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On the contribution of external cost calculations to energy system governance: The case of a potential large-scale nuclear accident

Erik Laes [a,*], Gaston Meskens [b], Jeroen P. van der Sluijs [c]

[a] Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium
[b] Belgian Nuclear Research Centre (SCK-CEN), Boeretang 200, 2400 Mol, Belgium
[c] Copernicus Institute, Department of Science Technology and Society, Utrecht University, Budapestlaan 6, 584 CD Utrecht, The Netherlands

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ABSTRACT

The contribution of nuclear power to a sustainable energy future is a contested issue. This paper presents a critical review of an attempt to objectify this debate through the calculation of the external costs of a potential large-scale nuclear accident in the ExternE project. A careful dissection of the ExternE approach resulted in a list of 30 calculation steps and assumptions, from which the 6 most contentious ones were selected through a stakeholder internet survey. The policy robustness and relevance of these key assumptions were then assessed in a workshop using the concept of a 'pedigree of knowledge'. Overall, the workshop outcomes revealed the stakeholder and expert panel's scepticism about the assumptions made: generally these were considered not very plausible, subjected to disagreement, and to a large extent inspired by contextual factors. Such criticism indicates a limited validity and useability of the calculated nuclear accident externality as a trustworthy sustainability indicator. Furthermore, it is our contention that the ExternE project could benefit greatly – in terms of gaining public trust – from employing highly visible procedures of extended peer review such as the pedigree assessment applied to our specific case of the external costs of a potential large-scale nuclear accident.

1. Introduction

In recent years there has been a resurgence of interest in nuclear power as a future energy option in both developed and developing countries (Adamantiades and Kessides, 2009). However, whether nuclear power qualifies as a sustainable energy option remains a hotly contested issue (see, e.g., SER, 2008). The controversial nature of the debate can be linked to a number of interrelated factors: the complexity of the relevant facts and the plural positions, values, and stakes that are in play (Funtowicz and Ravetz, 1990, 1993); the contested boundaries between scientific analysis and political decision making (Jasanoff, 1990); and the value-laden character of the sustainability concept itself (Dobson, 1998; Laes, 2006). For gaining insight in the debate, it is useful to refer to the three modes of practical reasoning available to us when deliberating on public policy questions (Richardson, 2002, p. 99):

- End-means reasoning, which starts from sustainability as a given end and determines the best means to it. Given the multi-dimensional and controversial nature of the sustainability debate referred above, it follows that deliberations on a sustainable energy future cannot be confined to this type of reasoning.
- Balancing of costs and benefits (or more generally 'pros' and 'cons') to determine which pathway (i.e. a succession of investment, behavioural and/or policy decisions) optimally achieves many objectives that matter when trying to realise a sustainable energy future.
- Reasoning about ends, which shapes, refines, or revises our conceptions of which ends matter when talking about a sustainable energy future.

The latter type of reasoning refers to setting up the framework of economic, environmental, social, and institutional sustainability objectives that can be counted as final ends, i.e. ends that are pursued for their own sake. Verbruggen (2008), elaborating on internationally accepted principles, proposes six fundamental sustainability objectives for energy supply: (virtually) unlimited resources, democratically decided, globally accessible, environmentally benign, low risk, and affordable. Of course, strategies aimed at sustainability in the long run will have to be embodied today in decisions on pathway choices, where inevitable trade-offs between the sustainability objectives have to be made. Here, the second type of practical reasoning (i.e. balancing costs and benefits) enters the picture. Furthermore, in this context

* Corresponding author. Tel.: +32 14 33 59 09; fax: +32 14 32 11 85.
E-mail addresses: erik.laes@vito.be (E. Laes), gaston.meskens@sckcen.be (G. Meskens), j.p.vandersluijs@uu.nl (J.P. van der Sluijs).

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other criteria such as (short-term) profitability, flexibility, adaptiveness, (ir)reversibility of decisions, and precaution in the face of long-term uncertainties must be considered.

This paper addresses one of the nuclear power's main drawbacks in view of the 'low risk' sustainability objective that besides proliferation risks and the challenge of nuclear waste management consists of the risk of a major reactor accident. More specifically, it addresses the question whether (and if so, in what way) external cost calculations of nuclear accident risks can contribute to the two types of practical reasoning involved in making sustainable energy policy decisions. The paper adopts an institutional economics outlook on this question. It approaches external cost calculations as institutions[1] in two senses of the word:

- Institutions as a process (i.e. the act of setting up a set of normative rules): because externality valuation methods determine who participates in the valuation process, how they participate and in what capacity (e.g. as citizen, consumer, expert, stakeholder), what counts as trustworthy data, and which data processing and aggregation procedures are used, the application of such methods invariably also embodies normative expectations about which values matter and how they should be expressed.
- Institutions as a product (i.e. the result of the institutional process): externality valuation methods also embody normative expectations about the type of institutional policy interventions, which can 'legitimately' be used to reduce (or 'internalise') the identified external costs.

In other words, institutional economics approaches external cost calculations not only as a scientific methodology, but also as a value-articulating institution (Deblonde, 2001; Stagl, 2009). In this perspective, what counts most is whether the mechanisms of energy governance that build on the outcome of such calculations can muster enough trust in order to act as a stable guide to societal choices (Rayner, 2010).

To explore if, and how, external cost data on a potential large-scale nuclear accident can contribute in a more effective way to energy system governance, we relied on literature analysis as well as on interactive stakeholder methodology. The paper starts with a concise description and analysis of the central concept of an 'externality' and of the methodological approach taken for the calculation of external costs of energy production within the framework of the EU-funded ExternE research network. The methodology adopted to estimate the external cost of nuclear accidents within this network is analysed in more detail (Section 2). Section 3 discusses the 'pedigree assessment' methodology applied in the stakeholder evaluation of the ExternE approach to nuclear accident risks. Section 4 discusses the results of the evaluation. Section 5 concludes by discerning the essential elements for enhancing the role of policy-related science (such as ExternE) in general. Although the workshop focused on the consequences of a potential large-scale nuclear accident in a Belgian nuclear power plant (in order to analyse the related externalities in a concrete and detailed manner), the workshop outcomes also allowed to discern essential elements for enhancing the role of policy-related science (such as ExternE) in general. These elements are not limited to what is generally referred to as 'better communication of science' but entail a true re-negotiation of the role that such science can play in policy processes.

