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ScienceDirect

Energy Procedia 107 (2017) 7 – 14

Energy Procedia

3rd International Conference on Energy and Environment Research, ICEER 2016, 7-11 September 2016, Barcelona, Spain

New trends in energy production and utilization

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Abstract

Energy has been the engine of nations' development, and this has driven mankind towards growing energy needs, in particular for transportation, agricultural and industrial activities and buildings. Energy for transportation is based on oil derived fuel, whereas energy in buildings consists mainly of electricity, which is produced from fossil fuels, nuclear power and/or from renewable energy sources, such as hydro and solar. Agricultural and industrial activities use a combination of fossil fuels and electric energy. To increase the sustainability of energy production and efficient energy use, it is urgent that better monitoring and control systems are used, and increase the energy production from renewable sources. This drives the energy sector towards the need for Life Cycle Analysis of energy processes to support the selection and implementation of more sustainable energy systems, as well as to develop better and more intelligent electric energy grids, where storage energy systems plays an essential role. These questions will be briefly discussed in this paper, focusing in the current situation, existing problems and potential solutions, and expected developments.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Energy and Environment Research.

Keywords: Energy distribution; energy production; energy storage; energy utilization; life cycle thinking; renewable energy

1. Introduction

Energy has long been associated with nations' development, ever since ancient times, when man started using fire for heating, cooking or safety purposes. Energy availability promoted the growth and development of population.

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Peer-review under responsibility of the scientific committee of the 3rd International Conference on Energy and Environment Research.
doi:10.1016/j.egypro.2016.12.122

The most conventional and renewable energy sources – sun, water, wind, biomass – became insufficient to fulfill the energy needs, and the utilization of coal, natural gas and oil allowed for the possibility of using larger amounts for new applications, such as industrial production or mobility/transportation, air conditioning and ventilation, communications, etc. But this endless cycle, where people need energy to further progress and where development demands the use of growing amounts of readily available energy, has its drawbacks: use of fossil fuel (FF) and fossil derived energy (FDE) is limited by the capacity of extraction and by the existence of reserves (limited and not evenly distributed in the world) [1]; use of FF and FDE contributes to the emission of large amounts of CO_2, volatile organic compounds (VOCs), sulfur (SO_x) and nitrogen oxides (NO_x), which in turn have acidification, eutrophication and ozone depletion potential, thus largely contributing to global warming and other severe environmental problems, such as acid rain and eutrophication [2,3]. Therefore, three main approaches have been used to solve the problem of energy availability: 1) reducing the amount of energy needed, through increasing efficiency of energy distribution (smart grids) and usage; 2) using other sources of energy , in particular nuclear energy (although recent years have proven that it poses significant risks and is also not available everywhere) or mainly through the use of renewable energy sources, including residual materials; and 3) developing new and more efficient energy storage systems. Furthermore, decision makers are starting to define their policies based on studies that take into consideration the whole life cycle of energy production: from the extraction of raw materials, considering transportation, construction and exploitation of the power units, and even their dismantling and reconversion, until the end of life, in a Life Cycle Assessment (LCA) perspective. Thus, in this paper it will be presented a brief insight of all of these approaches with their corresponding interactions, showing the new trends in the energy sector.

1.1. Energy demand

World development increased dramatically ever since the Industrial Revolution, in particular after WWII, which drove the rise of energy consumption. Thus, energy consumption in the World has been growing continuously in the past 50 years. The highest fraction corresponds to FDE: oil, followed by coal and natural gas; which increased by more than 280 % each. Energy from hydroelectric sources increased by 500 % during the same period. However, its share is still much lower than that of fossil fuels. Nuclear energy has also increased significantly but in the past 5 years has stabilized, possibly due to higher public awareness of the risks associated with it, following the accidents in nuclear power plants like the one that occurred in Fukushima in 2011. Growth in the consumption of other renewable energy sources increased in the last 10 years. However, its share is still insignificant (< 7 %), when compared to any other energy source [4]. The population growth in developing countries, like China and India, suggests that energy consumption in the World will be even higher, which is not sustainable. Thus, measures must be taken to revert this situation.

1.2. Energy sources and problems

As stated before, coal, oil and gas have been the main energy sources in the past 50 years. These are controllable but are not available in unlimited amounts neither evenly distributed. In what concerns nuclear power plants, although it is one of the most modern and secure energy producing technologies, the fact is that in case of an accident there is little that can be done to prevent from a world level catastrophe. The recent Fukushima tsunami made world leaders rethink their energy policy. The decision to postpone the closure of some nuclear power plants that are attaining their end of life was reverted, and Japan decided to change its energy policy on depending almost exclusively on nuclear energy.

