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STATE-OF-THE-ART OF DECISION SUPPORT SYSTEMS FOR THE CHOICE OF RENEWABLE ENERGY SOURCES FOR ENERGY SUPPLY IN ISOLATED REGIONS

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ABSTRACT

The promotion of renewable energy sources (RES) and ecologically clean technologies to reduce greenhouse gas emissions is a key policy of the European Commission. In isolated regions with great and unexploited RES potential, RES technologies can exploit local resources for electricity supply and substantial energy savings. The use of decision support systems (DSS) aims the multidimensional decision-making process regarding the choice of RES for energy supply in isolated regions. The network integration issues for the distributed energy resources (RES in our case) are challenging, since, in particular, the design of hybrid systems is strongly influenced by two components: one is the amount of energy that is expected from the renewable resources and the other is the ability of the power system to maintain a balance of power between generation and consumption. This paper reviews the DSS for the choice of RES in isolated regions and proposes some future developments.

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1 INTRODUCTION

1.1 General

The promotion of renewable energy sources (RES) and ecologically clean technologies to reduce greenhouse gas emissions is a key policy of the European Commission, as expressed in the “White paper on RES” and the Directive 2001/77 on the “Promotion of Electricity from RES in the internal electricity market”. In isolated regions with great and unexploited RES potential, RES technologies can exploit local resources for electricity supply, substantial energy savings and sustainable socio-economic development of the isolated regions [1].

The decision-making process regarding the choice of renewable energy sources for energy supply in isolated regions is multidimensional, made up of a number of aspects at different levels – economic, technical, environmental, and social. Therefore, reaching clear and unambiguous solutions may be very difficult. It is from this difficulty that the need arises to develop a tool for the design of renewable energy sources for electricity in isolated regions. Such a tool should enable the decision maker (e.g. policy maker, regulatory authority, investor, electric utility) to draw up a series of alternatives (based on a variety of, often conflicting, viewpoints) and to choose the best compromise, i.e. the one held to be the most acceptable. The work involved in seeking a compromise solution requires an adequate assessment technique based on multiple criteria methods.

The network integration issues for the distributed energy resources (RES in our case) are challenging, since, in particular, the design of hybrid systems is strongly influenced by two components: one is the amount of energy that is expected from the renewable resources and the other is the ability of the power system to maintain a balance of power between generation and consumption [2].

The use of decision-making tools under multiple criteria approach is intended to aid the decision maker in the creation of a set of relations between various alternatives. A decision support system (DSS) can be defined as an interactive system that is able to produce data and information and, in some cases, even promote understanding related to a given application domain in order to give useful assistance in resolving complex and ill-defined problems. Decision-making processes are analyzed from different viewpoints and the implementation of analytical methods and models and support tools must take into consideration not only the organizational structure into question, but also the procedures, processes and the dynamics of the decision makers involved. The main objective of a multiple criteria decision aid (MCDA) is to build or create a support tool for decision-makers that conforms to their objectives and priorities (a constructive or creative approach). The “ideal” solution, the option that performs best for all the criteria selected, is difficult to achieve. Therefore it is necessary instead to find a compromise from among the different hypothetical solutions. It is for that reason that a choice resulting from MCDA is “justified” and not “optimum”.

In comparison to interconnected systems, in energy systems in isolated regions, trade-off between reliability of supply level and cost of the system are much more pronounced [3]. The second important characteristic is that a demand curve shape has more impact on system dimensioning. Thus, at designing the system the future load characteristics and system operation modes need to be addressed in order to assess the future operation efficiency and its impact on project performance. The development of decision support methodologies for investment decisions in RES in isolated regions requires therefore the integration of advanced forecasting and simulation techniques, in order to investigate the operation of RES in hybrid systems. Such tools will use a multiple criteria analysis approach to adequately address the trade-offs between supply reliability (technological risks), economics, financial risks and environmental impacts with aim to improve the quality and transparency of decision-making.

1.2 Bibliographical Review

This Section briefly overviews research works that use decision support systems and/or multiple criteria methods for the choice of renewable energy sources for energy supply in isolated regions. The common characteristic of these works is that they are application specific that is why they are presented in a serial manner.

