# Computer Tools for Modelling and Evaluating the Potential of Energy Storage Systems with Reference to the Greek Islands Case

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**Abstract** In the effort to meet climate change targets the share of renewable energy in electricity market has to be increased. The augmented penetration of renewable sources in the electricity grids could be destabilizing and may create barriers to their future expansion. Energy storage technologies are being regarded as a potential solution to deal with the intermittent nature of renewable energy sources. Introduction of energy storage systems in a future Smart Grid is definitely a complex problem and requires the technological analysis of the energy system itself. The purpose of this paper is to present an up-to-date critical examination of the state of the art of different computer tools that can be used to analyse the integration of energy storage systems utilized in conjunction with distributed generation. Particular emphasis is given to the case of isolated Greek islands.

**Keywords** Energy storage systems · Energy tools · Energy systems modelling · Microgrids · Isolated islands

## 1 Introduction

The transition from conventional grid network with central stations in future networks with high penetration of decentralized production, dispersed/distributed generation (DG), mainly from renewable energy sources, involves the development and application of new technologies and the appropriate institutional

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framework [1]. Moving towards large penetration of renewable sources into the electricity grid could be destabilizing, mainly due to the intermittent nature of renewable energies (namely solar and wind); thus showing their unsuitability to be dispatchable. In order to overcome this deficiency of renewable energy sources one has to introduce energy storage devices [1–3]. Energy storage is expected to play a very important role in ensuring safety, reliability and overall efficiency of a low or zero $CO_2$ emission electricity grid [1]. Electrical energy storage offers the potential to store electrical energy once generated from low and zero carbon sources and to subsequently match supply and demand as required. The augmented penetration of renewable energy sources as well as the trend towards a network transformation into Smart Grid, supports the storage concept more than ever before. Another attractive feature towards energy storage utilisation is the appearance of newer and cost-effective technology options which makes it likely that energy storage will finally become a reality in the near future [4, 5]. Nowadays, the microgrid concept is under development and is being examined as a completely new approach in order to integrate Distributed Energy Resources (DER) to the grids and specially isolated areas such as small islands. The proper design, simulation and optimization a microgrid in order to integrate the distributed energy resources for the management of energy distribution within it, will not only assist managers responsible for capital investment decisions to value different technologies combination but also system operators to develop better integration control strategies for a more efficient operation of future hybrid power systems. A systematic investigation and evaluation of current energy storage technologies in conjunction with both centralized and distributed renewable sources electrical power generation [6], as well as analysis and computational simulation of various case studies [7] is, therefore, imperative.

In this paper an evaluation of energy tools used for analysing power systems is provided so as to assist the process of selecting the appropriate energy storage technology. The paper begins by describing the promising energy storage technologies for large and small scale applications and the current status of modelling these principal energy storage devices. Subsequently, the paper outlines the need for energy storage in microgrids and especially in isolated areas such as islands. A comparison and a brief discussion of some of the energy tools and studies available is carried out. Finally the main characteristics, that a power system design tool incorporating energy storage modules are presented and critically discussed.

## 2 Energy Storage Technologies-Modeling and Evaluation

Energy storage technologies, utilized in conjunction with distributed generation and the Grid can be divided into two categories. The first category includes those technologies related to direct storage of electricity (e.g. supercapacitors, superconducting magnetic energy storage-SMES, etc.). The second one is associated with the indirect storage of electrical energy, namely storing electricity to another form of energy (e.g. electrochemical, thermal, mechanical, potential or kinetic energy storage), which can be converted back to electrical, whenever there is a need to meet, an expected or unexpected high overall energy demand [3, 4]. The following sub-sections describe the promising energy storage technologies for application in large scale and in distributed generation with renewable energy sources, as well as the current status of modelling the principal energy storage devices.

