Energy Research & Social Science 22 (2016) 94–106

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

The role of sustainability in nuclear energy plans—What do national energy strategies tell us?

Fabienne Gralla[a,b,*], Beatrice John[b], David J. Abson[c,f], Anders P. Møller[d], Manuel Bickel[e], Daniel J. Lang[b,f], Henrik von Wehrden[a,f,g]

[a] Centre of Methods, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany
[b] Institute for Ethics and Transdisciplinary Sustainability Research, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany
[c] Faculty of Sustainability, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany
[d] Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Bâtiment 362, F-91405, Orsay Cedex, France
[e] Institute of Sustainability Governance, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany
[f] FuturES Research Center, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany
[g] Institute of Ecology, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany

ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
12 September 2016
Accepted 13 September 2016

Keywords:
Energy strategy
Nuclear energy countries
Nuclear energy
Sustainability

ABSTRACT

Energy supply and use play vital roles in transition towards a sustainable society. Nuclear energy is used or planned to be used in 40 countries globally, yet the contribution of nuclear energy to sustainable development remains an area of contention. The purpose of this exploratory study is to understand the framing of sustainability within national energy strategies of countries pursuing or planning to start nuclear energy production. The strategies were analyzed by assessing the occurrence of 56 facets of sustainability grouped into 7 dimensions. In addition, the definitions of sustainability used in the strategies and the information on consultation and public participation in their preparation was reviewed. Most strategies mentioned sustainability but did not provide its explicit definition. Risk, waste management and social aspects of sustainability were mentioned relatively less frequently than to environmental, governance and economic aspects of sustainability. The information on consultation and public participation portrayed a limited extent of such processes.

1. Introduction

Following the Brundtland commission's definition of sustainable development [1], the global energy demands of the current generation should be satisfied without compromising the ability of future generations to meet their energy needs. Yet, projections suggest that the aggregate global energy demand will increase by approximately 37% between 2014 and 2050 [2], with energy being identified as one of the key sustainability challenges of the 21st century [3]. At the national level, countries use diverse energy strategies to tackle this challenge, often claiming sustainable energy transitions to be their main motivation. However, multiple aspects of energy governance [4] intersect with the normative goals of sustainability and "clearly defined facets of sustainability" for assessing energy policy are lacking [5]. Hence, different governments can appraise the same energy sources very differently (from a sustainability perspective). For example, nuclear energy is considered a sustainable option in South Korea [6], but is excluded from sustainable energy strategies [7] in countries like Denmark [8] or Austria [9].

Here it is important to note that sustainability is an inherently normative notion, determined by underlying values and ethics. The overall aim of energy policy should be to produce affordable and clean energy, (as defined in the Sustainable Development Goals [3]), however, how this goal is achieved depends not only on a countries capacity to act, but also the strategy and vision that guide such actions. The term "strategy" is widely applied within management studies [10–12], as well as to describe political non-binding documents (e.g. the Lisbon Strategy [13], a development plan for the economy within the EU). An energy strategy might not be binding for a country, however, it shows the objectives, goals and targets for long-term actions, a direction of the energy policy agenda. Therefore, terms and wording used in the national energy strategies provides some insights into national perspectives on important issues regarding energy supply. We consider an analysis of energy

* Corresponding author at: Centre of Methods, Leuphana University Lueneburg, Scharnhorststr. 1, 21335 Lueneburg, Germany.
E-mail address: fabienne.gralla@leuphana.de (F. Gralla).

http://dx.doi.org/10.1016/j.erss.2016.09.003
2214-6296/

strategies relevant to how sustainability is currently envisioned in the energy sector.

According to Diaz-Naurin and Kovacic it is highly challenging to address the full range of sustainability dimensions related to nuclear fission energy production, particularly with regard to intergenerational equity issues such as long-term waste management and depletion of uranium resources [14]. The intersection between sustainability and energy use can be explored through narrative analysis of official documents [14], scientific literature [15], or reviewed global scenarios and national nuclear programs [16]. Alternatively, multi-criteria analysis tools [22] can be used to explore assess the sustainability of energy strategy. A variety of studies on sustainability assessments of energy systems and nuclear energy are available [7,23]. The sustainability criteria included for an assessment of nuclear energy can range from a focus on techno-economic, economic, social and environmental dimensions of sustainability [23] to further inclusion of risk [7,24] as well as governance/policy/institutional criteria [7,25]. However, the lack of a common sustainability evaluation scheme for (nuclear) energy production makes the comprehensive assessment of energy programs/transitions problematic. Here combining these two traditions we present a narrative analysis of official national energy strategies based on a set of predefined set of sustainability dimensions and sub-dimensions, which here after we refer to as facets of sustainability. In doing so we hope to provide insights of the sustainability and energy planning nexus within nuclear countries, with regard to key questions in energy policy, including issues of intergenerational equity, management of risks, participation in decision making and assessment of environmental harm caused by energy choices [27].

The purpose of this exploratory study is to summarize and thus make transparent the facets of sustainability that are reflected in official national energy strategy documents. In doing so we hope to contribute to on-going discussions related to the energy and sustainability nexus. Hence, our study investigates the perspective on sustainability within the national energy strategies of countries currently using, or planning to use nuclear energy (for brevity hereafter simply referred to as "nuclear countries") to answer the question: "Which facets of sustainability are reflected in the energy strategies of nuclear countries, and which are neglected?" An exploratory research design has been applied using a deductive approach based on the occurrence of 56 facets of sustainability in the energy strategies of nine case study countries. The results provide an overview of the sustainability criteria mentioned in the energy strategies of nuclear energy countries, related to either general energy strategies and specifically to nuclear power. Based on our analysis we formulate four recommendations which could be considered in order strengthen the relations between energy and sustainability in national energy strategies.

2. Methods

We performed an exploratory comparative study of officially published national energy strategies (with time frames spanning the next five to 25 years) of nine nuclear countries (Tables 1 and 2). An analysis of the contents of these documents was performed based on a predefined set of 56 facets of sustainability grouped into five dimensions of sustainability.

2.1. Case sampling

The initial set of countries for our analysis included 27 countries currently producing energy from nuclear reactors and 13 countries that have announced official plans to start nuclear energy production [17]. We reduced this initial set based on a purposeful sampling protocol [18,19] that followed two mandatory steps and one step to enable a diverse set of countries to be included in the analysis with respect to:

(i) Having an official governmental energy strategy. The results needed to be published by a government's ministry. We included various synonyms in the search string to gather those strategies. For brevity we refer to all such synonyms/descriptors (e.g. energy plan, energy roadmap, white paper etc.) using the term energy strategy.
(ii) To having been published in English.

Here it is important to note that it may be that in some of the countries studied specific sustainability concerns in relation to nuclear power may not be considered strategically important enough to be included in their strategy documents, however, they may nevertheless be addressed else in official documents. However, we would argue that the exclusion of such concerns in such key narrative building documents is in itself of interest regarding the prioritization of different facets of sustainability in relation to energy development context.

2.2. Content analysis based on facets of sustainability

In order to summarize the aspects of sustainability reflected in the energy strategy documents of nine nuclear energy countries, we analyzed them based on 56 facets of sustainability, related to five sustainability dimensions. In addition we considered (1) the definitions of sustainability employed by the strategy documents; (2) the links made between sustainability and nuclear energy; and (3) issues of procedural justice related to who was involved in the energy strategy decision process (Table A1 in Appendix A). The analysis made a distinction between sustainability criteria mentioned in relation to general energy strategies, or specifically in relation to nuclear energy use (Table A1 in Appendix A). Here we note that it is not possible to know how seriously these facets of sustainability are taken with regard to actual decision making, nevertheless, they do highlight which aspects of sustainability are acknowledged as relevant within this policy context.

The scheme for exploring facets of sustainability addressed in energy strategy documents was developed from various sources, including scientific articles and reports, in a deductive approach [31], with additional facets drawn from the energy strategies themselves (Table 3) [31,32]. The scheme consisted of five dimensions taken from Verbruggen et al. [7]: (I) environment/ecological (planet); (II) social (people); (III) economic (prosperity); (IV) risks; and (V) governance (institutional) (Table 3). Verbruggen et al's scheme was selected above other potential schemes (e.g. Gibson's [7]) because it was specifically designed for assessing sustainability in relation to nuclear power. The five dimensions included 53 facets of sustainability that are specified and described by additional codes (several keywords) (see Table 4) to allow for a precise coding of the documents. In addition we considered three foci: the definition for sustainability in the energy strategy; whether an explicit link was made between nuclear energy and sustainability; and the involvement of other actors (e.g. civil society and ministries dealing with other policies) in the energy strategies. In total 56 facets were considered, which were coded based on 90 keywords searched for in each document. The presence/absence data of the keywords associated with the 56 facets of sustainability were calculated for each of the five sustainability dimensions and three additional foci. If every facet of a particular dimension of sustainability was present in a document the overall score for that dimension would be 100%.

