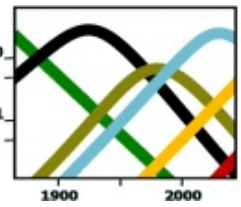
The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Marchetti's Curves

Posted by Luis de Sousa on July 10, 2007 - 10:30am in The Oil Drum: Europe
Topic: Supply/Production
Tags: energy market, energy substitution, energy systems, marchetti [list all tags]



This is a brief account of the Energy Susbstitution Model developed by Cesare Marchetti in the 1970s at IIASA. Using data from the latest BP Statistical Review the evolution of the energy market is compared with the model to understand why the Hubbert Peak of fossils fuels represents a problem today.

The early Energy Substitution Model is described and analyzed in detail in the following papers:

Marchetti, C., 1977
Primary Energy Substitution Models: On the Interaction Between Energy and Society,
Technological Forecasting and Social Change, 10:345—356

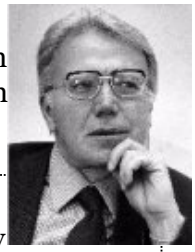
Marchetti, C., 1979
Energy Systems -- The Broader Context,
Technological Forecasting and Social Change, 14:191—203

Marchetti, C., and Nakicenovic, N., 1979
The Dynamics of Energy Systems and the Logistic Substitution Model part I part II,
RR-79-13, International Institute for Applied Systems Analysis, Laxenburg, Austria

These documents often offer an optimistic view of the future, characteristic of the author.

This post in large measure addresses the "Energy source X will do it" claims, and can be considered part the Contrarian Arguments series.

A lifetime of research



Cesare Marchetti was born in Luca (Italy) in 1927 and got a degree in Physics from the Scuola Normale at Pisa in 1949. We would then leave Academia to never return back. In his own words:

> I found University too constraining and in many ways petty, so, after my degree in physics, I chose to start free roaming, an attitude I did conserve for the following 50 years of my career.

By 1950 he was already working on Nuclear energy, researching heavy water reactors at CISE (Centro Informazioni Studi Esperienze). Later in the decade, after roaming some time in Argentina and Switzerland, he joined Agip Nucleare (now part of ENI) where he researched gas-

cooled reactors.

In 1959, with Agip Nucleare going to state hands, Marchetti joined Euroatom with his 50 person team assembled at Agip. In a few years he had one lab in Italy and another in the Netherlands.

It was during this time at Euroatom that Marchetti and his team produced the most lasting results: the concept of Hydrogen as an energy vector and a "Hydrogen Economy", the concept of the Atomic Isle and the self sinking of radioactive waste away from the Earth's crust. All of this still in the 1960s.

In 1973 Marchetti joined the recently assembled IIASA, in his words to veer away from an hostile environment at Euroatom. He started researching on energy with the intention of staying for some months, but a continued comfortable relationship kept him there for the rest of his life.

It was at IIASA that Marchetti brought successfully to energy systems analysis the simple concepts of logistic growth from the biology sciences. Although Hubbert had reached similar conclusions in the 1940s for the case of Oil, Marchetti widened the concept of deterministic behaviour of energy systems.

Beyond energy, Marchetti would study innovation, population dynamics, transport systems, war, banking and much more, using the same concepts of logistic predictive modeling.

An interesting auto-biography is available here.

The energy substitution model

The first problem Marchetti took on, after joining IIASA, was to find a long term energy market model, at the time an uncommon idea:

> The first problem was to meet a challenge set by our boss for the energy group Prof. Haefele, physicist and theologian: to find a simple and predictive model describing energy markets for the last century or so. For the beard of Newton.

Marchetti tried using logistic curves to describe the way energy sources enter and leave the market. Using the Fischer-Pry analysis technique he plotted the share each energy source had on the market. This kind of analysis was introduced as a tool to study the market penetration of new technologies. Simplifying, this approach consists in calculating the market share of each energy source, F, and then calculating $F / 1 - F$.

The interesting thing about this representation is that on a logarithmic scale a new element entering the market following a logistic curve will describe two straight lines, one during the growth period, another during the decline period, connected by an arch at the peak. Further insight on the Fischer-Pry analysis can be found here.