In [4], the NAIADE [5] multiple criteria method is applied in order to evaluate wind energy plants on an Italian island. More specifically, two types of criteria are considered: economic & technical criteria and environmental criteria.

In [6], the optimal sizing of stand-alone photovoltaic stations is studied and a procedure to evaluate different photovoltaic (PV) schemes considering the stochastic natures of the insolation and the load is presented.

The application of Analytic Hierarchy Process (AHP) and SIMUS multiple criteria methods to assist communities in pre-feasibility ranking of the alternative local renewable energy sources is discussed in [7].

The basic structural characteristics of a group DSS designed to assist decision makers in the promotion of RES are presented in [8]. The decision-making procedure basically consists in the multi-criteria analysis of alternative RES penetration scenarios by means of the PROMETHEE II multiple criteria method. Scenarios are evaluated by a group of actors directly or indirectly involved in energy decisions that arrive through a systematic negotiations procedure, at a wide consensus.

In [9], a decision support tool is proposed to evaluate alternative policies regulating wind integration into autonomous energy systems.

In [10], the ELECTRE III multiple criteria method is proposed for energy planning problems in regions presenting a significant potential of renewable energy sources.

The proposed method highlights the aspects that are crucial in reaching a compromise in regional energy planning problems.

1.3 Paper Structure

This paper presents the state of-the-art of DSS for the choice and design of isolated electrical system based on renewable energy sources (IESRES).

The paper is organized as follows. Section 2 describes the planning of the IESRES. Section 3 presents an overview of decision support systems. Section 4 reviews the software packages HOMER, Hybrid2, and RETScreen, which include modules for the choice and design of IESRES. Section 5 concludes the paper and proposes some future developments.

2 PLANNING OF ISOLATED ELECTRICAL SYSTEMS BASED ON RENEWABLE ENERGY SOURCES

The planning of an isolated electrical system based on renewable energy sources is composed of the following two main steps:

1. *Selection and pre-sizing*: selection of a RES technology that is best suited to a given installation and location.
2. *System design*: specification of a system (as a whole, and all system components/elements) for a pre-determined site.

2.1 Selection and pre-sizing

When several renewable energy sources are available at the prospective isolated region, the first step in planning an IESRES is selection of appropriate RES technology or technologies.

The assessment of appropriate RES technology should be done and justified by obtaining the precise data and information related to long-term availability of all possible RES (e.g., through meteorological, wind, solar radiation, and other RES measurements). This, however, can be a rather cumbersome and time-consuming task. For instance, the duration of the process of collecting relevant data and information for wind-based RES is one year [11]. At this stage, feasibility of using the hybrid systems, i.e., a combination of (several) RES and (several) fossil-based energy sources, for adequate backing of the primary RES (when primary RES is not available, e.g., during the night, or during the calm spells) should be determined together with the use of the adequate energy storage technology.

It is also very important that the operation of the IESRES is assessed with respect to an appropriate time frame. Usually, this is related to as precise as possible assessment of the present electrical energy demand and future development of the IESRES in order to meet change (i.e., increase) of energy demand.

2.2 System Design

After selecting the most appropriate RES technology (taking into account economic factors, like initial costs and investments, costs of maintenance, expected lifetime and other electrical and non-electrical factors), the next step is the assessment of the appropriate size, i.e., dimensioning of the IESRES. Selection of the appropriate topology is another fundamental task, most closely related to selected size of the IESRES, which should also include a margin for the expected future increase in the load consumption [12].

Sizing/dimensioning is the central part of the IESRES design procedure. The sole (or most important) factor of influence here is the ability of the IESRES to guarantee the continuity of the energy supply to all loads/users connected to the system. As a general rule, loads within the isolated electrical system should be, depending on their importance, prioritised and divided in several groups or categories. This categorisation should help the IESRES to meet the power demand of the loads, according to the available generated and stored electrical energy, while maintaining the highest possible levels of reliability, availability, stability and power quality.

Various IESRES design proposals should be compared, on the basis of technical specifications and projected energy generation and consumption profiles, ability to minimise risk of system outages, total costs of the installation, operation and maintenance, and, most importantly, expected or agreed system performance, regarding the delivering of electrical energy to all users according to their expectations and needs.

