Energy services security: concepts and metrics

Expert paper submitted as input to the ongoing IAEA project: 'Selecting and Defining Integrated Indicators for Nuclear Energy'

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ECN-E--09-080 Oktober 2009

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Acknowledgement/Preface

The author gratefully acknowledges the financial support provided by the International Atomic Energy Agency (IAEA) and the Dutch Ministry of Economic Affairs for research in preparation of this paper. He thanks Alex Roehrl, Gorazd Škerbinek, Adriaan van der Welle and Frans Nieuwenhout for helpful comments and suggestions.

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Abstract

This paper considers the notion of what is commonly referred to as 'energy security'. Typically, in analyses of this problem area, the supply side attracts most if not all of the spotlight. Yet this paper argues that point of embarkation for in-depth analysis should be the demand for energy services and advocates re-labeling the problem area as 'energy services security'.

Key questions on the demand side to be addressed first include:
- Which factors drive demand for a specific category of energy services?
- Can their demand be reduced without socio-economic loss, e.g. through change of consumption preferences and behavioural change regarding 'good housekeeping' economic actors?

Subsequently, key questions on the supply side will have to be addressed, such as:
- Can their demand be met in more fuel- and/or electricity-efficient ways, considering both more energy-efficient transport and conversion technology in relevant supply chains as well as switch to more efficient fuels/electricity?
- How can the physical reliability of procurement of the energy services concerned be enhanced? This is predominantly a short-term aspect.
- How can the delivery security be enhanced, among others in terms of affordable prices in terms of price trend of the services concerned and price volatility? This is a predominantly mid-term / long-term aspect.

The paper develops a theoretical frame for analysis of energy supply security to assess the resilience of society to absorb adverse (potential) trends and events regarding delivery of energy services. It identifies indicators for each of the framework's main components. Finally, a preliminary analysis is made under which circumstances introduction or expansion of nuclear energy in a country's energy supply system can make a positive contribution towards enhancing energy services security.

1. Introduction

This paper has been prepared as an input to the IAEA's ongoing project on 'Selecting and Defining Integrated Indicators for Nuclear Energy'.[1] It explains the concept of energy services security (ESS) and seeks to identify simple indicators to measure the conditions of a country with regard to distinct aspects of ESS focusing on electric energy services. Subsequently, it analyses the impact of new nuclear build on ESS.

In low and medium-income countries, security of supply (SoS) tends to be assigned a quite high priority on the national energy policy agenda. To date, the energy policy issue topping the agenda of policymakers in most OECD countries is 'climate change', while in emerging economies the issue is also contemplated more closely although so far allusions to hard commitments are prudently avoided. In OECD countries 'energy security' is currently also ranking high on the priority list, whilst certainly in the developing world and notably in developing countries poorly endowed with fossil fuels 'energy security' is considered important. The latter policy issue tends to get in a cyclical way - typically short-lasting - prime attention from policy makers in the wake of sudden price spikes in the world oil market or (threats of) market interventions and physical supply disruptions in the supply by major exporting countries of oil or natural gas. Cases in point are the 147 $/barrel of oil price spike in the summer of 2008 and the disruption in Russian gas supplies to the EU through the Drushba gas pipeline in January 2009.

Yet the world energy supply-demand system has all the ingredients in the making for a lasting SoS problem for humankind. Virtually all energy supply chains - both fossil-fuel and non-fossil-fuel ones - are facing wrenching supply limitations. Official projection providers such as IEA and EIA, tend to project roughly a 45% higher world primary energy use by 2030 than current use (approximately 500 exajoules, i.e. 5×10^{20} joules) and a nearly doubling by year 2050. Several energy policy analysts (e.g., Turner, 2008; Moriarty and Honnery, 2009) question the feasibility of these mainly demand-driven energy supply projections. Some even see the most optimistic - i.e. low energy and GHG emissions - IPCC scenarios quite hard to meet (e.g., Nel and Cooper, 2009; Rutledge, 2009). This is likely to pose a key challenge for many western countries, where the paradigm of market liberalisation holds sway.

No analyst can claim perfect foresight. Yet worrisome unfolding trends with regard to factors determining the long-term cost of energy use suggest that the broader SoS issue is deserving urgent and persisting attention by policymakers. The seriousness of limitations to global primary energy use, if true, may provide some comfort to climate change concerns. For instance, the potential for strongly increasing GHG emission from coal combustion seems to be typically strongly overrated as seems to be the case with global coal reserves (Rutledge, 2009; Kavalov and Peteves, 2007; EWG, 2007; Tao and Li, 2006).Yet in the absence of strong and enduring, effective policy responses these limitations are poised to be reflected by a steeply upward long-term trend in fossil fuel and electricity prices along with high price volatility as well as more frequent and at times more socially onerous physical supply disruptions. Consequently, the socioeconomic impacts of these limitations might turn out to be more catastrophic than the current financial crisis (Moriarty and Honnary, 2009). The positive side is that averting disasters associated with both the climate change and supply security issue warrants fast and drastic societal changes with respect to the demand for and supply of energy

[1] This project is undertaken by the Planning and Economic Studies Section (PESS), Department for Nuclear Energy of the International Atomic Energy Agency (IAEA). With the usual disclaimer, project officer R.A. Roehrl and participants to the project's technical meeting held in Vienna on 24-27 March 2009 are acknowledged for stimulating comments on an earlier version of this paper. The author is also grateful to Gorazd Škerbinek, Adriaan van der Welle and Frans Nieuwenhout for helpful comments and suggestions.

services. Hence both issues combined may garner more political clout needed to bring such changes about. Moreover, many - but not all - policies and measures to address each of these issues are overlapping.

