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"Energy transition": Ambiguity of the notion of variable geometry

Christian de Perthuis[1]

The "great debate on energy transition" launched by the French government in response to the Copenhagen environmental conference is arousing considerable interest and has captured the attention of the media. What is now on the agenda is no longer action on climate change, but energy transition, of which the climate seems to be only one of the components. This semantic drift, seen abroad as well as in France, is not innocuous: the concept of variable geometry can in fact justify policy orientations and strategies that turn their back on the issue of climate change. It is urgent to define more rigorously what is referred to as energy transition and what type of energy transition one wants to implement. The implications are important for decision-making, as shown by the issue of shale gas, which is used here as an illustration.

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1. University Paris Dauphine and Climate Economics Chair
Christian.deperthuis@chaireeconomieduclimat.org

Climate Economics Chair
Paris-Dauphine University
CDC Climat

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Christian de Perthuis
University Paris-Dauphine, Climate Economics Chair

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Since the Copenhagen conference of December 2009, the actors involved in climate negotiations seem be engaged in a game of mistigri, in which everyone is in a hurry to pass on any card that exposes them to the slightest commitment. The overall result is that deadlines are being pushed back, and the prospect of an international agreement coming into force from 2020 now seems optimistic in the extreme. The economic crisis has accentuated this turning away from the climate issue, or at least its decline in policy makers' scale of priorities. A curious semantic shift has accompanied this phenomenon: there is much less talk of global warming, while the media have turned their attention to the concept of energy transition. This shift is not innocuous, and may lead, if this novel concept is not defined more rigorously, to a justification of our collective resignation in the face of climate risk.

A variable geometry concept

If governments are finding it difficult to agree on ambitious policies to mitigate climate change, a consensus seems to be emerging around the concept of "transition energy", a concept recently introduced into the long-term scenarios of the International Energy Agency (IEA). The appeal of this concept is its malleability, which enables very different or even diametrically opposed policies to be justified. This is probably what explains its success with policymakers, at a time when environmental issues have fallen considerably in their scale of priorities.

In the United States, energy transition consists primarily of reducing the country's dependence on hydrocarbons imported from the Middle East. It justifies the large-scale deployment of new drilling technologies with a view to transforming an importer of liquefied natural gas and oil into a major producer of unconventional gas and oil. In the most ambitious[1] (but unrealistic) scenarios, shale gas, the new domestic miracle resource, is forecast to replace conventional fuels in one in every two American vehicles by 2020 and to extend the use fossil fuels well beyond what could have been foreseen only a few years ago.

In Europe, the same concept justifies the implementation of policies, ambitious on paper, aiming simultaneously to reduce greenhouse gas emissions, promote renewable energy and encourage energy efficiency. But as soon as we dig a little, it becomes apparent this package comprises uncoordinated and sometimes contradictory national strategies: in the name of energy transition, Germany is abandoning nuclear energy, the United Kingdom is seeking to return to it, and Poland to adopt it, while in France a major public debate around nuclear energy is under way.

In emerging countries, energy transition is primarily intended to ensure adequate supplies to meet the needs of industrialization and the massive demand of households, among which an increasing proportion aspires to the standards of the middle class in rich countries, both in terms of housing and mobility. In just a few decades, it is seeking

[1] Robert Hefner, *The GET: The Great Energy Transition*, Hoboken, HJ : Willey, (2009)

to accomplish a transformation that took more than a century in the rich countries, and to move from an energy system based primarily on the use of biomass to one dominated by coal.

In countries producing and exporting fossil fuels, energy transition is a concept that justifies using the rent procured by the exploitation of their underground resources to diversify the economy, including within their own energy supply system. Other than in advertising campaigns, little diversification actually seems to have occurred, particularly in the Gulf countries, even though they are richly endowed with sunshine and unoccupied land with plenty of wind.