Table 1
Overview of information on countries nuclear energy production [20,21].

Country	Nuclear electricity production in TWh within the country (2013)	Nuclear share in percent of the total energy production within the country (2013)	Nuclear plants in construction
Hungary	14.5	50.7%	0
India	30	3.5%	6
South Korea	132.5	27.6%	4
Russia	161.7	17.5%	9
Slovak Republic	14.6	51.7%	2
United Kingdom	64.1	18.3%	2
USA	790.2	19.4%	5
Lithuania		Construction	–
United Arab Emirates		Construction	–

2.3. Scope and limitations of the study

Our research study is limited to one document type, of countries pursuing nuclear energy and to information provided in English language. We can provide an overview of content acknowledged within those documents in relation to our sustainability criteria but cannot provide in-depth information on those countries in relation to other media and documents. Therefore the scope can be described as starting point in order to understand the perspective taken into account based on this documents. Another sustainability evaluation could reveal further information. It is one further puzzle piece to illustrate the perspective on energy and sustainability.

3. Results

The results summarize (1) all collected information on the definition of sustainability, whether the nuclear energy strategy is explicitly linked to the notion of sustainability and which actors were involved in designing the national energy strategy. (2) A comparison of which of the 56 sustainability criteria and dimensions were acknowledged for the energy system in general and for nuclear energy production specifically.

3.1. Nine energy strategies – definition of sustainability, information on involvement and sustainability related to nuclear energy

3.1.1. Sustainability definitions

All of the analyzed national energy strategies used the term sustainability or sustainable development, although five did not elaborate any definition of 'sustainability'. Two strategies (from the Slovak Republic and India) linked sustainability to, amongst other things, energy security. South Korea did include sustainability as objective for action and summarized measures to enhance sustainability in the energy sector by: "Environmental Protection, Improved Safety, and Technology Development" (p. 32) which can give an idea of their understanding and perspective. Only the strategy of Hungary [22] referred to an existing definition within the Brundtland report [1] and introduced sustainability as one of three pillars of the energy strategy (Security of Supply; Competiveness;

Table 2
Overview of the energy strategies of nuclear and nuclear planning countries (countries in alphabetical order).

Country (Year)	Publisher	Time Horizon	Pages	Name	Main Focus
Hungary (2012)	Ministry of Development	till 2030 plans, broad roadmap till 2050	132	National Energy Strategy	"The Energy Strategy focuses on energy savings, the guaranteeing of the security of supply for Hungary and the sustainable improvement of the competitiveness of the economy," [22].
India (2006)	Planning Commission of the Government of India	till 2032	168	Integrated Energy Policy	"[. . .] should be used as input into policy making and will help shape our energy policy in the 11th Plan [. . .]" [23].
Lithuania (2012)	Ministry of Energy	2020; guidelines till 2030 and 2050	67	National Energy Independence Strategy	"The main goal of this Strategy is to ensure Lithuania's energy independence before the year 2020," [24].
Russia (2010)	Ministry of Energy	2030	174	Energy Strategy for Russia	"[. . .] sets a course of long-term development of the energy sector [. . .]" [25]
South Korea (2014)	Ministry of Trade, Industry and Energy	2035	195	Second Energy Master Plan	Is more defined as an overall plan giving objectives for "energy-related plans source-by-source and sector-by-sector" [26].
Slovak Republic (2008)	Ministry of Economy	2030	~170 incl. appendix	Energy Security Strategy	The strategy is embedded in relation to decisions and aims of the European Union [27].
United Arab Emirates (2015)	Ministry of Energy	2021 and outlook till 2030	263	The State of Energy Report	"The transition from subsidized, fossil-based power generation to a diverse, sustainable energy mix," [28].
United Kingdom (2011)	Department of Energy and Climate Change	Main perspective till 2020 but with a vision till 2030 and targets till 2050	142	Planning our electric future: a White Paper for secure, affordable and low-carbon electricity	"This White Paper sets out the Government's commitment to transform the UK's electricity system to ensure that our future electricity supply is secure, low-carbon and affordable", [29].
United States of America (2001)	National Energy Policy Development Group	2020	170	National Energy Policy	"[. . .] a national energy policy designed to help the private sector, and, as necessary and appropriate, State and local governments, promote dependable, affordable, and environmentally sound production and distribution of energy for the future," [30].

Table 3
Overview of the dimensions and criteria of the evaluative sustainability scheme and the source references. The codes for each criterion are summarized in Figs. 2–5 and Table A1 in Appendix A: 1. Sharma and Balachandra [33], 2. Schenler et al. [34], 3. Verbruggen et al. [7], 4. International Atomic Energy Agency [35], 5. Stamford and Azapagic [36], 6. Sovacool and Mukherjee [37], 7. Gralla et al. [38]. Criteria were added later as part of an iterative analysis process.

Sustainability dimension	Sustainability criteria	Sources
I. Environmental/ecological (planet) (Verbruggen et al. [7])	Atmosphere	1, 2, 5, 6
	Climate Change	1, 2, 3, 5, 6
	Land area	1, 2, 3, 5, 6
	Water	1, 5, 6
	Waste	1, 2, 5
	Biodiversity	2, 4
	Natural resources	1, 2, 3, 5, 6
	Energy use efficiency	3, 6
II. Economic (prosperity) (Verbruggen et al. [7])	Transparency of costs (clear state of costs)	1, 2, 3, 5
	Investments in Research & Development	6
	Economic feasibility	3
	Supply	1, 3, 5, 6
	Innovation and Technology	3, 6
	Provision of employment	1, 2, 5, 6
III. Social (people) (Verbruggen et al. [7])	Human rights and corruption	5
	Participation	2, 3
	Human health	3, 4, 5
	Local community and residential environment	2
	Access to information	3, 6
	Affordability	1, 3, 6
	Education and knowledge	based on iterative process
IV. Risks (Verbruggen et al. [7])	Energy Production/Accidents/Incidents	2, 5
	Nuclear weapon	3, 4, 5
	Terrorism	2
	Liability of risks and costs	3
	Insurability of risks	3
	Financial or economical risk	2
V. Governance (Verbruggen et al. [7])	Institutions and Processes	1, 3
	Information availability and access	1, 3, 6
	Approaches of collaboration between other countries	based on iterative process
	Energy Risk Management	4, 7
	Energy Waste Management	2, 5

Sustainability in Hungary [22]) that are connected and build upon the fourth element Economic Recovery [22].

3.1.2. *Involvement of actors during the development of the strategies*

Some information was available within the energy strategy documents on the involvement of additional ministries, scientists, other experts or groups that contributed to the development of the strategies. In some cases working groups or committees were set up to decide on the energy strategies. Nevertheless, there was less information in strategies available on the involvement of ministries that dealt with social issues such as family, education, women rights etc. A participatory setting to create the energy strategy seemed to have taken place in two countries. Slovak Republic [27] and South Korea [26] involved civil society via bilateral participatory methods, e.g. discussions or public hearings, whereas three countries applied bilateral methods for feedback via interviews on a draft or parts of the strategy (Hungary [22]; India [23]; United Kingdom [29]). In four countries no information on participation of other actors' e.g. civil society could be found (Russia [25]; United Arab Emirates [28]; USA [30]). Here, we note that participatory approaches might have been conducted in the planning process but not mentioned in the strategy. Our study is limited to the information provided within the strategies so that it does not give a final result on involvement of actors. Nevertheless, as the involvement of actors plays an essential role in terms of procedural justice

Table 4
Overview of strategies with an explicit or implicit link between sustainability and nuclear energy.