It is consensual nowadays that current energy consumption and production patterns are unsustainable in the long term. Thus, current and future energy sources have to be more sustainable. In particular, it is necessary that they are renewable and cause lower negative impacts in all the three main dimensions of sustainability: environmental, economic, and societal. In fact, the availability of clean energy is one of the fundamental requirements for the sustainable development of modern societies. This is recognized both at governmental, institutional and even company levels, and a strong commitment exists among all relevant stakeholders that it is necessary to develop more effective and resilient Renewable Energy Systems (RES), and to increase its share in the global energy mix.

Presently, there is strong investment in either fundamental or applied research [5,6], and most countries and/or international organizations (e.g. in the European Union) have some sort of strategy or policies to promote the development and implementation of RES. Two examples are the German EnergieWende [7,8], and the European Union Energy 2020 and Vision 2050 strategies [9,10].

Despite all the interest and investment, the impact of existing RES on the energy mix is still limited. Although some success stories are available at a regional scale, such as bioethanol in Brazil, there is still much work to be done. Many of the reasons behind this situation result from the nature and how current RES are operated. In particular, most RES have limited scope, target markets and operational conditions, and the energy generated can only be used in limited settings. On the other hand, they are dependent on the local conditions and other external factors outside the producer's control [11]. Some examples are: climatic factors, local conditions that may limit the possible options (e.g. hydroelectric power requires availability of water), high production costs, their usage may lead to significant potential environmental, social and economic impacts (biofuels vs food controversy), difficulties in balancing demand and supply in electrical grids [12,13], among others This is the case of solar energy that is only available during daytime; wind energy, that both at too high or too low wind speed cannot be produced; or even hydroelectric energy, that strongly depends on the rainfall and water storage capacity. Finally, biomass and biofuels also present some drawbacks, as although its derived energy may be controllable, it also depends on its availability and the production may compete with the use of arable land or with food and feed. Besides all these problems, energy inefficiency is also large, and must be the subject of strong investments. Thus, many hurdles still need to be overcome and the RES are intended to provide a significant amount of the energy needs in future. Due to their intrinsic nature and characteristics, it is also understood today that a variety of RES are needed to ensure that they make an impact in global energy supply. Yet, currently existing RES are poorly integrated with each other, and more even with other systems, in particular of industrial production.

1.3. Nations commitment towards sustainability

The Brundtland Report [14], published in 1987, aimed to discuss the environment and development as one single issue, and was the turning point when environmental issues were firstly and strongly placed on the political agenda. The Kyoto Protocol [15], committed the 37 signatory industrialized countries and the European community to reduce greenhouse gas emissions (GGE), based on the premise that (a) global warming exists and (b) human-made CO_2 emissions have caused it.

The recognition of human impact on the environment and particularly, the huge increase on CO_2 emissions and ozone layer depletion caused by use of FDE has made nation governments decide that something must be done in order to change behavior and the current evolution trends. Thus, in 2012, at the Rio+20 (Earth Summit 2012), after several attempts not universally subscribed, an agreement [16] was finally signed by 192 governments who declared their political commitment to the promotion of a sustainable future. Recently, in July 2015 at the Conference of Paris, 193 signatories of the Paris Agreement [17] decided to set a goal of limiting global warming to less than 2 °C compared to pre-industrial levels and that they will also "pursue efforts to" limit the temperature increase to 1.5 °C. The agreement calls for zero net anthropogenic GGE to be reached half sometime between 2030 and 2050.

2. Solving energy problems

The above mentioned energy problems and sustainability awareness have motivated researchers, technologists and politicians to rethink their priorities and the energy policy. It is nowadays consensual that decarbonization of energy generation must be achieved very soon, in order to achieve zero net GGE. Also, intelligent energy grids must link nations, in order to rapidly access and distribute surplus energy. At the same time, energy storage systems are being further developed so that the surplus available energy may be stored for the periods of energy scarcity, or even allowing the utilization of the stored energy in other contexts. But above all, energy use must be much more efficient, in order to reduce energy needs.