## 2.1 Battery Energy Storage System

A Battery Energy Storage System (BESS) has energy stored in chemical form and produces electricity through an electrochemical reaction. Batteries can be found in many sizes, power ratings, various types [e.g. lead-acid (L/A), sodium-sulfur (NaS), Vanadium Redox (VRB), Zinc-Bromine (ZnBr), ion Lithium (Li-ion), Nickel Cadmium (NiCd) and Nickel Metal Hybrid (NiMH) etc.] and their technologies are in various stages of research and development. They have numerous advantages, such as high discharge depth, high capacity and reduced maintenance requirements. However, many battery types have only limited market penetration, are expensive, or have short lifetimes [2, 4, 5]. Several papers have been published on stand-alone renewable energy systems and the problem of a better integration of the energy produced by them. In work [8] three stand alone photovoltaic power systems using different energy storage technologies as hybrid systems were optimized and compared. An example of an isolated renewable energy-diesel system in conjunction with energy storage technologies is presented in Sebastian and Alzola [9]. Where a Wind Diesel Hybrid System (WDHS) has been modelled and simulated using a Matlab-Simulink Model, in order to investigate the improvement in the system dynamics by using the BESS. Another use of battery energy storage systems seems to be small scale applications such as the integration of renewable energy sources into commercial and residential buildings. Four battery energy storage technologies have been discussed and evaluated techno-economically, by using two different software tools Matlab-Simulink and HOMER in the work of Nair and Garimella [10]. In order to design hybrid energy systems, a complex problem with high number of parameters, researchers have already used available commercial simulation/software tools or have developed new tools, such as HOGA, presented in Dufo-Lopez and Bernal-Agustin [11]. The design tool HOGA has been developed in C++, uses Genetic Algorithms, can be used for different control strategies and can simulate energy storage technologies such as batteries.

## 2.2 Thermal Energy Storage

This technology is based on storing energy by changing the temperature of certain materials from a relatively low temperature to a higher one. The heat of the material is used to produce steam which in turn drives a steam turbine coupled to an electrical generator producing electricity. Thermal energy storage systems are efficient, robust, and relatively inexpensive. In work [12] thermal storage was evaluated for applications including concentrating solar power using the GCAM model. Gil et al. [13] discuss the materials used in concentrated solar thermal power generation along with modeling of thermal energy storage systems, pointing out that in order to properly design, simulate and analyze these systems the corresponding software tools should include detailed information on the materials used at high temperature operation.

## *2.3 Pumped Hydro Energy Storage*

Pumped storage hydropower is currently the most widely implemented storage technology especially for large scale applications. It is also the most mature technology, as it is being utilized since the early twentieth century. This energy storage technology is reliable, has a long lifetime and the operating cost is low. However, there are some limitations, such as suitable geographic siting and facility size/capacity. Furthermore, there are environmental concerns related to the construction of artificial water reservoirs and their impact on ecosystems [2, 3, 14]. In work [15] the current trends for new PHES plants in EU are pointed out. Bueno and Carta [16] present the case of an isolated power system, proposing an appropriate wind powered pumped hydro storage system to be installed on Gran Canaria island (Canarian Archipelago) in order to deal with the problem of the penetration of renewable sourced energy in their conventional electrical grid system. An algorithm for the selection of the optimum economic renewable system has been developed and evaluated. Another example on pumped storage systems introduction in isolated power production systems is presented in Katsaprakakis et al. [17] where two case studies for Crete and Rhodes island have been evaluated using a single criterion optimization algorithm.

## *2.4 Compressed Air Energy Storage*

As an alternative to pumped hydro storage is considered to be CAES, which also seems to be a good solution for large scale applications. This system stores energy in the form of compressed air in high pressure tanks or underground geological cavities such as aquifers or mines. Advantages of this energy storage system are: low storing losses, fast start-up time response and applications versatility to both large and small scale distributed generation. The main disadvantage is the existence of the appropriate geological structures, such as mines [2, 3, 14]. CAES could also be used for small and medium scale applications [14]. In paper [18] a deterministic model has been used to perform an evaluation of a compressed air energy storage

(CAES) plant in the Danish electricity system, in order to investigate the integration of wind power. EnergyPLAN computer model has been used as an analysis tool of the specific national energy system since it provides the ability to perform both system-economic and business-economic evaluations. An example of small scale application is that of wind–compressed air energy storage (Wind–CAES) systems in islanded electricity networks. A dual-mode CAES configuration in conjunction with wind farms is evaluated by Zafirakis and Kaldellis [19] using a developed simulation algorithm for the dual-mode CAES system.

