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Renewable transitions and the net energy from oil liquids: A scenarios study

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ABSTRACT

We use the concept of Energy Return On energy Invested (EROI) to calculate the amount of the available net energy that can be reasonably expected from World oil liquids during the next decades (till 2040). Our results indicate a decline in the available oil liquids net energy from 2015 to 2040. Such net energy evaluation is used as a starting point to discuss the feasibility of a Renewable Transition (RT). To evaluate the maximum rate of Renewable Energy Sources (RES) development for the RT, we assume that, by 2040, the RES will achieve a power of 11 TW (10^{12} Watt). In this case, by 2040, between 10 and 20% of net energy from liquid hydrocarbons will be required. Taking into account the oil liquids net energy decay, we calculate the minimum annual rate of RES deployment to compensate it in different scenarios. Our study shows that if we aim at keeping an increase of 3% of net energy per annum, an 8% annual rate of RES deployment is required. Such results point out the urgent necessity of a determined policy at different levels (regional, national and international) favoring the RT implementation in the next decades.

1. Introduction

The necessity of a global transition to sources of renewable energy production, or Renewable Transition (RT), has now a relevant place in the political agenda as illustrated by the recent commitment of G7 countries and the EU for a future sustainable energy security supply (EC news, may 2015) [1]. But even before this commitment, the last years have seen a very active debate about the need, and feasibility, of the RT in energy policy research. Currently, in climate forums, there is a general agreement that, in order to avoid the climate change most damaging effects and keep the global temperature under manageable limits, the RT must not be delayed anymore. In other words, although some scenarios consider the possibility to extract enough fossil fuels to keep the economic growth and maintain the system in the same way than today [2], the environmental and climatic impacts of keep increasing the GHG emissions would produce in the future disastrous consequences.

On the other hand, the feasibility and pace of the RT has been also a subject of intense debate regarding the necessary resources to be deployed to achieve a 100% global renewable energy system. The debate has focused basically on the amount of energy that could be produced by means of renewable sources [3] and whether renewable energy (mainly wind and solar) can fulfill, by itself, the present and future world energy demands given the inherent variability of renewable energy sources [4,5]. The global renewable potential estimated by different studies ranges between a few Terawatts (TW) [6,7] to the more than 250 TW [8], depending on the methodology used for the calculation.

A second crucial question in this debate is about the requirements in terms of available materials and fossil fuels [9–12]. Previous literature concluded that, in general, except from some critical elements the availability of raw materials required by the RT implementation would not be a limiting constraint. However, it has been found that the full implementation of any RT would require significant increase of raw material production [13], which could be a challenge for the mining industry if other economic or industrial sectors demanded additional material production.

Altogether, the transition to a renewable energy production mix is not a matter of a simple substitution, but the result of huge investments of capital, materials and energy. Following this vein, a subject that still urges to be studied in detail is how much energy would be available for fully implementing the RT in a period during which all or most of fossil fuels will be phased out.

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Such study has to take into account the rate of decline of the net energy available from current fossil fuels. To do so, two factors need to be further investigated and understood. The first one concerns the amount of net energy that the industrialized society would be able to extract from fossil fuels if only the geological constraints are taken into account. That is, how much fossil fuel net energy we will have at our reach? As it is going to be illustrated below, the non-renewable nature of fossil fuels (at the time scale of a few decades) results on a continuous reduction of the amount of net energy for discretionary uses. The second factor to be addressed, in connection with the reduction of the geophysically available fossil fuel net energy, is the pace of development of renewable resources that is required to balance such decrease of fossil fuel energy production.

In this study, we will not consider all the fossil primary energy sources (including gas or coal), but we will focus only on oil liquids because: i) oil (and particularly crude oil) is a key fuel for global transportation (as it accounts about the 94% of the total energy used for transport [14,15]: and, in turn, transport is a key factor in our globalized economy, thus the behavior of oil liquids production is crucial in economic terms for his role on connecting the flows of goods and services worldwide; and ii) this is the resource whose availability has been studied the most, and whose future production evolution, despite the well-known debate [16,17], has reached the largest consensus among the research community. At present the debate is no longer centered on the fact that curves with a maximum and posterior depletion should be used to represent/forecast the oil liquids production behavior, but on the assumptions on Ultimately Recoverable Resources (URR, thus the amount of resources estimation that can be potentially recoverable, on a given date, plus those quantities already produced therefrom) quantification, on the specific strategies to fit and forecast the production (Sorell et al., 2010 [18–20], and on the dependence of peak oil on prices [21].