It can be generally concluded that sizing of the IESRES directly depends on the assessed probability of having relevant RES available for generation and conversion into the electrical energy, on the one hand, and all requested, specified or contracted aspects of energy delivery service, on the other. Additional important factors of influence are provisions for efficient maintenance and servicing, business/economical/financial considerations and lowering of adverse environmental impact.

3 DECISION SUPPORT SYSTEMS

3.1 Definition

One of the most important tasks faced by decision makers in business and government is that of selection. Selection problems are challenging, because they require the balancing of multiple, often conflicting objectives, criteria, or attributes.

Decision support systems constitute an application of the capabilities provided by computer science to support decision making in ill-structured and complex decision problems, where no straightforward solution methodology can be applied [13].

3.2 Characteristics

The basic characteristics of a DSS can be summarized in the following five issues [14-16]:

1. Their major objective is to support the decision making process in complex and ill-structured problems.
2. They integrate decision analysis techniques with data access and management.
3. Their design and development is focused on user-friendliness so that decision makers that are not familiar with the sophisticated decision analysis methods or with the computer technology can take full advantage of the capabilities that DSS provide.
4. They have the flexibility to adapt to the changing decision environment as well as to possible changes/adjustments in the decision-making policy and the preferences of the decision maker.
5. They operate in an interactive way to enable real-time decision-making.

3.3 Characteristics

The basic structural components of a decision support system are the following [15]:

1. *The database*: this part of the DSS comprises all the necessary information and data required to perform the analysis of the problem at hand. Data management, i.e. data entry, access, update, storage, retrieval, etc, is performed through the database management system.
2. *The model base*: similarly to the database, the model base of a DSS is a collection of decision analysis tools that are used to support decision-making. The model base and the database are directly related so that the models are fed with the necessary information and data. The model base management system is responsible for handling the model base including the storage and retrieval of models that are developed, their update and adjustment.
3. *The user interface*: this is one of the key components of a DSS, with respect to the successful implementation of the system in practice. The form of the user interface defines the level of flexibility of the system and its user-friendliness. The user interface is responsible for the communication of the user with the system. A special part of the user interface, the dialog generation and management system is specifically designed to manage this communication.

3.4 Methods

Various DSS methods have been developed:

1. Some DSS methods are intended to select the best choice from a given set of alternatives. Examples are MAUT, AHP, REMBRANDT and preference cones [17-26].
2. Other DSS methods are based on the idea of developing a partial order, useful for sorting out large lists of alternatives down to a short list among which the decision maker can select. Examples are outranking methods (ELECTRE, PROMETHEE and their variants) and ZAPROS [22, 27-29].

In practice, methods used for the above two problem types (best choice and outranking) are not that distinct, in that outranking methods have been modified to allow identification of a best choice and MAUT and AHP have been modified to deal with large sets of alternatives [22].

The DSS methods all seek to help decision-makers select multi-attribute choices that best match their preference function. But, these methods vary in the types of problems they deal with, to include various dimensions of problem size and the specificity of the analysis. The methods also vary in the inputs required from decision makers.

4 SOFTWARE PACKAGES FOR PLANNING OF IESRES

Various models have been developed for the planning of IESRES. Examples include HOMER, Hybrid2, INSEL, MATLAB, PROLOAD, RETScreen, RPM-Sim, SIMENERG, WDLTOOLS, WINSYS. In this Section, only HOMER, Hybrid2 and RETScreen are reviewed because they are very highly cited in the relevant technical literature, they have been developed by large organizations that are very experienced with RES technologies, the packages have many users worldwide and all these 3 packages currently can be downloaded free of charge from the internet.

4.1 HOMER

4.1.1 General

HOMER [30, 31] is a computer model that assists in the design of micropower systems and facilitates the comparison of power generation technologies across a wide range of applications. HOMER models a power system’s physical behaviour and its lifecycle cost, which is the total cost of installing and operating the system over its life span [32]. HOMER allows the designer to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

HOMER can model off-grid and grid connected micropower systems serving electric and thermal loads, and comprising any combination of PV modules, wind turbines, small hydro, biomass power, reciprocating engine generators, microturbines, fuel cells, batteries, and hydrogen storage.