## *2.5 Flywheel Energy Storage*

Flywheels store energy in the form of mechanical-kinetic energy. The energy is saved via the turning of a mass spinning at high speed. It can be converted back to electrical energy by connecting the spinning mass to the rotor of a generator. Flywheels have long lifetime, high energy density and are relatively environmental friendly [2]. A flywheel farm approach, where several devices are networked together, could also be used for large-scale energy management. However, flywheels are a relatively "new" electrical energy storing technology, they require maintenance because of the moving mechanical parts involved, and have a high cost. Further development of the flywheel construction materials and improvement of the semiconductors seem to provide new possibilities for flywheels energy storage implementations, in renewable applications as well as transport systems [5, 20, 21]. In renewable energy systems, flywheels can serve as energy storage devices in islanded power systems where wind plants and diesel hybrid systems provide electricity, or in other isolated renewable energy distributed systems. A variety of different flywheels configurations have been studied simulated and compared to find the optimal for a given application in the work by Carrillo et al. [22].

## *2.6 Superconducting Magnetic Energy Storage*

SMES systems store energy in a magnetic coil of superconducting material which is cooled in very low temperature via a very cold liquid such as liquid helium [3]. The absence of moving parts in a SMES system, the limited maintenance requirement and the long lifetime are some of this storage technology advantages. Flywheels respond at microseconds with excellent voltage regulation and are environmental friendly [2, 3]. The cooling requirements and the high manufacturing cost are considered the main disadvantages of SMES [2, 3, 14]. One of the most important parts, when designing and selecting a SMES, is the size of the superconducting magnetic coil. In work [23] Genetic Algorithms have be used to identify the optimal SMES controller configuration considering both coil size and system uncertainties.

## 2.7 Super Capacitor Energy Storage

Super capacitor is actually a double layer capacitor, energy is stored in the electric field between two electrodes by applying a DC voltage. The principle of supercapacitors operation is the same as capacitors, though improved materials with higher dielectric constants offer higher storage capacity. Supercapacitors can be charged and discharged really fast, have long cycle life and are environmental friendly. Depending on the application supercapacitor may require a DC/AC converter and control equipment which affects adversely their efficiency and cost [2, 3, 24]. The improvements of the materials used in the construction of supercapacitors will lead to further integration of these energy storage devices to a variety of hybrid power generation systems [5]. A variety of mathematical models and equivalent circuits of supercapacitors have been proposed, the simplest equivalent circuit to model a supercapacitor is the classic RC model, a capacitor C with an equivalent series resistance (ESR) to represent the Joule losses. Other equivalent circuits are the RC parallel branch model, the RC branches series-parallel model, RC transmission line model. For these more detailed supercapacitor RC models is harder to experimentally obtain the characteristic parameters, so the simplest model is usually preferred as it is explained in work [25], where supercapacitor is modelled using Matlab/Simulink. A new supercapacitor model is introduced in Tironi and Musolino [26] able to obtain the parameters by a simple constant current charge test, providing a better representation of the dynamics of the storage device.

