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Renewable Energy Systems: An Intelligent Energy Systems Method for Selecting and Modelling Completely Renewable Solutions

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Research Article

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This document summarises the findings from a number of studies that use a smart energy systems methodology to assess the challenges and opportunities of transforming the current energy system into a 100% renewable energy system. Smart energy systems consider the complete energy system when determining appropriate energy infrastructure designs and operation techniques, in contrast to, say, the smart grid idea, which focuses only on the electricity sector. Transmission lines, flexible power needs, and electricity storage are the main ways to cope with the integration of variable renewable sources, according to the traditional smart grid's exclusive concentration on the electrical sector. However, due to the nature of wind power and related sources, these interventions are neither extremely cost-effective nor very successful. Combining the transportation and/or heating and cooling sectors with the electrical sector yields the most economical and efficient solutions. Furthermore, the design of future renewable energy systems may be significantly influenced by the integration of gas and electrical infrastructures. The study highlights the incorporation of flexible combined heat and power (CHP) generation in electricity balancing and grid stabilisation, and it demonstrates why electrical smart grids should be seen as a component of total smart energy systems. It also emphasises how to model and construct sustainable smart energy systems in the future.

Introduction

In order to define and characterise new paradigms in the design of future energy systems, a number of new terms and definitions of sub-energy systems and infrastructures have been promoted in recent years. These include power to gas (Gahleitner, 2013), vehicle-2-grid (Lund and Kempton, 2008), smart grid (Massoud and Wollenberg, 2005), and fourth generation district heating (Lund et al., 2014). A significant paradigm change in the development of future renewable energy solutions is represented by all these facilities, which are crucial new contributions. They are all subsystems and sub-infrastructures, however, and if they are not appropriately positioned within the larger energy system, they cannot be completely comprehended or studied. Furthermore, various institutions may define them differently or they may not always be clearly stated.

The idea of "smart energy systems" refers to the problem of sub-systems vs overall energy systems, which is thoroughly examined in (Lund, 2014; Connolly et al., 2013). Smart energy systems consider the complete energy system when determining appropriate energy infrastructure designs and operation techniques, in contrast to, say, the smart grid idea, which focuses only on the electricity sector. One key aspect is that defining the whole energy system in which the infrastructure should function is necessary for a thorough examination of any smart grid architecture. Another key issue is that many subsectors have an impact on one another, and if the best solutions are to be found, this effect must be taken into account.

Fossil fuels are the foundation of today's energy system. Because fossil fuels can store vast quantities of energy in liquid, gaseous, and solid form, the energy system is very versatile and dependable. This implies that energy may be supplied "on demand" as long as a sufficient fossil fuel storage facility is close by, such as a coal storage facility for a power station, a diesel tank in an automobile, or a petrol tank for a boiler. Fossil fuels have thus given civilisation a great deal of flexibility since they store a lot of energy that may be used whenever needed. This freedom will be constrained in the future, however.

1. Smart Energy Systems

Renewable energy sources like solar and wind power will be the mainstay of the future energy grid. These resources don't have a lot of stored energy; instead, the energy from the sun, wind, waves, and tides has to be caught and put to use right away. One of the main technical issues that energy systems will face in the future is this. The question is: How can the energy system of the future, which will be

based on renewable energy, function without the flexibility that large amounts of stored energy in fossil fuels currently provide, while still offering reasonably priced energy and making use of a sustainable level of available resources? Finding novel, cost-effective, and efficient ways to incorporate renewable energy sources into the energy grid will be the answer. We refer to this as a smart energy system.