In this paper we will introduce a selection of simple energy services security (ESS) indicators. In line with precursor IAEA activities to the current 'Selecting and Defining Integrated Indicators for Nuclear Energy' project, we take relevant indicators introduced in (IAEA et al., 2005) as point of embarkation. We focus on supply security issues in the power sector for two reasons:

1. We seek to limit the scope of the paper, while for the nuclear option it is the power sector that matters.[2]
2. A sustained trend towards electrification of the global energy system is ongoing. This further enhances the already high importance of electric energy services in an increasing number of domains for energy services.

This paper is structured as follows. Section 2 introduces the concept of energy services security. It is a broad notion with a wide-range of aspects. A theoretical framework for classifying simple indicators of energy services security (ESS) is presented in Section 3. A selection of ESS metrics focusing on the electricity sector are explained in Section 4. The paper winds up with concluding observations on energy services security and its measurement, focusing on nuclear power in Section 5.

[2] Here we ignore potential CHP applications of the nuclear option.

2. What is energy services security (ESS)?

An oft-adopted definition of *'energy security'* is "the loss of welfare that may occur as a result of a change in price or availability of energy" (Bohi and Toman, 1996).[3] According to this definition, a situation of extreme energy security would be characterised by uninterrupted supply of 'energy' - i.e. fuel(derivative)s and electricity - at competitive prices.

The issue label 'energy security' misses a fundamental point: energy is typically not in short supply. Rather it *is useful energy* rather than *energy per sé*, that is in short supply.[4] Walt Patterson refers to the First Law of Thermodynamics which implies that no single joule of energy gets lost (Patterson, 2007). By implication nobody produces nor consumes energy. Given these observations, strictly speaking energy security is a non-issue.

This seems trivial but it is not. Patterson observes that ambient energy is, by and large, plentiful across the earth: almost everywhere in orders of magnitude more than current needs for useful energy. Ambient energy includes sources such as wind power, solar energy, flow-of-the-river and marine energy. In principle, ambient energy can be used directly, converted directly into electricity or converted into a stored form of energy. The abundance of energy around the world is further enhanced, if in a globally rather poorly dispersed way, by natural resources that embody stored energy such as uranium, coal, natural gas, oil, biomass and geothermal. At the same time, world-wide expanding conurbations of mega-cities pose local challenges for adequate access to ambient energy sources.

This brings in the direct connection of supply security issues with *energy services*. Energy services can be defined as economic goods produced by deployment of useful energy.[5] In turn, useful energy is obtained directly from ambient energy flows, e.g. solar heating, or from energy contained in energy carriers including electricity. A major focal point of this conversion is the part of the energy transferred by energy carriers to deliver useful energy that does not meet this purpose (i.e., 'energy losses'). Note furthermore that energy services include outputs from non-energy industrial feedstocks.[6]

We propose to use the term *energy services security (ESS)* instead of energy security as the notion that covers the central topic of this paper.[7] Hereafter ESS refers to *the extent to which the population in a defined area (country or region) can have access to affordably and competitively priced, environmentally-acceptable energy services of adequate quality*. This definition implies an end-use orientation to enable a genuinely integrated approach to the multi-facetted ESS issue.

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[3] This section is based on Jansen and Seebregts (2009).

[4] A major point in case is that technology for the conversion of many kinds of ambient energy is still lackin commercial, and in certain instances even technical, maturity.

[5] Gary Kendall defines an energy service as a useful output of an energy input (Kendall, 2008: p. 153).

[6] The energy resources to meet this category of energy services are also part of the supply security equation. Hence, energy policy legislation neglecting this category - e.g. the newly adopted EU directive on renewable energy sources - weakens the coherence between different domains of energy policy.

[7] See also (Jansen and Seebregts, forthcoming).

3. Theoretical framing

Much recent work on ‘energy security’ focuses on vulnerability to supply disruptions of internationally traded fuels, notably oil and natural gas, affecting fuel prices and even outright physical availability of fuels and, consequently, the economy of fuels importing economies (e.g., Bohi and Toman, 1997; Lefèvre, 2007). The main theme in this approach is on (mitigating) supply-side market power and its adverse impact on economic welfare in fuel-importing countries. Other analysts also consider the vulnerability to international trade in fuels in fuel exporting countries, zooming in on economic aspects of ‘demand security’ (e.g., Alhajji, 2008) as well as social and political impacts investigating the validity of the ‘resource curse’ hypothesis (e.g. Karl, 1998; Bannon and Collier, 2003; Collier, 2008). Analysts considering the politics of (preventing) disruptions in international fuel supply chains consider destabilizing impacts on international political relationships (e.g., Müller-Kraenner, 2007; Klare, 2008).