Country	Citations collected of nine energy strategies
Hungary [22]	"[. . .] extension of the lifecycle of the Paks Nuclear Power Plant and the potential construction of new nuclear unit(s) [. . .] is set as tool within the energy strategy to make the primary energy supply more sustainable" (p. 58)
Lithuania [24]	"Sustainability. Both production and consumption of energy must be based on the principles of sustainable development. When ensuring sustainability the volume of emissions of greenhouse gas will be reduced by increasing energy production, transmission and consumption efficiency and encouraging energy production from environmentally-friendly resources (renewable energy sources and nuclear energy).(p. 15)
Slovak Republic [27]	"Nuclear power plants will be the basis in the balance of the electricity system of Slovakia, and will play an important role in safeguarding the security of electricity supply and sustainable development" (p. 110).
South Korea [26]	"Enhance Sustainability (Environmental Protection, Improved Safety, and Technology Development)" by promoting "[. . .] innovation in the nuclear industry [. . .]" (p. 32).
United Arab Emirates [28]	"[. . .] the energy sector, where a sustainable and diversified economy is fueled by an equally sustainable mix of energy sources. The innovation required will also help the transition to the competitive knowledge economy we are aiming for. The infrastructure to produce energy and water sustainably for residential consumption will need to meet world-class standards," (p. 23); "The 5.6 GW of nuclear power in Barakah will substantially diversify the UAE energy mix," (p. 35).
Russia [25]	"[. . .] development of an industrial investment policy and target programs which are to provide sustainability, renewal and increase in efficiency of the existing potential and development of the nuclear fuel base [. . .]" (p. 103)

we would argue that the use and documentation of such participatory approach should be included in national energy strategy documents.

Below, we present a more detailed overview for each country on their sustainability definitions and involvement of actors for creating the energy strategy:

Hungary [22]

Sustainability: The Hungarian energy strategy defines sustainability based on the Brundtland report [1]. It is embedded as one of three objectives: energy security, competiveness and sustainability; all are connected to the basic element "economic recovery" [22]. Sustainability includes measures on environmental protection and nature conservation as well as social and welfare considerations. The strategy also included scenarios without any nuclear energy use (p. 24). The energy strategy included links to other EU directives or national renewable energy strategies.

Involvement: The strategy was built on recommendations of consultative committees from the Ministry of National Development as well as the opinions of 110 stakeholders from industry and trade, scientists, social and economic organizations (p. 9). Proposals of other ministries seem to be included e.g. the Ministry of Rural Development (p. 56).

India [23]

Sustainability: India's energy strategy includes no sustainability definition. Nevertheless, sustainable development is introduced as an overall concept embedded in an: "[. . .] integrated energy policy linked with sustainable development that covers all sources of energy and addresses all aspects of energy use and supply including energy security, access and availability, affordability and pricing, as well as efficiency and environmental concerns," [23]. Energy security and independence are aims that can be tackled by new technologies so that risks, e.g. supply and technical risks, can be reduced (p. 53, 57) and clean energy should be promoted to decrease health risk for women and children (p. 6).

Involvement: Responsible for the content was an expert group that has been set up by order from the Prime Minister. Part of this expert group were officials from trade, industry, power, energy and environmental or climate institutions. The public could comment and provide feedback on the draft report online.

Lithuania [24]

Sustainability: Lithuania includes sustainability as one of the key principles of energy policy together with competiveness and energy security (p. 13). Further descriptions reveal a clear focus on technological aspects with regards to sustainability "[. . .] 2030–2050, the main priority of the Strategy is to further increase the sustainability of the Lithuanian energy sector. In this period, new breakthrough technologies will be selectively adopted, focusing on the sustainable and environmentally-friendly energy production and consumption [. . .]," [24].

Involvement: There was no involvement of other actors and ministries mentioned except one link to the Environmental Ministry that was set to provide further information on climate change targets (p. 54).

Russia [25]

Sustainability: Sustainability has not been introduced or defined as a concept but is used as a term e.g. to explain the role of energy as fundamental part in Russian economy which defines a "[. . .] necessary condition for sustainable social and economic long-term development [. . .]," [25]. This economic perspective can be found in relation to other issues like perception of risk: "[. . .] uncertainty and risks has significantly increased on world markets, including in connection with abrupt and unpredictable dynamics of oil prices, negative impact of the world financial crisis [. . .]" [25] or some social issues "reproduction of human capital in the energy sector," [25]. A noticeable difference in comparison to the other energy strategies is the description of climate change measures that shall help in "resistance to climate change" [25], which is described otherwise as climate mitigation or adaptation.

Involvement: Responsible for the content are 13 interdepartmental working groups with scientists and experts (p. 3). No further explanation was provided on the identity of the scientists and experts or their fields of research and expertise. Involvement of other ministries with social responsibilities was not mentioned nor was further information of actors included, e.g. civil society.

Slovak Republic [27]

Sustainability: The energy strategy of the Slovak Republic is mainly defined as energy security strategy that seeks to increase the competitiveness of the energy sector: "The objective of the energy security strategy is to achieve a competitive energy that would safeguard secure, reliable and efficient supply of all forms of energy at reasonable prices with respect to the protection of the consumer, protection of the environment, sustainable development, safety of supplies and technical safety," [27] (Chapter 7 p. 1). Hence, the term sustainability is used to describe a goal but no further definition was given. The way to achieve all goals in the energy sector is directly connected to the production of nuclear energy that will increase independence of energy import (Annex 3 p. 6) and cost stability (p. 105). Risks are mentioned in relation to the economy (p.13), risk of supply (p. 17), and risk areas (p. 12), which leads to risks for citizens due to supply shortage or less economic activities.

Involvement: The Ministry of Environment commented on the energy strategy as part of the environmental impact assessment; no further ministerial involvement was mentioned. Within the environmental impact assessment, a public hearing and the possibility to make comments online enabled civil society to be involved in parts of the strategy (chapter 7, p. 6–7). Also critical comments on nuclear power by a civic Slovakian organization were included in the publication.

South Korea [26]

Sustainability: Sustainability was introduced as a policy goal of the past energy plan together with considerations on energy security, economic growth and environmental impact (p. 8). The second and current energy strategy presents sustainability as an objective to balance environmental and safety concerns and increase technological development (p. 29–30).

Involvement: There were discussions about the content of the plan in joint working groups of various ministries (p. 39) and public hearings (p. 36). Public acceptance and trust needs to be built with safety measures after corruption scandals arose in the nuclear industry (p. 89, 93). A National Energy Committee was established with 24 members of science, government, industry and civil society (p. 36), whereas it was not clearly pointed out if ministries dealing with social issues e.g. education, family, gender equality were included nor if civil society groups were involved (p. 39).

United Arab Emirates [28]

Sustainability: Sustainability plays a role in the UAE Vision till 2021 under one of the four pillars in the energy vision described as "United in Prosperity – a nurturing and sustainable environment for quality living" [28]. The term sustainability is used in relation to specific goals e.g. green economy for sustainable development (p. 111). Among others, citizens should be engaged in "specifically rational use of energy and water, promoting air quality, encouraging conversion of waste to energy, clean and renewable energy, water security, sustainable transport and rational fuel use," [28]. Nevertheless there exists no defined conceptual basis for sustainability or introduction of the term.

Involvement: A lot of different sectors are acknowledged e.g. education or transportation. Some ministries are mentioned in the strategy e.g. Ministry of Water and Environment (p. 161), but with no further explanation of collaboration in the decision-process on the energy strategy. Some public-private partnerships seemed to have been implemented to run projects as part of the strategy e.g.

for the effective disposal and recycling of electronic scrap [. . .]" [28]. Nevertheless, the content of the energy strategy seemed to be decided by the Ministry of Energy without further collaboration.

United Kingdom [29]

Sustainability: The energy strategy has an economy focus, and does not define sustainability but uses the term to define a goal of the strategy: "By reforming the market, we can ensure future security of supply and build a cleaner, more diverse, more sustainable electricity mix." [29].

Involvement: Actors had the opportunity to take part in a consultation process on the Electricity Market Reform in 2010 (p. 17) and the White Paper was defined as governmental response to those comments (p. 18). It is not clear which departments or ministries had been involved.

USA [30]

Sustainability: No information about the underlying concept of sustainability was available, however, the term was used in relation to e.g. environmental sustainability: "The first step toward a sound international energy policy is to use our own capability to produce, process, and transport the energy resources we need in an efficient and environmentally sustainable manner," [30]. An elaboration on risk issues without using the term included: background radiation, radioactive impacts on humans in everyday life, proliferation and accidents (p. 3.10). The strategy mentioned the Three Mile Island accident, but emphasized that no injuries have been caused and new plant designs help make new nuclear power plants much safer (p. 3.10).

Involvement: Several ministries have been included and listed at the beginning (p. 3), but neither of the ministries was emphasized to deal with social issues nor was involvement of other actors described.

