ORIGINAL PAPER DOI: 10.7401/visions.04.04

The nuclear power option: exploring boundaries and limits, asking open questions

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Abstract. In this article we take up on the debate spurred by a recent paper published by Qvist & Brook on PLoS/ONE (May 2015), in which the Authors encourage 'a large expansion of global nuclear power'. We approach the topic from a variety of perspectives, drawing on a variety of sources, in order to highlight the complexity of the issue and the social, political and educational implications of presenting the nuclear option as a plain, linear, rational choice.

Adopting the paper by Qvist & brook as a 'case in contest' we develop a critique of conventional scientific research. We argue that for all scientific studies, authors should specify clearly and correctly the boundaries of the system under consideration which in turn, will determine the range of experimental data being collected. Results should be clearly separated from the conclusions which, in fact, are inevitably influenced by personal interpretations and collective imaginaries, which often remain unchecked.

Scientists and referees of scientific journals therefore have a great responsibility when dealing with complex and controversial issues, because their voices can influence both the public and policy makers alike. By virtue of the idea, still deeply rooted in the Western world, that science describes reality, scientific evidence is deemed to 'speak truth to power'(Wildavsky, 1979). Consequently, a model of governance by numbers (Ozga, 2015) seeking to be informed by the promises of scientific certainty (Nowotny, 2015) fails to recognize the areas of uncertainty, the multiple questions which yield opportunities for disclosing alternative imaginaries and visions for sustainability. Drawing on the insights offered by feminist epistemologies, and the educational tools here derived, we point to a reformulation of the role of science education in growing democratic expertise that is, the ability of the public to unmask the value and worldviews underpinning the 'products' of science by taking into account the wider, socio-cultural and socio-material discourses in which such products are embedded. We encourage the educational system to pay greater attention towards equipping young people with reflexive abilities and conceptual tools which are appropriate to cope with the global, socio-environmental conflicts of our time.
Keywords: Nuclear plants, uncertainty, imaginaries, epistemological reflection, educational tools

ISSN 2384-8677 **DOI:** 10.7401/visions.04.04

Published online: December 21st, 2015.

Citation: Camino, E., Colucci-Gray, L., (2015). The nuclear power option: exploring boundaries and limits, asking open questions. Visions for Sustainability 4: 22-42

Competing Interests: The author has declared that no competing interests exist.

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***Perspective**: Educational vision **Fields**: Economy and technology*

***Issues**: Educational processes, Globalised industrialisation and global product, Bio-geological equilibrium and ecological decay*

1. ‘Energy security’ as a major theme of our time

In May 2015, a research paper was published in PLoS/ONE by two scientists – S. Qvist, from Sweden and B. Brook from Tasmania. The authors advanced a positive vision about the prospects of developing a worldwide use of nuclear power energy. As first stated in the abstract, they claimed that they have been able to "demonstrate" the potential for a "large-scale expansion of global nuclear power", by drawing on empirical data collected over three decades in France and Sweden.

The experimental approach, the extended time scale of the study and the neat delimitation of the focus of analysis (that is, the production of electricity) are by all means the warrants for classifying this contribution as ‘scientifically correct' ... but this is true only in appearance.

Currently, the level of international interest in the production of nuclear power is quite high, even if the trend is declining. According to the World Bank (Kessides, 2010) more than 40 developing countries have recently approached United Nations officials to express their interest in starting nuclear power programs. China, Japan, the Republic of Korea, and India are forecast to display the highest growth in the Asian region. Information updated to 2015 (World Nuclear Power Reactors & Uranium Requirements, November 3rd) indicate that in this area 37 reactors are under construction, and 91 approved. However, there is a growing incertitude about the feasibility of the plants being proposed.

In this context, the relevance of the topic and – as stated by Qvist and Brook (2015) – the current outlook for the world "to meet the most stringent greenhouse - gas mitigation targets" (p 1) makes this paper a powerful flag for the proponents of the nuclear option in the upcoming Conference of Parties (COP21), to be held in Paris from 30 November to 11 December of this year.

COP21, also known as the 2015 Paris Climate Conference, for the first time in over 20 years of UN negotiations will set out to achieve a legally binding and universal agreement on climate, with the aim of keeping global warming below 2°C (UNEP, 2015).

According to Mike Fowler, of the Clean Air Task Force, in his introduction to The Nuclear Decarbonization Option (2012) “Nuclear energy provides more than 40 percent of all low-carbon electricity generated in the world today” (p. 7). Nuclear energy is also set to increase its contribution as a major low carbon energy source, with 66 civil nuclear power reactors under construction in the world (World Nuclear Association, 2015), while newly advanced reactor designs may offer substantial improvements in speed of construction, safety, waste management and control on risk proliferation (Walsh, 2013).

These data however are not confirmed by other authors: the International Energy Agency (2015) gives a 34% value for nuclear low-carbon electricity (data from 2012). As Jonathon Porritt underlines in his foreword to the World Nuclear Industry Status Report (Schneider & Froggatt, 2015), “there’s been no diminution in the intensity of the debate about the role of nuclear power in tomorrow’s low-carbon world. Indeed, it seems to become more intense by the day” (p 9). Well aware that people read the same data in very different ways, leading to very different conclusions, Porritt underlines the critical role played by this Report in informing both experts and lay people by means of longitudinal dataset and scrupulous attention to detail.

The question posed by Porritt at the end of the foreword clearly reveals his anti-nuclear position: “how long will it take before these seemingly inextinguishable hopes in the promise of nuclear will be finally overwhelmed by the delivered realities of an alternative model, which gains momentum not just year on year, but month by month?"(p 11).

For us as educators this is a key question and a tall responsibility. How can we deal with the "nuclear energy issue"? What meaning do we give to the expression 'energy security'? It appears that controversy exists between a reading of nuclear power as a reliable provider of clean energy 'secured' for the future and a reading of nuclear power as a 'false' security which may not deliver to the extent which people may hope or expect.