A shared concern in all these perspectives is a preoccupation with vulnerabilities arising from international fuel supply chains and the associated creation and appropriation of resource rents. A typical dimensioning of the multi-facetted ‘energy security’ issue relating to this shared concern is proposed by (APERC, 2007), that is:

1. *Availability* (depletion, inadequate upstream and midstream investments, etc.).
2. *Accessibility* (restrictions imposed by governments of fuel-exporting countries, exercise of market power, exposure of fuel supply chain components to disruptive events including weather-related ones, technical failures, human errors or acts of terrorism or war, etc.).
3. *Affordability* (cost of per unit of energy to end-users - broken down by the main components of fuel supply chains - might compromise societal security).
4. *Acceptability* (environmental concerns and social/cultural barriers hampering supply because of negative perceptions among the population).

Resilience as key concept

Seriously underexposed in most recent work on ‘energy security’ is the resilience of a defined country (or region) to cope with the impacts of adverse ESS (‘energy security’) trends and events. At best supply-side security enhancing measures, such as diversification of the fuel mix, foreign suppliers, and international fuel transport routes and modes are analysed. If at all, typically last on the list of recent ‘energy security’ policy research documents, some demand-side policies and measures such as energy intensities are mentioned without much further elaboration.

The magnitude of risks to ESS security, or for that matter ‘energy security’, is not only determined by exposure to vulnerabilities on the supply side of energy inputs driving the delivery of energy services. The measure of resilience of a recipient society to adverse supply-side vulnerability events/trends works as a cushion that dampens the impacts of supply-side vulnerability. This is depicted by Figure 3.1.

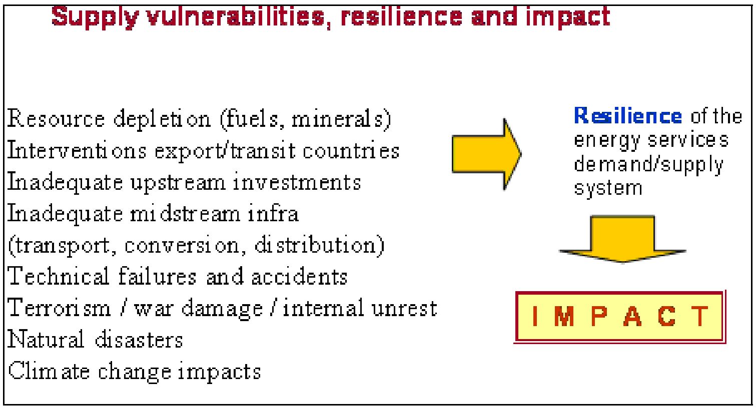

Figure 3.1 *Supply vulnerabilities, resilience and impact*

Energy services security (EES) is a more inclusive concept than 'energy security'. The timely performance and affordability of desired energy services at quality levels considered adequate by the end-users for the end-use applications concerned is not only affected (in a negative way) by all sorts of supply-side vulnerabilities. Key is that a broad range of resilience factors that exercise a stabilising influence on the robustness of the energy services delivery system are identified and thoroughly analysed as well.

ESS components and contextual attributes

We have defined ESS as "the extent to which the population in a defined country (or region) can have access to affordably and competitively priced, environmentally-acceptable energy services of adequate quality". A myriad of one-event impulses and gradually strengthening or declining forces exercise a negative or positive impact on the level of energy services security. In order to bring structure to the analysis of the myriad ESS aspects, we categorise these ESS-change-initiating phenomena into main ESS-content perspectives, *ESS dimensions*.

Each dimension consists of main components and, where appropriate sub-components, sub-sub components, etc., down to the most elementary dimension attribute level. Components (sub-components) are also referred main (sub-) themes or aspects. Hence, the dimensions have a branches structure, each branch being shaped by the distinct dimension components. Where feasible, we allocate indicators of ESS content attributes to dimension (sub-)components. Many ESS indicators are of a quantitative nature, while other ESS indicators are of an ordinal ranking nature with at least two scoring options. We like to restate that, for each relevant dimension next to major ESS-reducing vulnerabilities major ESS-raising system resilience attributes need to be identified to partly/fully/ more than offset these vulnerabilities.

In principle, each distinct ESS dimension has to bundle a broad range of related ESS content aspects. On the other hand, ESS content aspects encompassed by different dimensions should have no or at most a fairly remote logical relationship with each other. Furthermore, a clear differentiation among countries (regions) should in principle be possible with respect to their characteristics regarding each of these ESS dimensions. Based on these criteria we propose the following ESS dimensions:

I. *Reliability*
II. *Energy costs*
III. *Policy framework*
IV. *Public acceptance.*[8]

[8] We have refrained from introducing environmental impact as an additional dimension. In the *trias energetica* (competitiveness, security of supply, environmental impact), this dimension is covered by another principal energy policy domain. Moreover, to the extent that environmental impact is relevant for public acceptance of technologies used in major supply chains enabling the delivery of energy services it is encompassed under the public acceptance dimension.

