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A model for an economic evaluation of energy systems using TRNSYS

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HIGHLIGHTS

- A new model, tool, for technical-economic evaluation of energy systems is proposed.
- Built in TRNSYS, the tool dynamically links technical and economic variables.
- The tool works in parallel to the technical evaluations of energy systems.
- The tool allows evaluates self-consumption and energy generation systems.
- The tool was validated to evaluate net-zero energy communities.

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ABSTRACT

This paper presents a technical-economic model for the evaluation of energy systems called Energy Assessment Tool of Energy Projects (EATEP). It was created with the TRaNsient System Simulation Tool (TRNSYS) and works in parallel to the technical simulations in this software. The EATEP links, in hourly time steps, technical and economic variables that can determine the functioning of energy systems and the profitability of the investment required for their implementation. The economic calculation procedure, as described in the European standard EN 15459:2007, of the Energy Performance of Buildings Directive (EPBD) of the European Commission, has been adapted to the characteristics of TRNSYS to develop the calculation methodology of the EATEP. The final use of this resulting tool is the evaluation of the energy self-consumption of communities from the technical-economic point of view, analyzing the investment in distributed generation systems by consumers, prosumers and energy producers. The operation of the EATEP has been validated through two cases that demonstrate the wide range of its applicability and versatility. In the first case, the calculation of indicators identifies the best alternative among various investment options in the evaluation of self-consumption energy systems. The second case, evaluates systems in which producers, consumers and prosumers exchange energy and economic flows; the tool calculates indicators of costs, revenue and income (the margin between revenue and costs).

1. Introduction

The economic evaluation procedure regularly used in feasibility studies of energy systems, is carried out in *series* to the technical evaluations of its operation, as in the case of [1–14]. In other words, the economic evaluation of this type of systems is carried out after obtaining the consumption/generation/storage/energy saving data in technical simulations. This can limit the dynamic link that may exist between the technical, economic, and financial variables that determine the hourly performance of energy systems, i.e. when evaluating energy systems made up of consumption facilities and generation facilities. Another limitation in these feasibility studies of energy systems, is the difference in the terminology of economic and financial indicators calculated in energy generation projects and projects to reduce energy consumption. In this paper, we present an economic evaluation model built into the TRaNsient System Simulation Tool (TRNSYS) that serves as a tool that covers these limitations and also presents another series of novelties. This tool, called Economic Assessment Tool of Energy Projects (EATEP), permits the economic evaluation of the energy systems in parallel to their technical evaluation. In this way, the EATEP considers the effect of technological and environmental costs and the hourly variation of energy prices on the technical performance of energy systems and profitability of their investment. Likewise, the tool economically evaluates the energy exchanges between distributed

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generation systems (DG) [15] and centralized generation systems.

The economic calculation procedure of the EATEP is an adaptation of the European standard EN 15459:2007 [16] to operate with TRNSYS. This standard reflects the economic calculation procedure of the Energy Performance of Buildings Directive (EPBD), which is the main European legislative instrument for the promotion of buildings with close to zero energy consumption. The EATEP extends the scale of application of EN 15459:2007; which allows for the evaluation of net zero energy consumption, known as Net-Zero Energy Building (NZEB) and Net-Zero Energy Community (NZEC), in buildings and communities, and similarly with energy surpluses, known as Net-Plus Energy (NZEB) and Net-Plus Energy Community (NZEC). In addition, it broadens the focus of this standard: along with energy consumption systems, it also allows for the economic evaluation of the viability of investment in centralized and DG systems. On this basis, the tool can calculate indicators, equivalent to those proposed in the EPBD, but designed to analyse the current value of revenues and incomes from the sale of CO_2 emission rights. The result is a model that can calculate a wide variety of economic-energetic, economic-environmental, and economic-energetic-environmental indicators, in order to identify the best alternative within a group of investment options.

This model is thus proposed as a tool in TRNSYS to analyse, i.e., the profitability of the investment required by consumers, prosumers, and energy producers, in the process of energy transition in communities towards the use of their local energy resources through the development of the DG.

The following details the novelties presented by the model with the use of EPBD (EN 15459:2007) and TRNSYS.