4.1.2 Inputs

The HOMER inputs are split into the following categories:

1. *Loads:* primary, deferrable and thermal load.
2. *Components*: PV, wind turbine, hydro, generator, grid, battery, converter, electrolyzer.
3. *Resources*: solar, wind, hydro, biomass, fuel.
4. *Economics*: annual real interest rate, project lifetime, cost of unmet load, system fixed capital cost, system fixed operation and maintenance (O&M) cost, carbon tax.
5. *Generator control*: dispatch strategy (load following, cycle charging), which determines how the generator(s) charge the battery bank.
6. *Constraints*: operating reserve, maximum annual capacity shortage, minimum renewable fraction.
7. *Optimization*: it contains the values of each optimization variable that are used to build the set of all possible system configurations.

The input windows of HOMER have been designed so as to minimize the effort required to enter data that describes loads, resources and component performance and cost. HOMER provides default values for many inputs so that the analysis can be quickly started.

4.1.3 Outputs

HOMER implements three main tasks:

1. *Simulation*: estimates the cost and determines the feasibility of a system design over the 8760 hours in a year.
2. *Optimization*: simulates each system configuration and displays list of systems sorted by net present cost (NPC).
3. *Sensitivity analysis*: performs an optimization for each sensitivity variable.

4.1.3.1 Simulation

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric and thermal load in the hour to the energy that the system can supply in that hour. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries. If the system meets the load for the entire year, HOMER estimates the lifecycle cost of the system, accounting for the capital, replacement, operation and maintenance, fuel and interest costs. Hourly energy flows for each component as well as annual cost and performance summaries can be viewed.

The outputs of the simulation are split into the following categories:

1. *Cost*: total net present cost, and levelized cost of energy (COE) for the whole system. Also, cost breakdown (initial capital, annualized capital, annualized replacement, annual operation and maintenance, annual fuel, total annualized cost) for each component of the system.
2. *Electrical*: total annual output of each electrical energy producing component, total amount of energy that went to serve each of the system's electrical loads (plus any shortage or surplus).
3. *Thermal*: total annual output of each thermal energy producing component, the total amount of thermal energy that went towards serving the thermal load during the year.
4. *Generator*: hours of operation, number of starts, operational life, average electrical output, minimum electrical output, maximum electrical output, average thermal output, minimum thermal output, maximum thermal output, annual fuel usage, specific fuel usage.
5. *Battery*: total amount of energy that cycled through the battery bank during the year, battery bank life.

4.1.3.2 Optimization

After simulating all the possible system configurations, HOMER displays a list of feasible systems, sorted by lifecycle cost. The least cost system can be easily found since it is put at the top of the list and also the list can be scanned for other feasible systems.

4.1.3.3 Sensitivity analysis

Sometimes it is useful to see how the results vary with changes in inputs, either because they are uncertain or because they represent a range of applications. Sensitivity analysis can be performed on almost any input by assigning more than one value to each input of interest. HOMER repeats the optimization process for each value of the input so that the effect of changes can be examined in the value on the results. It can be specified as many sensitivity variables as are desired.

4.1.4 Background Mathematical Modeling

4.1.4.1 Physical modeling

The physical modeling within HOMER is flexible because systems can be modeled with one of the following two ways:

1. Using only basic inputs
   - Annual averages for resources and loads
   - Cost per kW or unit for equipment

2. Using more detailed information
   - Measured hourly data
   - Detailed cost curves
   - User-defined components (e.g. wind turbine, battery)

For example, to model a system comprising one or more wind turbines, the HOMER user must provide wind resource data indicating the wind speeds the turbines would experience in a typical year. The user can provide measured hourly wind speed data if available. Otherwise, HOMER can generate synthetic hourly data from 12 monthly average wind speeds and four additional statistical parameters: the Weibull shape factor, the autocorrelation factor, the diurnal pattern strength, and the hour of peak wind speed [32].