We will explain these dimensions in more detail in the next section.

Two principal *contextual attributes* cross-cut among components of each ESS dimension, i.e. *time scale* and *location*. They do not contribute content to the ESS concept but essential contextual information needed for interpreting an indicator of a ESS content attribute. The content of the ESS issue can change substantially, depending on the timescale and the location boundaries that we consider. Key questions are in this respect:

- For which time scale does the metric provide relevant information on the content attribute concerned? Typically, short-term ESS issues tend to relate to physical availability of energy services, whilst long-term ESS issues tend to focus on the price evolution of energy services at the backdrop of performance of markets for exhaustible fossil fuels and derived products. Short-term ESS issues as against long-term ESS issues may require rather different policies and measures.
- For which jurisdiction does the metric provide relevant information on the content attribute concerned? This, in turn, is relevant for the level at which possible public interventions should be considered.

We proceed to explain these contextual attributes in some more depth.

Time scale

The time scale for which energy services security is contemplated is quite relevant. Typically for very short-term time horizons, disruptions in physical availability of energy services and sudden price spikes attract key attention by private stakeholders and the public sector alike. For long term timeframes the risks of structurally rising fuel and electricity prices and increasing price volatility are key concerns for ESS policy analysts and informed policy makers. In the indicator overview in Appendix A for each indicator the timeframes are indicated for which the indicator can be used. The following time scales are discerned:

N (near real-time):	$t < 1$ minute
S (short run):	$t < 2$ years
M (medium run):	$2 \leq t \leq 15$ years
L (long run):	$t > 15$ years
V (very long term):	$t > 50$ years

To counteract the serious externality of myopic time-bounded rationality of most stakeholder groups, *long-term ESS* is of key importance for policy guidance. Indicators with L/V applications provide information on ESS attributes that are relevant for longer timescales. The time-scale indications can be used as a first screening of short/medium-term and long-term ESS indicators. Indicators with N/S/M applications can be used for information on ESS attributes that are relevant in the *short to medium term*. Most stakeholders are driven by time-bounded rationality and are primarily focused on ESS for these timeframes.

Location

Two alternatively localisation aspects of ESS problems can be discerned relative to the location where the energy services concerned are (to be) provided. Firstly, the ‘control area’, the jurisdiction within which the energy services concerned are to be delivered, is of relevance. Second, the location of impacts of an ESS-disruptive phenomenon along the relevant supply chains of energy services matter.

The first locational aspect, the relevant jurisdiction, is cross-cutting and of great significance for vulnerability risk (perceptions) and the design of effective ESS policy. For instance, in principle the central government of a country endowed with large natural gas resources is well-placed to implement an effective gas field development and gas distribution policy to enable its citizens access to gas-based energy services. Yet a resources-poor country and its citizens depend on the policies of (potential) natural gas exporters regarding the reliability (and energy costs) of gas-based energy services. We propose the following alternative attribute labels with regard to a jurisdiction/market perspective:

- HA: Home Area (a 'control area' within the home country or home region).
- HC: Home Country.
- HR: Home Region (multi-country).
- W: World.

Regarding the latter attribute category we note that the relevant (market) area for certain ESS aspects, e.g. the price of oil, is the world. Alternatively, from a power system's perspective, control areas of distinct synchronised power areas and system operators (TSOs, DSOs).

The second aspect regards the localisation of the impacts of an ESS-change-initiating factor. A good understanding the local conditions at each successive impact area contributes importantly to the analysis of ESS. Detailed analysis of each key component/node of the main supply chains that enable the performance of a certain category of end-use services are essential for a good understanding of risk and resilience factors affecting ESS for the category of energy services considered. Supply chain components/nodes are not necessarily cross-cutting across all ESS dimensions. For these reasons, it should be considered to include important supply chain components/nodes in the composition of those ESS dimensions, for which they assume relevance.

Hereafter we specify the general nature of fuel supply chain components for the electricity supply sector. The following main components are distinguished in a generic fashion:

- *Primary of primary energy sources (PES).*
- *Transport chains of PES (embarkation, haulage, disembarkation),* with routes and/or modes (e.g. LNG, piped natural gas) as possible sub-components.
- *PES conversion plants;* conversion into end-use fuel or (intermediate) secondary energy carrier (SEC).
- *Transport chain of SEC to electricity generation plants.*
- *Transmission & distribution network and ancillary system services.*
- *Electricity demand by end-use appliances.*

We propose to introduce the important ones of such chain components at sub-component level in the content dimensions, especially in dimensions I and II that reflect major ESS impact aspects. To give an example for the second component of dimension II, *price escalation*: the cost/price change of a primary fuel, e.g. natural gas, is transmitted to the cost of an energy service energy service as shown in Table 1.