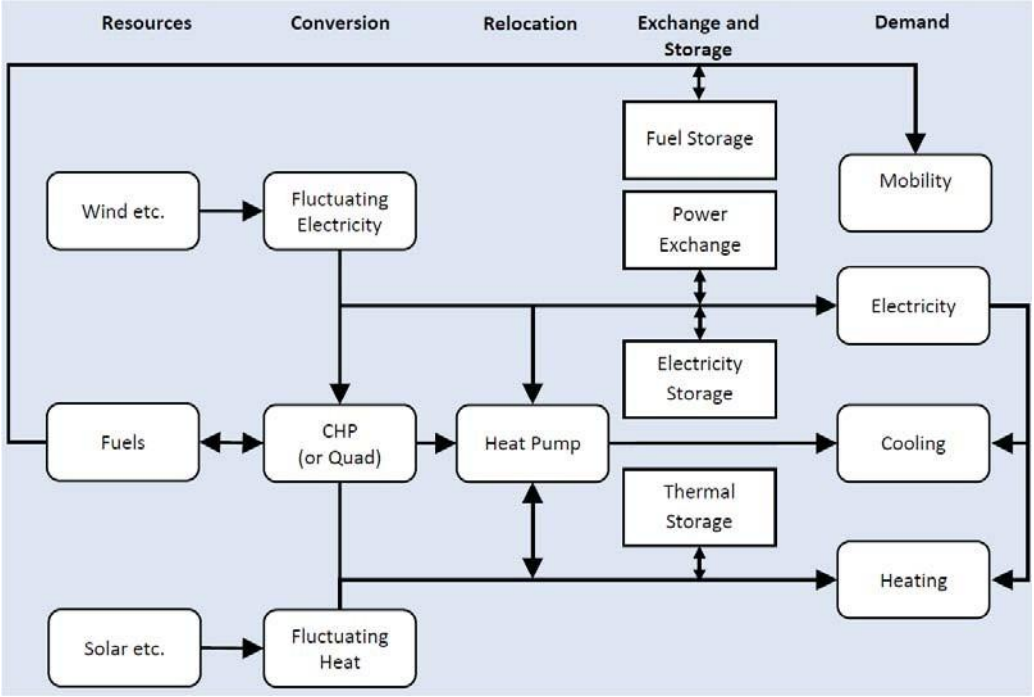


Figure 1: Illustration of a Smart Energy System based on the integration of the power, heating, cooling, gas and transportation sectors and infrastructures

A smart energy system consists of new technologies and infrastructures which create new forms of flexibility, primarily in the 'conversion' stage of the energy system. This is achieved by transforming from a simple linear approach in today's energy systems (i.e. fuel to conversion to end-use), to a more interconnected approach. In simple terms, this means combining the electricity, thermal, and transport sectors so that the flexibility across these different areas can compensate for the lack of flexibility from renewable resources such as wind and solar. The smart energy system is illustrated in Figure 1 and uses technologies such as:

- **Smart Electricity Grids** to connect flexible electricity demands such as heat pumps and electric vehicles to the intermittent renewable resources such as wind and solar power.
- **Smart Thermal Grids** (District Heating and Cooling) to connect the electricity and heating sectors. This enables thermal storage to be utilised for creating additional flexibility and heat losses in the energy system to be recycled.
- **Smart Gas Grids** to connect the electricity, heating, and transport sectors. This enables gas storage to be utilised for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be utilised.
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- Power-to-Transport
  Additional to the storage issue mentioned above, future energy systems also has to face the challenge of meeting transport demands without exceeding the sustainable biomass potential.