To model a system containing a PV array, the HOMER user must provide solar resource data in one of the following three forms: hourly average global solar radiation on the horizontal surface, monthly average global solar radiation on the horizontal surface, or monthly average clearness index. For example, if the user chooses to provide monthly solar resource data, HOMER generates synthetic hourly global solar radiation data using an algorithm developed by Graham and Hollands [33]. Each hour of the year, HOMER calculates the global solar radiation incident on the PV array using the HDKR model, explained in [34]. This model takes into account the current value of the solar resource (the global solar radiation incident on a horizontal surface), the orientation of the PV array, the location on Earth's surface, the time of year, and the time of day.

To calculate the battery's maximum allowable rate of charge or discharge, HOMER uses the kinetic battery model [35].

Rather than using complicated probabilistic logic to determine the optimal battery charging strategy, HOMER provides two simple strategies and lets the user model them both to see which is better in any particular situation. These dispatch strategies are called *load following* and *cycle charging*. Under the load following strategy, a generator produces only enough power to serve the load, and does not charge the battery bank. Under the cycle charging strategy, whenever a generator operates, it runs at its maximum rated capacity (or as close as possible without incurring excess electricity) and charges the battery bank with the excess. Barley and Winn [36] found that over a wide range of conditions, the better of these two simple strategies is virtually as cost-effective as the ideal predictive strategy.

4.1.4.2 Economic modeling

Renewable sources tend to have high initial capital costs and low operating costs, whereas conventional non-renewable sources tend to have low capital and high operating costs. In its optimization process, HOMER must often compare the economics of a wide range of system configurations comprising varying amounts of renewable and non-renewable energy sources. To be equitable, such comparisons must account for both capital and operating costs. Lifecycle cost analysis does so by including all capital and operating costs that occur within the life span of the system. HOMER uses the total net present cost (NPC) to represent the lifecycle cost of a system. In its optimization process, HOMER ranks the system configurations according to NPC.

4.1.5 Advantages and Weaknesses

The main advantages of HOMER are:

1. It includes an *optimization* module that automatically finds the combination of components that can serve the load at the lowest lifecycle cost.
2. Its *sensitivity analysis* module that automatically determines how the optimization results vary with changes in inputs.
3. Its very friendly, flexible and easy *user interface* that facilitates the user to model, analyze and optimize micropower systems.

The weaknesses of HOMER are:

1. Some renewable technologies are not supported, e.g. biogas and geothermal.
2. It is mainly an economical model dedicated to the system selection and pre-sizing, so the system design requires another package, e.g. Hybrid2.

4.2 Hybrid2

4.2.1 General

Hybrid2 [37, 38] is a combined probabilistic/time series computer model that assists a designer in sizing hybrid power systems and in selecting operating options on the basis of overall system performance and economics when site specific conditions and load profiles are known. Hybrid2 allows the user to easily consider a number of system configurations and operating strategies to optimize the system design.

The simulation models for hybrid power systems can be classified into two broad categories: logistical models and dynamic models. *Logistical models* are used primarily for long-term performance predictions, for component sizing, and for providing input to economic analyses. *Dynamic models* are used primarily for component design, assessment of system stability, and determination of power quality. Hybrid2 is a logistical model, since it allows the user to determine long-term system performance while taking into consideration the effect of the short-term variability of the renewable resources.

Hybrid2 is based on a combined time series and statistical approach. More specifically, Hybrid2 uses a time series approach to account for load and resource variations over intervals typically ranging from 10 minutes to one hour. Shorter term fluctuations within those intervals are dealt with by means of statistical techniques.

4.2.2 Inputs

The Hybrid2 inputs are split into the following categories:

1. *Loads:* primary, deferrable, optional and heating load.
2. *Site/resource:* site parameters as well as time series data of wind, insolation and ambient temperature.
3. *Power system:* It is based on a three-bus grid that includes an AC, DC, and shaft bus system. Specific types of components are then included in each subsystem that is attached to one of the buses. Components include wind turbine, PV module, diesel, dump load, battery, converter, synchronous condenser and dispatch strategy.
4. *Base case:* for comparison purposes, the user can supply the primary and deferrable loads using a diesel-only system. The technical and economic performance of a system with renewable can be compared to those of the diesel-only system.
5. *Economics:* costs of the various components as well as economic parameters that are used to evaluate the economic performance of the system.