Table 3.1 *Generic analysis scheme for determining the impact of (changes in) the unit value (unit cost; price) of a primary energy source on the cost of an end-use energy service, allowing for the various supply chain components*

Energy service (ES)	Description	(1)	
Unit:	Dimension A	(2)	
Unit value:	€2009	(3)	
End-use appliance	Description	(4)	
Final energy carrier (FEC)	Description	(5)	
Unit:	Dimension B	(6)	
Unit value:	€2009	(7)	
Units required/unit of energy services	Dim B / Dim A	(8)	
Cost of FEC input	€2009	(9)	= (8) * (7)
Cost share of FEC in ES	%	(10)	= (9) / (3) * 100%
Energy conversion plant	Description	(11)	
Input fuel for final energy carrier	Description	(12)	
Primary energy source (PES)	Description	(13)	
Unit (primary energy source):	Dimension C	(14)	
Unit value:	€2009	(15)	
Units required / unit of final energy carrier	Dim C / Dim B	(16)	
Cost of PES in cost FEC input	€2009	(17)	= (16) * (15)
Cost share PES in cost FEC input	%	(18)	= (17) / (9) * 100
Cost share of PES in ES	%	(19)	= (18) * (10) / 100%

Note that in principle main supply chains can include supply chains for non-energy inputs and even non-material inputs. Non-energy constraints may also create huge challenges to ESS. Just some examples are: skilled manpower limitations to operate the electricity T&D networks or to operate nuclear energy cycle facilities; shortages of dry-bulk carriers to transport hard coal; shortages on the steel market to produce all sorts of power plants including nuclear power plants and wind turbines; shortages of copper affecting notably T&D networks, wind turbines and PV equipment; shortage of platinum to produce fuel cells; shortages of lithium to produce lithium-ion batteries, etc.

4. ESS: proposed dimensions and simple metrics

Because of limited research resources and transparency reasons, the scope for ESS metrics to be presented hereafter is limited in two major respects. Firstly, we restrict the selection of ESS metrics to the electricity system, which notably includes nuclear power. In principle, the scope of our ESS metrics extend in principle to a few key scarcity issues with regard to primary energy resources and secondary energy carriers that are converted into electric energy. Yet, scarcity issues regarding non-energy backward linkages are beyond the scope of this paper, acknowledging that these can also be(come) quite relevant.[9] As for electricity from conventional sources, coal, gas and nuclear power plants dominate electricity supply in industrialised countries. In the developing world and many emerging economies, also oil-based generation plays a non-negligible role. Secondly, for transparency reasons most of the selected ESS metrics are so-called 'simple metrics' measuring one single ESS aspect. Composite indices, covering several ESS aspects, tend to give rise to problems of attributing subjective weights.

We have applied the following selection criteria for making a 'short-list' selection, for each ESS dimension, of simple indicators from the 'long-list' presented in Appendix A:

- Coverage of important aspects for each of the distinct ESS dimensions.
- Ease and unambiguousness of interpretation (as much as possible).
- Data availability: data should be available fairly easily in many (but not necessarily all) countries, including notably non-OECD countries (emerging economies and developing countries).
- Objectivity of the measurement (avoiding subjective weighting, value judgements as much as possible).
- Relevancy for assessment of the nuclear option.

Hereafter we explain the proposed ESS dimensions with for each dimension selected ESS metrics.

Dimension I: Reliability

The first ESS dimension we propose is *reliability*, i.e. the certainty level at which useful energy is adequately available to enable end-users to get the energy services they desire at desired time and quality.[10] Reliability is for instance a key dimension in the case of natural gas transported through trunk pipelines. This fact has been brought home in a harsh way by the major disruption in Russian gas delivery to the EU through the Drushba (Brotherhood) pipeline in January 2009. This pipeline currently accommodates 80% of total Russian natural gas exports to the EU.

For technical reasons second-to-second reliability is even more vital in the electricity industry. It is crucially important that total power injections into an electricity transmission and distribution network system matches total power evacuations from the system on a second-by-second basis within tight tolerance margins to ensure that voltage fluctuation remain within norms set by the applicable network code. The electricity network industry has developed a diversity of modelling concepts, tools, and indicators to measure reliability and ensure a desired minimum reliability level. As for delivery security we opt to adhere to the conventional delivery security framework applied by electricity network operators.

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9 Just a few examples of non-energy backward linkages impacting on the cost of energy services delivered by specific technological routes are: copper for PV, wind turbines, electricity transmission and distribution networks; steel for a variety of generation technologies ranging from wind turbines to nuclear power plants; lithium for plug-in hybrids and battery electric vehicles; platinum for hydrogen cars (fuel cells); dry weight bulk carriers for maritime coal transport; etc.

10 McCarthy et al. (2007: 2153) define overall reliability of an energy system as "the ability to supply the quantity and quality of energy desired by the customer when it is needed."

