Science and Pollution Research |
| 10  | Pablo Ponce, Cristiana Oliveira, Álvarez, Maria de la Cruz del Río-Rama | The Liberalization of the Internal Energy Market in the European Union: Evidence of Its Influence on Reducing Environmental Pollution | Energies |
| 11  | Pablo Ponce, Michelle López-Sánchez, Patricia Guerrero-Riofrío, Jorge Flores-Chambía | Determinants of renewable and non-renewable energy consumption in hydroelectric countries | Environmental Science and Pollution Research |
| 12  | Jorge Flores-Chamba, Michelle López-Sánchez, Pablo Ponce, Patricia Guerrero-Riofrío, José Álvarez-García | Economic and Spatial Determinants of Energy Consumption in the European Union | Energies |
| 13  | Elżbieta Szafranko | Methodology for assessment of the cost effectiveness of simple energy-efficient investments | Construction of Optimized Energy Potential |
which leads to making a decision whether or not to invest in the analyzed investment.

3 | CASE STUDY

An analysis of the economic efficiency of an investment was carried out using a case of a typical rooftop photovoltaic installation for the generation of electricity to supply a single-family house. The installation will be connected to the national electric power grid to sell the excess electricity it will generate to a local power plant, i.e., an on-grid system will be implemented. The investment is shown visually in Figure 4.

An assessment of the profitability of this investment will proceed as envisaged in the proposed methodology, illustrated in Figure 3.

Step I – gathering and processing the information about the investment

As mentioned above, the object of our analysis is a photovoltaic installation mounted on the roof of a single-family house. This is a detached house, raised with the traditional technology, and having the built-up area of 134.3 m² and the cubic capacity of 740 m³. The building is a cuboid in shape, covered with a tiled gable roof with the slope angle of 40°. The land parcel on which the house stands is very sunny.

All information on costs is given in original units of PLN, 1 EU = 4.59 PLN (exchange rate on 19/09/2021). Costs are used to show certain phenomena and trends described in the methodology, and the monetary unit has no influence on the results and conclusions.

The specific information related to the planned development is:

- Total annual demand for energy to supply to this building is approximately 2701 kWh.
- The cost per unit of electric power purchased from the supplier, including the distribution costs, is 0.61 PLN/kWh.
- The real annual cost of electric power – the total electricity bill is 1647.60 PLN/year.
- The predicted increase in the price of electricity in a year = 3.0%.
- The size of the photovoltaic system – 10 modules with the total capacity of 3.3 kWp,
- The compound rate of return is 5%,
- The predicted price of 1 kWh of energy in 20 years = 1.07 PLN,
- The surface area covered by the solar panels 18 m²,
- The estimated annual production of energy 3257 kWh, the useful life of the installation 20 years,
- The cost of the entire installation, including the equipment and mounting, is 23,911.20 PLN,
A grant from the “My electricity” program dedicated to the co-funding of photovoltaic micro-installations - 5000 PLN,

- The tax relief of 18% (the expenses incurred by the mounting of the photovoltaic installation are also deductible from the tax base) 18,911.20 PLN × 18% = 3404 PLN,
- The expected decline in the efficiency of the photovoltaic installation 0.3% a year,
- The co-funding in the form of a non-returnable grant from the “My electricity” program as well as an 18% tax relief, in total 8404 PLN,
- The current CO₂ emission 2952 kg/year,
- The efficiency of the photovoltaic installation is assumed to remain the same over the whole useful life,
- The generated energy will ensure meeting fully the demand for electric power by the household,
- The installation will work for 20 years without any failures, hence no additional maintenance costs.

Based on the predicted increase of electric power price at 3% a year and the assumed decrease in the efficiency of the photovoltaic installation of 0.3% a year, the cash flows during the twenty years of using the installation were set. The results are presented in Table 2.

**Step II** - a preliminary evaluation of the investment with a simple method

In line with the proposed methodology, the second step involved making a preliminary assessment of the planned investment with one of the simple methods. Having analyzed the preliminary set of data, the simple payback time method was chosen. The SPBT is the most frequently used indicator of the profitability of an investment. Formula (1) lets us determine the time period needed to recover the investment outlays allocated to the photovoltaic installation project, and counted since the installation is launched until the total inflows will set off the inputs. The annual gross profit Zi in the analyzed case is the financial savings owing to the decrease in the amount of energy bought from the supplier:

\[ Z_i = K_e \times E \ [\text{PLN/year}] \]

where \( K_e \) – is a unit cost of electric power bought from the supplier, including the distribution costs – 0.61 PLN/kWh, \( E \) – the annual gross amount of electricity generated by the planned installation - 3257 kWh.