With regard our own society's commitment to greening the economy, it is important to make a clear choice on the type of energy transition we want to implement. In his major work on the subject, Vaclav Smil notes that "two reasons for moving toward non-fossil futures stand out at the beginning of the twenty-first century: concerns about long-term effects of global climate change, and worries about rapidly approaching depletion of low-price, high-quality fossil fuels[2]." The type of transition to adopt is, however, very different depending on which of these two concerns is emphasized. To understand all the implications, it is worth recalling the role played by energy transitions in human history.

What is an energy transition? The lessons of history.

Following Smil (2010), we can view an energy system as a complex structure defined at three levels: the particular mix of primary energies used, their transformation by "prime movers", and the patterns of end-use, all of which are supported by a combination of tangible and intangible infrastructure with a high inertia over time. We speak of transition when this complex system changes from one dominant configuration to another. We find this triptych in Rifkin's book on the "third industrial revolution", which has received much more media attention than Smil's book, even though it lacks Smil's historical depth and analytical rigour[3].

Smil identifies four energy transitions that have marked human history. The first concerns the taming of fire, which gave the human species a major advantage over its competitors through the use of this energy for cooking, heating and, later, smelting metal. The second was initiated by the Sumerians who, thanks to irrigation, first succeeded in increasing crop yields, enabling them to feed domesticated animals and to adopt a settled way of life. In terms of energy, the revolution consisted in augmenting human muscle power with animal traction. For ploughing fields and transporting crops, productivity increased by a factor of between four and six.

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[2] Vaclav Smil, *Energy Transitions : History, Requirements, Prospects,* Praeger, Santa Barbara, California, 2010. (P107).

[3] Jeremy Rifkin, *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*, Palgrave Macmillan**,** 2011

The third energy transition, which began in England at the end of the 18th century, vastly increased the amount of energy used, through the large-scale use of an additional primary source, namely coal, which replaced wood and human and animal muscle power around 1900 and became the world's primary source of energy until the mid-1960s. Often presented as the energy of the 19th century, coal only began playing a significant role in the world energy system after 1880 and widely supported the industrialization of the 20th century. The technical innovations at the origin of its use were available from the mid-18th century. Thus about 150 years separate the technical innovation from its large-scale adoption, which transformed the economic system.

The fourth energy transition was based on a cluster of innovations that arose simultaneously during the last two decades of the 19th century and allowed the harnessing of electricity (generation, transmission, and use in lighting and then industry) and the development of the internal combustion engine operating on gasoline or diesel. We here see two of the three major technical innovations identified by Gordon in his analysis of the growth process[4]. In fact, the spread of these innovations is the source of successive growth waves over the course of the 20th century. It resulted in falling prices, which made possible the extensive use of new goods and services, such as the light bulb. Roger Fouquet makes clear that reduced cost of lighting occasioned by the move from candles to oil lamps to town gas and then incandescent bulbs was comparable to falling price of computer memory today[5]. Many goods would follow, from washing machines (the first models became available in 1907 in the United States) to computers and the various forms of modern transport. Their accumulation drastically altered ways of life and created the conditions for the mass consumption that underlies the rapid growth of the last fifty years. Again, many years separated the first appearance of such technological innovations, which occurred mostly before 1900, and their impact on growth which made itself fully felt only after 1950.

In terms of energy, this fourth transition involves two major changes. Firstly, it allows energy consumption to rise exponentially through the mobilization of the three primary sources – oil, coal and gas – which provide 80% of the world's energy consumption. In 2010, this consumption was about two tonnes of oil equivalent per capita worldwide (7.5 tonnes in the United States, 3.5 in Europe, 1.8 in China, and less than 1 in India and Sub-Saharan Africa). At the beginning of last century, the estimated figure is the equivalent of 400 kg of oil at most. Secondly, the system is organized around a sophisticated physical infrastructure that ensures the extraction, processing and

[4] See his meticulous analysis of the digital revolution "Does the New Economy Measure up to the Great Inventions of the Past?", *Journal of Economic Perspectives* 14 (Fall 2000, N°4) and his more recent paper *Is US Economic Growth over? Faltering Innovation Confronts the six Headwinds*, CEPR, Policy Insight N°63, September 2012.