3.1.3. Link between sustainability and nuclear energy

Three of the strategies (USA, United Kingdom and India) did not indicate a clear link between sustainability and nuclear energy (Table 4). Of the six strategies that did link sustainability to nuclear energy use, some of the linkages were explicitly stated e.g. the Hungarian energy strategy, whereas other links were made implicitly within the narrative. For example, the United Arab Emirates aimed for a sustainable energy mix and describe the role of nuclear power in creating a diverse energy mix (Table 4).

3.2. Sustainability dimensions of the energy system and nuclear energy

The presence or absence of a given facet of sustainability in the strategy document for each country was recorded for both the entire energy system, and nuclear energy production in particular. These data were then aggregated across the nine case studies for each of the five sustainability dimensions (Figs. 1–5). For example, climate change was a facet that all strategies of all countries mentioned in relation to nuclear energy and the energy system (Fig. 1).

The presences of facets sustainability were more often found in relation to energy systems in general rather than specifically related to nuclear energy (Figs. 1–5). Only in the risk related facets of sustainability was there a greater presences in relation to nuclear energy (Fig. 3). However, the facets in the risk dimension were mentioned less frequently than terms related to any of the other sustainability dimensions for both nuclear energy and energy system as a whole. The difference between the frequency of using sustainability terms with respect to the whole energy system and specifically for nuclear energy was highest in the social dimension (Fig. 5). For the economic dimension of sustainability (Fig. 2) some of the facets were present in all of the national energy strategies e.g. technologies that decrease fuel amounts/efficiency/safety;

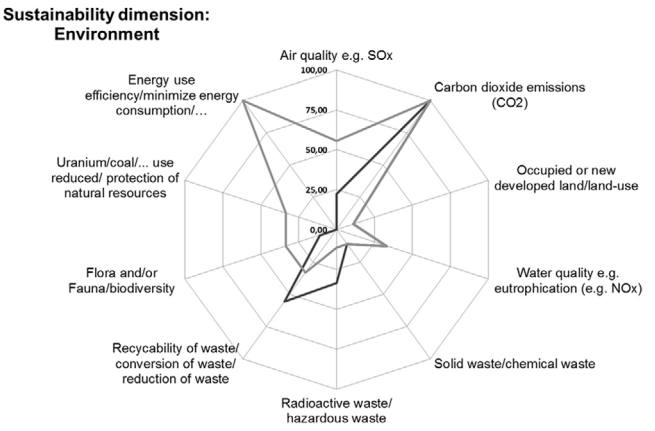

Fig. 1. Overview of the presence of facets of sustainability within the environmental dimension within the nine national energy strategies, 10,000 means that all nine energy strategies addressed this facet (black line: nuclear energy; grey line: energy system).

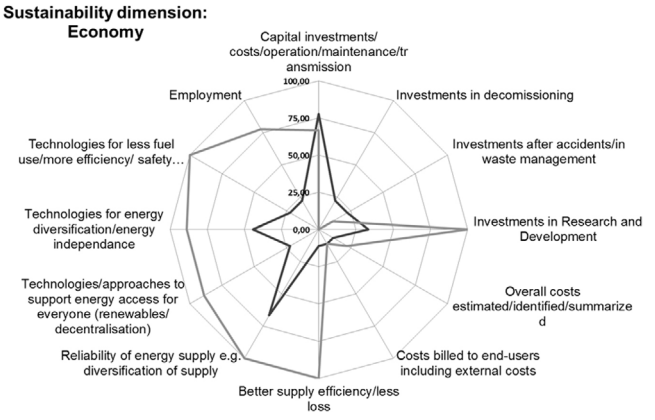

Fig. 2. Overview of the presence of facets of sustainability within the economic dimension within the nine national energy strategies, 10,000 means that all nine energy strategies addressed this facet (black line: nuclear energy; grey line: energy system).

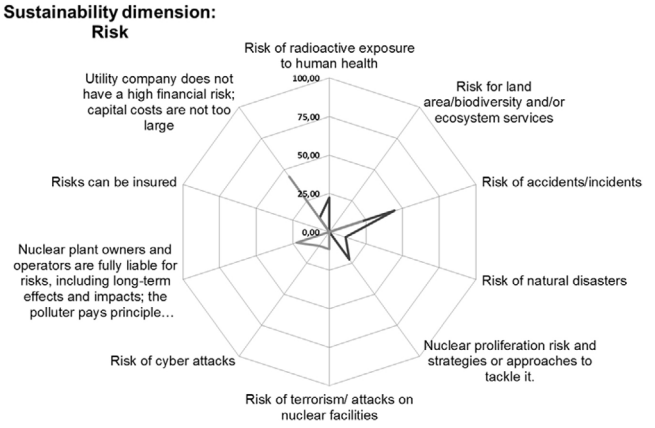

Fig. 3. Overview of the presence of facets of sustainability within the risk dimension within the nine national energy strategies, 10,000 means that all nine energy strategies addressed this facet (black line: nuclear energy; grey line: energy system).

reliability of supply or better supply efficiency (Fig. 2). Figure three shows that codes describing issues of risk were more related to nuclear energy than to the energy system (Fig. 3). The highest attention, number of codes mentioned, in relation to nuclear energy got the governance sustainability dimension (black line area) (Fig. 4)

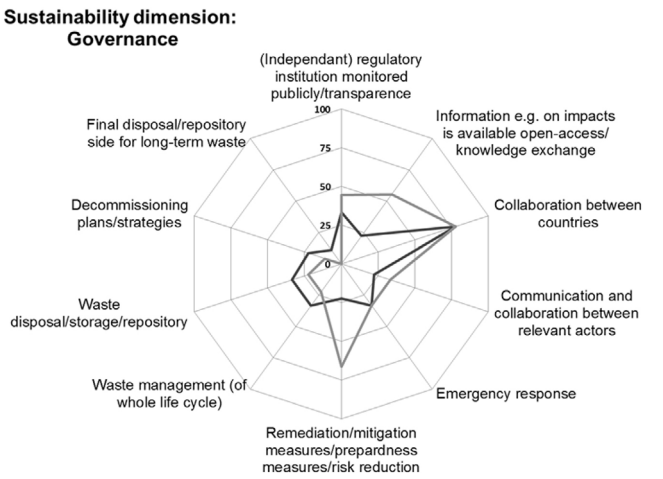

Fig. 4. Overview of the presence of facets of sustainability within the governance dimension within the nine national energy strategies, 10,000 means that all nine energy strategies addressed this facet (black line: nuclear energy; grey line: energy system).

whereas codes used in relation to social sustainability criteria was lowest (black line area) (Fig. 5) compared to all other dimensions.

4. Discussion

Our findings showed: (1) the energy strategies of all the case study countries pursuing or planning to pursue nuclear energy referenced the notion of sustainability, but in only three cases was any definition of the term provided. (2) Seven of the nine energy strategies mentioned little information on whether a diversity of actors was involved in the development of the strategy. (3) Facets of sustainability relating (directly or indirectly) to the notion of intergenerational equity, received surprisingly little attention (with the exception of climate change). For example, natural resource depletion, nuclear waste and risk management, all of which have serious implications for future generations, were each mentioned in a third or less of the analyzed documents. (4) The social and risk dimensions of sustainability (e.g. information on health issues, risk or safety measures for citizens etc.) consistently received less attention that the other three dimensions. Only one facet (risks of accidents/incidents) within these two sustainability dimensions was mentioned by more than two of the national strategy documents.

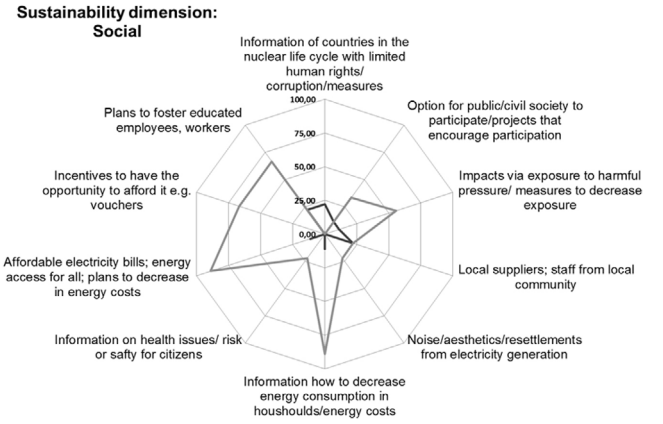

Fig. 5. Overview of the presence of facets of sustainability within the social dimension within the nine national energy strategies, 10,000 means that all nine energy strategies addressed this facet (black line: nuclear energy; grey line: energy system).