Following the conventional reliability framework (Mc Carthy et al., 2007; Energinet DK, 2007), we propose two components: *adequacy* and *delivery security*.[11] Adequacy (system adequacy) refers to the ability of a power system to supply the load in all the steady states in which the power system may exist considering standard operating conditions. Adequacy can be broken down into two sub-components *generation adequacy* and *transmission adequacy*. Generation adequacy of a power system is the ability of the generation on the power system to match the demand on the power system. Transmission adequacy is the ability of the electric system to deal with exchanges resulting from market behaviour (ENTSO-E, 2009a).

Regarding generation adequacy, the capacity of the relevant power system considered to provide frequency control services to ensure the power frequency remains within standard tolerance limits is of great relevance (ENTSO-E, 2009b). Generation adequacy needs to be maintained also under adverse contingencies. Typically, nuclear power stations have a relatively large size. Hence, countries considering the nuclear option should not have a too small electricity market and adequate baseload demand to cover. Also when facing unplanned outages of the largest nuclear power station, generation adequacy needs to be ensured by compliance with standards such as the deterministic 'n - 1' criterion.[12] Countries with a relatively small domestic power market boasting or that are considering nuclear power plants may have to rely in a non-negligible way on support from interconnected power systems in neighbouring countries for unplanned loss of generation contingencies.[13] This applies especially to reliance on system support from transmission system operators (TSOs) in neighbouring countries, the control areas of which are situated within the same synchronous area as the TSO control area in the country concerned. Reliance on existing interconnections capacity is reduced under congested conditions. To monitor this for a country with a liberalised electricity market in a fairly advanced stage of integration with corresponding markets in neighbouring countries by a high *nomination rate*[14] of interconnection capacity is a useful indicator (ENTSO-E, 2009d; see also Appendix A).

Delivery security is about minimising the risk and socio-economic impact of unexpected *physical* delivery interruptions. It includes the dynamic response of the system to unexpected physical delivery interruptions, i.e. the system resilience to absorb them at lowest loss of social welfare. We have categorised under delivery security: fuel availability (as e.g. roughly indicated by Reserves to Production Ratios); diversity for several kinds of supply components; as well as import dependency. Higher diversity and lower (net fuel) import dependency may lead to a greater system resilience. Evidently, perceptions of reliability of fuel-export trading partners can also matter a great deal. We have refrained from introducing 'political stability' indicators, as these are inherently subjective.

[11] The electricity industry, somewhat confusingly, coins the (relatively narrow notion of) delivery security plainly 'security'.

[12] Briefly and liberally stated, fulfilling the n - 1 criterion ensures that system operations will not be endangered by a contingency occurring after the trip of the highest-impact single network element. The 'n - 1' remaining elements should be adequate to prevent propagation of such incident into a cascading black-out. A contingency in general is the trip of one single or several network elements that cannot be predicted in advance. See (ENTSO-E, 2009c) for a more detailed explanation.

[13] Examples of countries with nuclear power generating facilities in combination with a relatively small national electricity market are Slovenia and Slovakia.

[14] That is, the utilisation rate of net transmission capacity by interconnections offered to the market.

Table 4.1 *Selected ESS metrics for Dimension I: Reliability*

Dimension	Component	#	Metric description
Reliability	Adequacy Generation	I.1.1	Total electricity demand
		I.1.2	Peak demand
		I.1.3	Base load demand
		I.1.4	Total installed capacity
		I.1.5	Generation capacity margin
		I.1.6	Secondary frequency control reserve
		I.1.7	Tertiary frequency control reserve
	Adequacy Transmission	I.1.9	Interconnection rate
		I.1.10	Nomination rate
	Delivery security	I.2.1	SAIDI: sum of customer interruption durations in minutes per year
		I.2.4	% non-fossil in electricity generation
		I.2.9	Import dependency (fossil fuels)
		I.2.12	Reserves/Production ratio domestic/region/world (fossil fuels, uranium)
		I.2.19	Fuel diversification
		I.2.20	Supplier concentration (fossil fuels)

Note: see Appendix A for more details.

Dimension II: Energy costs

The second proposed ESS dimension is *energy costs.* Energy costs are of key importance to society as a limiting factor for access to energy end-use services. Hence, the pricing of fuels and electricity is of high energy policy relevance. Energy carriers for energy services, that are priced at supra-competitive levels through exercise of market power result in welfare loss. In turn, this may lead to wider political insecurity when the suppliers concerned are outside the jurisdiction of the government(s) in the defined region under consideration. Essential energy services - i.e. basic energy services with a low demand elasticity - priced at unaffordable levels can give rise to internal political insecurity. To the extent that such unaffordable levels are caused by supra-competitive price setting of energy carrier input requirements by suppliers with market power, this is a key energy policy issue as well.

At macro level, energy costs can be contained by structural shifts towards low-energy services. At higher levels of economic development an autonomous structural change trend can be discerned from the primary and secondary sectors towards the less energy-intensive services sector.[15] Yet on top of that, behavioural changes can further relieve the energy cost burden to an economy.

The first component encompassed by the energy cost dimension is: *affordability*. Affordability of demand for energy services might be limited at various levels. At household level inhibitive cost of expensive energy services might give rise to fuel poverty. At macro level a mounting energy import bill to a significant share of GDP might give rise to economic and even physical energy supply disruptions in the country considered.

