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Review

Energy policies and sustainable management of energy sources

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Abstract: Sustainability of current energy policies and known mid-term policies are analised in their multiple facets. First an overview is given about the trend of global energy demand and energy production, analysing the share of energy sources and the geographic distribution of demand, on the basis of statistics and projections published by major agencies. The issue of sustainability of the energy cycle is finally addressed, with specific reference to systems with high share of renewable energy and storage capability, highlighting some promising energy sources and storage approaches.

Keywords: Sustainability; energy sources; renewable sources; energy efficiency; energy demand

1. Introduction

Sustainability involves a web of environmental, economic, and social factors and in the field of energy it clearly shows its complex interdisciplinary nature.

A major issue arises from the inescapable depletion of fossil fuels. Formidable challenges and dramatic choices will have to be faced to develop viable substitutes: development of renewable sources is mandatory, but it is not exempt from drawbacks for energy security; nuclear could be revitalized, but its well-known contraindications are to be faced and accepted. In general, development of low-carbon energy sources also rises an issue of affordability.

On the other hand, the main source of concern is climate change and the energy-related air pollution. It is well established that widespread exploitation of hydrocarbons is releasing Carbon Dioxide (CO_2) at a rate higher than absorption by forests, oceans, and other natural CO_2 sinks and that this is the main cause of the global temperature increase which is already perceived.

The scenarios and the outlooks for the emissions of Green House Gases (GHG) developed by several international organizations clearly show that the goal of stopping the temperature rise before half of the century would require strict energy policies. Even the commitments of the 196 countries who signed the Paris agreement on climate change enforced in November 2016, will be enough to slow and not yet to stop the rise in CO2 emissions. Stronger efforts would be needed, with heavy constraints about amount and quality of energy consumptions. This could be and has been in some extent accepted in many mature economies: it is possible to improve the energy efficiency of industrial processes, buildings, and vehicles, or even to modify certain lifestyles in a perspective of eco-sustainability. Otherwise in emerging countries a reduced use of hydrocarbons would be an unacceptable burden, as low-cost energy is essential for their industrial growth, which in turn is a prerequisite for enabling access to wellness for populations so far deprived of it.

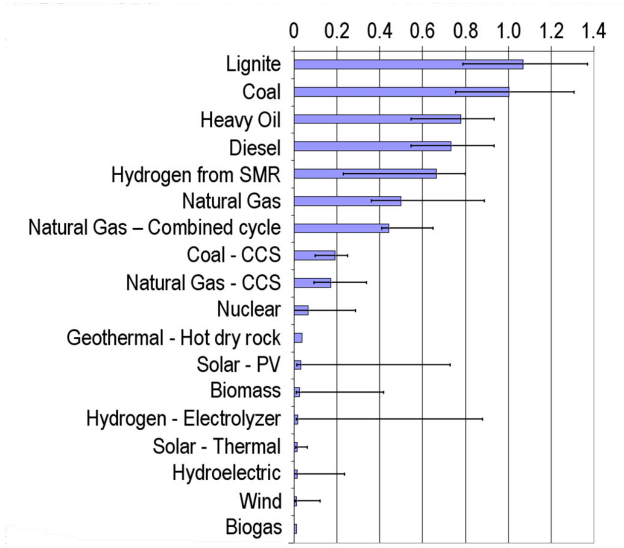

Figure 1. Emissions of Green House Gases for selected energy sources. The histograms refer to average values, while the error bars correspond to the reported values (Data sources: [1,2,3])

Actually, another issue of sustainability is access to energy: today swathes of the global population have no access to electricity (16% of world's population, and nearly un third of total African population [4]). Their number is going to reduce, but not to disappear in the next decades (they have been estimated to be still half a billion in 2040).

The perspective of reducing exploitation of fossil fuels could also pose an issue of sustainability for the prospected regulatory policies should manage in a planned way the reduction of global production of fossil fuels, avoiding sudden changes in availability of energy sources, as could arise in case of indefinite prosecution of current energy consumption patterns. They also should manage economic and social modifications in the countries that currently are more strongly linked to fossil fuel exploitation. This is also a matter of sustainability, when it is intended in its widest meaning [5].