2.1. Increasing energy efficiency and reducing energy intensity

By increasing energy efficiency, a reduction of energy consumption can be achieved. This can be done by better designing equipment, engines and particularly buildings, in which the energy represents one of the major consumption shares [18]. Reducing energy consumption in lighting and in heating and air conditioning systems, using more sustainable materials, harvesting locally water and energy for self-consumption, etc., are possible ways of increasing energy efficiency, towards near zero energy buildings (NZEB) or even zero energy buildings (ZEB). Also, it is important to better plan cities and the mobility inside them, in order to reduce individual use of vehicles, thus reducing not only the associated GGE but also the share of energy use for transportation. Production of goods must be equated differently, with a reduction of the distance from the place of production to the place of use, which will contribute to reduce the energy for transportation, and more efficient systems of production. This reduction of energy consumption will also be translated into lower energy incorporation in the goods, that is, lower energy intensity. Better waste management systems, with resource and energy recovery are also mandatory, in order to increase energy efficiency and to reduce energy intensity.

2.2. Increasing the sustainability of energy systems

The idea of developing biorefineries (Fig. 1), akin to the petrochemical complexes but based on the utilization of renewable raw materials and energy, is one of the concepts currently seen as more viable in the medium to long term [19]. From a sustainability point of view, they represent a good option, as they will allow the substitution of non-renewable resources by renewable ones, reducing the overall life cycle environmental impacts of products. Also, it will be possible to diversify the potential applications of RES, increasing their efficiency, resilience and economic potential when compared to presently used energy sources, in particular fossil fuels.

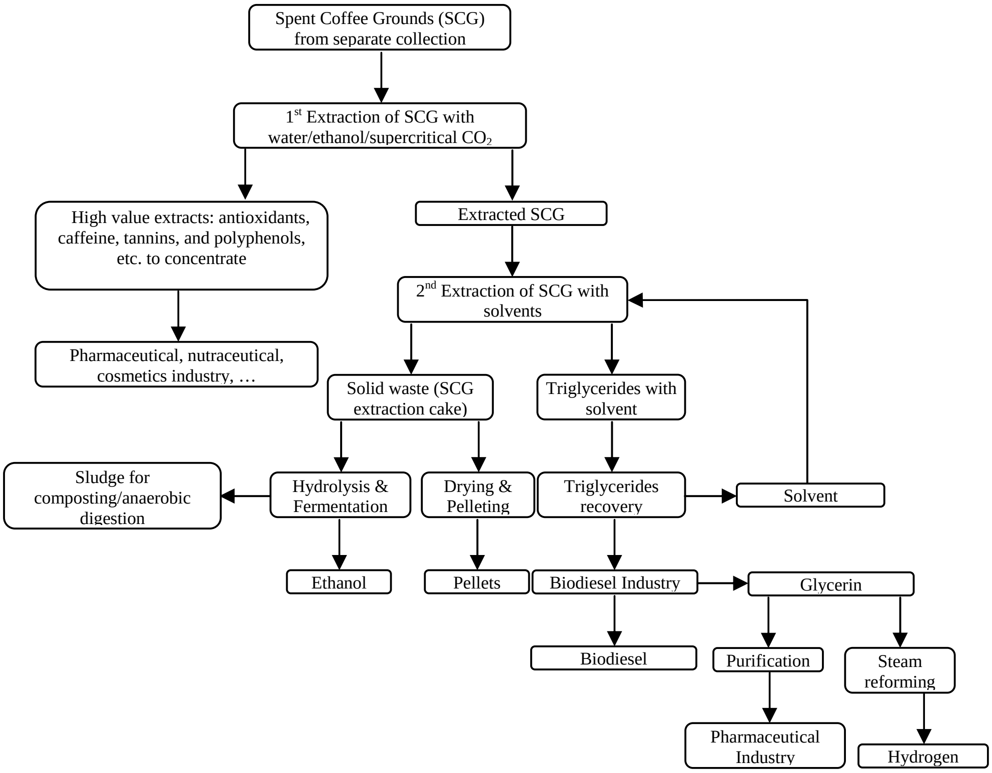

Fig. 1. A biorefinery based on spent coffee grounds [20]

This is clearly a fast moving area where a lot of investment is being made in R&D and in increasing the production capacity. Although it currently faces significant problems, it is consensual among all relevant stakeholders that on the long term they will be one of the key parts of future energy systems. It is also understood that their development, implementation and operation has to take into account, as much as possible, the principles of sustainability. This is already done for some RES, in particular biofuels, where certification schemes from a variety of organization and national or international institutions are already in place [21]. Also, some studies can be found on the literature that address the sustainability evaluations of some type of RES, in particular biofuels [22]. Yet, for other RES there are still open questions concerning their sustainability impact, and more objective methodologies are needed to assess them.