## 2.8 Hydrogen Energy Storage-Fuel Cells

Hydrogen produced via large or small scale electrolysis of water, is not a renewable energy source and maybe regarded more as an (electrical) energy storage agent. Fuel cells can be used to generate electricity for the grid or in transport applications. Hydrogen fuel cells are environmental friendly provided that the electricity required for electrolysis is produced via renewable energy sources [2]. Fuel cells technology is rather new and quite expensive and compared to batteries, fuel cells can produce electricity in a continuous way [27]. Decentralised power systems based on photovoltaic or wind generators can use electrolytic production of hydrogen ($H_2$) as a mean to store the excess energy produced by them [14]. Using $H_2$ as storage system can be used not only for load management but also for wind power fluctuations smoothing. Different control strategies for electrolytic production of $H_2$ may also maximize the utilization of wind power in weak systems. Simulation models and implementation of different control strategies for systems as described above have been developed as MATLAB-function and the power flow toolbox MATPOWER has been employed in the work by Korpaas et al. [28]. Avril et al. [29], have developed a multi-objective code using swarm optimization, which was used to compare batteries and Hydrogen storage in a distributed generation system (PV), for an isolated real case, in order to evaluate the storage technologies for a given period of time.

## 3 Microgrids and Distributed Energy Storage

Nowadays rapid changes in the power industry, augmenting distributed generation and the trend towards a network transformation into Smart Grids show the need to develop new power systems [7]. Research to identify the electric grid of the future is currently underway and the main goal is the wide utilisation of renewable energy sources. As the number of distributed solar photovoltaic (PV) installations and wind farms are growing rapidly [24] it seems that integration of significant quantities of distributed renewable energy, combined with storage, will lead to a new power network design allowing higher penetration of renewable sources [30], such as microgrid. A microgrid can be perceived as a group of dispersed generators, dispersed storages (DS) and a mixture of load consumers [31] (for extended review on definitions of the microgrid concept see [32]). A microgrid may be operated in grid mode, meaning interconnected to the main grid, or in islanded mode [33]. In general, islanding happens when dispersed generating units provide part of the energy needed disconnected from the main grid distribution system. One of the most important challenges faced when operating such DG system is not only the coordinated operation of the numerous generators and their power flow but also controlling the frequency and voltage of such a system. Designing an optimal microgrid is a complex task mainly because of the intermittent nature of distributed renewable sources (solar, wind) where traditional design and optimisation tools cannot be used [34]. Energy storage used in conjunction with renewable energy has been suggested as a means to increase the use of renewable energy while maintaining system stability [6]. The increase of small generation units, mainly including renewable energy sources, connected to Low Voltage (LV) networks has lead to the need of further development of microsource modelling and control strategies definition. The analysis of these microgrids demands appropriate dynamic models for simulation purposes. In work [35] a management and control strategy for optimally operating a microgrid in standalone mode is proposed. According to the authors a central controller is receiving data from a communication facility and with the help of an optimal function a suitable generation value for each one of the DG units is determined. Microgrid is considered to be a new concept but it is believed that research has reached the point where demonstration of practical operating systems is achievable. A stand alone mode system exists in Kythnos island, in Greece whose power system is not connected to the main Greek power grid exhibiting the main characteristics of a microgrid [32, 36].

According to Hanley et al. [37] new energy storage modelling tools, tools for further analysis of the power systems and business decision models will be needed for the optimal integration of energy storage systems. These modelling and simulation tools will help designers to evaluate the needs and effects of various storage technologies. When selecting the most appropriate storage technology, the most relevant criteria characteristics are capital cost, energy capacity, power capacity, lifetime (or cycling capacity), efficiency, self discharge rates, environmental impact, storage duration and technical maturity [4, 14, 24]. In work [14] the storage technologies have been divided in four categories based on their applications, (a) low power applications, (b) medium power applications, (c) network connection application with peak levelling and (d) power quality applications. A series of reports from Sandia National Laboratories [38] is providing useful information on the energy storage technologies evaluation, from the techno-economic point of view. In these reports another categorisation of has been proposed: (a) Grid System, (b) End-user/Utility Customer, (c) Renewables. Research shows that the choice of an energy storage technology depends on the application in either the conventional grid or in the DG grid and therefore a detailed techno-economic evaluation of different systems is difficult to be achieved [2, 3]. Energy storage technologies can provide a variety of services to the benefit of the electricity network [7]. Details on the subject can be found in Sandia National Laboratories report [39].