[5] Fouquet, R. and P. Pearson, "Long Run Trends in the Efficiency Cost and Uptake of Lighting Services: Implications for Current Policies", *Economics of Energy and Environmental Policy,* 2012, IAEE, 1. According to these authors, the price of lighting in the United Kingdom is divided by a factor 3000 between the years 1800 and 2000.

distribution of these energies. Added to which is intangible infrastructure, such as the markets and institutions that regulate a now highly complex system.

The first four energy transitions were the result of the ingenuity of men who went beyond the limits imposed by the scarcity of usable energy. As we have seen, this ingenuity led to remarkable gains in efficiency that have been reflected in an ever increasing use of energy since the beginning of the industrial revolution. As Jevons noted in his celebrated essay on coal: "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth[6]." Its reduced cost of use in fact led to a massive increase in its use.

The fifth transition: not enough or too much oil and gas?

The fifth energy transition will free the energy system from its addiction to today's three dominant fossil fuels. Its point of arrival will be a low carbon energy system, since reserves of such fuels, which emit carbon into the atmosphere, will be exhausted in proportion to their use. As suggested by history, this transition will be a process spanning many decades and may not be completed by the end of the century. The time required for technical innovations to exert their full effect on the functioning of the economy seems unlikely to be reduced. But the way we approach this transition and the paths taken early on are not insignificant in terms of climate risk management. Two typical scenarios are possible, depending on the importance attached to the stability of the climate.

a/ Is it a matter of finding the optimal path to respond to the diminishing stock of fossil fuels? If so, the way markers of the route are provided by energy prices, which will express their relative scarcities. In the very long term, the increasing scarcity of fossil fuels must be reflected by an increase in their prices due to the formation of a rent associated with the gradual depletion of the stock. This rise firstly encourages energy efficiency and progressively makes investments in renewables cost-effective. But it also tends to stimulate exploration, and energy transition becomes compatible with a prolongation of the use of fossil fuels once new deposits are found. In addition, the very bullish long-term outlook for scarcity rent becomes blurred whenever these incentives for investment in exploration lead to new discoveries that create temporary abundance: this was the case with the oil countershock that occurred in the 1990s, and is currently happening with shale gas and unconventional hydrocarbons in general.

We are here in a classic "Hotellinian" situation (from Hotelling, the economist who theorized the optimal exploitation model of a stock of exhaustible resources on the basis of rent).

The choices made by North America and oil exporting countries fall within the first scenario – a matter of replacing or supplementing the fossil fuels currently used with

[6] William Stanley Jevons, *The Coal Question: an Inquiry Concerning the Progress of the Nation and the Probable Exhaustion of our Coal Mines*, 1865, Macmillan, London (P.140).

other primary sources as these become less expensive. Thus it involves continued reasoning within the framework of a system limited by a set of scarce resources, of which we do not currently know how much can be extracted in the future, given changes in economic and technical conditions. In accordance with the Hotellinian scenario, the scarcity of the reserves generates a rent transmitted by energy prices to the producers, who are strongly incentivized to increase their investment in exploration. The experience of the last fifty years suggests that we are far from having exhausted all the known or unknown deposits, not to mention the potential represented by methane hydrates, which contain probably more energy than coal, oil and natural gas combined.

The energy transition implied by the preceding scenario eventually concludes with the gradual reduction of greenhouse gas emissions. The trajectory will be determined by the complex effects of the long-term increase of fossil fuel prices on supply and demand, with transient stages of fossil energy abundance reflected by bearish price cycles.

Given the great inertia of the energy system referred to by Slim and the powerful incentive to use oil and gas rent to increase investment in exploration, there is little chance that this type of trajectory is consistent with those required to limit the risks of climate change. According to IPCC estimations, the amount of carbon tied up in the form of fossil fuels underground is approximately four times the amount present in the atmosphere, mainly in the form of carbon dioxide. Burning just a quarter of these underground resources would double the atmospheric concentration of CO_2, with consequences for the climate system that difficult to predict. Yet adjustments on energy markets in their conventional operating mode spontaneously lead to such a scenario.

b/ Is the objective finding an optimal path in terms of greenhouse gas emissions trajectories to protect the stability of the climate, while taking into account the constraints of competitiveness and energy security? In this case, the energy transition strategy is quite different, because there is too much carbon in the stock of fossil fuels underground in relation to what the atmosphere can absorb without risk for the stability of the climate. However, the Hotellinian logic described above creates powerful incentives to recover an ever larger proportion of fossil fuel reserves[7]. It is therefore necessary to "force" the transition by introducing a new value into the equation, namely the scarcity of the atmosphere expressed by the price of the right to emit carbon, in other words, the carbon price. It is important to introduce the price from the start of the transition, because climate change is linked to the amount of greenhouse gases in the atmosphere and not to the annual emissions flow. The cost for the climate of a tonne of CO_2 emitted today is higher than that of a tonne emitted fifty or a hundred years from now.

[7] This point has been elaborated in various papers written with Pierre-André Jouvet. See: Pierre-André Jouvet and Christian de Perthuis, “La croissance verte: de l’intention à la mise en œuvre”, *Climate Economics Chair Cahiers, Information and debates series,* N°15, June 2012.

The transition required to protect humanity from the risks of climate change cannot therefore proceed without introducing of powerful incentives to avoid Hotelling's "curse of natural resources". These incentives could come from a combination of standards and regulations, whose cost, not expressed by a price, might be prohibitive for society. It is more effective to rely on public policies that incorporate the value of climate stability into the functioning of the economy. This value is currently known as the carbon price. Such a price is the only instrument that can provide the right incentives both to the demand side (energy efficiency and substitution of fossil fuels by renewables) and to the supply side (reorientation of investment flows toward low carbon). Above a certain level (currently estimated at €60-90 per tonne of CO_2 in Europe), the price of carbon also encourages the use of new carbon capture and storage techniques that would allow fossil fuels to be used in future with virtually no greenhouse gas emissions. Without such carbon pricing, which can be introduced through allowances markets or taxation, any energy transition strategy results in too much carbon being emitted into the atmosphere, as shown by the example of shale gas.

Shale gas: an energy transition to limit climate impacts?

The development of new extraction methods (horizontal drilling and hydraulic fracturing) has enabled the large-scale exploitation of unconventional gas to be launched in the United States. In the absence of carbon pricing and the currently almost non-existent pricing with regard to other environmental damage associated with its extraction (on land and natural areas used, the underground impact of fracturing, seismic risks, etc.), production costs are generally estimated in the range of about 5-7 dollars per thermal unit. Their accelerated development has reduced the market equilibrium price of gas to below $5 per thermal unit in the United States, against $9-10 dollars in Europe and more than $15 in Asia. Due to the abundance of North American reserves, the development of gas is the main vector of the U.S. energy transition. Gas has begun to replace coal in electricity generating plants. It is leading to a major relocation of the fertilizer and chemicals industry, using gas as its raw material. Its transportation applications are being rapidly developed, with the stated objective of reducing the proportion of imported oil. This economically consistent strategy is also presented by its promoters as virtuous from the standpoint of the climate, thanks to the decline in the use of coal.

This vision masks the real climate issues. Firstly, account must be taken of fugitive methane emissions associated with the development of shale gas exploitation (see the box below on this controversial topic). In particular, it is incorrect to say that the Wyoming coal that is no longer used by U.S. power plants is automatically a gain for the climate: a large part of the surplus made available has already made its way to Europe and Asia, where it results in a symmetrical substitution from gas to coal, since the relative prices of these two fuels for electricity producers is gradually being reversed. In Europe, this substitution of coal for gas is economically viable because the European CO_2 emissions trading scheme is in a dangerous phase of disintegration and will no longer allows a real carbon price signal to be sent. More generally, this type of transition leads to a very dangerous scenario for climate stability at the global level, as soon as shale gas is added to the coal resources used rather than replacing them.

Taking into account unconventional gas deposits has led to a massive re-estimation of global reserves: the IEA has upwardly revised probable reserves of gas from 60 to 230 years at current extraction rates. This is equivalent to a fourfold increase in the estimated amount of greenhouse gases that could be released into the atmosphere through the use of gas sources. In the absence of CO_2 pricing, it is almost certain that the majority of these new sources will be added to and not substituted for coal, as has already begun with exports of U.S. coal. This type of energy transition lands us directly in scenarios where much too much fossil energy is used, given the climate risk involved. That is the primary lesson to be learned from the development of shale gas: in the absence of pricing of environmental and climate externalities, the energy markets do not permit the requisite decisions to be made to ensure the transition of our energy system to a low-carbon target.

Faced with this situation, how is Europe responding? Initially in a very disorganized way! Poland and Ukraine were the first countries to grant exploration licenses to the major oil companies, for obvious strategic reasons. Russia, what's more, responded to the shale gas agreement between Shell and Ukraine by presenting this country with a $7 billion bill for a non-honoured agreement to buy Russian gas: an unambiguous way of indicating its annoyance with regard to a potential gain in Europe's energy independence through this new gas source. A majority of other countries are preparing to authorize drilling so as to get a better picture of their reserves. Five countries have for the moment refused, including France, where the first exploration licenses initially granted by the Government were subsequently withdrawn.

The French decisions were defended on the basis of local environmental considerations. It was this that led François Hollande to make clear that the government ban applied only to hydraulic fracturing, in view of its seismic risk and its impact on the underground environment (injection of water at high pressure and chemicals), but not to shale gas itself. This clarification leaves the way open for exploration of these resources as soon as engineers manage to better control the local environmental impacts of extraction techniques. Clearly, it is not the potential cost in terms of climate change that was the decisive factor in the French decision, but concerns about local pollution.

Natural gas, biogas and shale gas: the climate impacts

The gas used for energy purposes, predominantly methane, has three main sources. The most important of these involves extraction of gas from conventional fields, and this is referred to as natural gas. Methane can also come from the fermentation of organic matter, for example by being recovered from a landfill, composting process or agricultural methanization plant. In this case it is known as biogas, which after extensive treatment to bring it up to the quality of natural gas, can be used directly as fuel or fed into the natural gas network. Finally, it may come from the recovery of gas pockets in rocks, using new extraction processes (horizontal drilling and hydraulic fracturing). It is then referred to "shale gas".

During combustion, each of these three gases releases an amount of CO_2, equivalent on average to half that of a unit of energy from coal. Replacing a coal-fired plant by a natural gas plant can on average reduce CO_2 emissions by 50%. The climate impact of each of these gases, however, can really only be appreciated by following emissions throughout the production and consumption chain.

- In addition to emissions into the atmosphere from the combustion of natural gas, there are also emissions from possible leaks of methane during its extraction ("fugitive emissions") and emissions related to its transport, especially for gas that has to be liquefied for transportation by sea[8].

- The recovery of biogas forms part of the short carbon cycle and enables fossil fuels to be economized. It is therefore neutral in terms of greenhouse gas emissions, since the carbon released during combustion balances the carbon stored in plants at the beginning of the process.

- The shale gas used in the United States does not involve transport by liquefied gas tankers, but the volume of fugitive emissions associated with its extraction is uncertain. Initial assessments carried out by the U.S. Environmental Protection Agency suggest that fugitive emissions at shale gas extraction sites may be high because of laxity in relation to environmental standards. According to some analysts, the climate benefit obtained by substituting gas for coal in power generation may be more than offset by methane leaks during extraction[9]. We should not, however, generalize such conclusions because these standards are being strengthened in the United States and will be much more stringent in European countries that develop this type of technique.

[8] The gas is liquefied by compressing it as it is loaded onto tankers then regasified on arrival at its destination. Both procedures consume fossil energy.

[9] See in particular: Howarth R., Santoro R. and Ingraffea A., “Venting and leaking of methane from shale gas development: response to Cathles et al”, *Climatic Change* N°113, 2012, P.537–49. The experts at MIT take a more qualified position: Francis O’Sullivan and Sergey Paltsev, “Shale Gas production : potential versus actual greenhouse gas emissions”, *Environmental Research Letters*, IOP Science, December 2012

Conclusion: transition towards a low-carbon energy system

In actual fact, the elasticity of the concept of energy transition suits decision-makers nicely because it allows them to postpone choices regarding climate issues, though doing so makes future decisions all the more difficult. The history of energy systems, defined as complex assemblies articulating mixes of primary sources with the forces of transformation and types of use, teaches us that transitions take much longer and are more structuring than seems at first. Committing to them on the wrong basis risks paying much more in the long run.

Without a carbon price that correctly expresses rising climate risk, it is perfectly rational to invest heavily in shale gas in the United States and export surplus local coal to Europe and Asia. The same rationality will lead Europeans to make the same choice, if only to have additional cards in negotiations with foreign suppliers, in accordance with elementary geopolitics. China and many other countries will follow suit, and the outcome will be a fourfold increase in emissions generated by using gas. In the absence of carbon pricing, these emissions are likely to add massively to those generated by coal rather than replace them. In view of these effects, shale gas should not be considered a relevant vector of a transition to a low carbon energy system. On the other hand, if carbon is correctly priced in terms of climate risk, this system can become a provisionally effective way of economizing on the use of coal, pending the general adoption of carbon capture and storage techniques.

The overall response to this type of Hotelling-style transition would involve setting a world carbon price, which has no chance of being implemented before 2020 at the earliest. In the absence of such a prospect, what strategy should the EU adopt?

In the name of political realism, the temptation is to scale back the ambitions of European climate policy. An initial symptom of this is the elaboration of strategies uncoordinated with energy transitions in which the climate is viewed as only one of the factors to be taken into account. And a second is the way in which politicians in Europe are allowing the EU CO_2 emissions trading scheme to unravel, the only such multinational carbon pricing system in existence. Doing so risks leading straight to the marginalization of a tool that is viewed as the backbone of European climate policy. This is why it is urgent that a strong political message be sent by European governments on the need to rescue this system, which is potentially one of the pillars around which a future low carbon economy at an international level can be built. France, which has offered to host the "last chance" climate conference in 2015, has a special responsibility in this regard.

References

Fouquet, R. and P. Pearson, "Long Run Trends in the Efficiency Cost and Uptake of Lighting Services: Implications for Current Policies", *Economics of Energy and Environmental Policy,* 2012, IAEE, 1.

Gordon, Robert J. "Does the New Economy Measure up to the Great Inventions of the Past?", *Journal of Economic Perspectives* 14 (Fall 2000, N°4)

Gordon, Robert J. *Is US Economic Growth over? Faltering Innovation Confronts the six Headwinds*, CEPR, Policy Insight N°63, September 2012.

Hefner, Robert, *The GET: The Great Energy Transition*, Hoboken, HJ : Willey, (2009)

Howarth R., Santoro R. and Ingraffea A., "Venting and leaking of methane from shale gas development: response to Cathles et al", *Climatic Change* N°113, 2012, P.537–49:

Jevons, William Stanley, *The Coal Question: an Inquiry Concerning the Progress of the Nation and the Probable Exhaustion of our Coal Mines*, 1865, Macmillan, London (P.140).

Jouvet, Pierre-André and de Perthuis, C., "La croissance verte: de l'intention à la mise en œuvre", *Climate Economics Chair Cahiers, Information and debates series,* N°15, June 2012.

O'Sullivan, Francis and Paltsev, S., "Shale Gas production : potential versus actual greenhouse gas emissions", *Environmental Research Letters*, IOP Science, December 2012

Rifkin, Jeremy, *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*, Palgrave Macmillan**,** 2011

Smil, Vaclav, *Energy Transitions : History, Requirements, Prospects,* Praeger, Santa Barbara, California, 2010. (P107).

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Contact us :
Chaire Economie du Climat - Palais Brongniart (4e étage)
28 Place de la Bourse, 75 002 Paris, France
Tel : +33 (0)1 73 01 93 42
Fax : +33 (0)1 73 01 93 28
Email : contact@chaireeconomieduclimat.org

Directeur de la publication : Christian de Perthuis
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