2. Externalities of energy

2.1. The ExternE project series

The concept of 'externalities' conveys the idea that human interactions or interdependencies exist beyond established markets (characterised by prices and exchange of commodities).[2] Externalities of a traded product or service are defined as impacts borne by other agents (human agents, the environment) than those involved in the trade interaction. External costs are the calculated costs of those impacts. They are not included in the market price of the traded good or not compensated by its producers and/or traders. In 1991, the European Commission (EC) together with the US Department of Energy (USDOE) launched a joint research project to identify a unified methodology for the assessment of external costs associated with various types of electricity production. After the first phase of the project that established an operational accounting framework (named 'ExternE' in Europe, see the project website www.externe.info), the EC continued an independent programme of follow-up activities. The ExternE network is still actively engaged in updating and extending its methodology (e.g. updating cost parameters, integrating new findings on health and environmental impacts of different pollutants, applying the accounting framework to previously excluded types of externalities such as energy security, etc.), extending the network to new EU member states and broadening ExternE's scope of application (e.g. cost–benefit analysis of European environmental policy measures, green national accounting, etc.).[3] The ExternE project series thus represents the largest body of work in the field of the externalities of energy in the EU, and has become a recognised brand in policy-making circles.

At the core of the ExternE project series lies the impact pathway assessment (IPA) methodology. Impact pathway assessment is a bottom-up approach in which environmental benefits and costs (expressed in monetary parameters) are estimated by following the pathway from source emissions via quality changes of air, soil, and water to physical impacts. An illustration of the main steps of the impact pathway methodology applied to the consequences of pollutant emissions is shown in Fig. 1.

Application of the ExternE methodology to the main options for electricity production resulted in the following general findings (cf. Fig. 2)[4] :

- both renewables and nuclear power show very limited external costs (generally < 1 €/MWhe), with the exception of some biomass technologies;
- gas technologies have an intermediate external cost (generally in the range of 10–30 €/MWhe); and
- traditional oil and coal technologies fall generally within the high range of external costs (30–150 €/MWhe).

[1] With 'institution', we roughly indicate a rule or set of rules (e.g. procedures, norms, routines, and conventions), guiding people's actions and the accompanying views that provide the rule with meaning and with a relevant context of application. The rules embodied in the institution also carry normative connotations, in the sense that whoever violates these rules will be treated negatively (Hall and Taylor, 1996).

[2] Note that this definition of an externality does not in any way require that one adopts the standard assumptions of neoclassical economics. The presence of an externality merely conveys the idea that someone's wellbeing (co)depends on other factors that are not under his/her control, but are decided by other actors engaged in market transactions (van den Bergh, 2010, p. 2048).

[3] Most recent projects include CASES ('Cost Assessment for Sustainable Energy Systems', www.feem-project.net/cases) and NEEDS ('New Energy Externalities Development for Sustainability', www.needs-project.org).

[4] The figure is a very general and schematic representation of ExternE results. The ExternE methodology is aimed at producing more detailed technology and site-specific results.

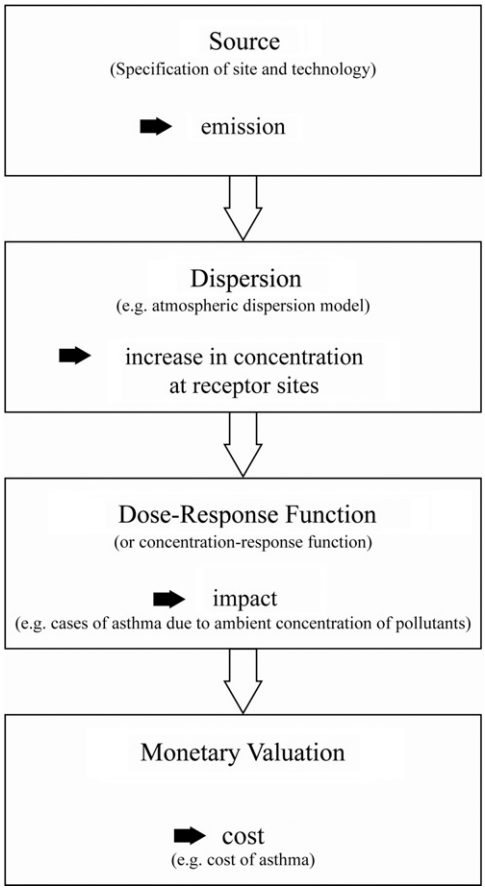

Fig. 1. Impact pathway methodology (www.externe.info).

Because of the potential catastrophic dimension of a nuclear reactor accident, the evaluation of the consequences of such accidents plays an important role in the overall assessment of the external costs of nuclear power. This issue is explored in more detail in the next section.

2.2. External cost of a potential large-scale nuclear accident

The methodology used in the ExternE project is based on expert estimates of expected damages of nuclear accidents. The estimate is calculated as the summation of the probability of the occurrence of an accident scenario (P_i) multiplied by the consequences from that accident (C_i) over all possible scenarios (EC, 1995). This approach can be represented by

$$\text{Expected damage} = \sum P_i C_i \quad (1)$$

In the case of a severe nuclear reactor accident, probabilistic safety assessment (PSA) has served as a basis to evaluate the potential causes of the accident, the probabilities of occurrence, and the resulting releases of radioactive elements into the environment (air, water, and soil). The calculated external costs of the accident fall into two categories:

1. costs of implementing countermeasures such as evacuation and relocation of people, costs related to loss of income, food bans, decontamination, etc.[5] and

[5] A problem with this reasoning is that there are many more effects of a nuclear accident that should principally be included in a monetary evaluation, but would be very difficult to calculate in any meaningful way. One example would be the psychic costs associated with the trauma of being evacuated and the fear that you might have received a fatal dose (even though you are not). Another example might be the economic impacts on nuclear programmes worldwide as a possible result of one severe accident somewhere in the world. In addition, variability of weather conditions, uncertainties about the speed and scope of evacuations, and uncertainties about food contamination pathways make the 'technical' risk assessment dependent on numerous assumptions from the part of the analyst.