## 4 Energy Storage for Greek Island Electrification

Isolated systems, mainly islands, have felt the pressure for higher penetration of renewable sources. The pressure is becoming even stronger and the reasons are mainly the excessive fuel costs caused by the additional costs of shipment but also to the relatively small system size. These isolated systems have often considerable renewable sources available, but the extensive utilization of these renewable resources, such as solar and wind, is often limited due to security reasons. The network must be operated within tight margins of voltage as well as frequency, though wind and solar plants and other renewable sources are not capable to support and maintain the system at the desired operating condition and may sometimes lead to a negative overall effect mainly due to the intermittent nature of these resources [30, 34, 37]. Most non interconnected Greek islands are depended on their autonomous (including both conventional and renewable) generation systems to cover the demand. It is expected that introduction of energy storage technologies in these systems will be considered an economic and reliable solution helping in the further augmentation of the penetration of renewable sources [40].

Wind and PV systems with storage consideration has been investigated for feasibility purposes for a number of scattered islands in the Aegean archipelagos [41]. Pumped hydro energy storage combined with wind sources looks promising for the island of Lesbos [42] and other islands with medium or large grid systems which are geologically suitable. In islands (either inhabited or deserted) renewable resources can also be used for hydrogen production which is another form of energy storage. Hydrogen can be used as fuel for cars or ferries as described in paper [28] for a case study of a Norwegian island. Gondal and Sahir [43] discuss modelling tools of hydrogen in conjunction with renewables in order to assist the decision makers to invest in this technology. Prodromidis and Coutelieris [44] investigate the utilisation of batteries and flywheels for autonomous renewable energy based systems for the case of the Greek island of Naxos concluding that these hybrid power systems seems to be economically competitive, while flywheels commercialization is expected in near future. Energy storage could also be used in hybrid renewable based power systems, which are not only responsible for electrification but also for desalination and production of potable water. An example of anhydrous areas or islands is the one presented by Karellas et al. [45] for the Greek island of Chalki.

## 5 Analysis Tools for Energy storage Impact in Micro-grid Applications

Developing an appropriate flexible tool for the design and capacity planning of renewable energy generation units combined with storage devices will help to localize the energy storage benefits to an intermittent renewable system. Therefore, various strategies for increasing renewable energy source penetration into the grid using storage technologies have to be studied. One of the main reasons for the limited implementation in practice of the energy storage technologies, is the lack of appropriate tools to investigate the operational cost and evaluation of the benefits using market models when planning the power system including the storage devices. Furthermore, the lack of a formal mechanism for calculating the value of the benefits and savings brought by energy storage is a major constraint for wider storage implementation [46–48].

Kuldeep and Bharti [3] defined the major factors to be considered when designing and implementing energy storage technologies both for grid connected and off-grid application. These characteristics should be included in an appropriate design and planning tool to obtain an optimized model of energy storage for use in a microgrid environment or in a smart grid. Very useful information concerning energy storage software tools is also included in a special purpose report prepared for the U.S. Department of Energy [49]. It is interesting to note that neither pumped hydro power nor compressed air energy storage systems due to siting limitations have been addressed in this report. It is evident that new tools or new modules within existing tools should be developed in order to help energy systems designers to appreciate quantitatively the value of storage introduction in the modern power grid.

Combining the results from work [3] and [49] the factors that should be considered while developing an energy storage optimisation and evaluation tool can be summarised as follows:

- Power plant generation capacity optimization.
- Identification of the application the storage technology is being used and its suitability.
- Modeling of the energy storage technology, optimal sizing of the storage system and optimization for specific use, such as ancillary services, renewable integration etc.
- Development of an energy storage dispatch algorithm.
- The interconnection requirements and constraints of energy storage in conjunction with distributed generation.
- Control strategies to ensure power system reliability, power quality and efficient planning functionality.
- Analysis of the investment effectiveness of the energy storage technology under evaluation, from techno-economical perspective such as the return of the investment on the end user costumer or the utility.