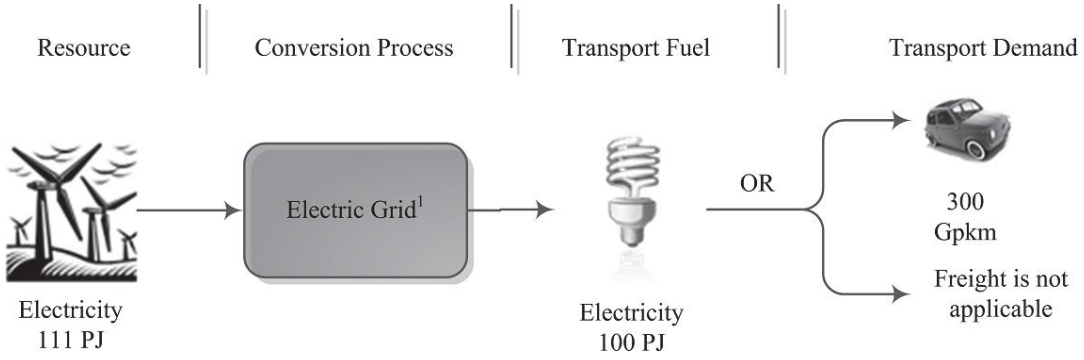


Figure 2: Direct use of electricity for transportation using battery storage

Direct usage of electricity, as shown in Figure 2, is the optimal strategy from a system perspective. However, not all travel needs can be met by direct power consumption. Some will need to be met by the use of biomass, but the amount of biomass that can be used for energy is limited by biodiversity, food, and material needs. Additionally, its limitations make it difficult to imagine how biomass might meet the transportation industry's present energy needs on its own. Furthermore, a transportation system that uses just renewable energy needs a petrol or liquid fuel derived from biomass to augment the direct use of power. The idea is that some biomass must be converted into either gas or liquid fuel in order for electricity to be utilised directly in batteries for transportation. Additionally, biomass in the form of gas aids in future CHP and power plants' increased flexibility and efficiency.

Power-to-Gas

But not only is biomass important for producing gas, but electricity in 'power to gas' systems may also be very important for enhancing and augmenting the finite biomass supplies. Combining these "power to gas" technologies with biomass-based gas production processes like fermentation, gasification, and hydrogenation might result in significant synergies. It will be necessary to increase the synthetic gas and liquid fuel from the biomass by hydrogenation, or power-to-gas in the form of hydrogen production on electrolysers, in order to produce enough gas and liquid fuel for the whole renewable energy system within the available biomass resources. There are distinct routes for various biomass resources and final applications. One such approach is shown in Figure 3.

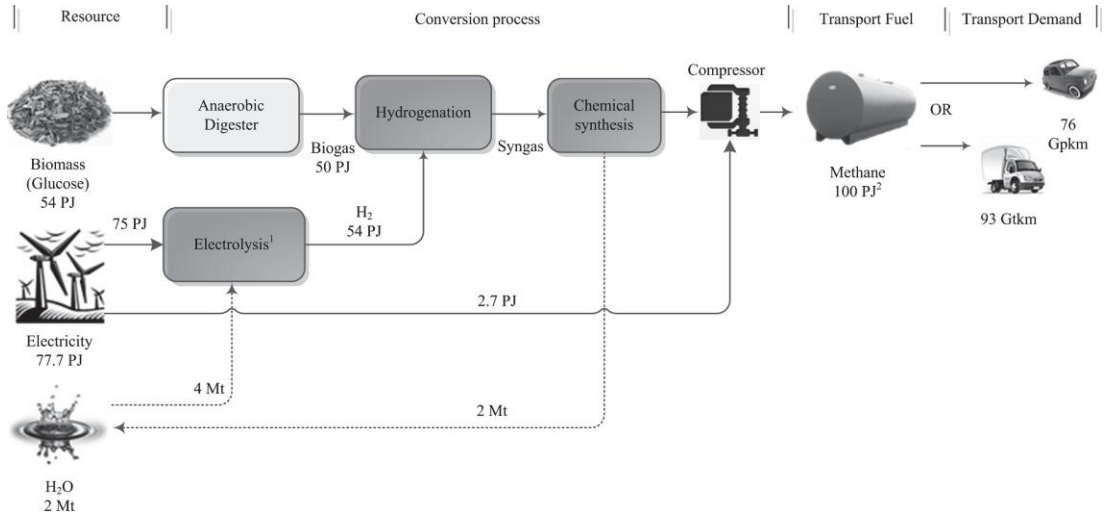


Figure 3: Example of a pathway using power-to-gas in hydrogenation to boost the amounts of

biomass based synthetic gas.

Power-to-Heat

Future renewable energy systems are usually designed using a mix of residual resources like trash and biomass and variable renewable energy sources like solar and wind power. As previously said, future alternative needs for food and materials as well as the effects on the environment are likely to put pressure on waste and biomass supplies. Feasible solutions to future renewable energy systems include significant components of energy conservation and energy efficiency measures to relieve the strain on biomass supplies and renewable energy investments (Lund et al., 2012).