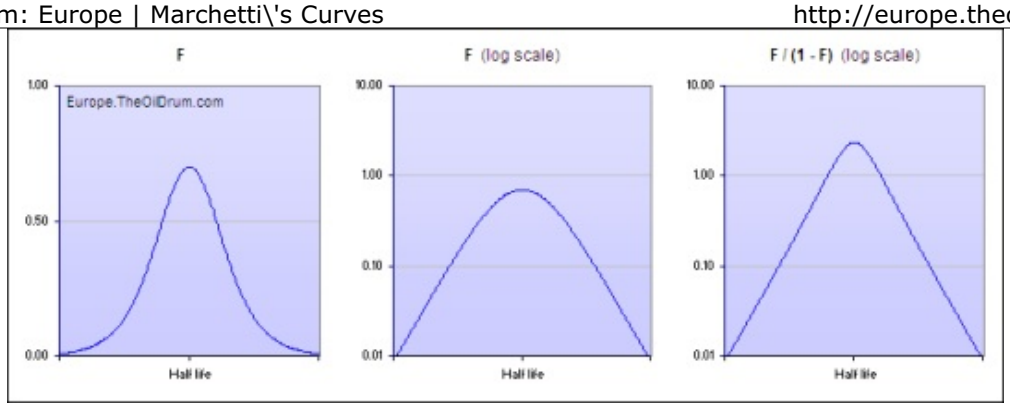


Figure 1 – Using the Fischer-Pry representation for a Hubbert curve. Click for full image.

Using data for Wood, Coal, Oil and Natural Gas, Marchetti found indeed that the long term market penetration of these energy sources was ruled by logistic growth and decline. In his first paper on the Energy Susbstitution Model [pdf] from 1977 the results published were these:

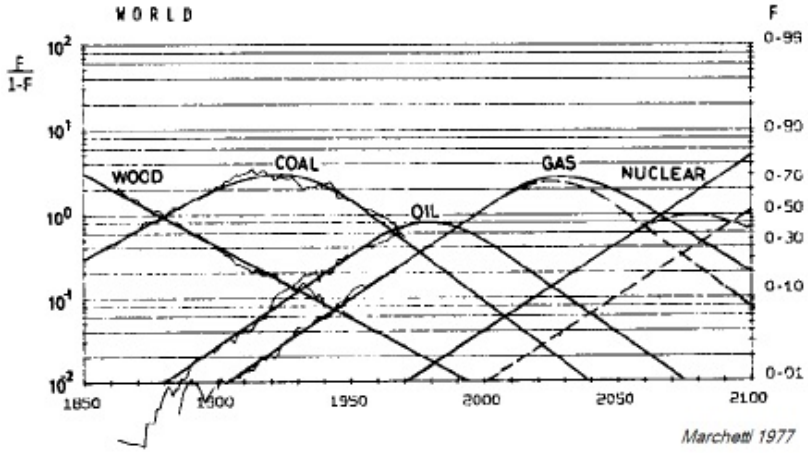


Figure 2 – The Energy Substitution Model identified by Marchetti in 1977. Click for full image.

Marchetti didn't use hydroelectric power in his analysis, probably due to lack of data. Hydroelectric energy has never penetrated more than 6% into the market; its absence changes little to the final result.

Beyond those elegant curves drawn in a logarithm-scale by the Fischer-Pry technique, this chart showed a very important thing: all of the Industrial Age energy sources follow a similar trend when entering the market. It takes 40 to 50 years for an energy source to go from 1% to 10% of market share and an energy source that eventually comes to occupy half of the market will take almost a century to do so, from the epoch it reaches 1%.

Internal Clocks

"Internal clocks" was a term Marchetti used to put in simple ways the deterministic behaviour of the energy market observed in the 1970s. From his analysis it seemed clear that energy sources enter and leave the market on a pre-determined fashion, beyond outside control.