In order to examine the introduction of energy storage modules in energy tools, a thorough investigation was conducted considering studies, models and planning software tools. The investigation was based on the work of Hoffman et al. [49], and Connolly et al. [50] and on internet sources [51–58]. For the sake of comparison purposes the results of the investigation are summarized and presented in tabular form in Table 1 below.

The energy tool characteristics evaluated are:

- Energy storage modeling availability.
- The energy tool is able to perform arbitrage involving the purchase of inexpensive electricity available during periods when demand for electricity is low, to charge the storage plant, so that the low priced energy can be used or sold at a later time when the price for electricity is high.
- As operation optimization tool it provides the option to optimize the system solution around particular uses.
- The tool is able to provide information on the impact of round trip efficiency of the energy technology used.
- An investment return optimisation tool is capable to financially optimize and provide information on the return of the investment.
- The energy tool as simulation tool simulates the energy power system under study for a one year period time using a time step, usually hourly.
- The energy tool as scenario tool can operate the results for multitime-period, combining the results into scenarios for a longer period of time usually 20–50 years.

For the sake of completeness simplified flow charts/diagrams from the user manuals for two of the most important energy tools evaluated in this study, RETScreen and EnergyPLAN, are presented below in Figs. 1 and 2, respectively [52, 58] and are briefly discussed.

RETScreen is a clean energy project analysis software which is used for the evaluation of energy production, life cycle costs, and greenhouse gas emissions,

**Table 1** Characteristics of energy storage in the tools investigated

| Tool | Energy storage technologies (modules) | Arbitrage | Operation optimisation | Round trip efficiency | Investment return optimisation | Simulation | Scenario |
|---|---|---|---|---|---|---|---|
| DIgSILENT | (batteries, fuel cells, flywheel (in PowerStore), Matlab Integration) | No | N/A | Yes | No | Yes | N/A |
| EnergyPLAN | (pumped hydro, hydrogen, CAES, thermal storage) | No | Yes | Yes | Yes | Yes | No |
| HOMER | (batteries, hydrogen, flywheels) | N/A | Yes | N/A | Yes | Yes | No |
| NEMS | (storage technologies to model load shifting) | N/A | N/A | N/A | Yes | N/A | Yes |
| PowerWorld | (possible) | No | N/A | No | No | Yes | N/A |
| PSAT | (batteries, fuel cell) | No | Yes | Yes | Yes | Yes | No |
| ReEDS | (pumped hydropower, compressed air, batteries, thermal storage) | Yes | Yes | Yes | Yes | N/A | Yes |
| RETScreen | (batteries) | No | No | Yes | N/A | No | Yes |

