Energy 35 (2010) 1312–1316

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

The fossil energy/climate change crunch: Can we pin our hopes on new energy technologies?

C. Gonçalves da Silva*[1]

Sandy Bay Consulting Ltd., Rua Maranhão 250/7, São Paulo, SP 01240-000, Brazil

ARTICLE INFO

Article history:
Received 19 August 2009
Received in revised form
3 November 2009
Accepted 15 November 2009
Available online 21 December 2009

Keywords:
Renewable energies
Deployment strategies
Energy costs
Net energy transfer

ABSTRACT

There is a growing perception by society of the risks of dramatic global climate changes due to anthropogenic greenhouse gases, in particular energy related emissions of CO_2. This has spurred a renewed interest in carbon free or carbon neutral technologies for converting sources of renewable primary energy to electricity and to transportation fuels. However, it takes energy to produce energy, even when the primary source is energetically cost free, such as solar or wind. The aim of this letter is to present a model which allows the simulation of the energy costs of the deployment of a new energy technology. We show that the new technology may actually be an energy sink, instead of an energy source, relative to the global total primary energy supply (TPES) for many years or decades, depending on its intrinsic energy costs and deployment path, even though stated aims for its gross energy output are achieved. As expected, the energy payback time of the conversion devices, as well as fuel and maintenance costs are critical parameters. We illustrate the general model with simulations of the deployment of photovoltaic electricity, at global and national levels.

In 2006, the total primary energy supply of the world was 11.741 Mtoe (million metric tons equivalent of oil), or 492 EJ ($1\ \text{EJ} = 10^{18}\ \text{J}$) [1]. The growing perception of the risk of catastrophic global climate change, brought about by increased concentrations of greenhouse gases in the atmosphere, have spurred the search for alternative, carbon free or carbon neutral, renewable, primary energy sources [2]. Among these we have, as main candidates for electricity generation, solar (thermal and photovoltaic), wind, biomass, wave/tidal and geothermal sources [3]. Biomass may also be used to produce renewable biofuels for transportation [4]. For some of the primary sources and technical pathways considered, such as wind, there are fairly well established technologies; for others, however, such as photovoltaic electricity or biomass conversion to biofuels there is need for further research, development, and demonstration [5–7].

Besides public policies and financial investments, the deployment of any new energy technology requires energy investments to produce conversion modules (photovoltaic modules, wind turbines, bioethanol plants…) and, in some instances, feedstock (biomass). Although there are many studies concerned with the evaluation of energy payback times and total energy output from renewable energy sources, as for instance, for photovoltaic electricity [8–13], this work is not concerned with any particular technology, but with general considerations, valid for any technology that may be considered to replace fossil fuels at the terawatts level. Only some key elements of the technology need to be taken into account, as described below.

The implementation of any desirable new energy technology is based on devices that can convert the original primary source either into electricity or transportation fuels, in a carbon free or neutral way. The manufacturing, installation, regular operation, and fuelling of such devices involve an energy cost. The devices have a finite lifetime, after which they must be decommissioned and replaced, bringing in additional energy costs. A new energy technology has to be capable of producing enough energy to cover these costs and to generate a surplus for external consumption. In this letter we examine, under ideal circumstances, the deployment rate for any new energy technology. We want to evaluate the net energy output from the new technology to the existing energy infrastructure for distinct technology parameters, deployment goals, and deployment paths. By net energy output, we mean the difference between the total energy output of the new technology and the energy required to deploy it, either on a year-to-year basis, or cumulated over the deployment period. As we shall see, the assumptions made correspond to a very best-case scenario. Any realistic deployment of the new technology will entail a reduction of its net energy output with respect to the numbers we calculate.

* Tel./fax: +55 1131513265.
E-mail address: sandybay@uol.com.br
[1] Emeritus Professor of Physics, State University of Campinas (UNICAMP), Campinas, SP, Brazil.

0360-5442/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2009.11.013

The basic premises of our approach are as follows.

(i) The technology is supposed to be based on standard modules (modules, simply), which convert a primary energy source into useful energy (for instance, solar or biomass into, respectively, electricity or liquid fuels). The technology itself is treated as a black box. Its internal workings are of no interest to our argument. The module may be as small as a 100 W photovoltaic module or as large as a half million litres a day bioethanol plant. Any real supply system based on the technology in question may be seen as a collection of such modules.

(ii) Each module is characterized by a certain number of parameters. These are:

(a) Z – the total amount of energy produced by one module in one year. This is simply a scale and can be set equal to 1. In this work, we will eventually take Z to be the total energy produced by the new technology in year one and indicate the desired goal of total energy output for the new technology after a certain number of years as a multiple P of Z.