On the other hand, there is a huge energetic potential within waste and biowaste. In fact, there is a need for adequate integrated waste management systems that allow to recover resources in a sustainable way, and when it is no longer possible to recover any kind of resources, finally waste and biowaste can be converted to energy, thus avoiding environmental risks and energy losses.

2.3. Developing energy storage systems

Energy storage systems are vital to maximize the production and utilization of energy produced from existing and/or future RES. In particular, many of the more relevant issues and problems troubling current RES can be significantly reduced or even solved by selecting the more adequate energy storing systems and/or technologies. Examples include a better management of the demand and supply balance, reduce the variations in energy production due to climatic factors, and allow the energy produced to be used in other systems, among others.

The topic of balancing demand and supply is important, as currently a significant part of the renewable energy produced is electricity generated in wind and photovoltaic power systems. Also, increase in the production of renewable energy will depend on wind and photovoltaic power, as other options have low growth potential, such as hydroelectricity, and even others are still under development, such as wave power. This trend is already observed at a worldwide scale, with most of investment in renewable energy such as wind and solar energy, in particular photovoltaic [23]. In many situations these RES produce surplus electrical energy that cannot be used due to existing difficulties in storing it. Reduction of losses of renewable energy, or improvements in the way the balance between supply and demand is achieved by implementing and integrating RES can have a significant impact on the short to medium terms, especially at an economic level.

Energy storage is fundamental to ensure that the balance between supply and demand is as close as possible, this way reducing the influence of external factors, in particular climatic conditions [24]. Further complicating things are the distributed nature of RES, in particular wind and solar, which poses significant challenges to the distributing grid and energy storage systems. An extensive database of projects is available at the Energy Storage Systems program of US Department of Energy [25]. From the listing it can be concluded that presently most of the energy storage systems implemented or under implementation are of pumped hydroelectricity. Although in many cases it is possible to use already existing dams and other infrastructure (in particular the energy distribution grid), the storage capacity is limited, and in many world regions it is not an option, due to climatic conditions or inexistence of adequate sites. Moreover, there might be significant environmental impacts in the operation of those systems, and although Environmental Impact Assessment Studies are required for these types of project, their sustainability is usually not properly assessed [26].

A wide variety of energy storage systems are used today in a variety of different situations and backgrounds, including our daily lives, as for example automobiles have a lead acid battery that stores the energy needed to start the engine. Many different methods are available based in different physical and/or chemical phenomena. Examples include mechanical energy storage, such as compressed air and hydroelectric energy storage, thermal such as phase change materials or underground thermal storage [27], electrochemical such as batteries, chemical such as hydrogen, among others. The various methods differ by their capacity, energy density, time frame in which the energy can be stored, potential applications of the stored energy, among others [28].

To be used in RES and have a significant impact on the global energy mix, energy storage systems should be able to store vast quantities of energy, at least in enough time to be used in conditions where energy production does not meet demand, and be flexible enough to be used in different settings or systems. Among the potential options chemical methods for storing surplus renewable energy are increasingly seen as a good option, in particular if the market penetration of renewable energy is to be increased. Some of the important advantages are listed below [29]:

- It is a long term form of energy storage, and if properly managed the energy content is not lost in time;
- They can serve as energy carriers and be transported;
- For some forms of chemical storage, there is already extensive expertise and technical knowledge exists for all the steps of their life cycle, namely production, storage and in obtaining energy from them.

Furthermore, depending on the form of energy storage, it may be possible surplus renewable energy in other settings. For example, it will be easier to integrate existing and/or future RES with each other, increasing their resilience and overall efficiency, or to use the energy in existing production processes. The diversification of potential uses of the energy produced is fundamental to improve the economic potential of existing and future RES, and some methods of energy storage can be used for that purpose, in particular chemical based.