A number of writers such as Levy-Leblond (2003) had identified some of the common patterns of change in contemporary scientific practice which are linked to wider patterns of social change in the global, neo-liberal economy. Amongst such processes we find:

a. The rise of uncertainty which is endemic to research but also to wider decisional processes; some authors (Beck, 1992) have referred to this social condition as 'risk society';

b. The growth of an economic rationality which is increasingly invoked to act as a filter for uncertainty;

c. The redefinition of the time dimension through the extensive role of expectations, forecasting tools, scenario-building and 'real-time' communication technologies which are converting the future on some sort of 'extended present' (Jasanoff, 2014).

As indicated by Nowotny (2015) the cunning of uncertainty is inextricably linked with notions of the future and vision of sustainability, yet such visions can only become intelligible to us as we become to identify the subjects, scenarios and contexts of their actions. On such basis, we approached the debate on nuclear power option by attempting to go deeper into the analysis of the paper authored by F. Qvist & B. Brook, and by deconstructing the epistemological and ontological premises of their argument to uncover the complexity of the issues involved. Following on the stimulus offered by J. Porritt, we argue that it is a responsibility for educational institutions to support greater analysis and debate in order to draw out the opportunities for alternative propositions.

2. Scientific research in the global, socio-environmental context: questions of identity and expertise

The reading of this article generated many questions for us, which we endeavored to answer through an extended documentary review, consulting websites, blogs as well as scientific articles and data sheets from a variety of sources. In the following sections, we wish to share with the readers some of the questions driving the analysis and the answers we tentatively gave. We locate our work within the wider frame of current debates in the epistemology and sociology of science discussing the role of 'evidence' as a means for governance (Ozga, 2015) and for the regulation of interactions across different social policy domains. Notably, the idea of 'science speaking truth to power' (Wildasky, 1979) is being challenged by a growing number of philosophers and sociologists of science who are stating the importance of acknowledging the changing nature of science and technology which are no longer (and they have possibly never been) simply laboratory investigations. Rather, science and technology are the stuff that makes our lives, as the Earth is being turned into a one, single global laboratory. From this perspective, science and technology are better understood as 'performative practices' (Barad, 2007) that is – as matters of intervening rather than representing (p. 54). In this view, all theorizing in science like in other fields of knowledge cannot be separated from the entangled apparatuses of power relations, democracy, world citizenship and, as Galison (2000) continued: “what is at stake is always practical and more than practical, at once material-economic necessity and cultural imaginary” (Galison, 2000, cited in Barad, 2007 p. 55). Inquiring into the performative practices of science is at the same time a process of reflexive interrogation of one’s own society and culture and a key task for education. From this perspective, we began by trying to clarify the socio-cultural background of the authors as inherent dimension of their research.

Who are the authors, and what is their expertise?

Staffan A. Qvist works at the Department of Physics and Astronomy, Applied Nuclear Physics. Amongst his most recent publications, we find contributions on nuclear power with the most recent one dealing with fuel assemblies (Qvist, 2015). Qvist also published papers with a more interdisciplinary approach, dealing with socio-scientific and environmental issues. As an example, he explored the possible environmental and health impacts which may be associated with the phasing-out of nuclear energy (Qvist & Brook, 2015). The paper written in collaboration with W. Barry Brook deals with a controversial and complex problem that concerns not only the academic community but the civil society at large: in fact – as the two Authors underline – the entire world community is a ‘stakeholder’ in nuclear issues.

Barry W. Brook is Professor of Environmental Sustainability, University of Tasmania. His specific field of research is Ecology. He recently collaborated on a paper looking at the interaction between the dispersal of organisms and landscape structure (Fordham et al., 2014). Similarly to Qvist, Brook cultivates also broader interests, which are developed in parallel with his specific professional competences. In 2010, he wrote together with Ian Lowe the book “WHY vs. WHY™ Nuclear Power, in which the two authors engage in an exchange head-to-head, each presenting 7 key reasons for why one should say yes/no to nuclear power” (Brook & Love, 2010).

In 2014, he co-published an interdisciplinary paper dealing with the physical and economic aspects of the nuclear power option in the journal Applied Energy (Hong et al., 2014).

So, from reading the biographies of the authors we can ascertain a level of both disciplinary and interdisciplinary expertise, demonstrated by their scientific publications. We also recognize the authors’ engagement with wider issues of public understanding and communication of science by means of their writings addressed to a more general audience interested in socio-scientific and environmental debates. By means of their professional affiliation, the authors are working within two countries members of the Organization for Economic Development (OECD) which is concerned with raising standards of technological innovation “and make better use of human talent to clear the path for higher and more inclusive productivity growth” (OECD, 2015, p. 3). We will now look at the design of the study conducted by the two authors to trace the influence of the background information in shaping their views of the future and of sustainability understood as a scientific and technological option.

What are the most significant variables that the authors measure/consider?

In conducting their study, the Authors focus on a set of key variables: CO_2 emissions, Gross Domestic Product (GDP), production of electricity from nuclear plants, power generated by reactors and cost of various components (building and running costs, delivered energy costs).

The choice of variables is crucial in every scientific report: it informs readers about the field of the research, and it relates the issues addressed with the expertise of the researchers. In this particular case, the two authors are experts in basic science, Physics and Ecology. Due to the interdisciplinary nature of their investigation however, the authors also make extensive use of variables that are typical of other areas such Economics and Sociology. Interdisciplinary studies themselves require inputs from other disciplines, as well as from various categories of citizens: the lives and destinies of many and diverse people in the world are concerned with and likely to be affected by the growth of global nuclear power, both in terms of anticipated benefits and risks. Referring back to Barad's (2007) notion of science as a performative practice, which well exceeds the boundaries of the laboratory, such notion supports an approach to complex and controversial issues (such as the case of nuclear power), which seeks to involve a plurality of subjects (the 'stakeholders') in the making of decisions. The performative nature of techno-science cannot be disentangled from ethical discourses. Some scholars have also referred to this approach as the 'post-normal' science approach (e.g. Funtowicz & Ravetz, 1993). In this view, epistemological considerations cannot be disentangled from views about the world and the values we hold. In particular, it is the key, metaphysical assumption of science as representation that views the world as composed of individual entities with separately determined properties that is being questioned. In complex, socio-environmental issues such reductionist tenet leads to inevitably and inherently partial views, which are embedded in the parameters and knowledge boundaries of the 'investigators': we shall discuss such points later.

The socio-economic context as a frame for research design

Following the standard scientific practice, the authors specify the boundaries of the system they analyzed. Admittedly in this case, the spatial boundaries of the issue are global: F. Qvist and B. Brook envisage a 'worldwide' substitution of fossil fuels fired electricity to nuclear-produced electricity. The time range is also clearly defined: the empirical investigation is based on data collected in two countries (France and Sweden) from 1960 to 1990, and provides projections about the future for up to 25-34 years.

By reading the article however, other boundaries emerge, which are not as clearly spelled out: these are spatial, temporal and conceptual exclusions which necessarily affect the choice and interpretation of the data and the inferences and conclusions which are derived, as we will observe in the next sections.

The two authors take the growing demand for electricity worldwide as a starting point for their study. The supply of electricity from nuclear plants therefore, obtained with low production of CO2, would allow for "a rapid expansion of economic activity and prosperity in the poorer regions of the world" (p 2). The authors are the implicit (and possibly unaware?) spokespersons of a specific worldview, which lays trust in the benefits of unlimited economic growth. Such view, however, has been challenged by a growing number of researchers within the scientific community worldwide who ascertained since some decades that the rate of consumption of natural resources exceeds the regeneration capacity of the biosphere: the concept of ecological footprint, introduced in the early 90s (Wackernagel & Rees, 1998) explains in a simple and clear way the physical impossibility for continued and fair economic growth on a finite planet, such as the Earth.

Qvist & Brook also signal, actually, that there are "poorer regions" in the world: also this vision is now largely superseded by social and economic statistics, reporting that greater wealth and expanding areas of poverty are simultaneously present in most countries. Such inequality is a result of an increase in power supply over time that was unfairly delivered, and it is doubtful that further production of electricity may actually solve it. There are in fact real problems for the distribution of electricity from centralized and highly militarized centers, such as nuclear plants, as compared to low power sources, which are decentralized and widely distributed over the landscape. From the analysis conducted so far, it is apparent that the projections for 'an expansion of nuclear power worldwide' as it was advocated by the two authors is embedded within a particular frame which in the main equates 'development' with material production and consumption, but which appears to 'exclude' ways of living that are not aligned with the Western, urbanized model, and which appears to disregard the limits of the Biosphere.

It is notable the similarity between the narrative advocating for the expansion of nuclear power in order to achieve global benefits and the narrative that already back in the seventies supported the experiments for nuclear agriculture undertaken by the International Agency for Atomic Energy (Hamblin, 2015). As reported by Hamblin, such experiments were deliberate attempts to modify the performance of agricultural systems by nuclear-induced mutations. Yet the evidence supporting their success was contested. What this case shows however was the crucial role played by the overall narratives of development that were used as a justification for the research:

> *"through the efforts of a cadre of officials beginning in the 1960s, to elevate the status of mutation plant breeding, first supporting a small transnational community of researchers in industrialized countries, and then trying to bolster the field's legitimacy by claiming victories for atomic energy in aiding the developing world"* (Hamblin, 2015, p, 408).

We will now turn our attention to the requirements for a more holistic and critical analysis of the case for nuclear power by drawing in a more extended set of parameters and perspectives.

3. Revealing entanglements of energy, people and materials: dealing with unspoken, unrecognized boundaries

The analysis conducted so far allowed us to gradually uncover the entangled nature of scientific research as enmeshed with material, practical and cultural practices. Far from achieving a single representation of the issue, we can see that the 'results' produced by Qvist and Brook – and which are apparently presented as the 'products' of a research protocol – appear to be located on the dotted trajectory of a 'discursive' move. Discourse as understood by the social sciences equates to perspective, that is, the portion of reality which 'comes into view' for the person that is viewing or intervening. By their very nature, each discourse – such as economic growth, energy security – cast a shadow over other aspects of reality, which are masked and/or prevented from view, but which are, nonetheless, integral part of the same reality. The discourse of economic growth for example may be supported by data pointing to the reduction of CO2 emissions, as in this case. Yet, other components of the system, located at different scales, in different disciplines, are necessarily left in disguise – or cut out (Barad, 2007) depending on the knowledge, awareness, values and even intention of the investigators.

In a previous study, we described an approach for drawing upon the range of disciplinary lenses in the natural sciences as a means for re-composing a holistic view, to highlight what is left out of the frame (Colucci-Gray et al., 2013; Colucci-Gray & Camino, 2014). Starting from the assumption that scientific language displays elements of continuity with everyday language, it is possible to deploy scientific ideas as 'metaphors' that is as linguistic devices which, by means of figures and images derived from a different domain, enable an observer to access portions of reality normally removed from direct experience (Lakoff and Johnson, 1999; Konopka, 2002). As such, metaphors retain in themselves the cultural background of the 'viewer' and express the particular biophysical, temporal and value positioning embedded in the way in which the observer puts oneself in relation with what is being viewed. In poetry, as well as in science, the linguistic dimension is the prime methodological frame through which a study is conceived and conceptualized. In this view, scientific ideas such as energy flows, matter cycles, webs and boundaries may be conceived not simply as concepts (as are commonly used in Physics, in Ecology and Biology), but may be deployed as 'conceptual tools' for analyzing and discussing a complex issue. Such of these concepts may be used as tools for a further analysis of the methodology adopted and data presented by Qvist & Brooks (2015).

Conceptual tool 1: Energy and Matter flows

"The operation of a nuclear reactor does not emit greenhouse gases or other forms of particulate air pollution" (Qvist & Brooke, 2015, p. 2). The authors take into consideration the working phase of a nuclear power. In this analysis, they are neglecting the fact that the construction of a nuclear reactor requires exceptional amounts of energy and materials (i.e. cement), whose production necessarily releases CO_2 in considerable quantities. In nuclear energy systems, the major construction inputs are steel and concrete, which comprise over 95% of the material inputs. The construction of existing 1970-vintage U.S. nuclear power plants built around 1970 required 40 metric tons (MT) of steel and 90 cubic meters (m3) of concrete per average megawatt of electricity (MW ave) generating capacity (Peterson et al., 2005). The building phase is also energy-consuming because of the need to operate powerful machinery and equipment. Hence the time-frame adopted by the authors, while extended over thirty years – did not consider the different phases of construction, functioning, and seemingly, of disposal of waste and decommissioning of the power plant.

No definitive solution is yet available for the disposal of radioactive waste. Even temporary solutions such as those adopted so far require significant consumption of energy and matter and so does the dismantling of a nuclear power plant. Taking into consideration the whole supply chain of electricity production which may be obtained from nuclear plants, it is evident that the choice of nuclear power still involves production of large amounts of CO_2. A reasonable approximation is 66 g CO_2 /kWh (Kleiner, 2008). A comprehensive analysis on the environmental impacts associated with a variety of nuclear power technologies and systems through a meta-analytical process called "harmonization" (Warner & Heath, 2012) led to the conclusion – drawing from life cycle assessment literature - that published median, interquartile range (IQR), and range for the pool of Greenhouse Gases Emissions from the Light Water Reactor were estimated at 12, 17, and 110 grams of carbon dioxide equivalent per kilowatt-hour (g CO_2-eq/kWh).

According to The National Renewable Energy Laboratory (NREL, 2015) the reported data show that nuclear power is similar to other renewables with regards to the total life cycle of Greenhouse Gases Emissions.

Conceptual tool 2: Geographical boundaries, from local to… global?

"The operation of a nuclear reactor… has been proved by historical experience to be significantly expanded and scaled up" (p.2). By citing Sailor et al. (2000), the authors draw on the geographical limitations of expanding, for example, hydrological power or chemical energy from biomass. However, by focusing on the positive experiences of the past, and looking at the problem from a European perspective, it appears that the two scholars are circumscribing their attention to France and Sweden: they neglect to mention the failure of two major nuclear power plants, Chernobyl and Fukushima as cases from which to take lessons. Similarly, there have been many instances of temporary closure of nuclear power plants due to breakdowns and malfunctions. The historical experience of the two, selected countries that are being mentioned (France and Sweden) seems to provide the basis for an expansion worldwide, thus using two significantly different geographical boundaries - namely a Eurocentric view – to evaluate the 'historical experience'. Interestingly, also when they make considerations about economics – and possibly mainly when talking in economic terms – the boundaries of the arguments become global. According to the Authors, "it is considerably easier to buy plants and nuclear fuel internationally today" (p. 5). They appreciate the chances offered by an 'open and competitive' market for the production and sale of nuclear energy. In this context, there are only few players and even less is the number of people or agencies holding nuclear technologies. The supply of technologies and fuel, then, is more akin to an almost absolute, monopolistic market. It is reported that two-thirds of the world's production of uranium from mines is from Kazakhstan, Canada and Australia. In 2014, eleven companies marketed 88% of the world's uranium mine production (WNA, 2015). Hence, the extrapolation of future projections regarding a world-wide expansion of nuclear power as pronounced in the title of the paper is phenomenally reduced to a few countries and a few players holding the strings of what is deemed to be a powerful, wealth-generating technology.

Conceptual tool 3: parts within systems. Widening the frame from economics to ecology

> *"Despite the uncertainties associated with the economics and logistics of recent nuclear expansion, the current global unit cost and construction-time of nuclear reactors are actually quite comparable to the Swedish experience" (p. 5).*

The Authors present their evaluation of the economic aspects of the nuclear option making reference to the Gross Domestic Product (GDP). This option hides a significant conceptual boundary: development is understood in the narrow sense of material accumulation which is apparently disjointed from the support ecosystems. Because of these limitations, the validity of this indicator as a proxy for desirable pathways of development has been questioned on several occasions and by many authors.

Mainstream economists assume that GDP is an expression of 'well-being' of a population or a country, but this indicator does not consider how economic outputs contribute to the quality of people's lives, and it does not measure the quality of the environment. Many scholars argue that GDP is a poor measure of social progress because it does not take into account harm to the environment. Herman Daly and John B. Cobb (1989) developed the Index of Sustainable Economic Welfare (ISEW), which they proposed as a more valid measure of socio-economic progress, by considering various other factors such as consumption of non-renewable resources and degradation of the environment. Robert Costanza et al., in the introduction to a paper of 2009, argued that *"This paper is a call for better indicators of human well-being in nations around the world.*

We critique the inappropriate use of Gross Domestic Product (GDP) as a measure of national well-being, something for which it was never designed" (p 1).

One would expect that a physicist and an expert in "Environmental sustainability" would not rely on the GDP indicator, by ignoring how this indicator was created and what are its implicit assumptions. More in line with the words of Nowotny (2015), the science community appears to be under pressure by policy-makers and funding councils to deliver benefits when in fact, complex situations are often uncertain and promises are difficult to maintain. In this case, the focus on one, single economic indicator is a short answer to the bigger question as to which research and which benefits society is really seeking. Once again, the methodological framework of the study appears to be enmeshed with values at the very point of origin, that is, the point of selection of the field under investigation.

Conceptual tool 4: Time.

How long is… long term?

Qvist & Brook (2015) claim that *"There is also a larger and more open fuel-supply market"* (p 5). In addition to overlook the condition of near monopoly of nuclear fuel, in this statement we notice once more the power of economic discourse in foregrounding economic sustainability by overshadowing long-term ecological and social impacts. Data on the availability of uranium clearly indicate that, just like fossil fuels, also this type of fuel will eventually be depleted as it is a non-renewable resource. According to Michel Dittmart (2013): *"Historic data from many countries demonstrate that on average no more than 50-70% of the uranium in a deposit could be mined. An analysis of more recent data from Canada and Australia leads to a mining model with an average deposit extraction lifetime of 10±2years. This simple model provides an accurate description of the extractable amount of uranium for the recent mining operations. Using this model for all larger existing and planned uranium mines up to 2030, a global uranium mining peak of at most 58±4ktons around the year 2015 is obtained"* (p. 792). This researcher asserts that without a plan for reducing the number of nuclear power plants in the short term, *"some countries will simply be unable to afford sufficient uranium fuel at that point, which implies involuntary and perhaps chaotic nuclear phase-outs in those countries involving brownouts, blackouts, and worse"* (p 792). So here is another 'limit' that Qvist & Brooke have not taken into consideration, despite the extensive documentation now available on the 'uranium peak' (Energy-watch-group, 2013): the time interval that they have considered is too short to give a realistic picture of the situation.

Time scales and life-cycles

Another approach to looking at the issue is to include a cyclical dimension to time which takes into account local, smaller cycles within their respective transformations. In this view, let us analyze the following statement, which draws a connection between time and money: *"Global data does not suggest that nuclear plants are necessarily significantly more expensive (as a fraction of the total economy) or time-consuming to build now than in the past, if efficiently managed*" (p.6). In the light of the specific cultural lenses which have been revealed and shown to permeate the study, it is legitimate to ask what are 'global data' which are being presented? Indeed, by drawing on the considerations conducted so far, we can see that information on costs of nuclear plants will vary greatly depending on the time boundaries that are put around the system: so for example, when considering the whole life-cycle of a nuclear power plant, the total economic costs are much higher than the sole running costs . Moreover, the growing complexity of the construction phase of nuclear power plants will impact significantly on the costs: the construction of Olkiuoko plant in Finland, started in 2005, will end up in 2018; Flammaville nuclear plant, begun in 2007, will enter into operation in 2018.

In addition, if social and environmental costs are added, an estimate of the actual costs becomes very difficult to achieve. In the present situation of global political instability the costs allocated to security systems are definitely increasing. Moreover, high charges (which are often not recorded) are derived from socio-environmental conflicts that for decades have seen many people (in India, USA, Australia, etc.) oppose to the extraction of uranium ore from the mines in their territories. Extraction processes in fact account for serious health and environmental impacts, as evidenced in the Report published by Raeva et al. (2014).

So a more nuanced and textured picture of the problem may be gained by widening the boundaries of the analysis and including human and environmental externalities in cost assessment.

4. A hidden connection: water availability and consumption

The most common types of nuclear power plants make use of water for cooling the system in two ways: to convey heat from the reactor core to the steam turbines; and to remove and dump surplus heat from the steam circuit. Water usage depends on the thermal efficiency of the plant, and on the temperature of the water: in Southern countries larger heat exchangers and condensers are required as compared with the Northern hemisphere (e.g. Sweden).

Water consumption of a nuclear plant ranges – depending on the type – from 0, 52 to 2, 36 liters/kWh. If any thermal power plant needs to be sited inland, the availability of cooling water is a key factor in the choice of location, due to environmental concerns (i.e. local warming of aquatic ecosystems) and competition with the demands of local populations (World Nuclear Association. Cooling Power Plants, 2015). For example, In France, all but four of EdF's[1] nuclear power plants (14 reactors) are inland, and require fresh water for cooling. Eleven of the 15 plants built inland (32 reactors) have cooling towers, using evaporative cooling, while the other four (12 reactors) use rivers or lake water directly. With regulatory constraints on the temperature increase in receiving waters, this means that during very hot summers the output generation may be limited. In the U.S., plants making use of direct cooling from rivers must reduce power in hot weather.

Forecasting of building nuclear power plants in countries with tropical climates, and in continental areas prone to drought, clearly raises problems, which are not mentioned in the analysis conducted by the two authors.

5. How much energy and how high the power? For what purposes? For which users?

Energy driver of changes

Since the global diffusion of Blue Marble, the photo of our planet taken by Apollo 17 in December 1972, the boundaries of the planet have become, even perceptually, visible. However, a collective vision still dominates: it is the view of the Earth's resources as endless, with limitless possibilities for man to tap into these reserves.

An extensive scientific documentation of the biophysical limits of the Earth has been presented and updated, in recent decades, and has been widely reported by the media. The carrying capacity of the planet has been exceeded in the 80s of the last century (Wackernagel et al. 2002). In 2009, a group of 28 internationally renowned scientists identified and quantified the first set of nine planetary boundaries within which humanity can continue to develop and thrive for

[1] Electricité de France

generations to come. We have already exceeded three limitations of 'safety', and we lack suitable measures available for other two parameters (Rockström et al. 2009). Crossing these boundaries could generate abrupt or irreversible environmental changes. Respecting the boundaries reduces the risks for human society of crossing these thresholds. In 2015, an international team of 18 researchers maintained that four out of nine planetary boundaries have now been crossed as a result of human activity, (Steffen et al. 2015); moreover the scholars introduced novel entities (e.g. organic pollutants, radioactive materials, nano-materials, and micro-plastics) as plausible variables to be checked, with yet unknown tipping points.

According to these results, not only the resources are limited, but it is limited the ability of the planet to 'manage' the transformations produced by human activities: in addition to the increasing levels of CO2, well known to the public for the effects on the climate, transformations of global reservoirs of nitrogen and phosphorus are taking place, and these are modifying the overall balance of the biosphere. The main driver for such huge planetary transformations is energy, mostly from fossil fuels: energy to excavate, to transport, to transform… Thanks to high density fuels, the engines' power has increased, andtransformations of ecosystems have taken place with increasingly accelerated pace.

Yet the idea persists that we need more and more energy: Global energy consumption is expected to double or triple over the next century, as millions of people achieve more modern living standards, which requires that we produce energy in ways that are cleaner, cheaper, and less intrusive on wild places (The Breakthrough Staff, 2014).

Which type of energy, and for whom?

In addition to questioning the amount of energy that is globally needed, and the impact of using such energy, a key question to be asked is 'for the benefit of whom'? As noted by Eric Rondolat (2015) the needs of 1.1 billions of people may be very different from the needs of the rich minority of the population: "we live in a world where 1.1 billion people – more than one in seven – still do not have access to electric light. […] Light poverty and the millions of associated deaths are avoidable – the technology to balance this inequality is all around us and taken for granted across most of the world. In those countries blighted by light poverty, the difficulty lies in administering the cure, not in creating it."

Centralized, high power energy sources imply a top-down control, and an extensive and efficient distribution network. Vaclav Smil, one of the leading experts in energy studies and author of a recent book on Power Density (2015) notes that "modern civilization has evolved as a direct expression of the high power densities of fossil fuel extraction" (p. 8). He argues that "our inevitable (and desirable) move to new energy arrangements involving conversions of lower-density renewable energy sources will require our society — currently dominated by megacities and concentrated industrial production — to undergo a profound spatial restructuring of its energy system" (p. 11) .

A scenario that Qvist & Brook do not consider, therefore, is that of a redistribution of sources and delivery systems, and a redistribution of the uses of electricity amongst social groups.

6. Risks, uncertainties and stakes

As indicated earlier, one of the key features of the article presented by Qvist and Brooke (2015) is that of drawing on data from apparently carefully conducted studies to argue for the expansion of nuclear power worldwide. It is also apparent however that the authors are presenting their work within a politically charged context in which science is expected to inform the action of policy-makers and the public in general. As it was reported by Petty and Cacioppo (1986) expert thinking differs greatly from lay people's thinking with regards to the need for fact-findings and information. In such case, attitudes of lay people and more generally , non-expert – tend to be shaped by the common sense routes, that is, what people perceive to be 'safe' and 'viable'. In this context, argumentation is not so much about winning the case and holding the truth as it is about persuasion, winning minds … and the hearts of people by means of appeals to what appears to be practically sensible and relatively risk-free within a given value-framework. We can identify some of these strategies used in the paper by Qvist and Brooke (2015). As reported earlier, one of the key rhetorical strategies used is to override uncertainty: "Despite uncertainties …" (p.5). By keeping the boundaries tightly focused on single variables and by overriding the geographical, political, social and environmental nuances of the global context, risk assessment and uncertainties are underplayed by the two authors, except for a nod to the absence of problems in the two countries studied: France and Sweden. Yet it is well-known that the nuclear option for the production of electricity presents numerous types and degrees of risk, uncertainty and ignorance.

Along the production chain of nuclear energy, there are well identified environmental impacts and risks for human health in several communities living close to uranium mines (e.g. Chareydon et al., 2014).

The option proposed by Qvist & Brook, of a system of 'free market' (therefore oriented to private investors)[2] can exacerbate the security and safety problems at various points of the supply chain: for example, the social and environmental impacts of digging for uranium ore but also the risks incurred during transport to power plants; other risks include the safety of the plant (the functioning of the reactors but also the good functioning of control and alarm systems); safety of evacuation plans in case of accidents which may occur from natural causes (earthquakes, for example) or human causes.

The increased production of energy from nuclear sources assumed by the authors ("*nuclear power can be added at a rate of about 25 kWh/y/y/1k$-GDP, which, if multiplied by current global GDP […] amounts to ~1500 TWh/y/y":* p. 5) could make it increasingly problematic to identify suitable sites. In India, for example, the planned construction of a nuclear power plant in Gorakpur, a town 160 km from Delhi (with its 17 million inhabitants), would make it impossible to evacuate residents in case of emergency (Newsclick, 2013). Equally difficult would be – in densely populated areas – to deal with hazards of radioactive emissions due to breakdowns or malfunctions. Moreover, the proliferation of nuclear plants would cause a surge in the production of radioactive waste, for which no country in the world has yet found a solution for a permanent disposal.

The present global socio-political instability is accompanied by growing and increasingly stringent security measures, mainly against possible terrorist acts. Any privatization (partial or total) of the nuclear plants would leave a gap in legislation and organization, in

[2] The recent liberalization of the electricity market in many countries has made the economics of nuclear power generation less attractive, and no new nuclear power plants have been built in a liberalized electricity market (Wikipedia)

the face of harm to human health and to ecosystems' integrity.

Another aspect related to security and safety is concerned with the possible deployment of waste material containing uranium for the production of nuclear weapons. One economically profitable way for "disposing" the by-products of the enrichment of Uranium for the production of nuclear fuel has been devised by the military sector for decades: the surpluses of depleted uranium have been used to construct part of armored vehicles and bullets with high penetrating power, with devastating environmental and human consequences (Al-Muqdadi & Al-Ansari, 2013; Fettera & Von Hippelb, 1999; U.S Department of Veterans Affairs, no date).

The partnerships between nuclear, civilian and military fields are a hot topic, which would require the adoption of laws to be enforced by those in charge of nuclear plants – both public and private.

Finally, many data are available that highlight the extremely low risk of incidents of nuclear power plants, comparing them – incorrectly – with the percentages of risk events and activities in which, however, the stakes are dramatically lower. An example may help to understand, and refers to the calculation of the ecological footprint of nuclear plants: this is a parameter cited to emphasize the environmental performance of this kind of energy production. According to Martin Nicholson (2013), when compared to coal, natural gas, and renewable energy sources, nuclear is the most land efficient, energy-dense source of power, with the lowest usage of construction materials per unit of energy generated per year, and one of the least expensive in terms of levelized costs[3]. Evaluating these different aspects of the 'footprint' demonstrates that nuclear is one of our most viable solutions to readily de-carbonize the economy. However, the picture changes significantly in the event of incidents. By itself, nuclear fuel makes relatively few demands on biological productivity when contained, but intentional and accidental releases of radioactive materials can seriously compromise human and environmental health. Failures of nuclear power plants can appropriate large bio-productive areas by making them unsuitable for human use for extended periods. The meltdown of Chernobyl has completely removed a 170.000 hectares as a ''zone of alienation'' from economic turnover and restricted activities on hundreds of thousands of additional hectares since the 1986 accident and possibly for thousands of years into the future (Wackernagel & Monfreda, 2004). On the Fukushima nuclear plant crash, no data are available on the changes affecting land and sea components of the ecological footprint, but "*there is evidence of a plume of increased concentration of Cesium-134, and other radioactive elements that have been observed at unprecedented levels, spreading out some 5,000 miles into the Pacific toward North and South America*" (Neill, 2015, blog entry). The Woods Hole Oceanographic Institution reported that a sample of ocean water taken off the coast of Vancouver, British Columbia on August 2014 tested positive for cesium-134, one of the radioactive elements released as a result of the Fukushima disaster (Ecowatch, 2014).

Products emitted during Fukushima plant crash are adding 'novelties' (Steffen et al., 2015) to the global cocktail of organic, chemical and radio-debris that are loading the Earth reservoirs, with unknown and unpredictable effects on human and ecosystem life.

Qvist & Brook, neglecting the elements of risk, uncertainty, indeterminacy and ignorance that are present in the nuclear power option, are fully immersed into the epistemology of

[3] Levelized costs: a measure of a power source which attempts to compare different methods of electricity generation on a comparable basis (from Wikipedia)

representation which is anchored to an imaginary of control (Benessia & Funtowicz, 2015). The consequences that lie outside quantitative and statistical models are therefore, unpredictable and unforeseen; they are defined as unintended consequences, and conceived of as anomalies. However recent crises, ranging from the 2010 Deepwater Horizon accident in the Gulf of Mexico to the Fukushima nuclear disaster in 2011 and more recently, the case of the French Nuclear giant Areva having been accused of bribery in Namibia (Finnan, 2015), illustrate the vulnerability to corruption of complex technological systems and the hubris of quantitative-based expert studies which ignored what they chose to ignore.

7. Responsibilities in publishing, disclosing and communicating research

The reading of this pro-nuclear article prompts several reflections about the responsibilities of publishing and dispersing "demonstrations" such as those presented by Quist and Brook: *"Here we demonstrate the potential for a large-scale expansion of global nuclear power to replace fossil-fuel electricity production, based on empirical data from the Swedish and French light water reactor programs of the 1960s to 1990s"* (p 1).

The first level of responsibility obviously rests with the authors themselves: in this case they not only provide data, but devote a substantial part of their text (explicitly extrapolating regional data) to provide suggestions for extension of the nuclear power option on a global scale, by drawing an implicit parallel between countries that have the most diverse, geographical, political, economic and social situations.

Moreover it is not clear – in their paper – where the line is placed between data and opinions. On the first page of the article the authors have declared that no competing interests exist, even though the professional commitment of Qvist suggests at least his 'passion' for nuclear installations; the pro-nuclear commitment of Brook clearly emerges from reading the presentation he offers about himself in his blog (Brave New Climate, 2015).

Referees too have a responsibility. PLoS/ONE uses anonymous peer review to determine whether a paper is technically sound and worthy of inclusion in the published scientific record. The opinion of reviewers is supplemented by that of the Academic Editor who takes into account the reviewers' comments, the PLoS /ONE Criteria for Publication and the editor's own assessment of the manuscript. In this process, an ongoing interrogation of the contribution that the paper will make to the academic community and the likelihood that the paper will be cited are key aspects of the decision-making process. Positive answers to such questions would reveal if the paper is likely to find consensus and if the level of the paper meets the expectations for quality set by the journal and the peer academic reviewers. In the case of this paper, we note from the front page of the publication that the article was submitted by the two authors on August 25th, 2014, accepted on February 26, 2015 and published on May 13, 2015. At no point in the process it is indicated when or whether the paper had been revised and resubmitted in revised form.

The third subject bearing responsibility is the mainstream academic community, which mainly values a disciplinary approach to problems, and the submission of quantitative data and statistical analysis of high technical standards, rather than questioning the context of research and the social and environmental implications of the conclusions.

Finally, a further responsibility is to be charged on science communicators, who draw the information from articles, published in scientific journals, select what they regard as most important and then 'translate' it to the public emphasizing the aspects they find most interesting and exciting. At the same time the quality of the source is acknowledged: it is the scientific information, which is taken to be objective and neutral, according to the mainstream imaginary.

Thanks to the proliferation of channels to reach the public (websites, blog, tweets as well as journals offering accelerated and open access routes to publication) these 'translations' are sent round to a much wider and varied audience as compared to a few years ago: communicators – thanks to a clever choice of language in their piece – can easily convey improper, partial or biased information.

Given the importance of the issue, the article written by Quist and Brook had an immediate echo in the popular press: the linearity of the approach and the ease of the conclusions offer a very effective tool for the proponents of nuclear energy as a means of choice for the production of electricity. Authors claim that: *“our modelling estimates that the global share of fossil-fuel derived electricity could be replaced within 25–34 years. This would allow the world to meet the most stringent greenhouse-gas mitigation targets.”*(p 1).

Soon the article is quoted in the Blog "Real Clear Science" (02 Jun 2015) by Danny Clemens, who claims: “*World can Rid Itself of Fossil Fuel Dependence in as Little as 10 Years*”. The paper by Quist and Brook is then quoted by David Biello on Scientific American (September 2015): “*The World Really Could Go Nuclear. Nothing but fear and capital stand in the way of a nuclear-powered future*”.

Finally, citizens and readers also have a responsibility. At this level however the problem extends upstream to the political responsibilities involving the educational system. This aspect is critical and it has been considered in detail elsewhere (e.g. Ravetz, 1997).

8. Towards participated research and shared 'expertise'

The paper by Qvist and Brooke concerns an issue – energy production and the implications on climate change – which owns relevance and scope far beyond the 'technical' data reported by the authors. It is a complex and controversial issue, where facts, interests and values are intertwined and interdependent.

Since the early 90s of last century two scholars, Silvio Funtowicz and Jerry Ravetz, attempted to systematize the features of such problems from the epistemological point of view, andsuggested some suitable methods for addressing them. Their perspective strongly questioned the consolidated view of science as neutral and objective research on the material world, offering undisputed provision of reliable knowledge. Such knowledge, compounded into disciplines and expressed quantitatively has been invoked as a source of legitimate and rational input for informing action and governance. According to the two scholars however, a more inclusive methodology for managing complex, science-related issues is "Post-Normal Science (PNS)", which rests on a three-fold distinction amongst different types of problem-solving practices, based on the severity of either of the two attributes, systems uncertainties and decision stakes:

> *“The modern programme of scientists teaching truth to power, deducing correct policies from incontrovertible facts, is, in the environmental field, in tatters”* (Ravetz, 2003, p 64).

PNS focuses on aspects of problem solving that tend to be neglected in traditional accounts of scientific practice: uncertainty and value loading. When either system uncertainties or decision stakes are severe, we are in the domain of PNS; in such circumstances the quality-assurance of the whole process requires an 'extended peer community' including all the relevant sorts of concerned lay persons. (Funtowicz & Ravetz 1993, Funtowicz & Strand, 2011).

When problems are complex and controversial, Funtowicz and Ravetz suggest to extend the circle of persons able to contribute positively to solve similar problems, beyond those traditionally 'authorized', i.e. scientists. For these new problems – they claim – the maintenance of quality depends on open dialogue amongst all those affected. This they call is an ‘extended peer community’, consisting not merely of persons with some form or other of institutional accreditation, but rather of all those with a desire to participate in the resolution of the issue. Under these new conditions, the appropriate style will no longer be rigid demonstration, but inclusive dialogue.

It took 25 years before the ideas of Funtowicz and Ravetz, which have more recently developed and enriched by many other scholars, could take hold in the scientific community. Even if the PNS approach is still being resisted by the academic world, there are an increasing number of publications which build on the ‘post-normal’ approach (as shown by the site of NUSAP net) and seek to address scientific and socio-environmental problems by a multiplicity of viewpoints, and involving a variety of stakeholders.

9. Energy and equity

“*Inputs from all involved*”: if the kind of problems we face globally requires the contribution of all involved, it is necessary that the subjects whom so far have been expropriated and excluded from view, are identified and listened to. ‘Expropriation’ is the term that Jerry Ravetz uses to illustrate a condition shared by poorer sectors of what some have called the ‘majority world’, but it is also a condition shared by Nature at large (Ravetz, 2006). The poor are often indigenous communities and rural people, who are expropriated, dispossessed from their villages and lands when ‘progress’ needs to build a dam or a nuclear power plant, to dig a mine, to start a new industry taking over their landscape. And what does it means that Nature is expropriated? The pressure that human economy exerts on the environment is regulated by the levels and patterns of material and energy flows between the sphere of economics and the biosphere. Such energy flows essentially consist in the transfer of power from Nature to Man, leaving nature degraded and depleted in the process. The corporate-driven consumer classes, in the North as well as in the South, have the power to bring the bulk of the world's natural resources to their service.

EJOLT, a global research project bringing science and society together to catalogue and analyze the ecological distribution conflicts and to confront environmental injustice, has produced and continuously updated the Atlas of Environmental Justice, an online platform that allows browsing by commodity, company, and type of conflict. Taking a look to the Atlas one may have an idea of the extent, number and variety of conflicts that are going on between powerful and powerless in the context of socio-environmental issues.

Sustainability of the ecosystems requires reducing the overall level of resource flows, in particular the primary flow of materials and energy on the input side (Sachs, 1993, 1999). At the level of ethics, this approach involves the realization that fundamental human rights must take precedence over all other activities, including the realization of one’s own, non-fundamental rights. Applied to ecological subsistence rights, this means that the right to living must take precedence over the non-fundamental resource needs of other agents. Subsistence needs to come before luxury needs (Sachs, 2003). Boosting economic growth is less important than securing livelihoods for the impoverished (Sachs, 2002).

So, the expropriation of Nature can be reversed by reducing the material and energy flows that mainly transform the natural into the artificial, leaving ecosystems degraded, squandered and polluted. Drawing inspiration from our biosphere, high power energy plants should be reduced, and energy sources decentralized. The expropriation of the poor can be reversed by recognizing and protecting their rights to live in healthy and thriving ecological and social systems.

10. Conclusions

Within the framework of post-normal science, science is far from being the simple domain of experts. Rather, scientific research and communication interfaces with the broader political, social and cultural sphere. In this view, even for 'non-expert' citizens it is possible to develop some competencies for a critical and reflective reading of scientific articles by acknowledging what is brought into focus in light or what is being hidden, underplayed and left in the shadows. The conceptual tools we have adopted in the analysis of the paper by Qvist and Brooke may offer some guidance when questioning boundaries of space, time, language and disciplinary focus. For example, one can check whether there is evidence of interdisciplinary approaches and integrations across various perspectives. A powerful tool is that of inquiring into the input and output flows of energy, materials and information underpinning the events and processes under consideration: in fact, despite the prospects of 'decoupling' the natural world from the artificial one (Blomqvist et al., 2015) within the Earth System, every component is inevitably interdependent and interconnected with others.

Moreover, being aware that "*for a given value-based position in an environmental controversy, it is often possible to compile a supporting set of scientifically legitimated facts*" (Sarewitz, 2004, p. 389), it is worth searching for the worldviews and related discursive narratives that are being expressed (often implicitly) by scholars in writing their papers.

We suggest moving the analysis and consideration of research papers upstream, to the level of the aims, values and selection of significant variables in the research process.

UPSTREAM research questions may be formulated according to the underlying worldview and they can be unmasked with some key, reflective questions:

- What kind of relationship is assumed to exist between humans and nature?

- Which are or what should be the most meaningful variables to be investigated?

- Who is entitled to participate in the research?

Such analysis can thus be used to make considerations DOWNSTREAM, involving questions about different concepts of risk, uncertainty and ignorance and which provide different answers to the question "what if?":

- How will natural systems react?

- How shall we cope with unforeseen outcomes?

- Who will benefit and who will suffer from any possible harm or damage?

Answering these questions may help to read the article by Quist & Brook (and many more...) in a new light.

Acknowledgments

The authors wish to thank Dr. Emanuele Negro for his precious contributions and comments on the technical aspects of the literature concerning nuclear power installations.

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