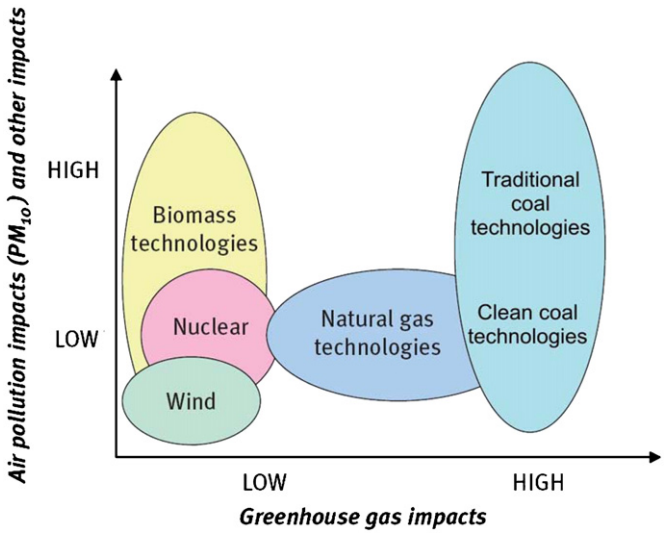

Fig. 2. General ExternE estimates of external costs of electricity production (Faberi and Gaggi, 2007, p. 15).

2. costs of expected health impacts: non-fatal and fatal cancers and severe hereditary effects (both based on collective dose calculations).[6]

In ExternE the estimation of nuclear accident externalities is based on a French PSA of a major core melt accident at a 900 MWe pressurised water reactor (PWR). A core melting probability of 10^{-5} per reactor per year is assumed for this type of reactor, and four hypothetical source term scenarios (describing the type and amount of radioactive materials that could be released following a core melt) are considered. Terrorist attacks as possible causes of radioactive releases were not considered, as it would be difficult (if not impossible) to find reliable figures on the probability and exact nature of such attacks. Finally, direct and indirect costs of the accident scenarios are calculated by hypothetically assuming that the reactor would be located in the central region of Western Europe.[7] Hence, no site-specific estimation of the consequences of a major nuclear accident in actually existing nuclear power plants (e.g. Doel or Tihange in the Belgian case) was undertaken.

The general results of the ExternE exercise are rather clear: the impacts from a single event can be very large, resulting in up to several ten thousands of fatal cancers, and in monetary terms they could amount to billions of Euros.[8] However, normalised to the (very low) probability of the event and to the electricity generation over the power plant's lifetime, the expected monetary value of the risk is low: between 0.104 €/

(*footnote continued*)

[6] Collective dose is a measure of the total amount of effective dose multiplied by the size of the exposed population. It needs to be mentioned however that the (abstract) concept of a 'collective dose' was launched in the context of radiation protection (in order to keep exposure to radiation 'as low as reasonably achievable'), and not as a measure of the real health consequences of releases of radioactive material.

[7] This assumption determines crucial input data for the external cost calculation: population density, land use types, presence of capital goods, etc.

[8] EC (1995) mentions an average value of 17 billion €.

MWh (for the worst-case scenario) and 0.0023 €/MWh (for core melt accidents with minor consequences) (EC, 1995, p. 205)[9] (cf. Fig. 2). A sensitivity analysis concerning accident probabilities does not significantly change this picture. Cost estimates of a large-scale nuclear accident however differ significantly. Just for illustrative purposes, some worst-case estimates end up at 5 trillion US$ for the USA (Ewers and Rennings, 1992) or 6.8 trillion US$ for Germany (Prognos, 1992, cited in Greenpeace, 2009).

The expected-value approach has been criticised in particular for ignoring risk aversion and lay assessments of nuclear risks (including perceived probability of an accident) (Krupnick et al., 1993; Markandya, 1995; Eeckhoudt et al., 2000). It has been known since long (see, e.g., Roth et al., 1990) that in the nuclear context the perceived risks are much greater than the expert estimates. It is clear in economic theory that perceptions matter to the extent that perceptions affect behaviour. Some studies have therefore tried to incorporate risk perception by the addition of a 'risk aversion coefficient'. A risk aversion coefficient (RA) takes into account the fact that the disutility of a potential loss of wealth experienced by an individual is higher than the expected value of the loss as calculated in Eq. (1). In other words: a risk-averse individual's willingness to pay (WTP) for avoiding the risk in question is higher than the WTP calculated by the expected value approach; hence, the external cost of the risk will also be higher. Based on the risk averse behaviour of investors, Eeckhoudt et al. (2000) assume a value of 2 for the RA. This assumptions leads to a multiplication of the nuclear accident external cost by a factor of 20. The assumption that the RA value for a potential large-scale nuclear accident is equal to 2 is however far from universally accepted, leading the ExternE 2005 methodology update (EC, 2005, p. 226) to the conclusion that more research is needed on risk aversion and that, due to the methodological difficulties encountered, risk aversion should not be taken into account in ExternE results.