In the next section an overview is given about the trends of global energy needs and production on the basis of the statistics and projections published by major international organizations [6] - [9]. The share among energy sources, the geographic distribution of consumptions and their medium-term evolution scenarios are reported and analysed. Sustainability of some promising technologies is analysed in Sec. 3.

2. Evolution of energy needs and regulation policies

According to the U.S. Energy Information Administration (EIA), to date the global energy production is larger than 15,000 Mtoe, and is mainly intended for industry and transportation [7].

The amount and quality of energy needs in the near future are the subject of great attention, as most anthropogenic CO_2 is produced in the energy sector. Thus, several organizations like EIA and IEA (the International Energy Agency), provide long term outlooks, referred to different sets of assumptions about international policies, economic growth and investments in the energy sector.

A crucial role will be played by the technological improvements achieved both in energy production and in user installations. In turn, they will be both affected by non-technological issues like the price of energy, which in turn is dependent on factors like the amount of oil produced by OPEC and the political stability in oil-producing countries.

Some effects of different assumptions on energy consumptions are addressed by taking into account, both a Reference Scenario with a reference 3%/year increase of the World Gross Domestic Product, and High/Low-Economic-Growth scenarios as well as High/Low-Oil-Price scenarios. The price of oil is indeed doubly linked to the rate of economic growth: in case of stagnation, the low energy demand could lead to an oversupply that would limit the oil price (the price of North Sea

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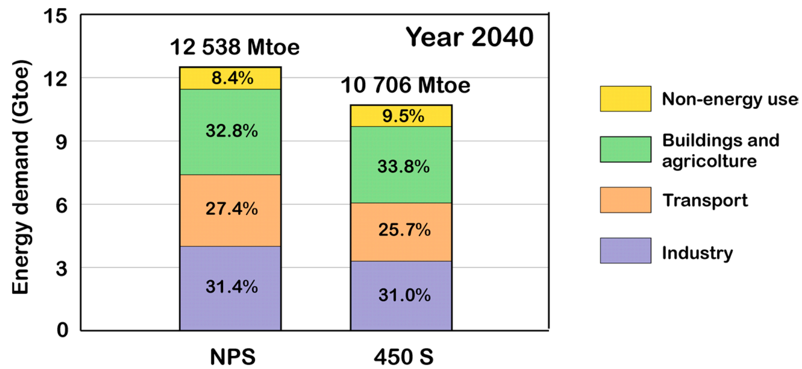
Brent crude could remain in the range 40-60 $/barrel (in 2016 dollars) until 2040). In this scenario, interest in the development of renewable energies and of the technologies for sustainability of energy consumption would be rather feeble. In contrast, in case of robust economic growth, the strong energy demand would push the price of oil, which could exceed $ 220/barrel in 2040. Despite the economic prosperity, in this scenario the attention to energy policies could be much higher. Therefore, EIA developed separate outlooks for the different scenarios.

IEA also developed outlooks referred to different sets of environmental policies. The reference scenario (IEA New Policies Scenario) is based on already-announced policy commitments and plains for reduction of greenhouse-gas emissions and improvements of energy efficiency. With respect to the prosecution of current trends, it predicts some mitigation of environment modification rates, which are indeed not sufficient to stop the global temperature increase, which would be around +4°C by 2035 instead of +6°C, as a result of unstopped increase of carbon emissions (the energy-related emissions would rise by 34% in 2040). According to this scenario, the global energy



Source of data: IEA Key World Energy Statistics 2017

Figure 2. Total final consumption by sector and scenario in 2040 and share among the fields of use. (Data from IEA, Key World Energy Statistics 2017 [6]

demand will rise to 16,000 Mtoe in 2020 and then will continue rising with an average growth rate of about 1.4 % / year, driven by increase of population and economic activities. It will exceed 20,000 Mtoe in 2040, with the industry sector still accounting for more than 31% of the overall energy consumption (Fig. 2).