N/A: Not explicitly information is available

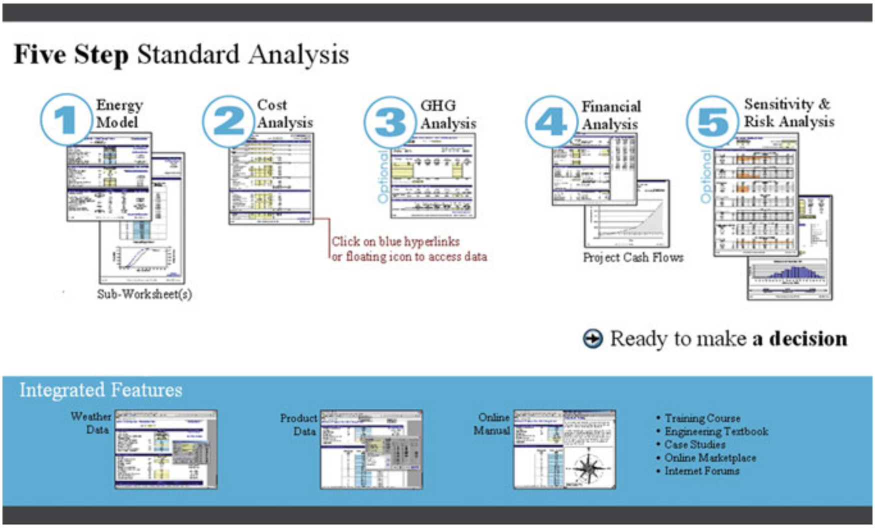


**Fig. 1** RETScreen model flow chart

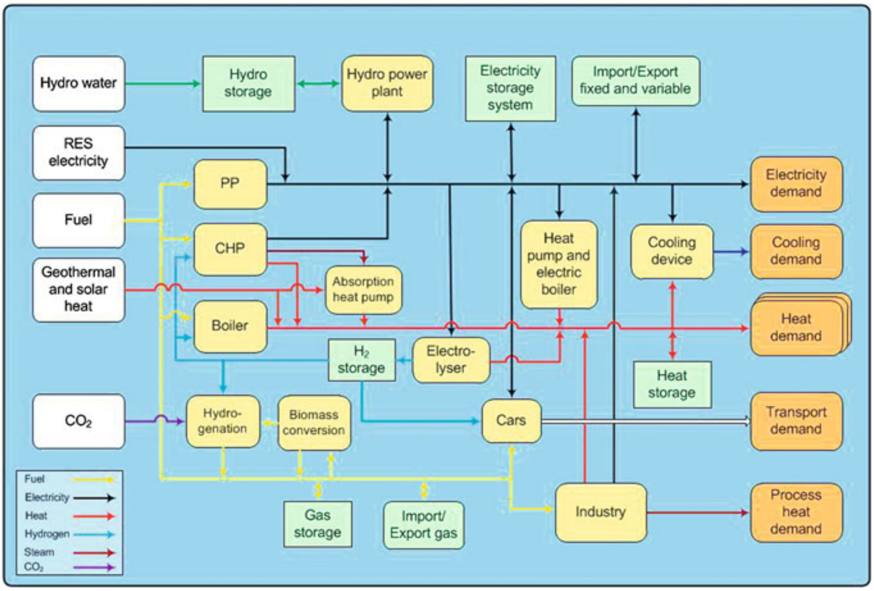


**Fig. 2** EnergyPLAN diagram

which has been developed as a Microsoft Excel spreadsheet file. It also has embedded data, such as product, weather and cost databases. In order to perform the analysis the software processes the input data from five worksheets. In the Start worksheet general information about the project is provided by the user such as title, location, weather condition etc. In the first step the Energy Model worksheet is used to define the basic technological parameters of the proposed case study such as the technology selected, the size etc., which then will be used, in combination with the internal databases, to perform the requested simulation to extract results. In step two, Cost Analysis is used to help the user estimate costs or/and credits of the case studied. Input data for initial cost, investment, cost standpoint etc. are inserted in this worksheet. In step three GHG analysis, Emission Analysis is provided to help in the evaluation of the emission reduction potential of the proposed project compared with the base case scenario. In step four Financial Summary, or Financial Analysis worksheet includes financial parameters input items of the project (e.g. discount rate, debt ratio, etc.), and its calculated financial viability output items (e.g. IRR, simple payback, NPV, etc.), which allows the decision-maker to evaluate the economic viability of the project. In step five the software includes the Sensitivity and Risk Analysis, this feature of the software shows the relationship between the key parameters and the financial indicators, as well as the risk of the investment.