Of course, the best mechanism to internalise the nuclear accident risk externality (including risk aversion) would be the insurance market. This logic is developed in more detail by Verbruggen (2008), who argues that in advanced capitalist societies the insurance sector is the most respectable institution for balancing widely variable risks for society and for itself properly. According to this logic, nuclear operators should pay full indemnity insurance. Assuming full internalisation, it should then be possible to calculate the market value of major nuclear risks from the risk premiums paid by nuclear reactor operators. However, nuclear operators are at present not required to follow this logic. Indeed, since the beginning of nuclear programmes worldwide, the choice was made to implement a strict, channelled, and limited civil liability rule in order to allow the growth of the nuclear industry (Faure and Fiore, 2009). Hence, in many European states these risks are covered by a particular international liability arrangement, constituted by a set of international conventions.[10] In particular, the Paris and Brussels conventions establish a system in which, on one hand, governments set a limit (in time and in amount) on the liability of their operators for nuclear damage, and on the other hand, the operator of the installation concerned is strictly and exclusively liable. Operators are required to obtain insurance coverage up to the liability limit (currently 700 M€ according to the Paris and Brussels conventions, which has not entered into force yet), with the national states being responsible for the rest of potential damages, again up to a certain limit (currently 500 M€ according to the Paris and Brussels conventions, also not entered into force yet). If the operator's and state's financing are still insufficient, the states party to the conventions must cover the exceeding damages up to 300 M€. Even though liability limits have been raised over the years, the principle of limited operator liability has been maintained. Application of this principle of limited liability thus amounts to an implicit subsidy for the nuclear sector. Faure and Fiore (2009, p. 436) estimate this subsidy for the French nuclear reactor park as a whole at 1.1–162.4 M€/year. However, this estimate is based on the expected value approach (cf. Eq. (1)) and does not take into account risk aversion of insurance companies. In Sevenster et al. (2008), speculative calculations taking into account different risk aversion factors and different assumptions on the total amount of risk coverage needed lead to a wide range of risk premiums to be paid by nuclear operators, which are indicative of nuclear accident externalities. These authors therefore come to the conclusion that as long as nuclear operators are not required to pay full indemnity insurance no reliable estimate of present nuclear accident externalities can be made.

3. Method for analysing the ExternE approach to nuclear accident risks

3.1. Institutional economics' point of view on external cost calculations

We now turn towards the main research question of this paper, i.e. how can external cost calculations of a potential large-scale nuclear accident contribute as institutions to practical reasoning about the sustainability of our energy systems? This line of questioning is informed by Miller (2005), who analyses the growing number of environmental or sustainability indicators being used to support policy formation from a political sciences' point of view. Even though Miller does not explicitly deal with external cost estimates,[11] the general lesson he draws from his discussion on the changing deployment of quantitative statistics in American environmental politics is very relevant to our case also. As Miller (2005, p. 427) himself puts it: "Put simply, numbers do not travel well outside of community, even in a highly mathematical world. No set of calculations, no matter how simple or complex, can provide by itself the glue to tie people together, absent other social connections. When numbers do seem to travel from place to place, look carefully for regularised social interactions, if not institutions or communities – odds on, you will find them." In other words: statistical measures about the state of the environment are not simply mathematical numbers; they inevitably carry social meanings, and the production of those meanings takes place in social communities. Hence, no matter how scientifically sophisticated an indicator is, its influence on policy making will be limited (at best) unless it is carried forward by a sufficiently influential community formed

[9] Compared to the production cost of nuclear electricity, estimated by the OECD (2010) at 30–70 €/MWh for new reactors.

[10] The 1960 'Paris Convention on third party liability in the field of nuclear energy' and the 1963 'Brussels Convention supplementary to the 1960 convention on third party liability in the field of nuclear energy' (both drafted within the framework of the OECD-NEA); and the 1963 'Vienna Convention on civil liability for nuclear damage' (drafted within the framework of the UN-IAEA). A common protocol to both conventions was signed in 1988 after the Chernobyl accident to coordinate the scope of application of both conventions.In the most recent Belgian legislation on the subject (Official Law Gazette, 4 October 2000), operator liability has been set at about 300 M€. As a signatory to the Paris and Brussel convention, Belgium will have to raise this amount to 700 M€ in the future.

[11] Miller (2005) focuses instead on efforts to 'green' the gross domestic product, community sustainability indicators, the UNFCCC greenhouse gas accounting framework, the 'Living Planet Index' (developed by WWF) and 'Metropatterns' (a geographic information system focusing on the development of metropolitan areas).

around that indicator.[12] Taking our cue from Miller's analysis, we became interested in studying why data on the external costs of a potential nuclear accident could be controversial in the first place, as well as the conditions under which such approaches could play a more relevant role in energy system governance. Using the pedigree assessment workshop methodology, a kind of 'laboratory setting' was created to test the chances of survival of this nuclear accident externality in the 'real policy world out there'. Before discussing the outcomes of this workshop, we first give some background on the pedigree assessment methodology.

3.2. Pedigree assessment

While making assessments of complex environmental problems, experts often have to revert to assumptions in certain parts of the 'calculation chain' behind a given outcome of interest (Kloprogge et al., 2011). Since assumptions by definition cannot be objectively determined, there is always an element of subjectiveness. Consequently, an assessment is never made up of 'value-free' scientific facts alone. Numerous studies from the history and sociology of science have by now problematised the distinction between facts and values. Taking an example from the field of external costs of electricity production, Stirling (1997) found that the values derived for energy externalities depend on assumptions in more than 20 important dimensions, yielding a variety of possible rank orderings for different electricity generation options. Such analyses explain how policy-related scientific assessments can become a *de facto* locus for socio-political contestation, and hence contribute to understanding the success or failure of translating the results of these assessments into workable policy instruments (Sarewitz, 2004). Confronted with a possible open divergence of views on the robustness of environmental assessment methodologies, it is necessary to gain a systematic insight to the influence of assumptions on the outcomes of the assessment and to take the communication of related uncertainties seriously (Craye, 2006). These uncertainties are not of the type that could be described by ranges of error and probability distributions. Neither can these uncertainties be seen as 'provisional deficiencies' (e.g. of external cost calculations) that can be best solved through an increased research effort, separate from the policy context. The relevant uncertainties to consider in relation to complex problems such as external cost calculations are those who find their source in different value-laden choices, assumptions, and framings entering into the (long) chain of calculations leading to an estimation of externalities. These uncertainties are of a deeper nature and are related to what has been described in the literature as ignorance ['not only we have no basis to estimate probabilities, but we don't know what can be the impacts' (Funtowicz and Ravetz, 1990)], indeterminacy ['causal chains are open and influenced by non-predictable behavioural systems', but also 'all knowledge is to a certain degree conditional and contingent upon framings, choices and assumptions' (Wynne, 1992)], and ambiguity ['precise meanings of the issue are not agreed, or unclear' (Wynne, 2001)].