Two examples are via water electrolysis with electricity generated in wind turbines that may be used as fuel in the transportation sector, or methane generated via the methanation/gas-shift reactions that can be used in the chemical industry [30,31]. In both cases the existing natural gas distribution system can be used to both store and/or distribute them, either mixed or not with natural gas, for which considerable expertise and a sizable infrastructure already exists [32]. This increase in the flexibility and resilience of existing and/or future RES, facilitates the integration between RES, and allows the surplus energy to be used in other contexts and activity sectors, in particular in the transportation sector as fuel [33]. Of particular interest is the possibility to use the stored energy in the chemical and process industry, for example to process feedstocks with higher productivity but not currently economically viable (such as microalgae) or residual biomass residues, to produce not only other fuels [34-39], but also chemical feedstocks or chemicals with higher value, for example using gasification or Fisher Tropsch synthesis [40-42], for which some expertise already exists. This can facilitate the transition to a more renewable and bio-based economy, through the integration of new RES in the existing production systems, according to the biorefinery concept [43, 44]. Despite the obvious interest in this option and the many ideas and/or technologies proposed, much work still needs to be done to properly diversify the potential applications of renewable energy and fulfil its full potential.

2.4. Energy for transportation

To reduce use of energy in transportation, several different approaches can be taken. Thus, although the use of electrical vehicles may be recommended to reduce GGE (questionable, depending on the primary energy source) and even minimize the unbalance between energy demand and supply, this poses huge challenges to the actual electric grid. Therefore, it may also be recommended the use of biofuels for internal combustion engines, which will allow to use the same vehicles until their end of life. Design for sustainability and LCA are mandatory, in order to reduce energy intensity of transportation systems and to reduce the negative impacts caused either by the extraction of materials or by the disposal at the end of life. Last but not least, better public transportation systems are needed to reduce inefficiency and GGE. The most developed countries are betting on public transportation systems and their quality of life is enormously improved with this.

2.5. Assessing sustainability of renewable energy systems

Other key issue when considering RES is the question of sustainability, in particular their contribution to sustainable development, and how they can be developed, implemented and operated to reduce their sustainability impacts. As RES contribution is still small, but it is predicted that it will increase significantly in the next years, there is still a window of opportunity to do things right from a sustainability point of view, for example by selecting the most adequate technologies and operating procedures. Some Sustainability Evaluation Frameworks (SEF) were proposed and applied for some cases [44,45], yet many significant aspects still need to be accounted for. For example, although there is a consensus that they should be built within a life cycle approach [46,47], there is still no consistent approach to adequately assess different RES, with open questions such as what are the most adequate indicators and how to objectively assess social and economic impacts. Besides that, economic and technical feasibility aspects, and local/regional resources and/or limitations, can also play a significant role in selecting the most adequate options and/or support the policies development. Therefore, LCA methodologies are becoming increasingly important in decision making.

2.6. Emissions control and abatement:

In what concerns CO_2 emissions, two different approaches can be considered, the first being its prevention and the second its capture and storage. Now, the challenge is in developing underground geological and ocean storage systems that are safe and long lasting, although CO_2 mineral conversion and industrial uses are also recommended [48,49]. Nevertheless, considerable attention is being driven to CO_2 use in microalgae cultivation, although the amount of CO_2 that can be converted in this way may be insufficient. Also, there is a growing interest in recycling the CO_2 emitted to obtain methane or other hydrocarbons, using hydrogen from electrolysis using renewable energy.

In what concerns NO_x emissions, again there is an urgent need for processes that allow to retain nitrogen, thus reducing negative environmental impacts and contributing to mitigate NO_x effects. Research is ongoing in NO_x removal systems from combustion gases, critical in waste incineration problems for energy valorization.

3. Conclusion

Although the world is under fast development and energy is required for that, it is urgent that the energy production/consumption paradigm changes. People are the key, when reduction of high energy consumption is needed/wanted. Changing behavior is hard and takes time, but it must be done an investment on that, taking advantage of environmental and social awareness.

There is still a long path to walk until sustainable energy systems fulfill most of energy needs of mankind. For that, collaborative and interdisciplinary work is fundamental to achieve the changes that are being proposed. Long are the times when experts could work isolated from the rest of the world. It is by sharing knowledge and resources that the required changes can be achieved.

Acknowledgements

This work was financially supported by: Project FCT UID/EQU/00305/2013 and Project POCI-01-0145-FEDER-006939 (Laboratory for Process Engineering, Environment, Biotechnology and Energy – LEPABE funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) – and by national funds through FCT - Fundação para a Ciência e a Tecnologia; T. Mata and A. Martins would like to thank FCT - Fundação para a Ciência e a Tecnologia for their support through provision of research grants with references respectively, IF/01093/2014 and SFRH/BPD/112003/2015.

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