In the following we will discuss the relevance of these four findings and formulate four corresponding recommendations which could be considered in order to better integrate sustainability issues in national energy strategies.

4.1. Energy strategies of nuclear countries and sustainability

4.1.1. Sustainability definitions in energy strategies

Linking sustainability with energy development has been a focus of global governance (e.g. Karlsson-Vinkhuyzen et al. [39]) and, more recently, in the sustainable development goals adopted by United Nations [3]. National energy strategies are one means of exploring how these linkages are being envisioned by different governments. The definition of sustainability depends on ethics and value judgements [40]. Currently, there exists no global independent authority that gives advice how to assess sustainability in relation to nuclear energy [5]. Hence, there is no framework by which the diverse perspectives on sustainability and nuclear energy can compared in order to serve as a common understandings and goal settings when implementing energy strategies that include nuclear energy use. The ten Bellagio principles to evaluate progress towards sustainability [40], may provide a useful starting point for situating national nuclear energy policy within the broader societal goal of sustainability. This includes beginning with a clear definition of sustainability. The lack of sustainability definitions in policy documents can hamper the collection of essential data for monitoring and evaluating sustainability [40]. Further, a transparent definition of sustainability can help identify aspects of sustainability in relation to the adoption of specific energy technologies.

The analyzed energy strategies rarely included an explicit and clear definition of sustainability. Although all strategies use the term in various ways, only three energy strategies included further explanations. Alternatively, a country's perspective on sustainability in relation to energy policy can be assessed through the facets of sustainability mentioned throughout the strategy documents. In the cases considered here, sustainability in relation to nuclear energy is mainly defined by governance and economy dimensions (Figs. 1 and 3), whereas the general approach to the sustainability-energy nexus was more focused on and economic and social dimensions. An emphasis on facets such as climate change (Fig. 5), efficiency of supply and technologies (Fig. 1) as well as investment costs (Fig. 1) have been identified as common criteria for sustainable energy decisions [41]. Our analysis suggested a similar emphasis within national energy strategies.

The lack of sustainability definitions increases the risk that sustainability may be used only as a buzzword instead of a theoretical foundation for strategy implementation. We argue that linking sustainability and nuclear energy requires a clear and unambiguous definition of the concept. Such a definition would enable better understanding and assessment of the role of nuclear energy in moving societies towards sustainability.

4.1.2. Involvement of public authorities and other relevant actors

The normative character of sustainability makes it essential to discuss sustainability and the underlying values that underpin its operationalization [40,41]. This dialogue enables shared understanding of criteria for assessing future strategies on energy development. An involvement of diverse actors in decision-making is written in the Agenda 21, decided by 178 states on the World Summit 1992 [42]. Pluralistic perspectives are assumed to enhance legitimacy and acceptability of decisions; trust in governmental authorities as well as decrease in conflicts for example in decision-making on radioactive long-term waste disposal [51] or after nuclear accidents [46]. In addition, social facets of sustainability were mentioned less in relation to nuclear energy compared to all other sustainability dimensions, except for the risk dimension.

Hence, we would support the call of Sovacool [43], who emphasized that policy-makers and researcher should include social topics in the energy sector for instance "future generations bearing the burden of pollution" [52]. Including diverse actors in the formulation of energy strategies might help to encourage decision-making that promotes procedural justice [44]. The involvement of ministries that deal with social or environmental issues might help to engage in further aspects for example to include social sustainability criteria in relation to nuclear energy. Furthermore, involvement of relevant actors on regional or community levels could enhance efforts on energy decisions and planning [45] (e.g. in relation to regional risk management) [38]. Hence, we recommend information within national energy strategies that (1) clearly communicate who is involved and to what extent (e.g. two-way communication) (2) if and how civil society and other relevant actors will be involved in energy strategies on community or regional levels.

4.1.3. Integration of risk criteria and a perspective on intergenerational equity

Intergenerational equity is a crucial element within the sustainability concept [1,3] related to several sustainability dimensions. It needs to be acknowledged by decisions on nuclear energy [7], or energy systems in general for example by a focus on impacts caused by pollution, waste and environmental degradation [44]. Here, we focus on facets of sustainability linked to intergenerational equity such as: long-term repository for highly radioactive waste and risk (management) (Figs. 1, 3 and 4), on biodiversity loss (Fig. 1) or depletion of natural resources (Fig. 1). Those facets were mentioned less frequently in the energy strategies (Table A1 in Appendix A). In contrast to that air pollution via carbon emissions were in all energy strategies. The climate energy nexus plays an essential role to justify energy decisions [46,47]. Our results show that climate change is acknowledged in all strategies which underlines the relevance of this aspects on intergenerational equity within the case study countries. Although reduction of carbon emissions is tremendously important, it needs to account that there are several further interrelations of energy production to e.g. waste products and risks that need to be taken care of and communicated to the public. For example, it is important to reduce carbon emissions (criteria in the ecological dimension), to combat climate change.

Energy production results in benefits and impacts across several temporal or spatial scales. A focus on intergenerational equity within an energy strategy needs to account all energy related risks over time and space (e.g. after accidents by Wehrden et al. [48]) and their management and liability. Countries referred to waste management issues in general but eight of nine energy strategies did not mention anything about their future plans for a final highly radioactive waste nuclear repository (Fig. 3). These decommissioning costs and external costs of environmental impacts and risk are underestimated in economic calculations on nuclear energy production benefits [49]. Hence, it is not surprising that the polluter pays principle is not mentioned in the energy strategies although Verbruggen et al. [7] emphasized its relevance. Especially in the case of nuclear energy with its long-term costs on waste and risk management addressing those issues could lead to another energy choice.

In the case of nuclear energy regional activities need to respond, mitigate and prepare for the risk of nuclear accidents [38]. There have been several studies on nuclear risks and safety in countries. For example, in Germany all operators of nuclear plants need to conduct a safety report by law after ten years [50]. Such risk research results would profit from yearly long-term data embedded in continuously updates on all spatial scales (global, national, regional) on the risk situation and an integration into governmental decision-making e.g. on investments. Compared to the discourse of risk within the water sector, which is embedded in e.g. flood risk management [51], the analyzed countries seemed to have less focus risk dimension of sustainability with regard to energy systems/strategy. Financial or supply risks are mentioned in some strategies, and climate change is described as a risk (e.g. in the United Arab Emirates [28] strategy document). Risks are seldom mentioned in relation to (nuclear) energy production, and sometimes the risk of an accident is mentioned although no further information on possible risks after nuclear accidents on biodiversity, ecosystem services, human health or the risks of proliferation is available. Energy strategies analyzed here used, for example, the term "safety" to describe risk management efforts e.g. "[. . .] measures to build public trust in nuclear safety [. . .]" [26] or "The Visaginas NPP operations will be safe and reliable: in the Visaginas NPP project planning phase, an appropriate power plant safety [. . .] will be selected" [24]. Nuclear accidents are human-made disasters and the term risk allows uncertainties to be included [52]. We argue that focusing more on risk(s) in energy strategies could enhance sustainability. These criteria need to be included in energy strategies of nuclear energy countries to evaluate impacts on intergenerational equity allowing for the building of a capacity for such addressing risks by proper risk management efforts [38] in relation to long-term human well-being.

We argue that missing information on intergenerational equity should be included in energy strategies and if available in other documents a link should be provided to foster access to all information on energy and the environment to contribute to energy justice [44]. Currently such links to other political documents or declarations that are interrelated with energy issues e.g. water or food security, resources, risk and waste management etc. were rarely mentioned in the energy strategy documents studied.

4.1.4. Acknowledge interlinkages between policy strategies

Energy issues are interlinked with sustainable development goals of other policy areas (e.g. water management and food security [53] or gender equality and women empowerment [43,54]. The link between energy and climate change has been set very clearly within the nine energy strategies (Fig. 5). The importance of the carbon emission criterion in energy decisions has been observed by Wang et al. [41]. Other topics have partly been included. For example, the. United Arab Emirates referred to the "energy, water and food security nexus in Abu Dhabi" with information on the water strategy [28], or India linked energy and women empowerment [23]: Xiii). As emphasized by the energy strategy of Hungary [22]: "The whole system of relations of the energy sector has changed and become more complex as it now has links to other policies (transport, environmental protection, agriculture, water management, education and employment)". We agree that those links to other policy fields need to be accounted for and argue that the content of energy strategies, its targets and measures, need to be coordinated and adjusted in accordance with other policy areas on the same regulating level e.g. global level.