The environmental burden, in terms of greenhouse (GHG) emissions associated to the geological depletion of conventional oil, has been revised by Berg and Boland (2013) using recent updates of remaining reserves estimations. The results indicate that, even if the concentration levels of GHG would be lower than previous forecasts by the IPCC (SRES2000), the concentration levels still would surpass the critical threshold of 450 ppm when those reserves are used. The introduction of other fossil fuels for a potential transition to oil substitutes, implies an increase of the environmental concerns, as non-conventional oils and synthetic coal-to-liquids fuels could raise upstream greenhouse (GHG) emissions significantly [18] [1]). Coal is environmentally more GHG polluting and its intensive development in the future, as a substitute of oil, would also have deep environmental implications [22–24]. However, a careful analysis of its availability and climate/ecological impacts is required; in addition, coal production is submitted to depletion as well and forecasts indicate that reserves will run out fast [25–27]. Natural Gas has also been suggested to be a valid resource to support future energy needs [28]. On the other hand, natural gas presents similar environmental problems as oil liquids, mainly related to GHG emissions [29], and its depletion is not either in a distant future [30]. identifies five local pollutants (PM2.5, NOx, SO_2, VOCs and NH_3) and one global emission (CO_2) generated by fossil fuel and traditional bioenergy uses which have health effects (arising from outdoor exposure and indoor exposure) and effects on agriculture. The costs derived from health effects are not supported by the producer but for the public sector, and the effects on agriculture cannot be detected by the producers, but they cause a lower global crop productivity that can be quantified. In both cases the costs are externalized out the production process. The total external costs estimated by IRENA for the base year 2010 amounts between 4.8% and 16.8% of global GDP (or USD 3 trillion-USD 10.5 trillion). The wide range is a result of significant uncertainties for costs associated with air pollution, as well as the assumption about carbon prices. The same report concludes that a doubling of the present renewable share would reduce externalities by USD 1.2–4.2 trillion per year in comparison to current policies. However, markets are unable to translate these costs into correct pricing signals and, therefore, a transition away from oil would require an active support form governments.

Due to such sustainability issues, the assumption here analyzed is to assume that, if there is a decline in the net energy coming from oil, and as a consequence, the future global transport and many other economic sectors appear to be in compromise [31], electricity coming from Renewable Energy Sources (RES) should keep the global net energy supply. The approach followed in this paper is first to estimate the time evolution of the net energy provided by the oil liquids, combining the production forecasts by the International Energy Agency (IEA) with the projections about Energy Return On energy Invested (EROI) of oil liquids. This choice is complemented with two models of Hubbert curves with different estimations of Ultimately Recoverable Resource (URR) [32] and [33]. Three models for the tendency of the EROI decline during the next decades have been used (e.g. Refs. [34,35]. Next, assuming that RES will be used and intensively deployed between 2016 and 2040 in order to fill the energy gap between predicted demand and the decreasing oil liquid net energy production, we evaluate the growth rates in the RES implementation in two different scenarios of global energy supply: a plateau of constant net energy production and a 3% annual growth in the total net energy supply till 2040.

One of the missing points in the current discussions about the necessity of the RES deployment is the rate at which they need to be developed and at what time they must be operational. The objective is to give some guidance to policy makers to plan more accurately the rate of development of the RES.

The paper is structured as follows. In section 2, methods, we introduce the concept of EROI, and we carefully review the IEA projections in terms of available energy, which are the primary data in this study. The projections obtained for the scenarios proposed are discussed in section 3, which is devoted to the presentation of results and to analyze the energy requirements for RT and rates of RES deployment. In section 4, we discuss the main results, and in section 5 we show the conclusions and the policy implications derived from this work.

2. Methods

2.1. Energy Return On energy invested

The EROI is a concept introduced by Charles Hall [36] based on the initial ideas used by Odum [37] to account for the use of energy in ecosystems. Therefore, EROI accounts for what might be called useful or net energy. The EROI is given by the ratio between the energy obtained from a particular energy production technology during its life span and the total energy invested during the whole life cycle of the technology; it can be expressed as:

$$\varepsilon = E_p / E_i, \tag{1}$$

where ε is the EROI, E_p the energy produced and E_i the energy invested to obtain E_p. We define the net energy gain of the system (E_n):

[1] We are not formally considering the increasing environmental burden associated with depletion, as it was examined by Refs. [18] and [20].