[12] A preliminary analysis by Bureau and Glachant (2006) (carried out in the context of the NEEDS project, one of the latest instalments of the ExternE project series) on the use of external cost calculations in the United Kingdom, France, and the United States of America confirms Miller's general finding. According to Bureau and Glachant, factors contributing to the diffusion of monetary valuation of environmental externalities in energy policy-making processes are (i) the existence of official requirements to consider full costs and benefits of proposed regulations and/or official guidelines; (ii) the nature of the relationship between economic researchers and policy practitioners (e.g. promotion by key academic figures such as David Pearce in the UK); and (iii) the development of economic expertise in environmental offices.

The pedigree assessment method as developed by Kloprogge et al. (2005, 2011) makes these deep uncertainties in assessment transparent. It is based on the following steps:

1. identification of explicit and implicit assumptions in the calculation chain underlying the assessment;
2. identification and prioritisation of key assumptions in the chain;
3. assessment of potential value-ladenness of key assumptions;
4. identification and discussion of 'weak links' in the calculation chain; and
5. discussion of implications in terms of robustness of results, communication of results and possible policy uses.

Step 3 involves the use of a 'pedigree matrix' (cf. Table 1), based on the concept of a 'pedigree of knowledge' developed by Funtowicz and Ravetz (1990). These authors discerned a set of criteria to trace the origin of certain assumptions (hence, a 'pedigree of knowledge') and qualify the potential value-laden character of these assumptions. 'Value laden' here is not to be exclusively understood as politically and/or ethically controversial. It refers to the fact that making an assumption involves going through a choice process. The criteria used to discuss the assumptions are (van der Sluijs et al., 2005a, 2005b)

- *Influence of situational limitations*: the degree to which the choice for the assumption can be influenced by situational limitations, such as limited availability of data, money, time, software, tools, hardware, and human resources.
- *Plausibility*: the degree, mostly based on an (intuitive) assessment, through which the approximation created by the assumption is in accordance with 'reality'.
- *Choice space*: the degree to which alternatives were available to choose from when making the assumption.
- *Agreement among peers*: the degree to which the choice of peers is likely to coincide with the analyst's choice.
- *Agreement among stakeholders*: the degree to which the choice of stakeholders is likely to coincide with the analyst's choice.
- *Sensitivity to the view and interests of the analyst*: the degree to which the choice for the assumption may be influenced, consciously or unconsciously, by the view and interests of the analyst making the assumption.
- *Influence on results*: in order to be able to pinpoint important value-laden assumptions in a calculation chain it is important not only to assess the potential value-ladenness of the assumptions, but also to analyse the influence on outcomes of interest of the assessment.

The qualitative discussion of each assumption is closed by giving a score (between 0 and 4—cf. Table 1) for the assumption for each of the criteria, as indicated by the pedigree matrix. The scoring is organised as an intersubjective process of negotiation that enables one to summarise the main points of discussion for each criterion, to explain why different participants suggest different scores, and to clarify any ambiguity in the descriptions of the criteria. The pedigree process allows one to qualify the robustness of the assumptions, as assessed by the participants in the pedigree assessment workshop, as well as to discern options for possibly making alternative assumptions to improve the external cost calculation or make them more meaningful. The practical application of pedigree assessment to our case (the external costs of a potential large-scale nuclear accident in Belgium) is discussed in Section 4.

Table 1
Pedigree scheme used to assess assumptions during the workshop.

Score	Influence of situational limitations	Plausibility	Choice space	Agreement among peers	Agreement among stakeholders	Sensitivity to views of analyst	Influence on results
4	No such limitations	Very plausible	No alternatives available	Complete agreement	Complete agreement	Not sensitive	Little or no influence
3	Hardly influenced	Plausible	Very limited number of alternatives	High degree of agreement	High degree of agreement	Hardly sensitive	Local impact in the calculations
2	Moderately influenced	Acceptable	Small number of alternatives	Competing perspectives	Competing perspectives	Moderately sensitive	Important impact in a major step in the calculation
1	Importantly influenced	Hardly plausible	Average number of alternatives	Low degree of agreement	Low degree of agreement	Highly sensitive	Moderate impact on end result
0	Completely influenced	Fictive or speculative	Very ample choice of alternatives	Controversial	Controversial	Extremely sensitive	Important impact on end result

4. External costs of a potential large-scale nuclear accident in a Belgian nuclear power plant

Crucial assumptions made to arrive at external cost estimates of a large-scale nuclear accident in Belgium were systematically discussed during a full-day workshop using the pedigree assessment methodology. This workshop was organised by the Belgian Nuclear Research Centre's research group on the social aspects of nuclear technology (SCK-CEN/PISA), in collaboration with the European Commission's Joint Research Centre (JRC) and Utrecht University (Brussels, 26 October 2006). A total of 15 experts in various areas related to the external cost calculation of a potential large-scale nuclear accident, representatives of administrations and stakeholders (e.g. the Belgian health council, labour unions, environmental NGOs, royal society of Flemish engineers, etc.) participated.[13] A procedure was developed to select key assumptions in a process involving all workshop participants. During the workshop, these assumptions were discussed and qualified using a scheme based on the concept of pedigree of knowledge. After going through the ExternE research reports and gathering information on points of disagreement and controversy, preparatory interviews with ExternE experts and stakeholders were held, allowing to list in a structured way the main steps in the calculation chain, as well as the crucial assumptions in each of these steps. In this way, a list of 30 assumptions was arrived at. Through an internet survey, held weeks before the workshop, workshop participants selected a final list of six assumptions. These included assumptions related to the scenario used for evaluating the impacts of a severe nuclear accident, to the estimation of the related health impacts, and to their economic and monetary valuation. Special attention was paid to the value-laden character of these assumptions (cf. Box 1).