Otherwise the goal of stopping temperature increases, albeit in the second half of the century, is achieved by the IEA 450 scenario. It is a set of challenging energetic policies, intended to limit the concentration of net CO2 in the atmosphere to 450 ppm in 2035, in order to have a 50% chance to limit the temperature increase to + 2°C.

On the other hand, this goal would require very strong efforts for decarbonisation and larger investments (nearly double than in the reference scenario) in low-carbon energy sources, as well as in efficiency and in Carbon Capture and Storage (CCS) systems [10]. As shown in fig. 3, in addition to an overall reduction of energy demand it entails a wider use of renewable and nuclear energy sources.

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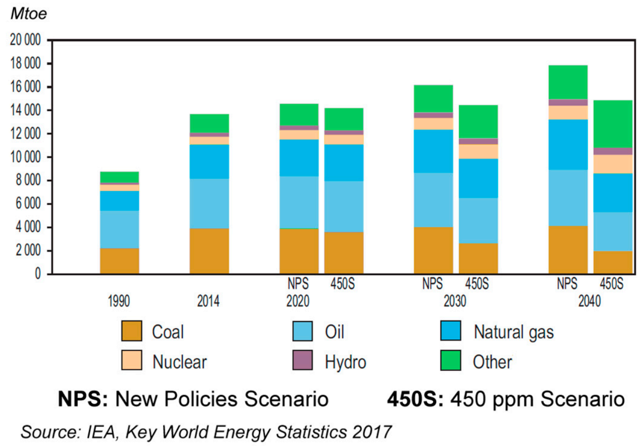

Figure 3. Outlook for world Total Primary Energy Supplyto 2040by source and scenario [6].

The target temperature increase (+ 2°C in 2035) set in the 450 Scenario is the same agreed by the 196 countries participating at the 2015 United Nations Climate Change Conference, COP 21, held in Paris [11]. They also pledged to make efforts to further lower the temperature increase to 1.5 °C, anticipating achievement of the zero net CO2 emissions and stopping of temperature increase to the period 2040 – 2060.

However, even in the most challenging scenarios, the prospected global reduction of fossil fuels would take place only in the long term. Thus, for the sake of energy security, in the short term a large share of investments will be still devoted to oil, gas and coal extraction, in order to maintain a fair set of operating oil fields.

Some countries (UE, Japan) are well underway to meet their climate pledges. The US, during the Obama Administration, enforced the Clean Power Plan (CPP), capable to give a 2.5% contribution to global carbon reduction. Unfortunately, it has been questioned by the Trump administration and the future environmental contribution from of the US is somewhat uncertain. Otherwise, developing countries, especially India and other non-OECD countries (Organisation for Economic Co-operation and Development, OECD), will be responsible of more than 80% of the increase in energy demand and fossil fuel consumptions (see Fig. 4).

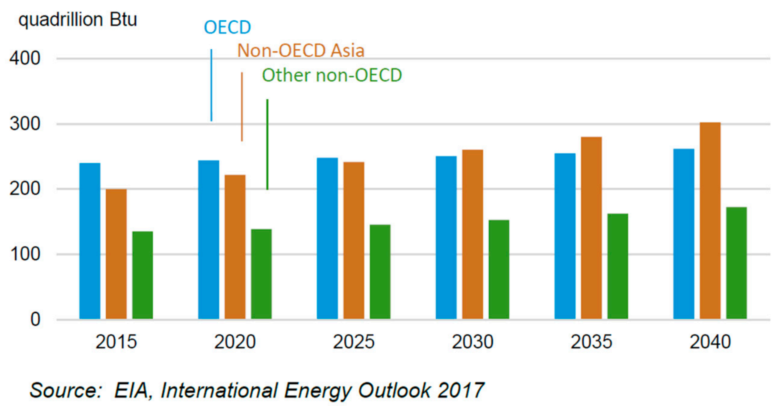

Figure 4. Projected growth in energy demand inside the OECD and outside it (quadrillion BTU)[7].

The outlooks also predict the trend of fossil fuels production.