Furthermore, some energy strategies already acknowledge their importance for other key policy areas. For example, the energy strategy of Hungary [22] referred to the National Renewable Energy Action Plan or in the energy strategy of Slovak Republic [27]: "[. . .] individual chapters of the Energy Security Strategy and annexes result from other strategic documents which were adopted by the Slovak Government (Raw Material Policy, Strategy for Better Use of Renewable Energy Resources, Energy Efficiency Concept, Action Plan of Energy Efficiency for 2008–2010). We recommend further research in to the application of such comprehensive approaches in order to decrease trade-offs and reveal overlaps between current strategies fostering action for sustainability based on a systems perspective. Increased transparency on data and information

availability in energy strategies may help in creating such integrated energy strategies and reveal lacks of data and information.

4.1.5. Global energy governance

An interest in exchange and connection with other countries was communicated in seven of nine energy strategies within the governance dimension. Since most of countries act in the global energy system [4] a willingness to cooperate is important. Apart from governmental officials other actors such as the International Atomic Energy Agency (IAEA) are engaged on a global scale. There is currently no global authority on energy governance [4], which might help actors to engage on a global level or foster integration of a comprehensive set of sustainability criteria in energy policy. Thus, we agree with Verbruggen and Laes [5], who concluded that such an independent authority could provide clearly defined sustainability criteria based on a normative foundation and monitoring of these to formulate 'advice on policy means to effectively increase performance in accordance with the sustainability criteria' [5].

5. Conclusions

Policy documents like the analyzed energy strategies can play a pivotal role as input for decision-making and implementation of measures within energy policy. Here, a document analysis has identified the extent to which, different dimensions of sustainability are mentioned within such policy documents. Our analyses of energy strategies of nine nuclear countries revealed a lack of explicit definitions of sustainability in relation to energy polices. In turn these energy strategies showed a focused perspective that underrepresented some facets of sustainability, such as issues within the social and risk sustainability dimensions. Further research is required on the involvement of multiple ministries and societal actors in building energy strategies, and the perspectives that they bring, may help to ensure the need for a sustainability definition in order to avoid misunderstandings, understand priorities and counteract trade-offs.

A full accounting of facets of sustainability within energy policy documents can help countries to tackle energy challenges in the future. Therefore governments could profit from a comprehensive view within energy strategies by: (I) defining the concept of sustainability that was used; (II) communicating clearly who is involved in the strategy preparation and enable diverse involvement of among others civil groups and public authorities; (iii) more fully accounting for criteria of intergenerational equity such as risk and waste management issues; and (iv) Greater focus on laying open the informational and data basis for strategy development as well as connections to other strategies and thematic areas to improve their synergy and avoid trade-offs between them. Global tasks could be implemented by a global independent energy authority which engages in an integration of sustainability criteria and monitoring to foster a comprehensive perspective for sustainable energy transitions and help governments engaging in this field.

Acknowledgments

FG was funded by a scholarship of Leuphana University. Thanks to Annika Weiser for great advice and comments on strategies and links to resource management, and Christopher Luederitz and Judith Kahle for their assistance with the structure and methods descriptions. Thanks to the three anonymous reviewer for your comments to improve the quality of the paper.

Appendix A.

See Table A1.

Table A1
Overview of the results from the sustainability evaluation scheme in two tables: energy system and nuclear energy.

Sustainability dimensions			Energy system									
	Sustainability criteria	Codes	#1 Hungary 2030	#2 India	#3 Lithuania 2050	#4 Russia 2030	#5 South Korea 2035	#6 Slovak republic 2030	#7 United Arab Emirates 2021	#8 United Kingdom 2030	#9 USA 2020	SUM
I. Environmental/ecological (planet)	Atmosphere	ozone layer depletion/photochemical smog (SO_x)/ air quality (e.g. NOx)	yes	yes		yes			yes		yes	5
	Climate Change	carbon dioxide emissions (CO_2) are low/climate adaptation/climate mitigation in relation to nuclear energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
	Land area	occupied or new developed/land-use									yes	1
	Water	eutrophication (e.g. NO_x); Ocean acidification; water ecotoxicity/water consumption/ withdrawal				yes			yes		yes	3
		solid waste/chemical waste									yes	1
	Waste	radioactive waste/ hazardous waste				yes						1
		recyclability of waste/ conversion of waste/ reduction of waste	yes						yes		yes	3
	Biodiversity	flora and/or fauna	yes					yes			yes	3
	Natural resources	uranium/coal/... use reduced/ protection of resources				yes		yes	yes			3
	Energy use efficiency	Energy use efficiency is improved/important / minimize energy consumption/ decrease energy intensity	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
		AMOUNT max 10	**5**	**3**	**2**	**6**	**2**	**4**	**6**	**2**	**8**	**38**
II. Economic (prosperity)	Transparency of costs (clear state of costs)	Investments I: capital and/or investments (e.g. fuel costs) costs/operation/maintenance/transmission				yes	yes	yes	yes	yes	yes	6
		Investments II: decommissioning										0
		Investments III: Accidents/waste management/...									yes	1

Table A1 (*Continued*)

	Investments in Research & Development	Investments in research and development	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
	Economic feasibility	overall costs estimated/identified/summarized			yes	yes						2
		billed to end-users including external costs					yes					1
	Supply	Better supply efficiency/less loss during transmission and distribution	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
		Reliability of energy supply (short- or long-term)/life-time of plant; vision/ approaches diversification of supply from other countries/sources	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
		technologies/approaches to support energy access for everyone; regional /local energy development; renewable energy sources/ decentralized electricity generation	yes	yes	yes	yes	yes		yes	yes	yes	8
	Innovation and Technology	technologies for energy diversification of supply and sources/ energy independence	yes	yes	yes	yes	yes	yes	yes	yes		8
		new technologies for less fuel use/ more efficiency/ safety/ less emissions/ less waste	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
	Provision of employment	employment/creation of direct and indirect jobs	yes		yes	yes		yes	yes	yes	yes	7
		AMOUNT max. 12	**7**	**6**	**8**	**9**	**8**	**7**	**8**	**8**	**8**	**69**
III. Social (people)	**Human rights and corruption**	Information of countries in the life cycle with limited human rights or corruption visible/ corruption prevention measures										0
	Participation	Possibility for public/civil society to bring in their opinion and interests in future activities/projects that encourage to participate				yes	yes		yes			3
	Human health	Impacts via exposure to harmful pressure/ safety measures to decrease exposure	yes	yes		yes		yes			yes	5
	Local community and residential environment	Spending on local suppliers; Hired staff from local community	yes						yes			2
		Noise/aesthetics/resettlements from electricity generation	yes						yes			2
	Access to information	Access to information on: decrease of energy consumption/ or energy costs	yes		yes	yes	yes	yes	yes	yes	yes	8
		Information on health issues/ risk or safety for citizens		yes				yes				2
	Affordability	affordable electricity bills; access possible for every citizen; decrease in energy costs	yes	yes	yes	yes	yes	yes		yes	yes	8
		incentives to have the opportunity to afford it e.g. vouchers	yes	yes	yes		yes		yes		yes	6
	Education and knowledge	plans to foster educated employees, workers	yes		yes	yes	yes	yes	yes			6
		AMOUNT max 11	**8**	**5**	**4**	**5**	**5**	**5**	**6**	**2**	**4**	**42**
IV. Risks	**Energy Production/Accidents/Incidents**	risk on radioactive exposure to humans/ risk on human health										0
		land area/biodiversity and/or ecosystem services communicated										0
		risk of accidents/ incidents		yes				yes				2
		natural disasters										0
	Nuclear weapon	Nuclear proliferation risk and strategies or approaches to tackle it.										0
	Terrorism	risk of terrorism/ attacks on nuclear facilities						yes				1
		risk of cyber attacks					yes					1
	Liability on risks and costs	Nuclear plant owners and operators are fully liable for risks, including long-term effects and impacts; the polluter pays principle comes into force for external and future costs	yes	yes								2
	Insurability of risks	risk can be insured										0
	Financial or economical risk	utility company does not have a high financial risk; capital costs are not too large;	yes			yes			yes	yes		4
		AMOUNT max 10	**1**	**1**	**0**	**1**	**1**	**2**	**1**	**1**	**0**	**10**
V. Governance	**Institutions and Processes**	(independent) regulatory institutions and processes that are monitored publicly/transparent decision-making and actions		yes			yes	yes	yes			4
	Information availability and access	information e.g. on impacts is available open-access/ knowledge on environmental issues exchanged		yes		yes	yes	yes	yes			5
	Approaches of collaboration between other countries	collaboration between countries	yes			yes	yes	yes	yes	yes	yes	7
	Energy Risk Management	communication and collaboration between relevant actors					yes	yes		yes		3
		emergency response				yes	yes	yes				3