Box 1–Assumptions assessed and qualified through a set of pedigree criteria during the workshop organised by the Belgian Nuclear Research Centre.

1. External costs of a potential large-scale accident in a Belgian NPP can be determined on the basis of a calculation for a hypothetical NPP located in the middle of Western Europe.
2. In a large-scale accident scenario for a Belgian NPP all radionuclide dispersion routes other than the atmospheric release route are negligible.
3. A linear correlation exists between exposure to ionising radiation and health effects, even for very small radiation doses.
4. All health impacts other than the radiological ones caused by exposure to ionising radiation can be neglected when assessing the consequences of a large-scale nuclear accident in a Belgian NPP.
5. The 'risk-aversion factor' for accidents of the 'low probability/high consequences' type cannot be determined in a reliable way, and, therefore, does not have to be reported.
6. The cost indicators adopted in the ExternE methodology (cost of countermeasures, direct economic damage, short- and long-term health impacts) are sufficiently representative for the total costs of a potential large-scale nuclear accident in a Belgian NPP.

4.1. Workshop procedure

Whereas traditional communication of policy-relevant science largely occurs through a one-way presentation and delivery of research reports, in its turn often provoking one-way critical reactions, the workshop showed the potential of direct and interactive discussion between experts, stakeholders, and policy makers. Until then, in the context of the Belgian nuclear debate, use of external cost data had been limited to defending ExternE results (by those in favour of nuclear power), with critics retorting by pointing out uncertainties, flaws, and arbitrariness in the calculations. Participants in the workshop were positively surprised by the possibilities created to go beyond this black/white treatment of external cost results as 'hard evidence' or as 'bad science'. Space was opened up to express and assess with nuance the merits, deficiencies, and limits of the approach as such and of the choices made in the calculation chain. Specific workshop preparations helped to assure such reasoned exchange of arguments. Workshop participants were selected with the particular concern to take into account the plurality of scientific and socio-political perspectives on the problem. The workshop protocol planned that, for each discussion, an introduction was provided by at least two experts—first one defending the external cost approach and/or particular assumptions made in it and the second one who was a 'critical judge'. Then, the discussion was

[13] Representatives of the main operator of the Belgian nuclear power plants (GDF-Suez/Electrabel) refused to participate in the workshop.

Table 2
Results of the pedigree assessment.

Assumptions	Situational limitations		Plausibility		Choice space		Agreement among peers		Agreement among stakeholders		Sensitivity to views of analyst		Influence on results	
	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.	Avg.	St. dev.
External costs of a potential large-scale accident in a Belgian NPP can be determined on the basis of a calculation for a hypothetical NPP located in the middle of Western Europe	1.1	0.5	1.6	1.0	2.1	1.0	1.9	0.8	1.2	0.8	2.7	1.0	1.3	1.2
In a large-scale accident scenario for a Belgian NPP all radionuclide dispersion routes other than the atmospheric release route are negligible	1.7	1.1	1.8	0.9	2.3	1.1	2.7	0.7	1.7	0.7	2.3	1.0	2.1	1.1
A linear correlation exists between exposure to ionising radiation and health effects, even for very small radiation doses	2.4	0.7	3.0	0.8	2.2	0.9	2.9	0.6	2.0	0.9	2.6	1.2	2.2	1.1
All health impacts other than the radiological ones caused by exposure to ionising radiation can be neglected when assessing the consequences of a large-scale nuclear accident in a Belgian NPP	1.8	1.1	1.5	0.8	1.8	0.8	2.0	1.1	1.8	1.1	1.7	1.1	1.5	1.0
The 'risk-aversion factor' for accidents of the 'low probability/high consequences' type cannot be determined in a reliable way, and, therefore, does not have to be reported	1.6	0.8	1.3	0.9	1.0	0.8	1.8	0.9	0.7	0.7	1.1	0.9	1.1	1.1
The cost indicators adopted in the ExternE methodology (cost of countermeasures, direct economic damage, short- and long-term health impacts) are sufficiently representative for the total costs of a potential large-scale nuclear accident in a Belgian NPP	1.5	0.7	1.3	1.0	1.6	1.0	2.0	0.8	0.9	0.9	1.1	0.9	1.1	1.4

explicitly extended to the views and reactions of the stakeholders and policy makers in the panel. The workshop moderator and a number of researchers, specifically trained in deliberative procedures and/or uncertainty assessment, had to guarantee an informed and fair debate took place. To this end, the moderator presented some guidelines (included in the protocol). He also had at his disposal a catalogue of possible questions in order to (re)focus the discussion if necessary.[14] These model questions were based on insights on the structure of argumentations (Toulmin, 1958), the content of actors' frames of meaning (Grin et al., 1997), and the different types of scientific debate and controversy when uncertainty is salient (von Schomberg, 1997). They were intended to make the process more reflexive (Craye et al., 2005), both in terms of content, that is opening up the problem definition and the scope of argumentation, and in terms of process, that is placing the participants in new roles and rules of interaction. In this particular setting, the traditional and often institutionalised division between the scientist as a provider of facts versus policy makers and the public as defenders of values was challenged. To provide a solid structure for the discussion, a pedigree matrix was used (cf. Section 3.2).

4.2. Workshop outcomes: disagreements on choices and assumptions

Table 2 gives the results for the scoring of the six most important assumptions selected through the internet survey. Overall the scores given were low, reflecting the stakeholder and expert panel's scepticism about the validity and tenability of assumptions made. Generally these were considered not very plausible, subjected to disagreement, and to a large extent inspired by contextual factors. The only real exception to this was the assumption that there exists a linear correlation between exposure to ionising radiation and health effects, even for very small radiation doses. This was the least contested assumption of the workshop.

