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Published in:
Quality - Access to Success

Publication date:
2012

Document Version
Early version, also known as pre-print

FUEL CONSUMPTION ANALYSIS AND OPTIMIZATION OF A SUSTAINABLE ENERGY SYSTEM FOR A 100% RENEWABLES SMART HOUSE

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ABSTRACT: Continuous increasing of fuel prices due to the limited stock, together with their negative impact on the environment open the gates for new technologies, more environmental friendly resource and free to use resources like the ones used by renewable energies. In this paper an economic analysis and a feasibility study of a sustainable energy system for a 100% renewables smart house (SH) in Denmark is presented. Due to the continuous increasing penetration levels of wind and solar power in today's energy system call for the development of high efficiency optimizations and Smart Grid (SG) enabling options. In case of renewable energies, one main challenge is the discontinuity of generation which can be solved with planning and control optimization methods. The results of the economic analysis and the feasibility of the sustainable energy system for a 100% renewables SH show that this could be possible and feasible.

1. INTRODUCTION

In the last years interest in sustainable supply chain management has risen considerably and more people are interested in this field due to costs, limited stocks, and environment problems caused by utilization fossil fuel energy which become increasingly pressing. [1]. Energy performance of buildings is today recognized as a major issue and lots of studies on this issue are running. Different concepts like: low-energy building, passive building, zero-energy building, and positive energy building, even autonomous building have been proposed as high energy performance building [2-3]. Systems which have pointed towards intermittency-friendly to bring improvements, and regional system optimizations for different areas have been also studied [4-5].

Despite the obvious advantages of renewable energy, it presents important drawbacks due to the discontinuity of generation, as most renewable energy resources depend on the local climate, which is why their use requires complex design, planning and control optimization methods. In most countries, buildings account for a substantial part of the energy supply. Therefore, the development of sustainable buildings plays an important role in the transformation of national energy systems into future sustainable energy supplies aiming at reductions in fossil fuels and CO2 emissions.

The efficient utilisation of energy nowadays is a very important issue for the industry, businesses and services, residential sector and agriculture. The impact of energy generation, transport and consumption systems on environmental pollution have both local and global effects [6].

In this paper the model and techno-economic calculation of a 100% renewable energy system for a Smart House (SH) in Denmark is presented. The calculation comprises technical requirements and potentials for an optimal design of electric consumer, heating, cooling, and hot tap water production techniques, also balancing fluctuating wind power. Economic optimisation, fuel consumption, and production for the SH using a reference house RH for comparing in the project is analysed. Using 100% renewable energy system the SH can produce enough energy to sustain its demands and also the possibility of selling energy is taken in account. The question for this research is if the energy supply system, 100% renewable, designed is capable of covering the demands for the SH now and in the future and if is feasible. Seen as a small mart grid (SG), from energy system perspective, the most critical area is the storage which has to take care of energy balance between the intermittent energy sources as wind and solar power [7]. A drawing of sustainable energy system is presented showing the main components and characteristics of it followed by results and conclusion.

2. DESCRIPTION OF SUSTAINABLE ENERGY SYSTEM 100% RENEWABLES FOR A SMART HOUSE

The 100% renewable energy system for the SH is divided in three main areas as follows: SH energy demands, storage and process. Figure 1 presents a drawing of the energy system functioning for the SH.

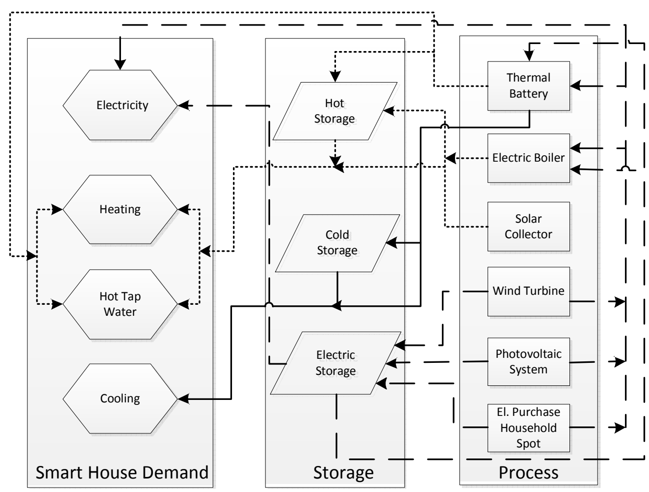

Figure 1. Drawing of energy system functioning for a 100% renewables SH.