The second and third components encompassed by the energy cost dimension are: *(fuel or power) price trend* and *price volatility*. Positive real fuel price escalation (price escalation on top of general price inflation) can assume major significance when the substitutability of a certain energy carrier to perform an energy service is limited. A case in point is petroleum-based

[15] Although the services sector tends to be appreciably less energy-intensive than manufacturing (especially basic industries), galloping electricity use in for example the ICT branch is a concern deserving special attention.

gasoline for light-duty transport vehicles.[16] Typically substitutability increases on longer time frames. Yet serious negative externalities might be associated with public-sector policy makers completely relying on market forces to address long-term price escalation. This relates to myopic time-bounded rationality of market actors, policymakers, coupled with system inertias because of long capital turnover periods (dwellings, nuclear and coal-fired power plants, gas-pipelines and power transmission and distribution infrastructure) and instances of technology lock-in. High fuel price volatility contributes to investor's uncertainty and, to the extent that the price of a fuel (e.g. oil) is negatively correlated with macro-economic business cycles, high fuel price spikes may contribute to downturns of the economy.

Given the fuel mix of many power systems, prospective price volatility of natural gas and coal can be quite relevant. Historically, gas price volatility is closely correlated with oil price volatility through oil-based long-term gas contracts, whilst coal price volatility and its correlation with oil price volatility tended to be low. Yet a trend towards receding substitution possibilities from gas to oil for various applications and consequently more 'gas-to-gas competition' seems to be emerging (Stern, 2009). This, in turn, makes for a tendency towards increasing gas price volatility as gas spot prices (at trading platforms such as Henri Hub, NBP, TTF) are quite sensitive to imbalances between gas supply and demand.

The competition between coal and gas for power generation is increasing. The emerging carbon market in some parts of the world, notably Europe, seems to be contributing to this trend. In principle, this could moderate gas price volatility. Yet in 2004 the stable, cheap coal price era seems to have lapsed, following a demand surge for hard coal and bulk shipping transport capacity exercised by China. Lately the correlation of the price of internationally traded hard coal with the oil price appears to have significantly increased. Since 2004, market participants seem to have started to perceive that cheap hard coal is much scarcer than was widely deemed before 2004. In conclusion, world-wide the power supply sector has to reckon with structurally increasing coal price levels coupled with higher volatility.

As the fourth component of energy costs we propose *energy intensity*. As is energy price, energy (fuel and electricity) intensity is a major underlying factor determining energy costs. A decrease of energy intensity is mainly driven by: (i) the adoption of energy-efficient technologies; (ii) structural change through substitution towards less energy-intensive production; (iii) substitution towards more efficient energy carriers; (iv) energy conservation through 'good housekeeping' and related behavioural change; (v) shifting consumer preferences in favour of low-energy products and leisure activities. Energy-efficient technology relates to all energy processing (extraction, transportation, conversion) steps from primary energy source to eventually end-use energy services provision. Fuel efficiency improvement encompasses the introduction of more energy-efficient capital goods for energy conversion and transportation as well as enhanced implementation of good housekeeping measures up to delivery of end-use energy to the end-user's 'door step'. Fuel conservation includes good housekeeping measures by the end-user (e.g. use of end-use appliances at optimal intensity of use, good maintenance practices) and outright fuel waste reduction (e.g. reduction of stand-by mode use coupled with improved stand-by mode performance, reduction of 'unnecessary'[17] use of end-use appliances).

[16] In the short run, possibilities substitution of internal combustion engines are quite limited, whilst large-scale production of biofuels also has limitations because of competing land uses and sustainability issues.

[17] Unnecessary use is a value-driven concept that is partly culturally determined. What end-users consider necessary might be changed through awareness campaigns and education without necessarily infringing upon consumer rights and 'consumer sovereignty'.

Table 4.2 *Selected ESS metrics for Dimension I I: Energy costs*

Dimension	Component	#	Metric description
Energy costs	Affordability	II.1.1 II.1.2	Electricity/fuel /carbon price: - Marker prices for oil, gas, coal, uranium, electricity (day-ahead wholesale price), carbon (e.g., EU ETS) - End-use energy prices by fuel/energy carrier (electricity) and by sector
		II.1.3	% of HH income spent on electricity/ fuel & electricity
		II.1.4	Ratio of net annual fuel import bill to GDP
	Fuel price trend (net of general price inflation)	II.2.1	Electricity/fuel /carbon price (time series): - Marker/wholesale prices for oil, gas, coal, uranium, electricity, carbon - End-use energy prices by fuel and by sector GDP price index
	Fuel price volatility	II.3.1 II.3.2	Electricity/fuel/carbon price volatility: - Standard deviation of (average or ultimo) fuel price per time interval (week, month, quarter, year) over a multi-interval period
	Energy intensity	II.4.1 II.4.2	Electricity use (per capita / per unit of GDP)
		II.4.8	Fuel chain efficiency of conversion and distribution
		II.4.9	Efficiency of generation, transmission & distribution

Note: see Appendix A for more details.