[14] Examples of such questions include the following: what are the ethical choices implied in this particular assumption? How uncertain is this particular assumption? What type of geographic and temporal delineation is operated through this particular assumption?, etc.

Three experts agreed that the so-called 'linear no-threshold hypothesis' (LNT) constitutes the best scientific basis to regulate the risks of ionising radiation and that the LNT assumption could be qualified as a precautionary approach to managing radiation risks. This statement was qualified to some extent as a result of the discussion with stakeholders. There was a suggestion, however, that perhaps different dose–effect curves should be used for different fractions of the population.

Clear suggestions for improvements in the external cost calculations were made in relation to the assumptions regarding the nuclear power plant (NPP) location that was used as basis for the calculation, and regarding the neglect of other than atmospheric release routes for the dispersion of radionuclides in case of an accident. The main criticism of the first assumption was that, because of the specific location of the Belgian NPPs – near major cities with important industrial activities – the results obtained using a hypothetical location in the middle of Western Europe would (seriously) underestimate the externalities of a potential accident for the Belgian context. Therefore, the critics among the stakeholder group argued that a study of the potential consequences of a severe accident (a 'PSA-Level 3') for the specific case of a Belgian NPP would likely bring much more insights into the nature and extent of the resulting externalities. A PSA-Level 3 would also allow for the exploration of worst-case scenarios, such as the impact of a concentrated dispersion of radioactive elements in the direction of a major population centre (e.g. Antwerp in the Belgian case). The ExternE experts present at the workshop agreed in principle to this objection. In relation to the second assumption, a PSA expert present at the workshop explained that contamination of groundwater and river water by radionuclides in the case of a severe nuclear reactor accident cannot be entirely excluded. Such contamination could be caused by a failure of the NPP's pressure vessel and a possible melting of the reactor core through the bottom of the reactor building, resulting in steam explosions. This accident sequence is considered to be highly improbable, but would nevertheless result in long-term ecosystem pollution, which is not included as an externality in the ExternE approach (only impacts on human health count). This view was not challenged in the discussion.

The assumption that the used cost indicators (cost of countermeasures, direct economic damage, short- and long-term health impacts) are representative for the total costs of a potential

large-scale nuclear accident in a Belgian NPP was also heavily criticised. Mainly, representatives of environmental NGOs pointed out that an entire catalogue of economic impacts was not included in the ExternE methodology: direct and indirect costs of lost production in industries adjacent to the NPP, forward ripple effects in the entire European economy (for example, caused by an evacuation of the Antwerp harbour), costs of 'stigmatisation' of a region contaminated by nuclear fallout, economic impacts on the nuclear sector worldwide (for example, costs of cancelling new nuclear programmes, enhanced safety measures in existing plants, etc.), and so on. The discussion on this assumption led most participants to the conclusion that there would be a continued great potential for public contestation.

Some assumptions were clearly seen as problematic although it was not clear how to overcome the related problems through other ways of calculation. This category of assumptions included the neglect of all health impacts, other than the radiological ones, caused by exposure to ionising radiation when assessing the consequences of a large-scale nuclear accident in a Belgian NPP. This was criticised by a radiation protection expert on the basis of the experience after the Chernobyl reactor accident in 1986. Follow-up studies show a significant increase in the population suffering from post-traumatic stress symptoms, anxiety, estrangement, dislocation, etc. However, according to this expert it is difficult (if not impossible) to relate these psychological impacts unequivocally to a nuclear accident as such or rather to the risk management interventions of (Soviet) authorities. Therefore, he concluded that non-radiological (psychosomatic) health impacts of a potential reactor accident could prove to be a major – albeit hardly quantifiable – factor. The overall average pedigree score attributed by the workshop participants to this assumption shows that this expert qualification was largely shared. A similar reasoning was applied to the acceptability of not reporting a 'risk-aversion factor' for accidents of the 'low probability/high consequences' type. The ExternE experts present at the workshop admitted that within the ExternE network, a better conceptualisation of the 'risk aversion factor' for potential severe nuclear accidents was not considered to be a priority issue. Within the ExternE network the prevailing opinion was that since risk aversion is a highly contextual factor that varies enormously from individual to individual, no robust theoretical framework could be advanced to determine the exact extent of the externality resulting from risk aversive attitudes. Participants in the workshop found this to be one of the weakest links in the calculation chain since it is not up to researchers to implicitly decide that individuals or segments of society should not have different degrees of aversion for different categories of risk.

4.3. Workshop outcomes: implicit framing imposed by external costs

The reasoned exchange of arguments and the expression of a lot of nuance during the detailed discussion of the assumptions were helped a lot by the fact that, preceding the pedigree assessment, the implicit framing imposed by the overall approach of valuation and monetarisation had already been debated. In this way, a forum was given to the more fundamental critique of the external cost approach. This critique, that is, that reasoning in terms of external costs establishes particular meanings of the issue of sustainable energy, was confirmed in the workshop discussions. Through a presentation by researchers involved in ExternE project, it was made explicit that the project fits in a policy framework that attaches crucial if not exclusive importance to market-based instruments to achieve sustainable growth. Based on cost–benefit type of assessments and correct prices, optimal allocation of resources can be achieved. In this framework, it is believed that external cost results can play a determining role by providing the basis for the adequate taxation of certain energy sources. This view is one of 'weak' sustainability, that is, in which material welfare can be exchanged against taking risk with the environment and *vice versa*.

Critics wanted to see it explicitly recognised that the external cost approach

- only partially deals with the issue of sustainable energy, as, even if it aims for price corrections, it leaves other fundamental mechanisms of importance for sustainability such as the role of growth in economy and society untouched;
- reduces citizenship, also with its socio-political dimensions, to consumer behaviour (expression of individual preferences through the willingness-to-pay approach);
- reduces the nature of public goods to consumer goods, thereby overlooking the ethical concerns with nature conservation; and
- takes a decisionist position towards time, neglecting the historical context that led to current possibly unsustainable patterns as well as valuing future impacts according to today's preferences.