4.2.3 Outputs

Hybrid2 provides three kinds of output:

1. *Performance summary files:* summary of the cumulative energy flows and fuel consumption during the simulation run.
2. *Economics summary file:* net present value of total costs, levelized cost of energy, simple payback period, discounted payback period, internal rate of return, yearly cash flows, etc.
3. *Detailed files:* they include values of a number of system variables for each time step. Examples of system variables include the power going to each type of load, the unmet load, the power produced by each generating unit, the power going into storage, the power conversion losses, the hybrid system diesel fuel consumption, the base case system diesel fuel consumption, and the time step energy balance.

4.2.4 Background Mathematical Modeling

4.2.4.1 Time series/probabilistic method

Hybrid2 considers short-term fluctuations in the wind power and the load (short-term fluctuations in the PV power are not considered in Hybrid2). Using the time series/probabilistic method, it is considered that the short-term fluctuations are randomly distributed about the mean value, and furthermore that the distribution of values can be described by a probability density function. In most cases, the normal (Gaussian) probability density function is used. In a few situations (such as when, for physical reasons, a distribution can only be positive) a Weibull distribution is applied.

Hybrid2 assumes that the wind speed, wind power, and load are all normally distributed over the time step [38]. This assumption is based on previous work that showed that the wind speed and wind power are approximately normally distributed around the mean value over time intervals of approximately 10 minutes [39]. In addition, other work indicates that the electrical load for an autonomous diesel grid is also approximately normally distributed over a short time interval [38].

4.2.4.2 Physical modeling

In Hybrid2, the user specifies a power curve and the wind speed time series data to calculate the wind power produced by the turbine. The calculations assume that the wind is normally distributed during the time interval. A variety of factors affect the results of the calculations. If the wind data is not measured at the turbine hub height, or was averaged over a different time period than that used to generate the power curve, or if the turbine is to be operated under non-standard atmospheric conditions, then Hybrid2 makes the necessary adjustments. The total mean power from multiple wind turbines is found by summing the individual mean wind power from each turbine. In the case of multiple wind turbines, the variability in power is reduced. This reduction depends to a large extend on spacing between the turbines. Hybrid2 accounts for the effect of spacing by following specific algorithms [40-41].

Hybrid2 calculates the power output from a PV panel based on an analytical model that defines the current-voltage relationships based on the electrical characteristics of the panel. The basis of the model used in Hybrid2 essentially follows that described in [34].

Hybrid2 assumes a linear relationship between diesel generator set load and fuel consumption. A linear relationship has been shown to be a good approximation for many diesel generator sets and is commonly used in wind/diesel system modeling [42].

The battery model used in Hybrid2 is an expanded form of the kinetic battery model [35,43].

In meeting the net load, Hybrid2 considers two types of components to be dispatchable: diesel generator sets and batteries. Additional information on dispatch can be found in [44].

4.2.4.3 Economic modeling

The economics model of Hybrid2 is based on the use of conventional lifecycle costing economics, i.e. Hybrid2 performs a first level economic evaluation of a hybrid power system. In addition, the analysis has been designed to allow for a side-by-side comparison of the economics of a hybrid power system with those of a diesel-only powered system.

4.2.5 Advantages and Weaknesses

The main advantages of Hybrid2 are:

1. It is mainly a *technical model* dedicated to system design, so Hybrid2 can simulate some important technical constraints, including bus voltage levels, intra-hour performance of components and complex diesel generator dispatch strategies.
2. It has *detailed dispatching options*: over 180 different configurations are allowed as well as a library of 12 different commonly used dispatch options. The dispatch options are based on decisions relating to how batteries and diesels will operate if included in the power system.

The weaknesses of Hybrid2 are:

1. Several renewable technologies are not supported, e.g. biomass, hydro, biogas and geothermal.
2. It does not include optimization and sensitivity analysis modules.

4.3 RETScreen

4.3.1 General

RETScreen [45] is a standardized and integrated renewable energy project analysis software. This tool provides a common platform for both decision-support and capacity-building purposes. RETScreen can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for various renewable energy technologies. RETScreen is dedicated to the preparation of pre-feasibility studies.

RETScreen includes the following eight technology modules that are working independently (not linked): wind energy, small hydro, photovoltaic, solar air heating, biomass heating, solar water heating, passive solar heating, and ground-source heat pump project analysis.

RETScreen has been developed in Microsoft Excel. Each of the eight technology modules includes the following five worksheets: energy model, equipment data, cost analysis, greenhouse gas emission analysis, and financial summary.

4.3.2 Inputs

RETScreen has three families of input parameters: site conditions, system characteristics, and financial parameters. For example, the main input parameters for the PV project analysis module are the following:

1. *Site conditions:* project location, latitude of project location, annual solar radiation (tilted surface), and annual average temperature.
2. *System characteristics*: application type, nominal PV array power, PV module type, nominal PV module efficiency, slope of PV array, inverter

capacity and average inverter efficiency (if inverter exists), battery data (if battery exits), load data (for off-grid applications).

3. *Financial parameters*: initial project costs (feasibility study, development, engineering, PV equipment, transportation, system installation), annual costs (property taxes/insurance, operation and maintenance), annual savings or income (energy savings/income, capacity savings/income, greenhouse gas reduction income) and parameters for the economic evaluation of the project (energy cost escalation rate, inflation, discount rate, project life, debt interest rate, debt term).

4.3.3 Outputs

The main outputs of RETScreen are the following:

1. *Annual energy balance:* renewable energy delivered, net greenhouse gas emission reduction.
2. *Project costs and savings:* total initial costs, incentives/grants, periodic costs and credits, total annual costs, total annual savings.
3. *Yearly cash flows:* pre-tax, after-tax, and cumulative yearly cash flows.
4. *Financial feasibility:* internal rate of return, net present value, year-to-positive cash flow, simple payback, and profitability index.

4.3.4 Background Mathematical Modeling

4.3.4.1 Physical modelling

The wind energy model uses a user-specified power curve and a Weibull wind speed probability distribution function to calculate the energy curve of a turbine. Energy production is then adjusted for pressure and temperature effects, as well as for various user-specified losses. RETScreen only requires 1 point of wind speed data versus 8760 points of data for most hourly simulation models (e.g. HOMER).

The PV model of RETScreen only requires 12 points of solar resource data (monthly average daily radiation on horizontal surface) versus 8760 points of data for most hourly simulation models (e.g. HOMER). The solar radiation model is that of Klein and Theilacker described in [34], which model is extended to include the case of moving surfaces. The PV array model is based on work by Evans and takes into account temperature and orientation effects [46].

The RETScreen small hydro project model uses generic formulae for the calculation of turbine efficiency for a variety of turbines. These efficiencies, together with the flow-duration curve, enable the calculation of energy delivered by a proposed small hydro power plant. Condensed formulae enable the estimation of project cots; alternatively, a detailed costing method can be used.

The RETScreen solar air heating project model calculates energy savings resulting from the installation of a perforated plate solar collector. Energy savings are the sum of solar energy actively collected, building heat recapture savings, and destratification savings.

The RETScreen solar water heating project model uses Liu and Jordan's isotropic diffuse algorithm (described in [34]) to compute monthly average radiation in the plane of the collector. Energy delivered by hot water systems with storage is estimated with the f-Chart method [34]. For systems without storage, the utilisability method [34] is used.

The RETScreen passive solar heating project model calculates changes in heating demand and solar gains that result from the adoption of energy efficient window technologies. Changes in heating demand between the base case and the new proposed design are calculated by evaluating the variation in heat loss coefficient related to the proposed changes in the size and U-value of the windows. Changes in solar gain are evaluated by calculating solar gains in both the base and the proposed design, and estimating what part of the solar gain is usable for heating purposes. The same methodology is applied to calculate the associated penalty in cooling demand during the summer months.

4.3.4.2 Economic modeling

RETScreen uses the following five financial criteria for the economic evaluation of the projects: internal rate of return, net present value, year-to-positive cash flow, simple payback, and profitability index.

4.3.5 Advantages and Weaknesses

The main advantages of RETScreen are:

1. It uses international *product data* from 1000 suppliers. It also uses international *weather data* from 1000 ground monitoring stations.
2. It evaluates the *greenhouse gas emissions reduction* for various renewable energy technologies.

The weaknesses of RETScreen are:

1. It cannot evaluate systems with more than one renewable technology (e.g. PV and wind energy).
2. Several renewable technologies are not supported, e.g. biogas, fuel cells and geothermal.
3. It does not include optimization and sensitivity analysis modules.