In order to satisfy the needs of these limited resources, district heating is crucial (Connolly et al., 2014). Future renewable energy systems that include district heating will be able to employ CHP in conjunction with waste-to-energy and other industrial surplus heat sources, as well as geothermal and large-scale solar thermal heat. In the future, diverse methods of turning solid biomass fractions into bio(syn)gas and/or other kinds of liquid biofuels for use as transportation fuel might be part of industrial operations.

The current district heating system needs drastically evolve into low-temperature district heating networks that interface with low-energy buildings and smart electricity grids in order to fill its function in future renewable energy systems. Fourth Generation District Heating Technologies and Systems, or 4GDH, is the term used to describe these next district heating technologies (Lund et al., 2014).

2.2 Cooling with Power

District heating has more potential in cold-climate nations than in warm-climate nations, for obvious reasons. District cooling, however, may be an alternative in hotter areas, and both kinds of networks or a mix would be ideal in certain nations. District cooling may be used in two ways, in theory. One option is to employ a district heating network to disperse heat, which is then converted into cooling in each building by separate absorption units. This choice is ideal for places where buildings need to be heated and cooled at various times of the year. Additionally, the network may be utilised to simultaneously provide the building with hot water and cooling. Distributing the cold water and creating central cooling is the alternative. One benefit of this approach is that it may use "natural" cooling, such cold water from rivers or harbours.

2. Smart Energy Systems Synergies

As illustrated above, all smart grids are important contributors to future renewable energy systems. However, each individual smart grid should not be seen as separate from the others or separate from the other parts of the overall energy system. Firstly, it does not make much sense to convert, e.g., the electricity supply to renewable energy if this is not coordinated with a similar conversion of the other parts of the energy system. Secondly, better solutions arise for the implementation of the smart energy system and the individual sectors if their implementation is coordinated.

In other words, there are several synergies connected to taking a coherent approach to the complete smart energy system compared to looking at only one sector. This does not only apply to finding the best solution for the total system, but also to finding the best solutions for each individual sub-sector. Such synergies include the following:

- Electricity for heating purposes makes it possible to use heat storage instead of electricity storage, which is both cheaper and more efficient. Moreover, it provides a more flexible CHP production.
- Electricity for heating may be used for balancing in regulating power markets, etc.
- Biomass conversion to gas and liquid fuel needs steam, which may be produced on CHP plants, and produces low-temperature heat, which may be utilized by district heating and cooling grids.
- Biogas production needs low-temperature heat which may be supplied more efficiently by district heating compared to being produced at the plant.

- Electricity for gas such as hydrogenation makes it possible to use gas storage instead of electricity storage which is cheaper and more efficient.
- Energy savings in the space heating of buildings make it possible to use low-temperature district heating which, in addition, makes it possible to utilize better low-temperature sources from industrial surplus heat and CHP.
- Electricity for vehicles can be used to replace fuel and provide for electricity balancing.

