Technological Forecasting & Social Change 96 (2015) 266–276

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Long term dynamics of energy systems: The Italian case

Paolo Vestrucci [a,*], Serena Schiavi [b], Carlo Maria Orlandelli [a]

[a] *Department of Industrial Engineering, University of Bologna, Bologna, Italy*
[b] *G.D SpA, Manufacturer Company of Bologna, Bologna, Italy*

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 22 December 2014
Accepted 17 January 2015
Available online 1 May 2015

Keywords:
Energy system
Logistic substitutions
Market penetration
Energy modelling
Energy transitions

ABSTRACT

This paper analyses the dynamics of the Italian energy system, considering a long period of time: 1861–2010. The worldwide context is considered too, for the sake of comparison and in order to have a general framework. The aim is to uncover and characterize the mechanisms governing primary energy substitutions. The logistic replacement model is used, following the IIASA approach. Some characteristics of energy substitutions – such as penetration regular patterns, great inertia, de-carbonization – are verified, as well as some features not explained by the model — such as the coal resistance during the last few decades. Some particular aspects of the Italian system are highlighted; in particular – although Italy does not have nuclear energy production – according to the model it can be considered a country with an appreciable nuclear energy contribution to national consumption.

1. Introduction: *post*diction vs prediction

Fig. 1 (Weingart and Nakicenovic, 1978) shows a series of predictions for energy consumption in the United States dating back to 35 years ago. Whereas there is only *one* past, an almost *infinite* series of future scenarios were posited, as if all of them were possible, irrespective of the immediate past, as if we lived in a world without memory. The figure is even more significant if we add the actual energy consumption in 2010 (dark circle): it was estimated fairly accurately only by scenario 12, based on the limiting hypothesis of zero economic growth, and by scenario 5, based on entirely unrealistic hypotheses about the development of alternative energy sources. In both scenarios, the most accurate predictions were provided by assumptions and hypotheses that were utterly unfounded and unrealistic!

Aware of the difficulty in making predictions or, to put it aphoristically with Niels Bohr: "Prediction is very difficult, especially about the future", this article has the aim of presenting some *post*_dictions of the development of Italian energy, with some reference to the worldwide context, studying its history from 1861 onwards. In other words it does not make *pre*_dictions. Nevertheless, investigating 150 years of energy development leads to some thoughts and questions about what may happen in the future.

The *post*dictions, i.e. the analysis of the past with the aim of uncovering the mechanisms, laws and rules, are developed in particular via the use of models of logistic replacement for the energy sector as applied at IIASA in the seventies (Marchetti and Nakicenovic, 1978).

The data base used can be found at www.datienergeticiitaliani.ing.unibo.it, and is described in the book "L'Italia e l'energia" — Italy and Energy (Vestrucci, 2013).

2. Energy fractions and energy penetrations

The energy balance adopted to aggregate and represent energy data broken down into their various sources is based on production, imports, exports and bunkers (international marine bunkers).

Quantifying these items gives the Primary Energy Consumption (or Apparent Internal Energy Consumption), obtained from the balance according to the following formula:

$$\text{PRIMARY ENERGY CONSUMPTION} = \text{PRODUCTION} + \text{IMPORTS} - \text{EXPORTS} - \text{BUNKERS}.$$

* Corresponding author at: DIN Viale Risorgimento 2, 40136 Bologna, Italy. Tel.: +39 051 2087708.
E-mail address: paolo.vestrucci@unibo.it (P. Vestrucci).