From the above figures, the SPBT is: SPBT = \( I/Z_i = 15,507.20/(0.61 \times 3257) \) = 7.8 [years].

The investment consisting of the mounting of photovoltaic panels with the total power capacity of 3.2 kWp to generate electricity for a single-family house in the on-grid system will pay off after 7.8 years. Considering the assumed life of the panels, the investment is profitable because it will begin to yield tangible profits as soon as the eighth year of operation.

**Step III** - an assessment with the net present value NPV method

The following data were taken to make an analysis with the NPV method: the previously identified savings, discount rate, time period of using the installation, and the cost of the investment. Table 3 presents the determined discounted stream of cash flows, including own capital engaged in the investment, and considering the grant and tax relief obtained as inflows. The initial negative cash flow is therefore the value of the total investment cost, covered from the investor’s own capital, whereas the cash flows in the subsequent years include the savings obtained from the electricity bills which will not have to be paid.

The NPV = 10,796.38 PLN, which is >0, showing that the investment is profitable. In the calculations presented in Table 2, negative cash flows appear only at the launching of the investment and these are the investment outlays. The analysis does not take into account the risk of a failure of the installation.

| Year | Production [kWh] | Savings [PLN] | Cumulative cash flow [PLN] |
|------|------------------|---------------|---------------------------|
| 1    | 3257.2           | 1647.6        | -15,507.2                 |
| 2    | 3247.4           | 1697.0        | -13,810.20                |
| 3    | 3237.7           | 1747.9        | -12,062.3                 |
| 4    | 3228.0           | 1800.4        | -10,261.9                 |
| 5    | 3218.3           | 1854.4        | -8407.5                   |
| 6    | 3208.6           | 1910.0        | -6497.5                   |
| 7    | 3199.0           | 1967.3        | -4530.2                   |
| 8    | 3189.4           | 2026.3        | -2503.8                   |
| 9    | 3179.8           | 2087.1        | -416.7                    |
| 10   | 3170.3           | 2149.7        | 1733.1                    |
| 11   | 3160.8           | 2214.2        | 3947.3                    |
| 12   | 3151.3           | 2280.7        | 6228.0                    |
| 13   | 3141.9           | 2349.1        | 8577.0                    |
| 14   | 3132.4           | 2419.6        | 10,996.6                  |
| 15   | 3123.0           | 2492.1        | 13,488.7                  |
| 16   | 3113.7           | 2566.9        | 16,055.6                  |
| 17   | 3104.3           | 2643.9        | 18,699.6                  |
| 18   | 3095.0           | 2723.2        | 21,422.8                  |
| 19   | 3085.7           | 2804.9        | 24,227.7                  |
| 20   | 3076.5           | 2889.1        | 27,116.8                  |
Step IV – the internal rate of return method

A decision-support criterion, alternative to the NPV, is the internal rate of return method (IRR). It is such a discount rate for which the NPV assumes the value of zero. The IRR is a measure of the profitability of an investment.

The higher the IRR value, the higher the profit earned from the investment. By substitution and successive approximations, the goal is to determine such a discount rate “r” for which the NPV will be = 0. The assumption made in the analysis made at step three was that the discount rate would be 5%, and then the NPV was 10,796.38 PLN. The result is positive but what remains unknown is the value of the discount rate that would result in the NPV close to zero.

Subsequent calculations were made, increasing the required discount rate gradually, by 1% each time, and in parallel, the net present value NPV was computed from the appropriate formula. The results are set in Table 4. The IRR searched for lies within the r range of 11–12%, and using the previously cited formula (7), it is possible to determine more accurately the value of the internal rate of return:

\[
\text{IRR} = r_a + \frac{\text{NPV}_{a} \ast (r_b - r_a)}{\text{NPV}_{a} + |\text{NPV}_{b}|}
\]  

(11)

where: \(r_a\) – the discount rate for which the NPV is positive close to zero, \(r_b\) – the discount rate for which the NPV is negative close to zero, \(\text{NPV}_a\) – the net present value for \(r_a\),

\(\text{NPV}_b\) – the net present value for \(r_b\).