Later, in 1978, Marchetti was invited to address the methodology of energy systems analysis at

the IIASA Third Energy Status Report. A written version was published in 1979 entitled Energy Systems – The Broader Context [pdf] where he took a somewhat informal approach on the subject:

> I am originally a physicist, a bit of the Bridgman school, and I always try to find an operational description of certain statements. The best operational description for our case is that of Alice in Wonderland who sees flowers and flowers, picks them, and then sees better flowers, so she throws the old flowers away and so on.

Marchetti also tried to grasp who decides which flowers Alice picks:

> But the question now is who pick the flowers [...] perhaps politicians, or the heads of large companies, are decision makers. Well, I had long discussions with them and a lot of them say: "We *seem* to be decision makers but we are so strongly conditioned that finally we don't recognize any decision in our decisions. We are just *optimizers*."

But a subtle warning remained; the market doesn't have to evolve exactly as the models predict:

> Waiting for more insight, I would suggest not underrating the built-in wisdom of the system. As Nakicenovic showed, a "natural" phase-out of the old primary energy sources, and a phase-in of nuclear and perhaps of a new source around year 2020, may provide a smooth transition, with no muddling whatsoever, to the year 2030. The real constraints appear to be not in the realm of physical resources, but in that of international cooperation. There perhaps decision makers (optimizers!) should concentrate their action.

All of this was written before Iraq invaded Iran removing 8 Mb/d of Oil from the market almost overnight.

Looking at it today

Thirty years later it is interesting to see how the market behaved. Using the data from the latest BP Statistical Review of World Energy, the result is the following:

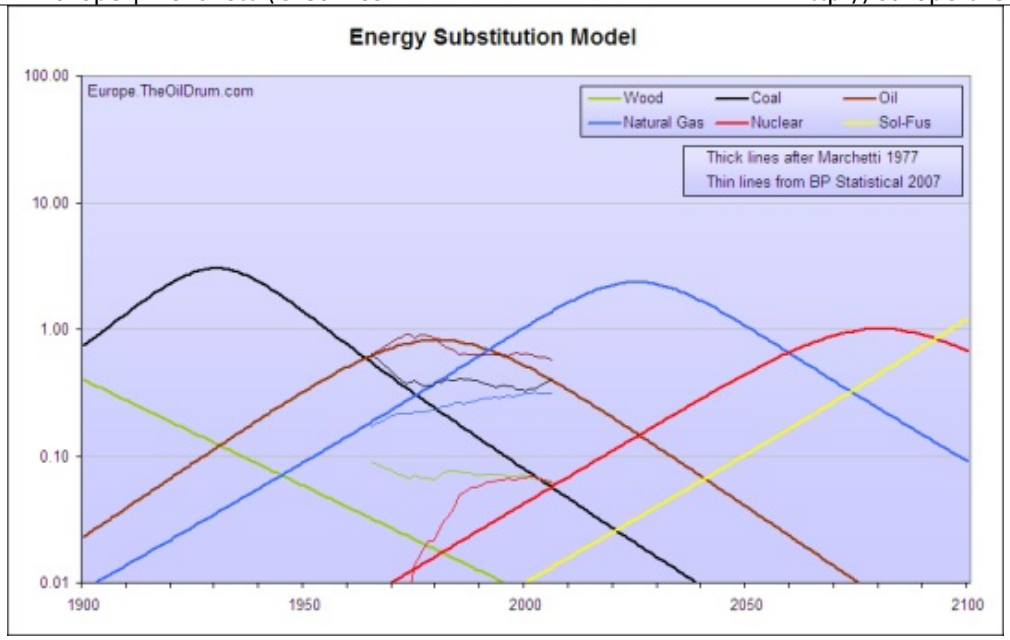


Figure 3 – The Energy Substitution Model from 1977 and data from the BP Statistical Review of 2007. Wood fuel data from FAOSTAT. Click for full image.

In large measure the real data moved away from the model of the 1970s. This was probably due to the Oil shocks that upset the market, but the prolonged effects are not as easily explainable. What immediately emerges to view is that after the Oil crisis was surpassed in the 1980s, the market seems to have frozen, with each energy source maintaining its market share.