According to EIA [7] natural gas is going to undergo the fastest growth among fossil fuels: in 2040 its production will be increased by 50% (nearly 1.5%/yr), supported by the production of non-conventional gas [8], and will provide 28-29% of global consumption, with a share nearly equivalent to coal and renewable energy sources. The growth of natural gas will be only limited by economical competition with other sources: despite the low carbon emissions, low capital costs and

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high operational flexibility of gas-fired plants, the gap with costs of coal supplies will be still limiting their economical appeal.

An interesting market development will arise from the quick increase of Liquified Natural Gas (LNG). It allows gas trading among countries not connected to specific infrastructures, and will promote the expansion of exporters like US and Australia, allowing new actors to step into this market.

Consumption of oil and other liquid fuels (see Fig. 5) will be almost stable in the long term the, as the increase in the developing countries will be offset by decrease in the OCSE countries, where oil demand will be limited to petrolchemicals, aviation, freight. Oil production will take place mainly in middle-east, with a minor contribution from US arising by the tight oil, extracted by hydraulic fragmentation from geologic formations of low permeability.

In general, the oil demand will also depend on economic trends, especially in the emerging countries, which in turn will be linked to a series of geopolitical factors that hardly can be traced back to a mathematical model. Indeed after the OPEC decided to reduce oil prices (from over $100

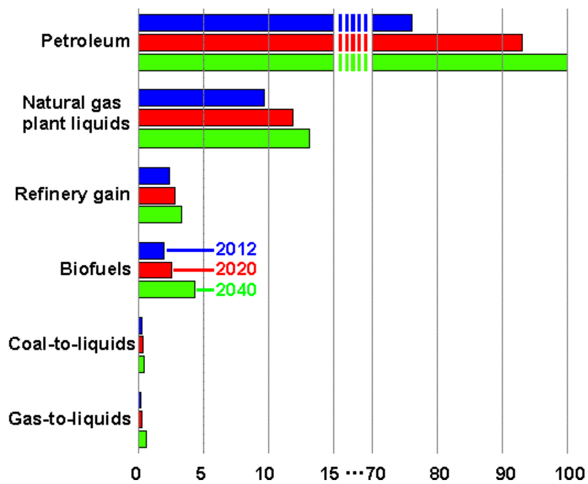

Figure 5. Production of liquid fuels by type (millions of barrels per day) (1 barrel = 0.14 toe). Source of data EIA, *International Energy Outlook 2017* [7].

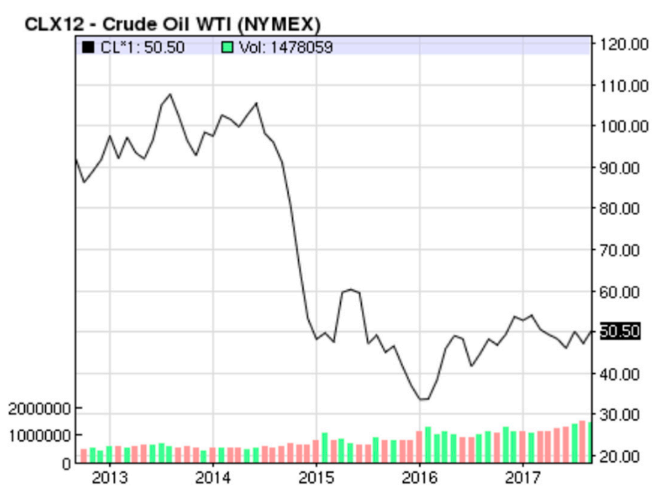

Figure 6. Price of crude oil in the last 5 years (US $). (Source of data: Nasdaq [12]).

per barrel in mid-2014 to below $40 in early-2016, see Fig. 6), a certain uncertainty arose about the payback times of the upstream investments to search and develop new oil fields. Thus after 2015 investments sharply dropped. This situation is harmful for energy security, as the existing fields

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have a limited operating time and in the first 2020's they could be not sufficient to match demand, with a likely new boom of prices and backslashes on the global energy market. In that situation the tight oil produced in the US would be a valuable resource, even if with limited geographical spread.