Table A1 (*Continued*)

		remediation/mitigation measures/preparedness measures/risk reduction		yes		yes	yes	yes	yes		yes	6
		waste management (of whole life cycle)	yes								yes	2
		waste disposal/storage/repository	yes						yes			2
	Energy Waste Management	decommissioning	yes									1
		final disposal side for long-term waste/ final repository/ long-term waste storage										0
		AMOUNT max 10	**4**	**3**	**0**	**4**	**6**	**6**	**5**	**2**	**3**	**33**
	Further focus											
	Definition on Sustainability	1. No sustainability definition mentioned; 2. There has been mentioned a definition for sustainable development or sustainability (e.g. Brundtland Declaration); 3. Sustainability definition specified in own words without referring to a specific concept.	2	3	1	1	1	3	1	1	1	
	Link set between sustainability and nuclear energy	1. Yes (sustainability has been mentioned in relation to nuclear energy); 0. No connection between both	1	0	1	0	1	1	1	0	0	
	Involvement: Ministries in building the energy strategy	1. yes, more than one ministry/ experts or groups got involved, 2. Information that social ministries got involved, 3. no information on further involvement of more than one ministry or actors available	1	1	3	1	1	1	3	3	1	
	Involvement: Public participation in building the energy strategy	1. Not at all; 2. Yes via comments (one way communication); 3. yes via discussion (two way communication)	2	2	1	1	3	3	1	2	1	

Sustainability dimensions			**Nuclear energy**									
	Sustainability criteria	**Codes**	**#1 Hungary 2030**	**#2 India**	**#3 Lithuania 2050**	**#4 Russia 2030**	**#5 South Korea 2035**	**#6 Slovak republic 2030**	**#7 United Arab Emirates 2021**	**#8 United Kingdom 2030**	**#9 USA 2020**	**SUM**
I. Envi	**Atmosphere**	ozone layer depletion/photochemical smog (SO_x)/ air quality (e.g. NOx)				yes					yes	2
	Climate Change	carbon dioxide emissions (CO_2) are low/climate adaptation/climate mitigation in relation to nuclear energy	yes	yes	yes	yes	yes	yes	yes	yes	yes	9
	Land area	occupied or new developed/land-use		yes								1
	Water	eutrophication (e.g. NO_x); Ocean acidification; water ecotoxicity/water consumption/ withdrawal		yes		yes					yes	3
	Waste	solid waste/chemical waste		yes								1
		radioactive waste/ hazardous waste		yes			yes				yes	3
		recyclability of waste/ conversion of waste/ reduction of waste	yes	yes		yes		yes			yes	5
	Biodiversity	flora and/or fauna		yes								1
	Natural resources	uranium/coal/... use reduced/ protection of resources										0
	Energy use efficiency	Energy use efficiency is improved/ important/ minimize energy consumption/ decrease energy intensity										0
		AMOUNT max 10	**2**	**7**	**1**	**4**	**2**	**2**	**1**	**1**	**5**	**25**
II. Economic (prosperity)	**Transparency of costs (clear state of costs)**	Investments I: capital and/or investments (e.g. fuel costs) costs/operation/maintenance/transmission	yes	yes	yes	yes	yes	yes			yes	7
		Investments II: decommissioning					yes				yes	2
		Investments III: Accidents/waste management/...				yes	yes				yes	3
	Investments in Research & Development	Investments in research and development			yes	yes					yes	3
	Economic feasibility	overall costs estimated/identified/summarized			yes							1
		billed to end-users including external costs					yes					1
	Supply	Better supply efficiency/less loss during transmission and distribution				yes						1
		Reliability of energy supply (short- or long-term)/life-time of plant; vision/ approaches diversification of supply from other countries/sources	yes	yes	yes	yes				yes	yes	6
	Innovation and Technology	technologies/approaches to support energy access for everyone; regional /local energy development; renewable energy sources/ decentralized electricity generation	yes		yes							2
		technologies for energy diversification of supply and sources/ energy independence	yes			yes		yes	yes			4
		new technologies for less fuel use/ more efficiency/ safety/ less emissions/ less waste						yes			yes	2
	Provision of employment	employment/creation of direct and indirect jobs	yes						yes			2

Table A1 (*Continued*)

		AMOUNT max. 12	**5**	**2**	**5**	**6**	**4**	**3**	**2**	**1**	**6**	**34**
III. Social (people)	**Human rights and corruption**	Information of countries in the life cycle with limited human rights or corruption visible/ corruption prevention measures	yes				yes					2
	Participation	Possibility for public/civil society to bring in their opinion and interests in future activities/projects that encourage to participate					yes					1
	Human health	Impacts via exposure to harmful pressure/ safety measures to decrease exposure	yes									1
	Local community and residential environment	Spending on local suppliers; Hired staff from local community	yes		yes							2
		Noise/aesthetics/resettlements from electricity generation										0
	Access to information	Access to information: decrease of energy consumption/ or energy costs					yes					1
		Information on health issues/ risk or safety for citizens										0
	Affordability	affordable electricity bills; access possible for every citizen; decrease in energy costs			yes							1
		incentives to have the opportunity to afford it e.g. vouchers										0
	Education and knowledge	plans to foster educated employees, workers	yes		yes							2
		AMOUNT max 11	**4**	**0**	**3**	**0**	**3**	**0**	**0**	**0**	**0**	**10**
IV. Risks	**Energy Production/Accidents/Incidents**	risk on radioactive exposure to humans/ risk on human health		yes							yes	2
		land area/biodiversity and/or ecosystem services communicated										0
		risk of accidents/ incidents	yes	yes				yes			yes	4
		natural disasters					yes					1
	Nuclear weapon	Nuclear proliferation risk and strategies or approaches to tackle it.		yes							yes	2
	Terrorism	risk of terrorism/ attacks on nuclear facilities										0
		risk of cyber attacks										0
	Liability on risks and costs	for risks, including long-term effects and impacts; the polluter pays principle comes into force for external and future costs										0
	Insurability of risks	risk can be insured										0
	Financial or economical risk	utility company does not have a high financial risk; capital costs are not too large;	yes									1
		AMOUNT max 10	**2**	**3**	**0**	**0**	**1**	**1**	**0**	**0**	**3**	**10**
V. Governance	**Institutions and Processes**	(independent) regulatory institutions and processes that are monitored publicly/transparent decision-making and actions					yes		yes		yes	3
	Information availability and access	information e.g. on impacts is available open-access/ knowledge on environmental issues exchanged	yes				yes					2
	Approaches of collaboration between other countries	collaboration between countries	yes	yes	yes	yes	yes		yes		yes	7
	Energy Risk Management	communication and collaboration between relevant actors					yes	yes				2
		emergency response					yes	yes			yes	3
		remediation/mitigation measures/preparedness measures/risk reduction	yes		yes		yes				yes	4
		waste management (of whole life cycle)			yes	yes					yes	3
		waste disposal/storage/repository	yes	yes			yes					3
	Energy Waste Management	decommissioning		yes			yes					2
		final disposal side for long-term waste/ final repository/ long-term waste storage									yes	1
		AMOUNT max 10	**4**	**3**	**3**	**2**	**8**	**2**	**2**	**0**	**6**	**30**