1.1. Use of the EPBD in the design of the EATEP

The European standard EN 15459:2007 normalizes the economic calculation procedure of the EPBD, which is the legislative instrument developed in the European Directive 2010/31/EU [17] and supplemented by Delegated Regulation (EU) No. 244/2012 [18]. The objective of the EPBD is to establish a common framework to assess the energy performance of buildings. Its economic calculation procedure is an analysis of the expected costs during the useful life of the energy systems. It includes the calculation of the Global Cost (CG), as the current value of the costs, and the comparative analysis called Cost-Optimal. The latter classifies the CG according to the primary energy consumed by each evaluated investment alternative [19]. The application of these indicators is highlighted in the economic evaluation of NZEB [20–22] and the study and development of NZEC [23] and Smart Cities [24]. In the EATEP, the CG and Cost-Optimal indicators are both used in the analysis of the investment in Energy Efficiency Measures (EEMs) in NZEB, NPEB, NZEB and NPEC. Indicators equivalent to these are proposed here, but are designed to analyse, within the same evaluation framework, the investment in energy generation systems. The new indicators are Global Income (IG), used to calculate the present net value of revenues and the margin between Revenues and Costs (ISC) used to calculate the present net value of the margin between IG and CG. A comparative analysis indicator has also been designed to classify the ISC according to the amount of energy, in terms of primary energy, that can be exported by each of the investment alternatives considered in the evaluation of energy generation systems. Finally, on this same basis of calculation, financial indicators proposed by the National Renewable Energy Laboratory (NREL) [25] and the Effect-Cost-Index [26], have been adapted.

1.2. Use of TRNSYS in the development of the EATEP

The EATEP was created using the dynamic simulation software of energy systems, TRNSYS. This software has been used because of the technical advantages it has in the expansion of the scale and focus of the application of the indicators proposed in the EPBD. TRNSYS is a complete and expandable simulation environment for the simulation of systems. Its operation is based on the interconnection of subroutines, called Types, fed by variables, known as Inputs and Parameters, which are processed to deliver Outputs as results. During the simulation, Inputs vary, Parameters remain constant, and Outputs become Inputs of other Types. Although there is a wide variety of models and software available for the technical-economic simulation of energy systems [27] with different purposes and approaches, including specific methodologies on renewable energies [28] and DG [29], TRNSYS allows: (1) to evaluate different types of renewable energy systems, as in the case of [9–11,30,31]; (2) to customize and add subroutines [32] to simulate new technologies, as in the case of [8,33], and to develop technical-economic models of energy systems, as in the case of [34]; and (3) to link its operation with that of other simulation software, as in the case of [12,13]. TRNSYS has in its library two Types to perform economic calculations, Type 19 and the Type 580. Neither of these two models has the characteristics proposed in the EATEP. The first one is only applicable to the analysis of the life-cycle cost of a solar powered system, comparing capital and back-up fuel costs to the fuel costs of a conventional non-solar powered system [35]. The second, is similar to Type 19, uses the P1 and P2 methods described by Brandemuehl and Beckman, and Duffie and Beckman, [36].

The operation of the EATEP is described below in Section 2, its validation in Section 3, and finally, Sections 4 and 5 provide discussions and conclusions.

2. Description of the operation of the EATEP

EATEP, working in parallel in hourly time steps with the simulation of the energy systems in TRNSYS, seeks to determine Annual and Global results, to later calculate a group of indicators, called Comparative Indicators, with which it is possible to identify the best alternative within a group of investment options, called Packages. The Annual results are the sum in each year *t* of the evaluation period T, of energy, environmental and economic values, and the Global results are the sum of each of these groups of annual results. The economic results are delivered in terms of the current value of the cash flows expected in each year. Each Package is a set of EEMs and/or energy technologies, called Components. The Packages are numbered from 1 to p, number 1 being the reference case against which the other evaluated packages are compared. The energy systems that are feasible to evaluate with the EATEP are grouped into the following three categories of energy projects:

1. Energy Efficiency Projects (EEP): projects at final energy consumption points in which the investment in EEMs and/or self-consumption technologies seek to reduce energy consumption and/or reduce the consumption of external energy resources and their associated costs. It includes projects carried out by Consumers or Prosumers, in buildings and communities, and projects of Smart Grids [37].
2. Energy Generation Projects (EGP): projects at energy generation facilities carried out by Producers in which the investment in energy generation technology systems and/or EEMs seek to reduce energy consumption and/or increase energy export to increase the margin between revenues and costs.
3. EEP-EGP projects: projects in which EEP and EGP energy systems are jointly evaluated in the same economic scenario. The EGPs are evaluated as systems supplying energy for the EEP systems. This includes NZECs of DG systems evaluated independently as EEPs and EGPs.

Fig. 1 presents the operating diagram of the EATEP. Boxes 1, 2 and 3 represent the calculation process in the evaluated Packages, and Box 4 the calculation of Comparative Indicators. Box 1 details the Parameters and Inputs (data that vary in hourly time steps) that feed the EATEP during the evaluation period, in order to obtain the annual and global