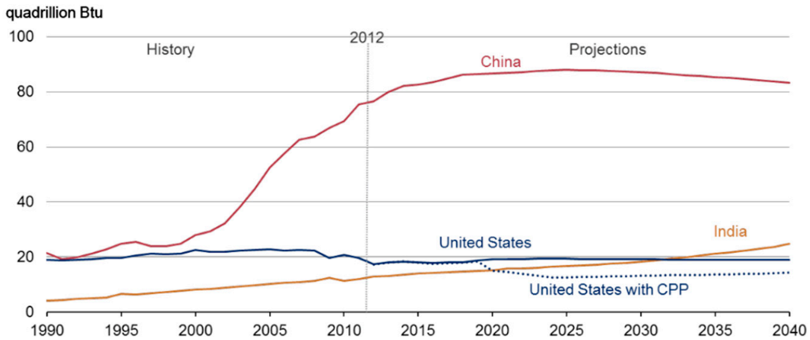

Figure 7. Projected coal consumption in the largest coal consumers (quadrillion Btu). The expected effect of the Clean Power Plan is also highlighted. (Source: EIA, *Analysis of the Impacts of the Clean Power Plan*, **2015**[13]).

Coal production will remain nearly stationary on a global scale, at least in the Reference scenario (Fig. 7): it is going to reach a plateau in China [7] and to decrease in higher-income economies (-60% in the EU, -40% in the USA). On the other hand, this reduction is going to be offset by the increase expected in India and, in a lesser extent, in other emerging economies, which cannot afford to neglect such a low-cost source. In fact, coal prices, despite the rebound observed in 2016, (Fig. 8) currently are going to level off at values making coal still economically competitive with natural gas.

Figure 8. Price of coal in the last 5 years (US$/t) (Source: [14]).

Nearly 25% of the global increase in energy production is currently destined to electricity production. In future this share is going to rise to 40% in the main scenario and up to 85% in the 450 scenario. Only 15% of this increase will occur in OECD countries. The increase will mostly take place in non-OECD Asia, notably in India and China. Thus, the environmental impact of energy production will be mostly determined by the energy policies taken in these countries.

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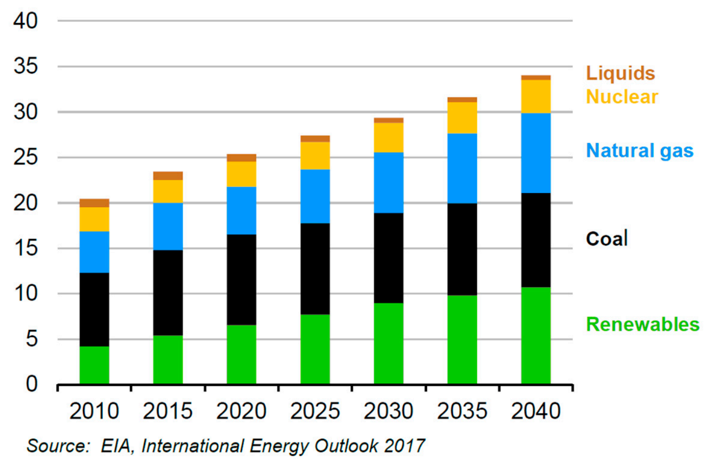

Figure 9. Projected growth of electricity production from different energy sources (PWh).(Source of data: EIA, *International Energy Outlook 2017* [7]).

Production of electrical energy is currently supported for about 75% from fossil fuels, for 10% from nuclear, for 10% from hydroelectricity and only for 5% from renewable sources. It is expected that global production of electricity will rise from the current 25 billion kWh to 37 billion kWh in 2040 (see Fig. 9). The use of fossil fuels for electricity generation will continue to rise, mostly for increase of natural gas [8].

Coal plants for electricity production are the largest source of energy-related CO2 emissions and will remain so in the next decades, even if their share of pollution will be reduced due to a larger exploitation of natural gas.

In the market of energy production, CO_2 emissions are continuing to rise in the non–OECD area, despite specific emissions are expected to decrease from today's 515 gCO2/kWh to 335 gCO_2/ kWh in the Main Scenario or down to 80 gCO_2/ kWh in the 450 scenario (Fig. 10). Otherwise in OECD countries the trend of emissions will be sharply decreasing, as a result of increased deployment of alternative energy sources, like renewables and nuclear, and of enhanced efforts to increase energy efficiency.