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**Table 3** Specification of the discounted cash flows in the analyzed investment

| Year | Savings [PLN] - NCF | Discount rate \(r = 5\%\) | Discount factor \((1 + 0.05)^t\) | Discounted cash flow \(\frac{\text{NCF}}{(1 + 0.05)^t}\) [PLN] |
|------|---------------------|-------------------------|-------------------|----------------------|
| 0    | -15,507.2           | 0.05                    | 1.05              | -15,507.20          |
| 1    | 1647.6              | 0.05                    | 1.05              | 1569.14             |
| 2    | 1697.0              | 0.05                    | 1.05              | 1539.25             |
| 3    | 1747.9              | 0.05                    | 1.05              | 1509.94             |
| 4    | 1800.4              | 0.05                    | 1.05              | 1481.17             |
| 5    | 1854.4              | 0.05                    | 1.05              | 1452.96             |
| 6    | 1910.0              | 0.05                    | 1.05              | 1425.29             |
| 7    | 1967.3              | 0.05                    | 1.05              | 1398.14             |
| 8    | 2026.3              | 0.05                    | 1.05              | 1371.51             |
| 9    | 2087.1              | 0.05                    | 1.05              | 1345.38             |
| 10   | 2149.7              | 0.05                    | 1.05              | 1319.76             |
| 11   | 2214.2              | 0.05                    | 1.05              | 1294.62             |
| 12   | 2280.7              | 0.05                    | 1.05              | 1269.96             |
| 13   | 2349.1              | 0.05                    | 1.05              | 1245.77             |
| 14   | 2419.6              | 0.05                    | 1.05              | 1222.04             |
| 15   | 2492.1              | 0.05                    | 1.05              | 1198.76             |
| 16   | 2566.9              | 0.05                    | 1.05              | 1175.93             |
| 17   | 2643.9              | 0.05                    | 1.05              | 1153.53             |
| 18   | 2723.2              | 0.05                    | 1.05              | 1131.56             |
| 19   | 2804.9              | 0.05                    | 1.05              | 1110.01             |
| 20   | 2889.1              | 0.05                    | 1.05              | 1088.86             |
| NPV  |                    |                         |                   | 10,796.38           |

**Table 4** Determination of the discount rate at which the NPV is close to zero

| Required discount rate [%] | NPV [PLN] |
|---------------------------|-----------|
| 5                         | 10,796.38 |
| 6                         | 8484.38   |
| 7                         | 6458.05   |
| 8                         | 4675.97   |
| 9                         | 3103.37   |
| 10                        | 1711.00   |
| 11                        | 474.03    |
| 12                        | -628.25   |
| 13                        | -1613.63  |
| 14                        | -2497.39  |

The result is positive but what remains unknown is the value of the discount rate that would result in the NPV close to zero.
(calculated in Table 5), \( NPV_b \) – the net present value for \( r_b \) (calculated in Table 6).

Tables 4 and 5 show a detailed analysis of cash flows at the discount rates equal 11% and 12%.

The following results were obtained:

\[ r_a - \text{the discount rate for which the NPV is positive close to zero} = 11\% \]
\[ r_b - \text{the discount rate for which the NPV is negative close to zero} = 12\% \]
\[ NPV_a - \text{the net present value for} \ r_a = 474.03 \text{ PLN} \]
\[ NPV_b - \text{the net present value for} \ r_b = -628.25 \text{ PLN} \]

\[ IRR = r_a + \frac{NPV_a \times (r_b - r_a)}{NPV_a + |NPV_b|} = 11 + \frac{474.03 \times (12 - 11)}{474.03 + | - 628.25|} \]

\[ = 11 + \frac{474.03}{1102.28} = 11.43\% \]

The discount rate at which the net present value of installing solar panels equals zero as well as the highest required interest rate at which the implementation of the project will be efficient is the IRR 11.43%.

**Step V** – analysis of results

Table 7 shows the results of all analyses carried out at the consecutive steps of the assessment, in line with the proposed methodology. It becomes apparent that each subsequent step provides more precise information about the planned investment.

### RESULTS AND DISCUSSION

The following conclusions can be drawn when reviewing the above procedure:

- In the first step of our assessment, it was necessary to generate the largest possible database describing the planned investment. The information regarding the economic aspects of an investment is very important. The description of cash flows prepared at this stage shows an approximate moment when the cash flows