The SH is considered to be situated in Denmark and all the data and profiles for hourly consumption used for simulation are according to Danish policies. As it can be seen in the figure above the SH demands it contains the electricity, heating, hot tap water (HTW), and cooling. All this demands are supplied by the processes which are: thermal battery (TB) or water source heat pump (WSHP), electric boiler (EB), solar collectors (SC), wind turbine (WT), photovoltaic system (PVS), and the electric purchase household spot (EPHS) from the national energy system. The storages are: hot storage, cold storage, and electricity storage. All the storages play an important role of balancing the energy demand with the processes mostly because of discontinuous generation of renewables. A more detailed description, also showing the capacities, for all the components of processes and storages of the 100% renewable system is presented in Table 1.

Table 1. Process and Storage description for the SH.

Process	Technical data	Capacity
Water source heat pump operated in simultaneous heating and cooling production mode	- 2 stage scroll compressor - refrigerant CO_2 (R744) - water-water	4.5 kW
Electric boiler	- no. of elements: 2 - element size: 3000W	6 kW
Solar collector	- flat plate collectors	7 kW
Wind turbine	- permanent magnet synchronous generator	11 kW
Photovoltaic system	- Peak efficiency 97.5% - CEC efficiency 97.0%	6 kW
Storage	**Technical data**	**Capacity**
Hot water storage	- two internal HEX coils - max temperature 95ºC - ΔT is 50ºC - utilisation 90%	1000 l
Cold storage	- ΔT is 12ºC - utilisation 90%	1000 l
Electric energy storage	- Li-Ion battery	24 kWh

The demand specifications of the SH used for simulation can be found in Table 2.

Electricity demands for "end-use" and for processes are provided by the WT, PVS, electric storage and EPHS at the end if needed for balancing the electric energy consumption which cannot be ensured by the renewable system processes. All the SH demands and processes who need electrical energy (WSHP, EB) will use firstly the energy from the processes which provide it, than from electrical storage and in the last case from EPHS. The electrical energy surplus (after filling the storages) can also be sold and reducing the costs, giving back the energy used from EPHS, or even can make profit.

Table 2. Design specification and demands for the SH.

SH demand	Demand/Year [kWh/m^{2}Year]
Heating demand and domestic hot water	85
Cooling demand	20
Electricity demand end-use, no process	40

The WSHP is a widely used conversion technology for providing building thermal energy services; cooling, heating, and water heating as air source heat pump, ground water, and soil heat pump. WSHP is also a good option for increasing energy efficiency, producing heat or cold from the electrical energy supplied by the WT and PV when this is not needed. Flexibility for such a system plays a key role for optimizing, increasing its efficiency, and reducing the energy consumption costs. The SH is well-insulated, fully equipped with all automation and high tech technologies and it has a surface of 130m^2. As reference house model for the simulation an average house of 130m^2, using EPHS for electricity demand, gasoil boiler for heating and HTW, and air conditioning unit for cooling was chosen.

The analysis is performed using the COMPOSE software that combines detailed operational simulation under the deterministic techno-economic constraints of the SH and the existing appliances with a least-cost marginal-dispatch model for the energy system in which the SH is analysed. The energy system model allows for an identification of the marginal system-wide consequences with respect to the intermittency-friendliness of operation and CO2 emissions [4]. These particular system analysis methodologies are described in further detail below.

In COMPOSE, the user defines an energy option in terms of end-use requirements, storages, and conversion processes (e.g. heat pump). Options may be designed from scratch or based on build-in libraries. Furthermore, the user defines an energy system in terms of spot markets, candidate marginal power producers, electricity demands, and intermittent production. For both option and system, parameters are specified on an hourly basis for each year of analysis. System specific parameters may be imported from utility databases, or adapted from COMPOSE's build-in libraries [8].