Actually the share of renewable sources is expected to undergo a strong increase (300%), mainly driven by wind farms (see Fig. 11), while hydroelectric production will grow at a smaller rate (40-50%).

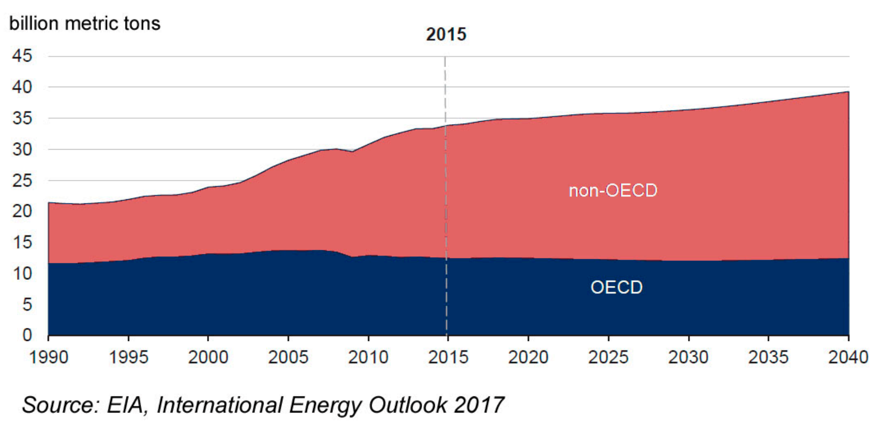

Figure 10. Energy-related CO_2 emissions (billion metric tons). (Source of data: EIA, *International Energy Outlook 2017* [7]).

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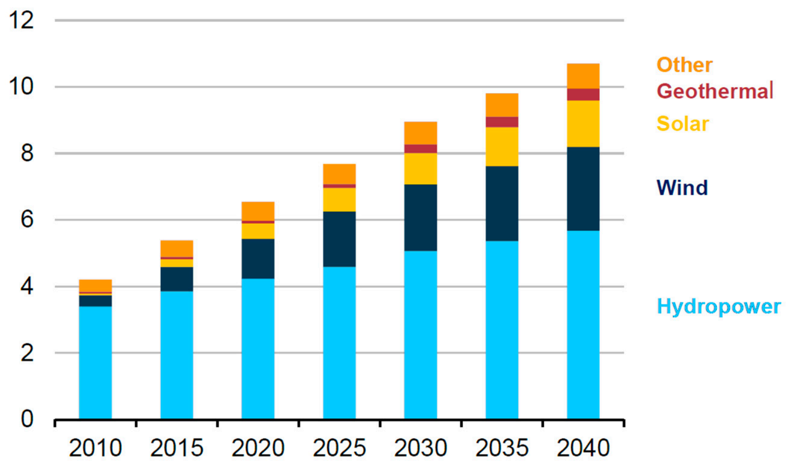

Figure 11. Projected growth of electricity production from renewable sources (PWh). Other sources include: Biomass, waste, tide/wave/ocean.(Source of data: EIA, *International Energy Outlook 2017* [7].

Similarly, an increased share of nuclear power is considered in most scenarios. In particular, the planned stop to the increase of coal consumption in China will be enabled by a massive deployment of nuclear installations. On the other hand, despite nuclear power is undoubtedly a low-carbon technology and cannot be neglected in a world where the main concerns arise from global warming and depletion of fossil fuels [2], its sustainability is largely questioned for the release of radioactive waste. Reprocessing techniques are available, but a small amount of radioactive end product still is produced and has to be stored over a very-long term. Concrete structures have been built with an expected life of 10,000 years (twice the Egyptian pyramids), but after this enormous amount of time the radioactivity and the lethal potential of nuclear waste will be only partially mitigated. Even the idea of storing nuclear waste in deep geological cavities is not free from drawbacks [15], [16].