| Year | Savings [PLN] - NCF | Discount rate \( r = 11\% \) | \( 1 + r \) | Discount factor \( (1 + r)^t \) | Discounted cash flow \( \frac{NCF}{(1 + r)^t} \) [PLN] |
|------|---------------------|-----------------|---------|-----------------|-----------------|
| 0    | −15,507.2           | 0.11            | 1.11    | 1.0000          | −15,507.20      |
| 1    | 1647.6              | 0.11            | 1.11    | 1.1100          | 1484.32         |
| 2    | 1697                | 0.11            | 1.11    | 1.2321          | 1377.32         |
| 3    | 1747.9              | 0.11            | 1.11    | 1.3676          | 1278.05         |
| 4    | 1800.4              | 0.11            | 1.11    | 1.5181          | 1185.98         |
| 5    | 1854.4              | 0.11            | 1.11    | 1.6851          | 1100.50         |
| 6    | 1910                | 0.11            | 1.11    | 1.8704          | 1021.16         |
| 7    | 1967.3              | 0.11            | 1.11    | 2.0762          | 947.57          |
| 8    | 2026.3              | 0.11            | 1.11    | 2.3045          | 879.27          |
| 9    | 2087.1              | 0.11            | 1.11    | 2.5580          | 815.90          |
| 10   | 2149.7              | 0.11            | 1.11    | 2.8394          | 757.09          |
| 11   | 2214.2              | 0.11            | 1.11    | 3.1518          | 702.53          |
| 12   | 2280.7              | 0.11            | 1.11    | 3.4985          | 651.92          |
| 13   | 2349.1              | 0.11            | 1.11    | 3.8833          | 604.93          |
| 14   | 2419.6              | 0.11            | 1.11    | 4.3104          | 561.33          |
| 15   | 2492.1              | 0.11            | 1.11    | 4.7846          | 520.86          |
| 16   | 2566.9              | 0.11            | 1.11    | 5.3109          | 483.33          |
| 17   | 2643.9              | 0.11            | 1.11    | 5.8951          | 448.49          |
| 18   | 2723.2              | 0.11            | 1.11    | 6.5436          | 416.17          |
| 19   | 2804.9              | 0.11            | 1.11    | 7.2633          | 386.17          |
| 20   | 2889.1              | 0.11            | 1.11    | 8.0623          | 358.35          |
| NPV for \( r = 11\% \) | | | | 474.03 |
will shift to the gains side. These data are illustrated in Figure 5.

The second step involved the application of formula (1), an example of a simple method. This formula does not take into account a decline in the efficiency of the installation, which affects the volume of generated energy. This explains the discrepancy between the results obtained in the first and second steps. However, this is just a preliminary stage of an assessment and the results are merely an approximation. The outcome of an assessment at this stage is only to implicate whether or not an investor should be interested in the analyzed project.

The third step, as recommended in this procedure, is to make an evaluation with the net present value NPV approach. Table 2 shows the discounted stream of cash flows, including the own capital engaged in the investment and treating the grant and tax relief secured as inflows. Hence, the starting point for the calculations shown in this table is the value (−15,507.20 PLN). The NPV value achieved is 10,796.38, and, as such, it indicates that the analyzed investment is profitable at the assumed discount rate. However, the discount rate value is oftentimes difficult to estimate and frequent changes in the long-term perspective, which means that the results obtained at this stage of an analysis

| Year | Savings [PLN] - NCF | Discount rate \( r = 12\% \) | Discount factor \( (1 + r)^t \) | Discounted cash flow \( \text{NCF}/(1 + r)^t \text{ [PLN]} \) |
|------|---------------------|-------------------|-----------------|----------------------------------|
| 0    | −15,507.2           | 0.12              | 1.12            | −15,507.20                      |
| 1    | 1,647.6             | 0.12              | 1.12            | 1,647.6                          |
| 2    | 1,697               | 0.12              | 1.12            | 1,697                            |
| 3    | 1,747.9             | 0.12              | 1.12            | 1,747.9                          |
| 4    | 1,800.4             | 0.12              | 1.12            | 1,800.4                          |
| 5    | 1,854.4             | 0.12              | 1.12            | 1,854.4                          |
| 6    | 1,910               | 0.12              | 1.12            | 1,910                            |
| 7    | 1,967.3             | 0.12              | 1.12            | 1,967.3                          |
| 8    | 2,026.3             | 0.12              | 1.12            | 2,026.3                          |
| 9    | 2,087.1             | 0.12              | 1.12            | 2,087.1                          |
| 10   | 2,149.7             | 0.12              | 1.12            | 2,149.7                          |
| 11   | 2,214.2             | 0.12              | 1.12            | 2,214.2                          |
| 12   | 2,280.7             | 0.12              | 1.12            | 2,280.7                          |
| 13   | 2,349.1             | 0.12              | 1.12            | 2,349.1                          |
| 14   | 2,419.6             | 0.12              | 1.12            | 2,419.6                          |
| 15   | 2,492.1             | 0.12              | 1.12            | 2,492.1                          |
| 16   | 2,566.9             | 0.12              | 1.12            | 2,566.9                          |
| 17   | 2,643.9             | 0.12              | 1.12            | 2,643.9                          |
| 18   | 2,723.2             | 0.12              | 1.12            | 2,723.2                          |
| 19   | 2,804.9             | 0.12              | 1.12            | 2,804.9                          |
| 20   | 2,889.1             | 0.12              | 1.12            | 2,889.1                          |
| NPV for \( r = 12\% \) | | | | −628.25 |
FIGURE 5  Diagram of streams of cash flows

FIGURE 6  Discounted cash flows

FIGURE 7  A schematic presentation of changes in the discount rate over the 20-year useful life of the investment
might be unreliable. This led to the inclusion of a subsequent step.