References

[1] G.H. Brundtland, World commission on environment and development, in: Our Common Future: Report of the World Commission on Environment and Development, Oxford University, 1987.
[2] IAE International Energy Agency, World Energy Outlook: Executive Summary 2014, 2014.
[3] United Nations, Draft Outcome Document of the United Nations Summit for the Adoption of the Post-2015 Development, 2015.
[4] A. Goldthau, B.K. Sovacool, The uniqueness of the energy security, justice, and governance problem, Energy Policy 41 (2012) 232–240.
[5] A. Verbruggen, E. Laes, Sustainability assessment of nuclear power: discourse analysis of IAEA and IPCC frameworks, Environ. Sci. Policy 51 (2015) 170–180.
[6] S. Hong, C.J. Bradshaw, B.W. Brook, South Korean energy scenarios show how nuclear power can reduce future energy and environmental costs, Energy Policy 74 (2014) 569–578.
[7] A. Verbruggen, E. Laes, S. Lemmens, Assessment of the actual sustainability of nuclear fission power, Renew. Sustain. Energy Rev. 32 (2014) 16–28.
[8] The Danish Ministry of Climate and Energy, Energy Strategy 2050: From Coal, Oil and Gas to Green Energy, The Danish Government, 2011.
[9] Bundesministerium für Wirtschaft, Familie und Jugend & Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Energie Strategie Österreich, Wien, 2010.
[10] C.A. Montgomery, M.E. Porter, Strategic Choices: Seeking and Securing Competitive Advantage, Harvard Business School Press, Boston, 1991.
[11] R.S. Kaplan, D.P. Norton, The Balanced Scorecard: Translating Strategy into Action, Harvard Business Review Press, Boston, 1996.
[12] H. Mintzberg, The Strategy Process: Concepts, Contexts, Cases, 4th ed., Prentice Hall, Upper Saddle River, NJ, 2003.
[13] European Union, Presidency Conclusions: Lisbon European Council – 23 and 24 March 2000, 2000.
[14] F. Diaz-Maurin, Z. Kovacic, The unresolved controversy over nuclear power: a new approach from complexity theory, Global Environ. Change 31 (2015) 207–216.
[15] L. Hermwille, The role of narratives in socio-technical transitions—Fukushima and the energy regimes of Japan, Germany, and the United Kingdom, Energy Res. Soc. Sci. 11 (2016) 237–246.
[16] L. Mez, Nuclear energy–any solution for sustainability and climate protection? Energy Policy 48 (2012) 56–63.
[17] World Nuclear Association, World Nuclear Power Reactors & Uranium Requirements, 2014, Available from: http://www.world-nuclear.org/info/

Facts-and-Figures/World-Nuclear-Power-Reactors-and-Uranium-Requirements/#.UbXDyJwsbl5 (April 2014).
[18] M.Q. Patton, Qualitative Research and Evaluation Methods, 3rd ed., Sage Publications, Thousand Oaks, Calif, 2002.
[19] M. Schreier, Fallauswahl, in: G. Mey (Ed.), Handbuch Qualitative Forschung in der Psychologie, 1st ed., VS, Verl. für Sozialwiss, Wiesbaden, 2010, pp. 238–251.
[20] IAEA, PRIS – Power Reactor Information System: Under Construction Reactors, 2016, Available from http://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.asp.
[21] World Nuclear Association, Nuclear Share Figures, 2004–2104, 2004, Available from http://www.world-nuclear.org/info/Facts-and-Figures/Nuclear-generation-by-country/.
[22] Hungary National Energy Strategy 2030, Ministry of National Development, Budapest, 2012.
[23] Government of India Integrated Energy Policy: Report of the Expert Committee, 2006.
[24] Ministry of Energy of the Republic of Lithuania, National Energy Independande Strategy of the Republic of Lithuania, 2012, Vilnius.
[25] Institute of Energy Strategy, Energy Strategy of Russia: For the Period up to 2030, 2010, Moscow.
[26] South Korea, Korea Energy Master Plan: Outlook & Policy to 2035, 2014.
[27] Slovak Republic, Energy Security Strategy of the Slovak Republic, 2008.
[28] United Arabic Emirates, UAE State of Energy Report, 2015.
[29] United Kingdom, Planning Our Electric Future: A White Paper for Secure, Affordable and Low-carbon Electricity, Stationery Office, London, 2011.
[30] United States Reliable, Affordable, and Environmentally Sound Energy for America's Future: Report of the National Energy Policy Development Group, The Group, Washington, DC, 2001, For sale by the Supt. of Docs., U.S. G.P.O.
[31] P. Mayring, Qualitative content analysis [28 paragraphs], Forum: Qual. Soc. Res. 1 (2) (2000).
[32] U. Flick, An Introduction to Qualitative Research, Sage, Los Angeles, 2014.
[33] T. Sharma, P. Balachandra, Benchmarking sustainability of Indian electricity system: an indicator approach, Appl. Energy 142 (2015) 206–220.
[34] W. Schenler, S. Hirschberg, P. Burgherr, M. Makowski, J. Granat, Final Report on Sustainability Assessment of Advanced Electricity Supply Options, New Energy Externalities Developments for Sustainability (NEEDS), 2016 (Project no 502687 2009).
[35] International Atomic Energy Agency, Guidance for the application of an assessment methodology for innovative nuclear energy systems: INPRO manual – overview of the methodology, in: Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). IAEA-TECDOC-1575 Rev. 1, 2008, 1 of 9.
[36] L. Stamford, A. Azapagic, Sustainability indicators for the assessment of nuclear power, Energy 36 (10) (2011) 6037–6057.
[37] B.K. Sovacool, I. Mukherjee, Conceptualizing and measuring energy security: a synthesized approach, Energy 36 (8) (2011) 5343–5355.
[38] F. Gralla, D.J. Abson, A.P. Møller, D.J. Lang, U. Vilsmaier, B.K. Sovacool, et al., Nuclear accidents call for transdisciplinary nuclear energy research, Sustain. Sci. 10 (1) (2015) 179–183.
[39] S.I. Karlsson-Vinkhuyzen, N. Jollands, L. Staudt, Global governance for sustainable energy: the contribution of a global public goods approach, Ecol. Econ. 83 (2012) 11–18.
[40] S. Bell, S. Morse, Sustainability Indicators: Measuring the Immeasurable? 2nd ed., Earthscan, London, Sterling, VA, 2008.
[41] J.-J. Wang, Y.-Y. Jing, C.-F. Zhang, J.-H. Zhao, Review on multi-criteria decision analysis aid in sustainable energy decision-making Renew. Sustain. Energy Rev. 13 (9) (2009) 2263–2278.
[42] United Nations, Agenda 21: United Nations Conference on Environment & Development, 2016, Available from https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.
[43] B.K. Sovacool, Energy studies need social science, Nature 511 (2014) 529–530.
[44] B.K. Sovacool, M.H. Dworkin, Global Energy Justice: Problems, Principles, and Practices, Cambridge University Press, Cambridge, 2014.
[45] J. Whitton, I.M. Parry, M. Akiyoshi, W. Lawless, Conceptualizing a social sustainability framework for energy infrastructure decisions, Energy Res. Soc. Sci. 8 (2015) 127–138.
[46] T. Teräväinen, M. Lehtonen, M. Martiskainen, Climate change, energy security, and risk—debating nuclear new build in Finland, France and the UK, Energy Policy 39 (6) (2011) 3434–3442.
[47] A. Corner, D. Venables, A. Spence, W. Poortinga, C. Demski, N. Pidgeon, Nuclear power, climate change and energy security: exploring British public attitudes, Energy Policy 39 (9) (2011) 4823–4833.
[48] Wehrden H. von, J. Fischer, P. Brandt, V. Wagner, K. Kümmerer, T. Kuemmerle, et al., Consequences of nuclear accidents for biodiversity and ecosystem services, Conserv. Lett. 5 (2) (2012) 81–89.
[49] L. Harvey, Energy and the New Reality 2: Carbon-free Energy Supply, Earthscan, 2010.
[50] Bundesregierung der Bundesrepublik Deutschland. Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz – AtG): Neufassung vom 15. Juli 1985 (BGBl.I 1985, Nr. 41, S. 1565, zuletzt geändert durch Artikel 1 des Gesetzes vom 20. November 2015 (BGBl.I 2015, Nr. 46, S. 2053); Available from: https://www.bfs.de/SharedDocs/Downloads/BfS/DE/rsh/1a-atomrecht/1A-3-AtG.pdf?__blob=publicationFile&v=7.
[51] J. Schanze, E. Zeman, J. Marsalek, Flood risk management: hazards, in: Vulnerability and Mitigation Measures, Springer, Netherlands, 2007.
[52] T. Aven, On some recent definitions and analysis frameworks for risk, vulnerability, and resilience, Risk Anal. 31 (4) (2011) 515–522.
[53] M. Bazilian, H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, et al., Considering the energy, water and food nexus: towards an integrated modelling approach, Energy Policy 39 (12) (2011) 7896–7906.
[54] A. Sundström, A.M. McCright, Women and nuclear energy: examining the gender divide in opposition to nuclear power among swedish citizens and politicians, Energy Res. Soc. Sci. 11 (2016) 29–39.