The workshop showed that, to play a more relevant role, the presentation of external cost data should openly refer to its basic values in which it finds its foundation and not be communicated as if it was the normal, neutral, and naturally privileged approach. On top of this, it should be made clear that other equally valid views of sustainable energy exist, and that this should be recognised by providing the policy debate with insights obtained through other approaches. This advice is in line with Stirling (2010), who argues that when knowledge is uncertain, experts should avoid pressures to simplify their advice and hide value-laden choices in order to render decision makers accountable for decisions. Critical aspects that are not considered or neglected by the ExternE approach but that should be addressed in policy relevant research and in policy debates include

- concerns of distributional justice;
- institutional factors influencing the relation between the organisation of an economy and its ecological performance;
- assessment of visions of sustainable energy systems as well as different political visions of future organisation of society, as external costs implicitly promote a status quo (through the WTP approach that is very much dependent on current income structures and distribution);
- collective decisions for which there is co-responsibility in society, not just the sum of individual preferences;
- uncertainty about societal values in the future, as external costs imply that these remain stable; and
- sustainability criteria for innovative technologies.

Finally, it was seen to be of utmost importance that together with the results of external cost studies, the limitations are communicated. The inherent problem of 'demarcation' in all external cost studies makes the results critically conditional on system boundaries set. But all too often, a view is conveyed as if external cost results allow to make manageable all the complexities and uncertainties of the sustainable energy issue. It is presented as if one can unequivocally define what the optimal choices are to ensure sustainable development, and thus to be sure of what sustainable development is.

5. Discussion and conclusions

In this article we presented and demonstrated the pedigree assessment methodology, which enabled us to identify, prioritise,

analyse, and discuss uncertainties in key assumptions in external cost assessments of a potential large-scale nuclear accident. This method was applied in order to answer the question if (and if so, how) external cost calculations could contribute as institutions to practical reasoning about and governance of sustainable energy systems. Based on the results of our enquiry it can be argued that the traditional envisaged institutionalisation of external cost calculations in the science–policy interface (i.e. one-way communication of experts to policy makers) should be at least complemented, if not abandoned. The underlying fundamental critique of the approach can only be dealt with adequately through a re-negotiation of the place and role of external cost data in the sustainable energy debate. The assumed 'ideal' relation between external cost results and policy measures (i.e. 'getting the prices right in order to create a level playing field') has to be openly discussed and debated, allowing to surface the implicit meanings and value-laden assumptions behind the uncritical presentation of such direct link. Possibilities for such re-negotiation can be created through direct interaction between involved stakeholders, relevant experts, and policy makers in a setting that allows experimenting with the socio-institutional roles 'normally' taken up in the science–policy–society interface. In this respect, the pedigree assessment workshop showed the potential to critically assess assumptions made in external cost studies. Using pedigree assessment the following results can be achieved:

- qualifying assumptions when they are communicated to the policy sphere;
- evaluating how assumptions relate to different perspectives and frameworks, as held by involved actors;
- generating suggestions for improvements in the calculation chain to deal with disagreements and divergence over assumptions as well as suggestions for communicating this type of policy relevant science; and
- conveying a more adequate image of policy-relevant science.

Part of the current debate on the costs and benefits of the nuclear option compared to other methods of electricity generation is the question of who pays in case of an accident (and what is the resulting 'full' price of nuclear electricity). Our assessment clearly shows that unless the nuclear sector is submitted to full indemnity insurance, there is no reliable and robust way of calculating the 'full' or 'true' cost of nuclear power. A further finding emerging from our analysis is that the liability limit currently taken up in international conventions (300 M€ in the Belgian case, soon to be increased to 700 M€) is less than the expected monetary value of nuclear accident damages as calculated in ExternE. Moreover, the ExternE value is very likely a (serious) underestimation of the 'true' externality, because it ignores other factors such as risk aversion and the full catalogue of psychological, moral, cultural, and economic 'ripple effects' of a large-scale nuclear accident. A simple representation of external costs of different electricity generation options as portrayed in Fig. 2 in the case of nuclear power therefore lacks robust scientific support and is likely to be perceived as very controversial by key stakeholders in the debate.

What can the analysis tell us about the sustainability of nuclear power?

In advanced capitalist societies, risk regulation by a civil liability regime with mandatory insurance is a widely accepted sustainability principle, i.e. the 'precautionary polluter pays' principle (Daly, 1999). Deviating from this principle (which amounts to an implicit subsidy in favour of nuclear operators) can of course be justified (temporarily) by referring to principles of a higher priority. One could for instance argue that when the nuclear industry stood at the beginning of its development, the technological expectations, political support, and public acceptance of the nuclear option made such favourable government intervention at least 'understandable'. The decision on that liability limit was therefore a political one, based on a consensus around nuclear energy at that time. This political context has however thoroughly changed, not in the least because the accidents at Three-Mile-Island, Chernobyl, and Fukushima have shown that the risk of a serious nuclear accident is not merely hypothetical. The consideration of new nuclear pathways – e.g. a lifetime extension of existing reactors or the construction of new (GenIII+) reactors – could at the political level lead to a debate on why, some 50 years after the introduction of nuclear energy, this energy form still deserves an implicit subsidy through a financial limit on liability. Valuable insights as gained through ExternE complemented with the pedigree assessment as implemented in the workshop will have to be blended with principle-based political deliberation if one wants to take decisions regarding (new) nuclear pathways and regulation of the risks that these pathways entail. External cost calculations can contribute to the structuring of such debate but it cannot decide that debate.

Summing up our findings, it is our contention that the ExternE project as a whole could benefit greatly – in terms of gaining public trust – from employing highly visible procedures of extended peer review such as the pedigree assessment applied to our specific case of the external costs of a potential large-scale nuclear accident.

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