A closer look to each source is useful.

Wood

Marchetti only had data for Wood up to 1950 and extrapolated future production falling and loosing market share in line with the previous trend. FAO has published data for wood fuel consumption since 1961 that is considerably higher than the curve Marchetti projected. Wood fuel consumption data is something considerably hard to assess, and even FAO has preformed considerable revisions in later years. The discrepancies can be attributed to poor quality of the data prior to 1950, but the current trend in consumption is markedly different from what the model projected, still growing although not as fast as the Fossil Fuels.

Coal

Coal was following a logistic phase-out of the market when the Oil shocks came; it immediately stopped losing share. Since the year 2000 Coal has been moving upwards and looks as the best candidate to take Oil's dominant place, as soon as the former peaks.

Oil

Interestingly, although Oil was the most battered energy source since the 1970s, it is the one following closer the substitution model. This means that Marchetti probably underestimated Oil's trend which was bound to hit the 50% market share in the 1990s, soon before peaking. Today Oil is clearly loosing ground and will likely follow a downward trend not far from that inscribed in the model.

Natural Gas

Unlike Coal, Natural Gas was already in an alternate trend at the start of the 1970s. By then the understanding of this energy source was not the same it is today, and the model looks highly optimistic. The underestimation of Oil is probably reflected here in an overestimation of Natural Gas. Still it is interesting to see that the projected peak in market penetration by 2030 is in the same epoch of the presently expected production peak.

Nuclear

Marchetti expected Nuclear to enter the 5-10% interval by the year 2000, but that happened much sooner, Nuclear went over 5% in 1987. Up to the 1990s Nuclear energy greatly surpassed his expectations in the wake of the Oil crisis (which facilitated market penetration) but as liquid hydrocarbons production started growing again, Nuclear's penetration in the market slowed down. By 2000 it hovered around 6.5%, but has fallen below 6% since then.

An interesting thing to note is that Nuclear is today very close to what Marchetti's curve showed it would be. The difference is that the trend is currently downwards, while Marchetti expect the world to be entering the Nuclear Age by now.

Sol-Fus

There isn't much to say about alternative energy sources, except that they never shown up. As a benchmark, Wind energy occupies today 0.2% of the energy market, a point Nuclear energy crossed still in the 1950s.

Looking ahead and back

What is the importance of the Energy Substitution Model? It seems that it broadly failed to achieve its intents: to predict future market dynamics.

First of all it is essential to observe that the growth trends were only broke during the Oil crisis, Nuclear energy's spectacular growth occurred between 1975 and 1985. Besides this brief event never the growth trend was surpassed.

Most important of all is to understand what didn't happened. Although Nuclear is today very close to where Marchetti expected it to be, it is in a clear downward trend, that even in the face of Peak Oil might not immediately reverse.

The last time an energy source crossed over 1% share of the energy market was **35 years** ago. The last time an energy source crossed over 10% share of the market was more than **50 years** ago. **This is why the Hubbert Peak is a problem today**.

To have a new energy source with 10% of the market by 2010, it had to have crossed the 1% threshold by 1970 the latest. Using the same metaphor, It seems that Alice feel in love with some flowers and forgot about picking more.

Does this mean that abandoning Nuclear energy was an error? Possibly. But more relevant than abandoning Nuclear energy was doing it without opting for an alternative. Abandoning Nuclear could have been an option back in the 1970s if a clear alternative had been pursued with proper research and development.

Naturally, in exceptional times a new energy source can penetrate the market much faster than the pace predicted by the model. Either by Society's commitment to it, either by the decline of other sources, a new element can rapidly take its share, like Nuclear did during the Oil crisis. But

these are exactly the disturbed times Society should avoid.

Finally it is important to stress that Oil is much more than an energy source today. It is the world's most important manufacturing commodity, paramount to most industries, from Pharmaceuticals to Civil Construction, from Electronics to Clothing. And above all, the base of modern Agriculture.

Will Society ever be able to plan in advance for multi-decade cycles?

Luís de Sousa
The Oil Drum : Europe