(b) q/Z – the energy payback for the module total energy cost, from manufacturing to fully functional unit to decommissioning, expressed in terms of the number of years of operation of one module required to supply said energy. (By setting $Z = 1$, only q will appear in the equations, but we should remember its meaning.) It is clear that, at least for technologies based on primary sources such as solar and wind, a unique energy payback time cannot be defined. A photovoltaic module in the Sahara, for instance, could have a shorter payback time than exactly the same module in Germany, depending on how it is installed. This illustrates some of the difficulties involved in defining and computing reliably energy payback times. We can only speak of an average value for a given module technology and for a given deployment strategy. In this work, q will be treated as a free parameter.

(c) T – the lifetime, i.e., number of years before the module conversion efficiency drops to $1/e$ of its original out-of-the-box efficiency (left unspecified). This parameter determines the rate of loss of efficiency of the modules, represented by:

$$\varepsilon = \exp\left(-\frac{1}{T}\right). \tag{1}$$

For simplicity sake, we assume an exponential decay, but more realistic descriptions of performance as a function of time can be considered. However, given the weak dependence of our results on T, for accepted values of T, we shall not worry about further refinements at this moment.

(iii) In each year k, a fraction $f(k)$ of the energy produced by the new technology is used to produce new modules. The fraction $1 - f(k)$ is fed into the grid (i.e., is available to consumers). We allow for the possibility that $f(k) > 1$ in some periods, which means that the new technology will actually draw energy from existing supplies.

(iv) Also, in each year a fraction $h(k)$ of the energy produced by the new technology is required to produce "fuel" (i.e., raw primary energy) for its own use in the following year, as well as to be spent in the conversion processes. Naturally, the cost of solar, wind, and geothermal "fuels" is zero, but it is nonzero for biomass fuel. Additional energy costs are incurred in converting the renewable feedstock into other forms of energy depending on the technology, the nature of the feedstock and processes, and the maintenance costs of the conversion modules. All of these energy costs must be taken into account when calculating the net energy exchanged with the grid, but they are irrelevant for calculating the total energy produced by the new technology, which depends, in our model, only on the number of standard modules and their age.

(v) K – the number of years the deployment of the new technology is expected to last, that is, before the new technology enters the mainstream supply of the world's total primary energy supply with an equilibrium growth rate.

All factors of production and installation for the new technology are considered infinitely available, and there are no market barriers for its introduction. Under these circumstances, only the endogenous energy factor may limit its deployment. Obviously, this is a best-case scenario, in terms of deploying a new technology. Any realistic situation will, necessarily, be less optimal than this one.

In order to deploy the emerging technology, a certain amount of energy has to be invested initially from existing sources. After this initial period, we expect the new technology to grow endogenously in terms of energy. Naturally, for reasons other than total energy supply, for instance, imminent and demonstrable anthropogenically induced climate catastrophes, it may be considered necessary to subsidize energetically, for many years, a very promising new technology, in order to accelerate its deployment. But, in the time period considered, the net energy supplied by the new technology may be zero or negative, thus defeating the purpose of increasing the global TPES.

With the assumptions above, we can write the equations, which describe the evolution of the system.

The total energy produced in the kth ($k > 1$) year is given by:

$$E(k) = N(k-1) + \varepsilon(k-1)E(k-1) \tag{2}$$

The first term in Eq. (2) represents the energy generating capacity added in year k by the modules manufactured in year $k - 1$, whereas the second term represents the existing energy generating capacity due to all previously installed modules, reduced by the factor ε representing their diminished performance with age. The initial condition is given by:

$$E(1) = N(0), \tag{3}$$

where $N(0)$ is the number of modules manufactured initially, employing the kick-start energy drawn from exogenous sources. It is worth recalling that, throughout this discussion, the energy scale is set equal to unity. An alternative interpretation of $N(0)$ is to take it to represent any given initial situation, not necessarily that of a nascent technology.

The total number of new modules produced in the kth year, assumed installed and operational in the following year, is:

$$N(k) = f(k)\frac{E(k)}{q(k)}, \tag{4}$$

where $f(k)$ is the fraction of the total energy $E(k)$ dedicated to the production of new modules and $q(k)$, the energy cost of each module.

All other energy costs, including "fuel" costs, are considered proportional to the total energy produced, with a proportionality constant that may vary with time:

$$C(k) = h(k)\,E(k). \tag{5}$$

The energy fed to ($f + h < 1$) or withdrawn from ($f + h > 1$) the grid in the kth year is given by the total energy produced in that year – $E(k)$ – minus the energy spent to manufacture new modules – $f(k)$ $E(k)$ – minus the energy spent to maintain and operate the existing modules – $C(k)$: