A few thoughts concerning energy mix evaluation

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1. Introduction

It is my great pleasure to open this week on "Science for Energy Scenario". It is all the more my pleasure that a number of competences, ranging from physics to economy and social sciences have been gathered by the organizers, and that this variety reflects exactly the complexity of the problem we have to deal with.

Energy scenario are a crucial step in our industrial development, either to provide energy, or to control our commercial balance for fossil fuels, or to export our technologies or import the one of our neighbourgs. It also reflects what our citizen consider as admissible in terms of risk. As a consequence, **Selecting Energy mix and scenario for energy mix transitions is certainly a political exercise.** And as a political exercise, it is loaded with inertia of historical habits, of the existing system. Investigating former energy transitions in modern history, identifying the cultural and structural difficulties will certainly help us avoiding no way roads. In democratic country , one doesn't change the social habits by decree. No state institution is legitimate to impose on the citizen the amount of meat he should eat or the temperature he should keep in his bedroom. It is somewhat worrying to see state agencies dreaming of such a power.

Energy scenario, at the bottom line, should be a choice of the citizen , not of the market. Having a sufficient amount of energy available for all, at a reasonable price should be seen as a right of any citizen. It is not reasonable to assume that our fellow citizens should be in a situation of, following Marcel Boiteux sarcastical statement, "being able to see into an empty plate". Stating that something is feasible technically discarding the question of the price is just dishonest. Any suggestion of massive change should come with a funding scenario, and the comparison should not only be made in “integrated terms”, but also in “peak investment”. In addition, the investment to be considered being huge, states play a key role , via subsidizing the choices. .Subsidies is a use of public money, and it should be done in a fair manner. It is worthwhile keeping in mind that, no matter how fashionable is the option, subsidies should not benefit only to the wealthiest part of the population. We have seen in recent years a number of examples of what I call the “Opera effect”: the Opera ticket being heavily subsidized without being accessible to the whole population, this creates a situation where the poorest are subsidizing the leasures of the richest. Definitely **the choice between different energy mix is an economical and a political issue.**

Science is what is most needed and most lacking currently in the public debate on energy transition. Science is lacking in the way the problems are set, in the way they are analyzed, in the way the comparisons are made. In the first place , comparing end points is not useful, one should compare trajectories. There is a constant confusion between the objectives (where we aim to go) and the obstacles to overcome (what prevents us from going): a research program can’t rely only on defining goals, it has to suggest path, and in order to do so it has to identify stumbling blocks. We have here a very vivid example of the difference between a goal and a path. If being in Les Houches you want to go to Courmayeur, a mere interpolation neglects a minor detail which is the Mont Blanc! For sure, a tunnel can help you to overcome the obstacle and reach the goal, or a plane. But you need to invent the plane if there is no tunnel, or to drill the tunnel. Without this step, explicating the trajectories, we don’t have research programs, we have “letters to Santaclaus”. **Selecting energy scenario is definitely a matter of science and technology**.

Why science is so important, and why is it so absent from the debate in a self proclaimed “Cartesian country”? The absence of science, and the disqualification of scientific experts has a deep rooting in the latent conflict between political legitimacy and scientific evaluation, and a long history of a patronizing attitude of the politicians toward science (as not being part of culture). The gathering of communities like the ones present here, between social scientists and physical scientists and engineers can help to bridge the gap between the two cultures, but we have to be conscious of the difficulties, and the only thing which could be worse than the current divorce between these two culture would be a fake collaboration.

The importance of science becomes obvious as soon as one realises that it doesn't make any sense to address these questions (political opportunity, social acceptance, economical value..) on scenario which would be scientifically or technically unfeasible. The very first requirement on a scenario is that it should not be in blatant contradiction with the basic scientific facts. The question of technical feasibility is not a simple one. There are the ones which are in shear violation of Kirchof law for networks, or Carnot's law for thermal machines, or even energy conservation: they are simply not possible and easy to disregard. But as we will see the discrepancy may be more subtle. It may rely on over-optimism on the possibilities offered by science to solve a given problem. In any case, the acceptance of a scenario should come after the difficulties of the scenario have been carefully identified, and possible strategies to overcome the major ones have been made accessible. **Choosing between scenarios is not a game**, it is a crucial choice for a country and jumping from the plane is a thing you do after having checked the parachute, not while knitting it!

2. Context of the presentation

The debate is currently loaded with political and industrial issues. It is necessary to bring back in the discussion, as a prerequisite, the basic scientific questions which have to be quantitatively documented before any energy mix is chosen and progressively implemented. Any brutal change in a context of a weak economy can be a real disaster.

There is no reason why the different European countries, with their specificities (in terms of available resources, in terms of current initial situations…), should have an identical energy mix. On the other hand, the existence of a wide interconnect network for electricity implies that the energy mix of our countries, especially when the issue of variability[1] of energy sources is raised, cannot be though independently. Furthermore, when the counties have the intention to move closer together, as we may hope within Europe, this may have impact on the energy sector in a broader way.

It seems useful to everybody if a few scientific advisors or former scientific advisors of a few European countries could come to an agreement not on the **result**, but on the **methods of evaluation** of the various possible energy mix, and on the necessary actions when a decision is made. Deriving such methods and applying then honestly to the various propositions offered to governments is in itself a valuable contribution to the debate.

A few points have to be clarified beforehand, stating some of the ideas underlying the present contribution:

- Global climate change related to human activity is a major environmental issue and that the limitation of CO2 emission is a major goal in some countries (and should be a global goal). As a consequence we think that de-carbonising economy is related, in the long term to electrification of economy by CO2 free electricity.

[1] often called “intermittency” before variability was chosen as a less frightening term…changing the wording doesn’t solve the problem!

- The security of energy supply is an important issue for individual countries and may be for groups of countries who operate closely together. The supply of electricity is **not** the only question to be addressed: **fuel** for transportation, heating (or cooling) for buildings , making use of processing heat for energy intensive industry (such as cement, steel, glass…) are also of high importance.

- Besides the transmission of electricity the transport of energy (both electricity and heat) may become also a key issue. **Producing** electricity is a central question, but should not hide important issues such as **energy distribution**, **energy storage**, **energy management**.

- The efficient use of energy in all sectors seems to be a prerequisite for achieving the above mentioned goals an addressing the challenges highlighted.

The possible solutions may depend on one country or the other (windmills decrease CO2 emission in Denmark while, due to the networking problems it could increase CO2 emission in France, in absence of an efficient massive storage of electricity). In spite of these differences in the results, **the scientific method** to evaluate the energy-mix for a given country could be common, and this common approach would be more robust if developed jointly between scientific advisors of different countries. This would minimize extra-scientific lobbying and would give an extra strength to a rational approach. The thoughts I am presenting here have been elaborated through discussions with scientific advisors in Germany (J.Luther) and in UK (D.McKay).

The aim of the present note is to provide people who are making decisions with a **list of questions which have to be addressed** before any structural decision can be rationally made, announced, and even more , implemented.

3. **Some basic prerequisite**

No engineering problem is ever solved forgetting initial conditions, boundary conditions and optimization goal. Similarly, evaluation of the energy mix for a given country (or a larger region) should set clearly:

- **What are the initial conditions** (the current energy mix) ? These are very different between our different countries and will be summarized at the end of the present document. These initial conditions result in an inertia in the system and strongly influence the rate at which any change can be reasonably implemented[2].

- **The boundary conditions set by nature have to be respected** : the laws of physics are invariant by translation: Carnot's efficiency for thermal machines, Kirchoff law for the networks, etc. are not negociable! The most obvious one is that the electric energy produced (including the one imported and transferred to and from storages – including spinning reserves) should match the electricity consumed (in the main sectors , Housing, transportation, industry, including exportation of electricity) while energy management can influence (to a certain extent) the load.

[2] Another aspect to be taken into account is the degree of connection between a country or a group of country , and its neighbourgs. An geograohic island may be or not an "electric island". The issue of network and intermittency is strongly influenced by the degree of interconnection and outerconnection of the zone with a unique political decision center. This sets initial conditions in terms of international treatises, and boundary conditions on the possible decisions.

Any scenario which doesn't meet this criterion at any time should be refused as non-relevant.

- **The optimizations searched for should be explicitely and operationally defined** (e.g. minimize CO_2 emission -quantify goal and time line- and/or increase CO_2 storage, minimize cost, maximize energy independence, avoid certain energies as socially unacceptable, maximize safety, minimize insurance cost, promote future compliant jobs, minimize geopolitical risks). This goal should be explicitely evaluated not only for energy production, but also for energy consumption. The confusion between the goal (decarbonizing energy) and the means (developing renewables) may drive decisions which are based on agenda uncorrelated or even contradictory with the urgent need to fight global warming and its consequences.

- **The question of the trade-off between different objectives**, as well as the acceptability of a given form of energy production will have to be addressed but this is not the purpose of this contribution since this trade-off departs from purely scientific approach, and is intrinsically a political decision, and thus depends strongly on the country (or groups of countries) considered.

- **Similarly, the economical aspects** , the investments required, the way to finance them and to have them supported by the different actors of economical life is also very important, but again requires input which are beyond a purely scientific and technological analysis proposed here as a preselection step for scenario. However it seems clear that the question of cost should involve not only the investment and operation of the production tool, but also the investment related with the inclusion of this production in the overall "energy system" (such as reinforced transmission networks, or the cost of waste management for nuclear energy). Finally, ant decision , compatible with physical law should address the triple question : how much will it cost, who will pay for it, what are the driving forces and the regulations to enforce the decision of "who pays the bill?".

In spite of being very much interconnected, the choice of an energy mix is among the "regalian function" of each country. It would be counterproductive to impose one's choice on one's neighbours, and would generate unwanted tensions. But each country should be aware of the consequence of its own choice on his neighbours' freedom of choice. Furthermore potential benefits for closer cooperation (synergies) between certain countries should be identified. It is absolutely necessary that a fair discussion is carried out, in order to have a **common approach** for the **evaluation** of the possible choices, and for the determination of the actions implied by any decision, to go beyond the current situation which is often influenced by intense lobbying.

Energy issues, as well as in previous times material resources issues , are key in the development of our societies, they have major consequences on international relations. The choices should be realistic. It is our responsibility as scientist, to help deciding by distinguishing clearly between the **possible now**, the **possible tomorrow (2025?)** , the **realistic long term vision (2050?) and the claims which are simply not possible**.

- For the "possible now", to help evaluating industrial and economical strategies
- For the "possible tomorrow" the research necessary to reach a goal. We have to consider the technologies available now, and the ones which may

be available tomorrow, in a very honest manner, and not oversell any of them. And if possible clarify the scientific and technological bottlenecks.

The debate on energy is very passionate, we have to express clearly what science tells us. The decision itself is in the hand of political power, and should be so. The questions to be addressed in a systemic approach, with numbers, are:

- The various ways of the production of energy
- The issue of networking and storage, especially in relation with variability of renewable energies
- The issue of safety, waste disposal especially for nuclear energy, but also for the consequences of a major breakdown, including the heathcare issues. For nuclear energy the issue of weapon proliferation should be addressed.
- The issue of the efficient use of energy (including the transport and storage of energy), especially in building, transport, and industry

4. Rules for evaluating an energy mix.

For a given country a proposed energy mix should be evaluated according to the following rules:

- Is it scientifically and technically possible ?:
    - *1rst step* : what is produced annually equals what is needed : the physics limiting the maximum power possible for a given source should be OK, the orders of magnitude correct, the sum "must add" (including the import/export and storage between different regions/countries)[3].

[3] See for instance the book from D.McKay « Sustainable energies without the hot air », and his software on www.

This is a basic elementary step, which is by no way sufficient to choose, but it is enough to discriminate against the totally stupid scenario.

- *2nd step* : there are energies that you have full control of (such as coal or gaz or hydroelectricity), and other (such as windpower or solar energy) which depend on non controlled parameters (meteorology). The "maximum of consumption every day" minus the "minimum of the energy produced from a non dispatchable source" has to be matched by the energy produced or leveled by storage or load management in a controlled way (including import and export). If this is not fulfilled, there is a risk of electricity breackdown. Depending on the stability of the network, this energy lack (as well as an excess energy input) could lead to a collective breackdown with major impact. Of course this match of the fluctuation of fatal energies by the controlled ones has to be compatible with the time scale with which the controlled production, the storage systems and the load management can technically react.

- *3rd step:* Any discrepancy in the previous balance has to be managed either by a storage capacity, or by a transportation of energy from another production place (possibly coming from a neighbouring country). The quantitative matching should be analysed in terms of the storage possibilities, and in terms of the necessary networking [4].The question of cost will enter as a major component of the discussion. But a simple evaluation of the magnitude of the necessary networking and storage is a prerequisite before entering into more economical issues.

[4] This point is important , from a technical as well as from a political viewpoint, since massive storage is a rare good, and since importing and exporting energy puts a load on other countries networks, or storage facilities that they may not be willing to accept. It is important to combine the freedom of choice of each country with the necessary compatibility between different choices. A related question could be "what can a country charge for this service".

- The question of **energy consumption management** is another possible way-out if step 3 appears to be a problem. Intelligent user/grid interfaces can allow to smooth out consumption, but its efficiency remains to be proven.

- **Intelligent use of energy**, especially in building heating, can provide substantial energy savings: it is necessary to evaluate quantitatively these possibilities taking into account the natural inertia of the construction market and the presence of a huge "already built" park. In all sectors, cost of efficiency measures, inertia of implementation is an issue. It is of almost no use to develop "positive energy building" while having a built park with deficient insulation. On this issue the economical model for investing into insulation should go beyond a simple sanction[5].

- **The issue of the spatial localization** of energy production and energy use, in relation with storage and networking, have to be addressed in a quantitative manner for the various energy sources and for the various uses. The worst possible case is when energy must be harvested in large regions and then sent away to distant places (factories) where it is needed in concentrated fashion[6].

- Is it industrially acceptable ?

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[5] When people are living in a poorly insulated building, they also happen to have low revenue. Having a financial punishment on them is not only unefficient, (since they can't pay), it is also socially unfair.

[6] One has to keep in mind the technical requirements imposed by a given type of industry: if Europe is to conserve large industries, energy intensive, the issue of concentrating either energy production, or energy distribution toward industrial sites, can't be overlooked.

- A number of technical innovation are possible to increase the energy efficiency of massive industrial consumers, or to re-use the degraded forms of energy such as heat in the 100°C-400°C range. The same is true of CO_2 emission. The question of the economical viability of these innovation in an international competition (especially between EU and non EU economies) can't be discarded.

- An industry for devices aiming at energy production does not appear by magic, some inertia is present, some assets in each country have to be taken into account.

- The question of how fast can one ramp up this industry, and at what investment cost, and of the possible transformations between various industries is important.

- The question of today's industry availability becomes essential for the issue of the commercial balance of the country. These questions are not in the scope of a scientific evaluation, but they are definitely on board when a political decision is to be made.

5. Developing a roadmap for an energy mix

"Where to go?", and "how to get there?" are different but related questions…

- It is not sufficient to have set a goal (a projected energy mix) and to have made sure that it is scientifically and technically feasible. Even if the goal seems economically and industrially reasonable, it is necessary to develop a **roadmap**, with well identified steps, and at each step a "go/no go" decision, with a possible “back up” strategy. This roadmap can be modified according to possible changes in boundary conditions , but whatever the political decision for a given energy mix is, the only way to implement it is progressively.

- The need to deal with global climate change reasonably rapidly requires that the decision taken can **be progressively implemented** without a major short time rupture in the energy provision system (currently e.g electricity as a dominant energy vector , and fuel for road transportation).

- **Alternative energy vectors?** In a longer term (meaning in 50 years) the issue of the energy vector (electricity or alternative energy vector such as Hydrogen) should be on the agenda, having in mind the current situation, the possible evolutions, and the path between which can be reasonably achieved. It seems unlikely that it will replace rapidly electricity as an energy vector. A variety of possibilities could be envisaged: incorporated into gas pipelines, or used to convert biomass into biofuel, or possibly as a mean of energy storage, or as fuel for vehicles.

- **What kind of network is optimal?** The energy network is qualitatively different from the information network. The rapid transition from a centralized distribution network to a totally decentralized one seems unlikely and requires a substantial investment on research on “smart grids” before one can get a clear view on the possibilities of these strategies for managing the network

For each country , a proposition for an energy mix, once analysed through the prism of the previous criteria, should therefore be proposed with a **roadmap for implementation**, a plausible rate of implementation, a detailed analysis of the transition between each step, and a roadmap for the research program to be launched to overcome the identified bottlenecks[7]. If such a progressive and cautious route is not proposed, the risk is to run into dead-end routes where some of the objectives will have to be given up. We can't afford this risk, therefore progressing step by step is crucial. Running too fast , for political or ideological reasons, into non secured solutions, or subsidizing a speculation bubble without feedback loop, may be very damaging even for the energies promoted by such hastily taken decision. It is just like throwing directly in the bath a child without teaching him to swim: his chances to reach an adult age and swim properly are substantially reduced…

Certainly, whatever the energy mix chosen by the various European countries, safety, sober use of energy, efficiency in distribution and massive storage will be keywords in all the plausible energy mix which will appear in the coming years. These topics should be identified as major fields for collaborative research as well as conditions for efficient and realistic "combined roadmaps".

6. Carry on the exercise

Anybody is legitimate to cook his own "energy mix", and we have currently a jungle of them. But the scenario proposed by state agencies whose function is to make recommendation to the political decision power should be examined very carefully. If an energy mix is proposed by a state agency to the political power, the following method is applied. First of all, the evaluation of the proposal is collegial, with experts which are not within the proposing agency, and it has to be done in agreement with the authors of the proposal. This evaluation will remain confidential and is provided to the government only. The collegium is constituted only from

[7] If one is really serious about implementing massively renewable enrgies with all the problems related to variability, it is absolutely clear that a major research effort on energy strorage is required, This effort should be a priority on ant research program aiming at increasing the efficiency of solar cells, or permanent magnet for windmills for instance since the alternance between day and night and the relation between cyclonic/anticyclonic dynamics and wind are not amenable to legislation, nor corrected by technology!

people with competence and not hierarchically involved into producing themselves the scenario under investigation. After a few hours of face to face discussion (from written documents, not from mere and always superficial powerpoint presentations) , the next step is to send a list of questions, structured as a hierarchy. The hierarchy is as follows:

- General aspects : challenges, hypotheses, robustness
- Consumption: building, transportation, industry
- Production mix: Fatal energy, Nuclear energy, Biomass
- Overall system: networking, mass storage

In the end, any reasonable energy mix proposition, meaning one which can be used as a guide for political decision, should explicitely clarify the obstacles and the research program necessary to overcome them. A research program can't be structured as long as the confusion between the goal and the obstacles is blurring the picture. The questions are then answered by the institutions proposing the scenario, and for each question the expert commitee states why the question is felt to be important, and if he is satisfied by the answer. The advice given to the government is simply this list of "key questions" which have to be addressed before any decision is taken. The natural follow up on this procedure would be either to obtain from the agency proposing the scenario full clarification on the question, and/or to lauch a research program focused on these precise questions.

7. What is missing?

The key issue for energy mix are clearly mass storage and networking. These will remain the main issues as long as energy production and consumption is somehow centralized (due to energy-consuming industries and urban dominated lodging). There is a need to derive the scaling laws between temporal correlations of fatal energies and storage efficiency, spatial correlation of intermittencies and networking range. It is crucial to understand, for a given proportion of fatal energies, the amount of networking of storage needed to avoid a breakdown, localized or general. That will set the goal for storage and networking for a prescribed proportion of intermittent sources, and a realistic path for a progressive transition respectful of environmental issues, in the facts and not only in the claims.