In order to understand the relevance of nuclear technology, in 2011 IEA also developed a low-nuclear 450 scenario [17] with a share of nuclear energy halved with respect to the Reference Scenario. In order to achieve the 450ppm target large costs would be required for a wider deployment of CCS and other means to absorb the residual CO2 emissions. Limitations to the growth of energy consumption would also need to be applied, with relevant effects especially in the economy of developing countries. Most of all, a larger contribution from variable renewable sources would be required, with implications on the energy security.

Energy efficiency has been also acknowledged as a basic energy source [18]. Its potential highlighted by comparing the data on the global energy production (15000 Mtoe) with the final energy consumption (< 9000 Mtoe)[19]. For example: the average efficiency of the coal-fired and gas-fired thermal power plants around the world is around 33%, whereas the best plants currently in operation can provide efficiencies larger than 50%.

In different application fields the potential energy savings are bounded to specific technological issues: for example, in the industrial field relevant energy savings can be provided by improvements in the process efficiencies; in the field of transportation, advantages would arise by shifting a share of road freight traffic to rail or to ship; in private transport, savings would arise by increasing the share of electric vehicles; in the residential field, improvements could arise by introduction of sustainability criteria in building construction and by more efficient air conditioning techniques.

Electricity consumption could be also halved in a range of end-use applications (e.g. fans, pumps, compressors, refrigerators) simply by upgrading electric motors power supplies with inverter drives.

Further relevant savings could arise from reduction of the losses along electricity distribution grids: they are nearly 2% in Europe, are larger than 5% in many countries, including India where, despite recent improvements, they are still close to 20%.

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3. Renewable sources and sustainable management of the cycle of energy

Renewable energy sources are important not only for being never-extinguishing, but also for their reduced environmental footprint or, more generally, for their sustainability.

In general, the requirement of sustainability involves closed-cycle energy sources, where negligible amounts of resources are absorbed and released, and/or the produced end results can be used as base resources for other cycles. [20].

In the field of thermal generation, thermal solar and biomasses are maybe the most interesting technologies. Moreover, biomasses are characterized by a close approximation to a closed life-cycle: in fact, energy is produced releasing as a waste product CO2, which can be fixed in new vegetal species by photosynthesis and solar radiation, so that the process can be supplied indefinitely. The consumption of other resources is linked to construction of the conversion plants and of the energy distribution infrastructures, transport of the biomasses to the facilities themselves and energy transport to the user. Among other advantages, biomass installations can easily operate at variable power, with short response times, following the trend of energy demand.

Actually, environmental sustainability of biomasses is the subject of a quite lively debate. Cultivation of the biomasses intended for energy production takes territory, and for this reason it is in competition with the crops intended for food production. Consequently, the relevance of their contribution for global energy production is still debated. Other doubts on their use derive from the concern that the profitability of crops intended for energy production can boost deforestation and anthropization of wild lands, that otherwise should be protected as a shelter for biodiversity.

Among biomasses, an interesting development occurred for wood pellets, which are establishing as an energy source for heat generation in homes and small industries. Moreover, in countries like United Kingdom, The Netherlands and Belgium, they are also in use for utility-scale electricity generation.

In the field of energy production, a large growth is expected for renewable sources (2.6%/yr in the NPS scenario, i.e. nearly 60% of new energy installations by 2040). Technological advances and economies of scale are expected to make them competitive even in the presence of reduced or null subsidies: e.g. prices of solar PV are expected to drop by 40-70%, prices of onshore wind by 10-15%. Environmental footprint of solar photovoltaic is quite large, mainly for the amount of energy required for solar cells manufacturing of solar cells , which is just a few orders of magnitude smaller than their expected energy production over the lifetime. From this point of view, wind energy is preferred.

On the other hand, the variable renewable sources like solar PV, wind and waves show prominent periodic variations, both hourly and seasonal, superimposed to large random fluctuations. As long as they will be providing a minor share in the energy systems, it will be possible to stabilize the balance between demand and production against their variations by strengthening the grid, or arranging other power plants ready to dispatch at short notice. Otherwise, in the systems where they will provide relevant share (say, higher than 25%) this approach will not be feasible. First, in order to guarantee energy security against their fluctuations, an extra capacity has to be provided (it has been estimated that at least 40% extra capacity would be needed for the EU grid). This, in turn, will make available surplus energy for long periods (estimated 1/3 of time in EU and 1/5 of time in the US and India). Therefore, spreading of renewable energy sources will be accompanied by deployment of a consistent storage capacity.