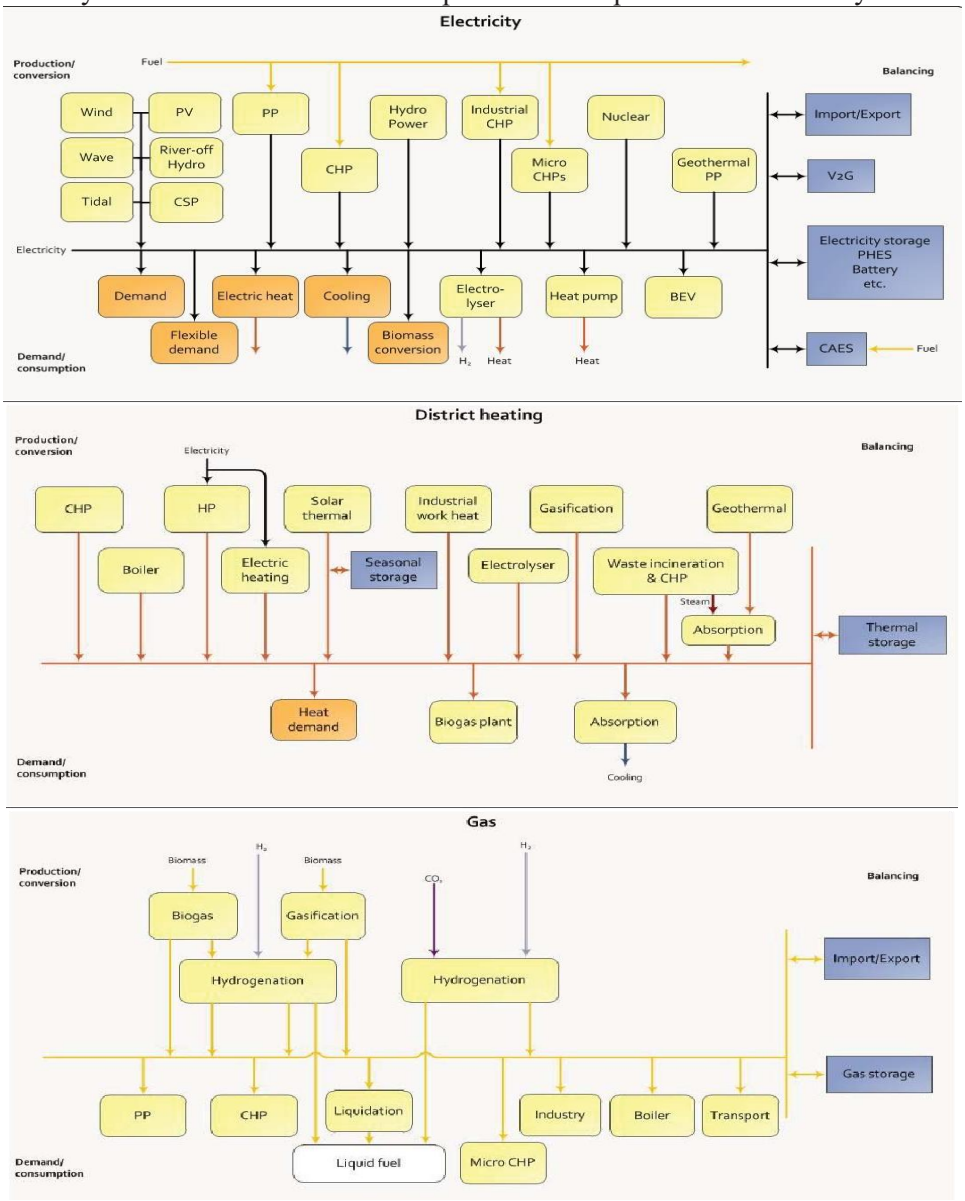


Figure 4: Illustration of three infrastructures and their components analyses on an hourly basis in EnergyPLAN. EnergyPLAN also include hourly analyses of district cooling, hydrogen and desalination

3. Smart Energy Systems Modelling

Tools and models that can give comparable and parallel evaluations of electrical, heat, and gas grids are necessary for the examination of smart energy systems. To achieve this goal on an hourly basis, the sophisticated energy systems analysis model EnergyPLAN was created (www.EnergyPLAN.eu) in order to find the best solutions. The model's primary goal is to support the creation of national energy planning strategies based on technical and financial evaluations of the effects of various national energy systems and investments. Nonetheless, the approach has also been used at the local level, such as towns and/or municipalities, as well as at the European level. The opportunity to see the whole energy system as a whole is emphasised in the design of EnergyPLAN. As a result, EnergyPLAN is intended to be a tool that allows, for example, the coordination of electrical smart grids with the use of renewable energy for uses other than producing electricity.

The device transforms renewable energy into carriers other than electricity, such as heat, hydrogen, synthetic gases, and biofuels, as well as energy conservation and efficiency enhancements, like CHP and enhanced efficiencies, like fuel cells. All of these actions have the potential to increase the system's fuel efficiency or replace fossil fuels. Systems that combine these strategies with energy conservation and system efficiency enhancements are considered long-term relevant. Because of this, the EnergyPLAN tool computes hourly balances for district heating, cooling, hydrogen, and natural gas in addition to electricity, including contributions from biogas, gasification, electrolysis, and hydrogenation. Figure 4's diagrams. provide an overview of the production and conversion units that are used to balance the various grid structures.

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