4.4 Synthesis

Table 4.1 provides a comparative assessment of the modeling characteristics of HOMER, Hybrid2 and RETScreen.

Table 4.1: Modeling characteristics of HOMER, Hybrid2 and RETScreen.

Characteristic	**HOMER**	**Hybrid2**	**RETScreen**
Hybrid Systems	√	√	
Optimization	√		
Sensitivity analysis	√		
Mainly Technical or Economical	Economical	Technical	Economical
Photovoltaics	√	√	√
Wind energy	√	√	√
Biomass	√		√
Biogas			
Geothermal			
Hydro	√		√
Diesel	√	√	
Cogeneration	√		
Microturbines	√		
Batteries	√	√	√
Fuel cells	√		
Electrolyzers	√		
Solar air heating			√
Solar water heating			√
Passive solar heating			√
Ground-source heat pump			√

4.5 Summary of Results

The review of the three software packages, namely HOMER, Hybrid2, and RETScreen leads to the following conclusions:

1. HOMER and RETScreen are mainly economical (dedicated to the choice of RES), while Hybrid2 is mainly technical package (dedicated to the design of RES). This means that, for example, in a first stage HOMER can be used for the choice of RES and in a second stage Hybrid2 can be used for the design of RES.
2. HOMER and Hybrid2 are for hybrid systems, while RETScreen considers only single RES.
3. Only HOMER includes optimization and sensitivity analysis capabilities.
4. The above three software packages support different RES technologies, while some RES technologies (e.g. biogas and geothermal) are not supported.
5. The above three software packages do not support multiple criteria analysis.

5 CONCLUSIONS AND FUTURE DEVELOPMENTS

DSS are computer technology solutions that can be used to support complex decision-making and problem solving such as the choice and design of RES for energy supply in isolated regions.

This paper reviewed the DSS for the choice of RES in isolated regions. The software packages HOMER, Hybrid2, and RETScreen that help in planning of IESRES were reviewed. These three packages are by far the more representative and they were selected for review because they are very highly cited in the relevant technical literature, they have been developed by large organizations that are very experienced with RES technologies, the packages have many users worldwide and all these 3 packages currently can be downloaded free of charge from the internet. This paper also presented a bibliographical review of the DSS for the choice and design of RES for energy supply in isolated regions.

The conclusion from the review of the bibliography and the software packages (HOMER, Hybrid2, and RETScreen) is that the DSS for the choice and design of RES for energy supply in isolated regions can be further improved. It is proposed that an improved DSS for planning of IESRES should have the following characteristics:

1. DSS software packages support multiple criteria analysis. Key criteria in the analysis are:
   - *Economics*: specific energy price (annual production costs per unit of energy delivered to end consumer) and value at risk (measures the worst expected loss in a portfolio over a given time horizon at a given confidence interval)
   - *Reliability of supply*: average system availability index, modified energy not served, power supply quality (voltage variations and voltage fluctuations, frequency variations, harmonic emission and total harmonic distortion, voltage unbalance, voltage sags and short interruptions)
   - *Environment*: CO_2, SO_2, NO_x emissions
   - *Sociological risk*. Indeed, remote power system will work better if the local community is strongly involved in the whole electrification process.
2. The DSS model addresses uncertainties using Monte-Carlo simulation, scenario analysis or some other suitable method.

3. The uncertainties under investigation comprise the main uncertainties and risks related to market, operation and project. The main uncertainties to be included in the analysis are:
   - *Demand*: load fluctuations (operational risk)
   - *Generation*: resource availability
   - *Investment costs*

A preliminary list of other important uncertainties to be implicitly treated in the analysis of an improved DSS includes:

- *Energy price*: CO_2 certification, rival technology, grid connection
- *Project risks*: preparation and construction time, business risks
- *Regulatory uncertainty*: laws, standards, taxes, politics
- *Cost of operation and maintenance*
- *Reliability of supply*
- *Generation*: operation regimes, unplanned outages (generation only, local net assumed 100% reliable)

An improved DSS with the above characteristics is currently under development within the frame of RISE project [3].

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