http://dx.doi.org/10.1016/j.techfore.2015.01.020
0040-1625/

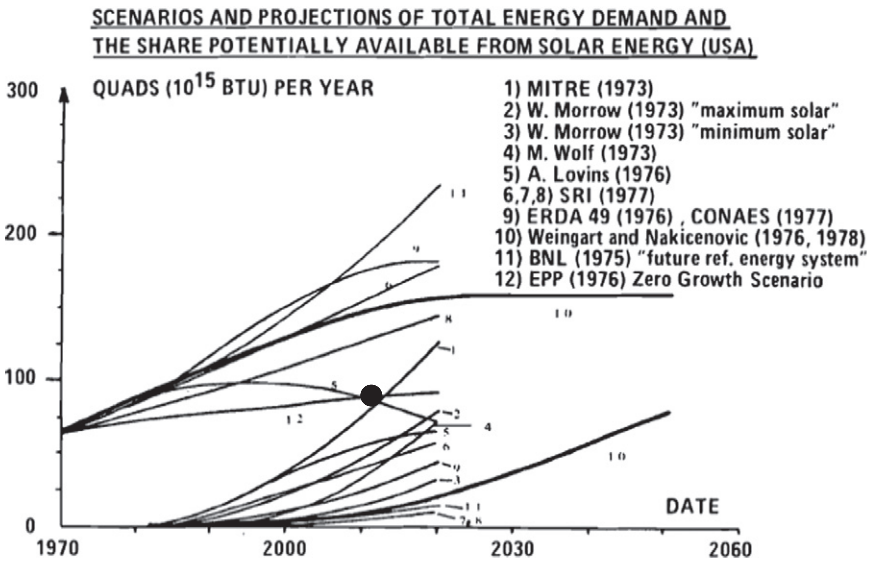

Fig. 1. USA — past scenarios and projections of total energy demand (Weingart and Nakicenovic, 1978). The 2010 data is added with the black circle (1 quad ≈ 1055 GJ).

Electrical energy is transformed into quantities of energy using the energy equivalent required to produce it in an "average" Italian power station, both for the production of primary energy and for import–export.

Using the energy balance, the fraction (i.e. the market share) of the Italian energy market occupied by one primary energy "i" can be calculated as

$$F_i = C_i/C \times 100, \text{ in percentage terms, or}$$
$$F_i = C_i/C, \text{ as a fraction,}$$

where C_i is the primary consumption of the energy source "i" and C is the total primary energy consumption. Naturally, the sum of all F_i is equal to 100 (or 1 as a fraction).

The imports and exports of electrical energy constitute a special problem, without a single solution: how should the data be handled? If we treat the import and export of electrical energy like the import and export of a primary source, then the apparent internal consumption derived from it should be used without alteration in calculating the fraction. But electrical energy is a secondary source derived from other primary energy sources and considering it a primary source is equivalent to assuming that all imported and exported energy is hydro/geoelectric, for example. In Italy, over the past decades, since the import of electricity became significant, various methods have been used, each according to a particular logic (as shall be shown) but with different numerical consequences. For example, in 1995 the percentage of primary electrical energy in the market was 11% or 6% according to whether import–export is or is not considered a primary source. For the moment we will consider the import–export of electrical energy as a primary source, altering as little as possible – but other hypotheses could be quite different and no less legitimate – the data relating to coal, crude oil and gas. However, it should be remembered that this decision leads to an overestimation of the fraction of hydro- and geo-electrical energy from the eighties onwards.

The cited source (Vestrucci, 2013) gives the fraction numerical values, shown here only graphically (the thin lines in Fig. 2).

For every energy source it is – in general – possible to observe a period of initial growth (very slow and uncertain at the beginning, exponential later), an intermediate period in which the energy source achieves the maximum percentage of the market, dominating the others, and a period of decline – not without oscillations – in its market share.

The mechanism for the replacement of energy sources can be shown more effectively considering a penetration P_i of energy source "i" defined as

$$P_i = F_i/(1-F_i),$$

where F_i is expressed as a fraction ($0 \leq F_i \leq 1$).

The Italian market penetrations of the energy sources for the period under examination are shown graphically – by the thin lines – in Fig. 3.

The logarithmic scale shows the three periods for an energy source, its growth, maximum development and decline, as well as the different "waves", each corresponding to one energy source. Below, these characteristics are interpreted – as in a model – as a genuine process of logistical replacement.

Very similar fraction and penetration patterns can be found in all industrial countries worldwide (Marchetti and Nakicenovic, 1978; Smil, 2010; Malanima, 2011). In order to offer a term of comparison for the Italian case, in this paper the world case is considered. For the world, trends in fractions are shown – again with the thin lines – in Fig. 4, and penetrations in Fig. 5. The trend is very regular: on a semi-logarithmic scale, energy sources penetrate in a linear fashion, become saturated, then decline, again in a linear fashion. The figures for coal, from the seventies onwards, show a considerable deviation (both at national and worldwide level), something we will be returning to. The data relevant to the world are from IIASA (Marchetti