COMPOSE then identifies the option's optimal operational strategy by mixed-integer linear programming under the objective function of minimizing the economic cost of meeting heating and cooling demands for the period of simulation under given techno-economic constraints and boundaries, including hourly values for end-use requirements, capacities and efficiencies, market prices, variable O&M costs. The resulting detailed energy balance includes e.g. fuel and electricity consumption, storage states, energy losses, energy costs. For the SH, based on the identified least-cost operational strategy, COMPOSE uses the resulting net electricity profile – the Smart House's hourly electricity consumption profile - as a basis for calculating the resulting energy system impacts, including system-wide primary energy consumption and system-wide marginal CO2 emissions [9].

3. RESULTS AND DISCUSSION

Figure 2 illustrates the demand, production of energy of the SH with 100% renewable energy and the fuel consumption costs for all processes. Net electricity exchange is positive for the calculated period in the case of SH, meaning that it doesn't buy any electricity from EPHS. The energy produced by the renewable resources covers the electricity end-use demand of the SH, the electricity demands for the processes which produce thermal energy like: WSHP (TB), EB. In the period when spot market prices are high and the storages can fill the demand of that period, the extra electric energy produced by the processes (WT, PVS) is sold. For the period when spot market prices are low the energy produced by the processes (WT, PVS) is converted to thermal energy thru the WSHP (TB) and stored in hot or cold storages which will supply the demand of space heating, HTW, and cooling. As it can be seen in Figure 2 the 100% renewable energy system of the SH it produces sufficient energy for its demands and for balancing the discontinuous generation the storages are playing a key role.

Figure 3 illustrates electricity demand, fuel consumption, and net electricity exchange for the RH. As Figure 3 shows net electricity exchange is negative, all the energy used for end-use demands or other processes is bought from EPHS.

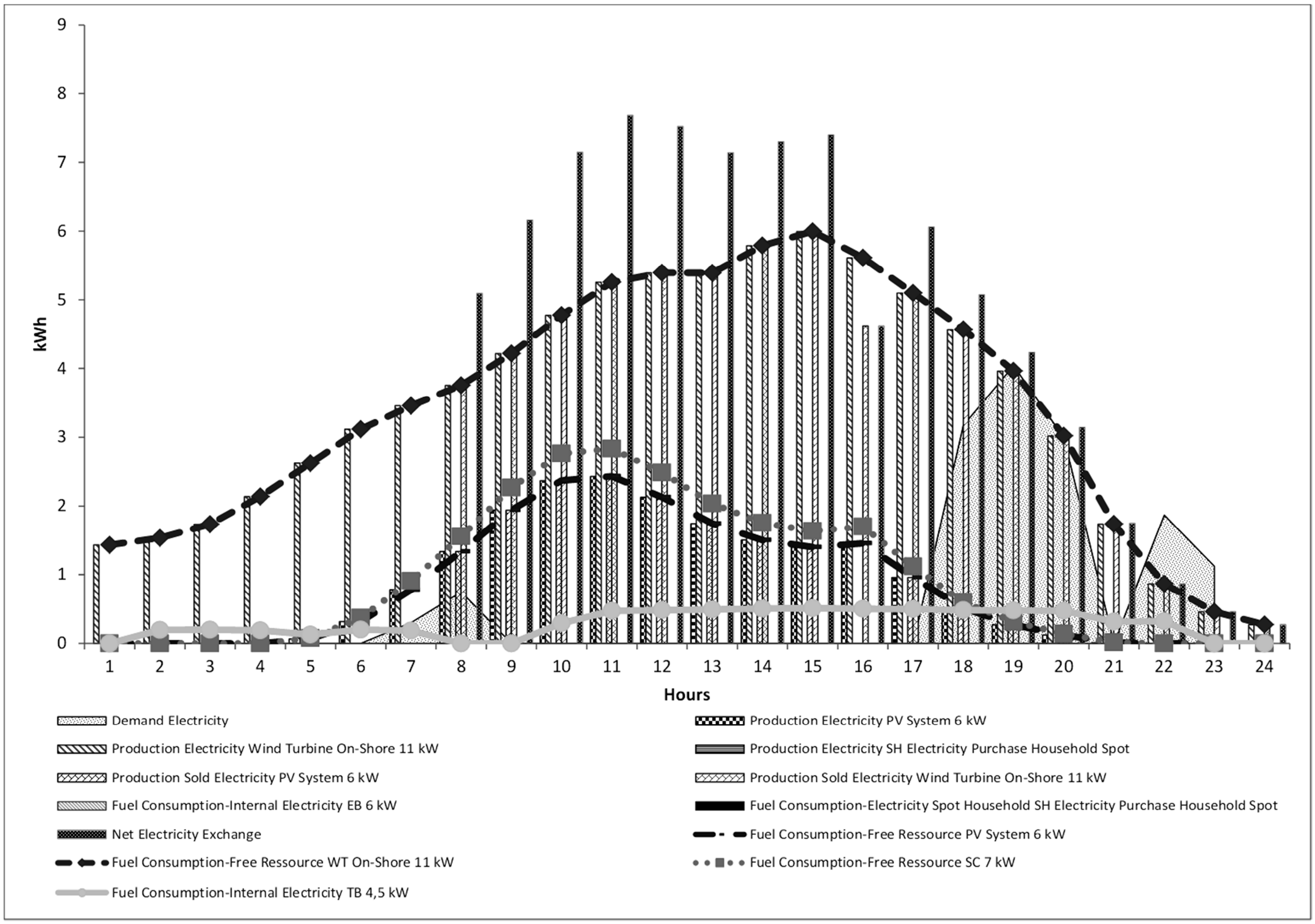

Figure 2. Electricity demand, fuel consumption, and net electricity exchange for 100% renewable sustainable energy system of SH for 24 hours period.

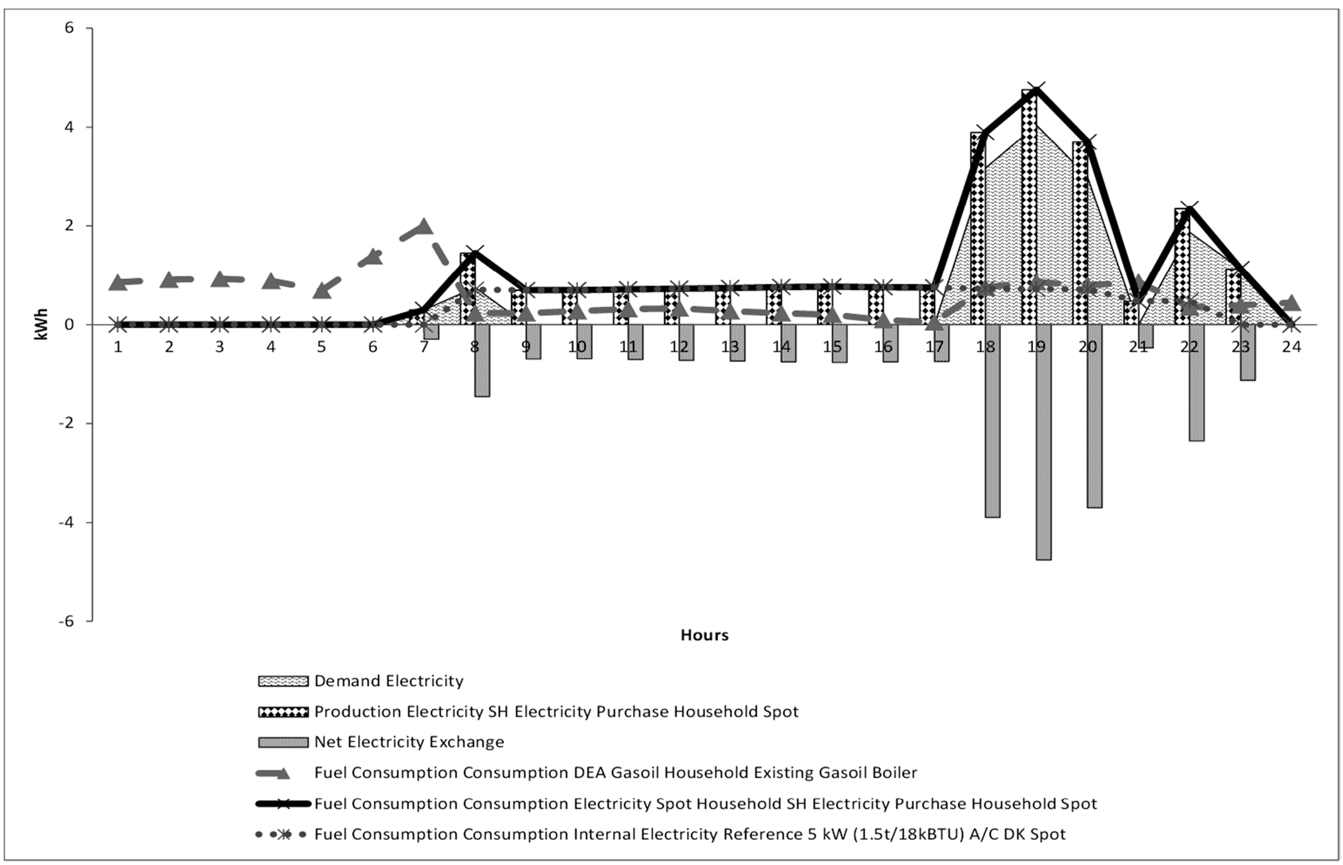

Figure 3. Electricity demand, fuel consumption, and net electricity exchange for the RH for 24 hours period.

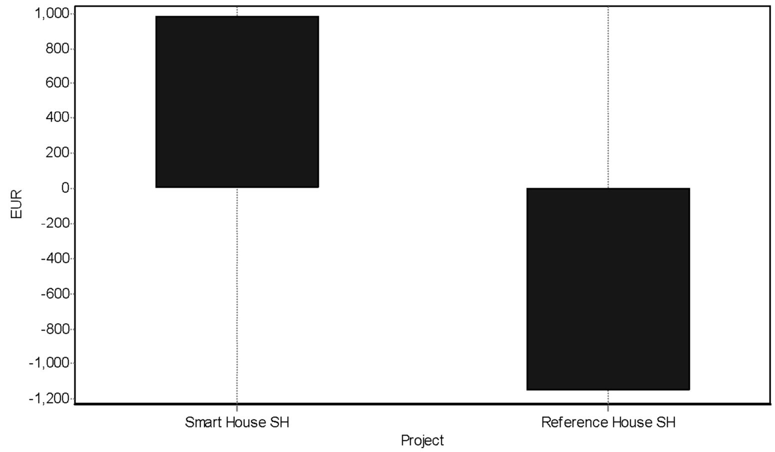

Figure 4. Economic cost benefit operational comparison between SH and RH.

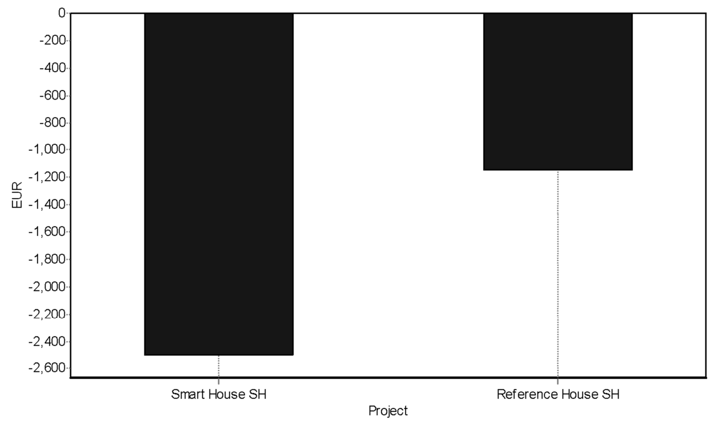

Figure 5. Economic cost benefit (net present value) comparison between SH and RH.

Figure 4 and Figure 5 illustrates comparisons between the SH and RH related to economic cost benefit for operational respectively net present value. Our research is basically concerned with the question of how to design 100 % renewable based energy supply systems is indeed both possible and relatively feasible.

4. CONCLUSION

In this paper an economic simulation for a sustainable energy system 100% renewable SH is presented. The main purpose was the design of a 100% renewable based energy supply system. Simulation shows that such a system could be possible for implementation and relatively feasible. The results present that the SH 100% renewable energy system can bring profit from optimizing the demands with the processes and storages. Also the electric energy produced by the intermittent energy resources like wind and solar can be sold when spot market prices are high reducing the period for investment recovery. A feasibility study for the simulated sustainable system is considered as future work.

5. ACKNOWLEDGEMENTS

This work was partially supported by the strategic grant POSDRU/88/1.5/S/50783, Project ID50783 (2009), co-financed by the European Social Fund – Investing in People, within the Sectorial Operational Program Human Resources Development 2007 – 2013.

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