The available energy storage technologies use different forms of energy (Table 1): gravitational in hydroelectric reservoirs, electrochemical in batteries, electrostatic in supercapacitors, kinetic in flywheels, magnetic in SMES, mechanic in compressed-air tanks.

At present no technology has been established as the most promising, both for different performance in terms of storage duration or response time and for different issues of sustainability. Among technologies suitable for seasonal storage, the batteries have problems with raw materials, which could be toxic (e.g. Lead, of Cd) or not abundant on the Earth's crust (Li [21]). Hydro-electrical basins have a relevant impact on landscapes, could modify local microclimate and could affect economy of the downstream populations. Therefore, the available sites are nearly saturated.

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Table 1. Storage technologies

Storage technology	Specific Energy (MJ/kg)	Energy density (MJ/liter)
Liquid hydrogen	141.86	8.491
Hydrogen (compressed at 700 bar)	141.86	1.3-1.6
Li-Ion batteries	0.4-0.9	0.9-2.7
Alcaline batteries	0.5	1.3
Lead batteries	0.17	0.56
Supercapacitors	0.01-0.04	0.06-0.05
Air (compressed at 200 bar)	0.5	0.14
Water (100m height)	0.001	0.001

Compressed air requires enormous geological cavities, like depleted oil fields, and are not easily found.

A very attractive approach is energy storage in the chemical bonds of hydrogen molecules [18],[19]. Hydrogen is easy to be transported, in tanks or via pipelines. It also allows long term storage, similarly to hydroelectricity and compressed air. Moreover, its specific energy (142MJ / kg) is by far the largest among the considered energy carriers.

On the other hand, energy density of H_2 is considerably lower than that of fossil fuels (e.g. it is nearly 20% of that of natural gas, at the same pressure), albeit comparable with other storage technologies, (V. Table 1) [22].

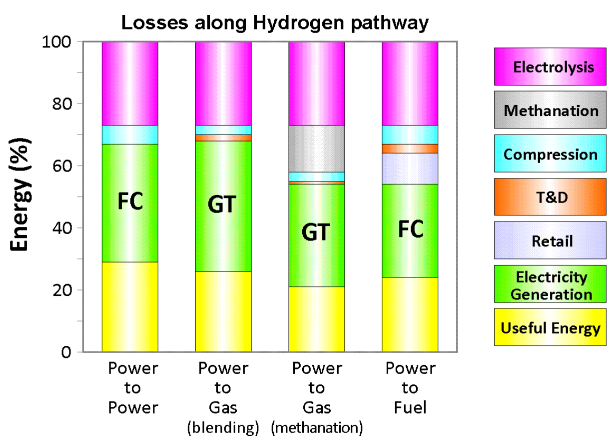

Figure 12. Energy balance in the different hydrogen integration schemes.(FC: Fuel Cell, GT: Gas Turbine). (Source of data: IEA 2015 [23]).

The environmental impact of the life-cycle of hydrogen depends on the specific production process: the most efficient process is Steam Reforming, but it is using some form of hydrocarbons. On the other end, hydrogen could be produced by electrolysis, consuming mainly water and electricity, which could be entirely supplied from renewable sources. Unfortunately, the overall efficiency varies between 20% and 30%, depending on the specific process (see fig. 12), so that potential appeal of Hydrogen for widespread use is to some extend limited.

4. Conclusions

Sustainability of energy cycles has been analysed in terms of some economic, social and environmental facets. The projections on energy consumption show that in the next two decades major changes will take place in energy consumption, in its geographical distribution and in the composition of the energy portfolio. Relevant climate and economic changes are forthcoming and immediate promotion of policies for sustainability, as agreed among the countries participating at the Conference of Paris, appears the only option to avoid, or at least to minimize, the shocks connected to unmodified prosecution of current energetic and environmental policies.

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