The fourth step entails the use of a method leading to the determination of the internal rate of return, that is, the threshold value of the discount rate at which the investment will no longer be profitable. The calculations proved that this threshold value is the IRR = 11.43%. Compared with the rate assumed in the earlier stages of the assessment, this value is nearly twice as high, which suggests that the investment is a safe one. According to the economic assumptions, changes of the discount rate within the 50% of the value are quite common and acceptable. For the analyzed investment, it is possible to change the discount rate within the range of 2.5–7.5%, and these values lie in a safe distance from the threshold value.

The cash flows discounted at an 11% and 12% discount rate have a similar effect on the accumulated effect of savings. The visual presentation of the savings can be seen in Figure 6.

The diagrams (Figures 6 and 7) clearly show that an increase in savings is more rapid in the second half of the useful life of the implemented project. How the changing discount rate influences the discount factor over the twenty-year-long useful life of the investment is illustrated in Figure 7.

The line representing the discount factor at a 5% discount rate grows quite uniformly over the entire analyzed time period and shows the smallest fluctuations. Meanwhile, the curves plotted for the 11% and 12% discount rates rise quite rapidly around the twelfth or thirteenth year of the project’s life. Obviously, this has an impact on the final result of calculations made to determine the economic efficiency of the investment, by changing dynamically the value of cash flow sums after the passage of this time period. This is also the cause underlying the phenomenon depicted in Figure 6, where it is exactly after that time, 12–13 years after the investment was completed that the effect of accumulated savings becomes more evident.

The analyses presented above ensure a more detailed insight into all economic aspects involved in the planned investment. Studies carried out and described in the research papers reviewed while preparing and conducting this study provide some albeit incomplete information. While it is possible to find examples of the application of a few methods concomitantly, they are not included into a system, a complete procedure or into calculations of the return period of energy-saving investments. Frequently, they are elements of an assessment of the life cycle of a building or building structure. I have been unable to find in the literature an approach which would consist of a stepwise, systematic assessment. Hence, the methodology presented in this article can fill in this gap.

5 | CONCLUSIONS

An assessment of the economic efficiency of a building investment is becoming an essential element of all analyses performed prior to making a decision to construct or to refurbish a building. One reason is that certain investments, apart from economic savings, generate benefits for the environment, mainly ones which involve the modernization of how the demand for heat and electricity supplied to buildings is satisfied.

The literature dealing with this subject provides many methods for evaluation of the economic profitability of investments. Some are more and some are less complicated, and they all have downsides and upsides, but an analysis made with just one method may not give an exhaustive answer to the question about all economic aspects of a planned construction project. Thus, this article suggests methodology based on the application of several methods, which will allow the user to make a complex analysis of benefits and costs connected with the construction and use of a building investment. The procedure was presented using an example of a typical rooftop photovoltaic installation for the generation of electric power to supply a single-family house, and the assessment included such information as the costs of the investment and gains calculated on the basis of the technical data describing the planned project. The assessment procedure consists of a few steps leading from a preliminary to a more detailed appraisal. The first stage is an analysis of the projected cash flows (Table 1), which in this case demonstrated that the payback would appear after 9 years. Next, the payback period was estimated with a simple method and this more precise evaluation showed that the payback period in this investment could be expected after 7.8 years. The following stages of calculations take into account the time value of money, having included a discount rate. The net present value method proved that if the assumed discount rate was 5%, the planned investment would be profitable (Table 2). The next step, where the aim was to compute the internal rate of return, showed at what threshold value of the discount rate the investment would continue to yield profit (Tables 3-5). The IRR value obtained, which was 11.43%, is extremely valuable information as it reveals the safety margin for the investment. The final stage summarizes the results.

The methodology discussed in this paper, which consists of a complex approach to an assessment of investments, especially in renewable energy sources, can yield much better outcomes than evaluations based on single
methods, applied separately. The case presented as an example of the application of the proposed methodology, including each stage together with a detailed analysis of the results, shows the usefulness of this approach in practice. This method has been developed by the author and may be considered as an innovative one.

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How to cite this article: Szafranko E. Assessment of the economic efficiency of energy-saving projects, methodology based on simple and compound methods. Energy Sci Eng. 2022;10:423-438. doi:10.1002/ese3.1032