EnergyPLAN is a user friendly energy analysis software tool, designed in a series of tab sheets. The main goal of the model is to assist the design of national or regional energy planning strategies implementing different energy systems and investments. EnergyPLAN considers, actually three primary sectors of any national energy system, namely electricity, heat, and transport sectors. The model is hourly simulation deterministic input/output model. In the front page a holistic view of the energy system as shown in Fig. 2 is provided. In the Input tab, information of the energy system is inserted in the model such as, energy demands (heat, electricity, transport, etc.), energy production units and resources (wind turbines, power plants, oil boilers, storage, etc.). In the Cost tab fuel costs, taxes, variable and fixed operational (maintenance) costs, investment costs and lifetime are introduced in the model according to the technology selected by the user. In the Regulation tab, the regulation and operation of each plant and the system including technical limitations are defined. In the Output tab the output results of the analysis can be shown and/or exported from the model in the three following ways: View on the screen, Print or see in Graphics. Finally, in the Setting tab, user has the option to define the energy units and monetary units.

It should be noted finally, that various 'real world' case studies have been carried out world-wide using the available energy analysis software tools. EnergyPLAN has been used for simulation of a renewable energy system for the case of Mljet island in Croatia [59]. Additionally EnergyPLAN has been used to model the Chinese energy system in order to study the large-scale integration of wind power in their system [60]. HOMER software has been used to find the optimal energy solution for a given GSM Base Station Site in Nigeria [61], the software has also been employed to evaluate a stand-alone PV system comprising of batteries as described in the work of Nair and Garimella [10] from the technoeconomical point of view. In another work by Castañeda et al. [62], HOMER is used as a sizing tool for a stand-alone hybrid generation system integrating renewable energies for comparative purposes. The latter case study concerns a load, located in Álora

(Málaga), Spain and the system has batteries and fuel cells. NEMS is used to create the annual energy output of USA [50]. RETScreen has been used to evaluate the cost of a stand-alone photovoltaic system for a 4-person residential house in Malaysia [63].

## 6 Discussion and Concluding Remarks

It can be seen that *none* of the eight tools presented has *all* the storage technology models or the important characteristics. None is also absolutely dedicated to energy storage optimisation. In addition there is no single software tool suitable for the investigation of evaluating the various energy storage technologies in conjunction with renewable energy sources, in terms of a micro or smart grid [49, 64]. In order to define the role and amount of storage, research should be focused on the determination of an evaluation method to monetize the benefits provided by energy storage technologies. There has been a number of projects aiming at this development of an energy storage evaluation tool such as RESET (Renewable Energy Storage Engagement Tool), which calculates the maximum economic value of excess renewable generation by optimally sizing energy storage systems allowing comparison and evaluation of the economic profitability of multiple energy storage technologies at their site [65]. One of the most sophisticated, energy storage evaluation tool is the one produced from the partnership between the Sandia National Laboratories and KEMA funded from the DOE's Energy Storage Program, the ES-Select™ Tool [66]. The aforementioned tool has been released for public download which will help utilities, developers and regulators to select the best storage option based on the application studied. It provides a graphical comparison of statistical distributions for characteristics of feasible energy storage technologies, such as installed cost and payback, to help users make informed final decisions. It is a preliminary investigation tool which will help users to decide whether or not a further detailed simulation run and site specific analysis should be conducted.

It can be concluded, therefore, that the selection of an energy storage technology depends on the specifications of the application to be addressed. Also, even though there is a wide range of energy tools only a limited number includes energy storage modelling. It is obvious that there is no single software package able to deal with the optimal sizing, sitting and operation of energy storage in distributed renewable energy generation that would be useful to managers responsible for capital investment decisions to value energy storage technologies and introduce these technologies in present grid infrastructure development. Adopting energy storage technologically will require appropriate modelling tool offering system analysis, information on the economic and operational benefits and most important including a methodology of evaluation of the different energy storage technologies to determine the suitability and selection for specific application such as the integration of various renewable energy resources.

Electric storage is expected to play a larger role in islanded systems not only by helping to stabilize generation and load variations but also minimise the operation cost of the existing systems. Greek islands which are isolated and exhibit tremendous amount of wind and solar power potential do indeed present a suitable field of applying such energy storage technology analysis and evaluation tools.

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