Dimension III Policy framework

The level of ESS in a distinct country (region) and for a certain timescale is significantly influenced by the policy framework setting. We distinguish *Regulation* and *Market functioning* as key components of this framework. Specific legislation and regulations can affect the ESS results regarding specific ESS topics. Moreover, good market functioning with price flexibility, transparency on issues such as energy price discovery, trade volumes and (intended) capacity expansions or contractions and a large size/depth of the market will help to emit important price signals to market participants. Under such circumstances the price mechanism can help importantly to bring about quick demand responses to sudden supply constraints.

Table 4.3 *Selected ESS metrics for Dimension III: Policy framework*

Dimension	Component	#	Metric description
Policy framework	Regulation	I.1.1	Rate of contractually flexible demand (interruptible contracts, fuel switch on government order): - Total flexible demand - Total peak demand
		I.1.2	Existence independent energy regulatory agency with mandate to ensure competitive prices/tariffs (yes/no)
		I.1.3	Regulator has mandate to ensure adequate T&D infrastructure capacity (yes/no)
		I.1.4	Periodic publication of official medium-term demand/supply planning document (yes/no)
	Market functioning	I.2.1	Volume of the spot market: annual dayahead market volume as % of annual total demand for electricity
		I.2.2	Market concentration - Share largest 3 suppliers - HHI index

Note: see Appendix A for more details.

Dimension IV Public acceptance
Adoption of technological options in support of energy services security is crucially dependent on public acceptance. Without claim to completeness, we distinguish three major components: *Operation safety*, *Proliferation of dangerous materials*, and *Waste production*. Note that the second component notably regards the nuclear power option.

Table 4.4 *Selected ESS metrics for Dimension IV: Public acceptance*

Dimension	Component	#	Metric description
Public acceptance	Operation safety	IV.1.1	Accident fatalities per energy produced by fuel chain
	Proliferation of dangerous materials	IV.2.1	Proliferation events
	Waste production	IV.3.1	Radioactive waste produced per unit of electricity
		IV.3.2	Non/low radioactive solid/liquid waste produced per unit of electricity
	Emissions	IV.3.3	GHG emissions per unit of electricity
		IV.3.4	Non-GHG pollutant emissions per unit of electricity

Note: see Appendix A for more details.

5. Impacts of the nuclear sector on energy services security: some preliminary general observations

Which general conditions are to be in place in a country where introduction or expansion of nuclear power capacity is likely to enhance energy services security? In this section we will first consider long-term EES aspects and subsequently proceed to a discussion of short-term ESS aspects. It goes without saying, that for a specific country case a detailed analysis is warranted.

Long-term ESS

Key broad pre-conditions for the introduction of nuclear power in a country with an ESS aspect include the following:

- Adequate institutional warranties should be in place that nuclear power facilities and any materials originating from facilities of the nuclear power cycle in the country will not be diverted from peaceful electricity generation applications.
- Available manpower should be adequately capable to safely operate nuclear power facilities.

Focusing on long-term ESS aspects as such, introduction or expansion of nuclear power capacity should contribute to a more efficient national portfolio of electricity generating assets (Awerbuch and Berger, 2003). That is, the (expected) portfolio cost of electricity (COE) should diminish without increasing (expected) portfolio COE risk or, the portfolio COE risk should diminish without the COE rising (Jansen et al., 2006). The *volatility of portfolio COE, with power price volatility as a proxy indicator*, can be considered as an overall indicator of long-term ESS. In comparison to a coal-fired and even more so a gas-fired power plant, nuclear has relatively low fuel price risk, as the cost of uranium requirements are a small fraction of total COE. The COE risk of nuclear is concentrated in the investment stage: the construction period uncertainty over the long construction period in comparison with other generating technologies is coupled with high financing cost during construction. At the end of the operational phase the decommissioning cost and waste disposal liability can pose significant risk depending on the institutional and regulatory settings to deal with this including 'fraternity' risk sharing arrangements within (part of) the nuclear industry. How the COE of nuclear compare to the average COE of a country's portfolio of generating assets, depends in part of country-specific factors, such as availability of cheap fossil fuel resources, existence of carbon pricing and fossil fuel price (risk) expectations. For example, under current conditions the economic attractiveness of nuclear tends to be much higher in the European Union than in the USA (higher cost of coal and gas as well as non-negligible carbon pricing in the EU). The risk profile of the nuclear option is quite different from competing fossil-fuel options. In principle, this makes nuclear a likely constituent of efficient portfolios.

Yet the future base load demand gap net of injections by intermittent renewable generators in the relevant electricity market should be large enough to absorb at the very least the output of at least one (additional) nuclear power plant. To that effect, important factors include:

1. Current and projected *size of the power market* (population growth; per capita income growth, structural changes in the economy; growth of large megapolises, further electrification of energy services, etc.).
2. Current and projected *base load.*
3. *Flexibility of power demand* (e.g. demand response by industry and households, take-off of electric vehicles).
4. *Flexibility and controllability of power supply.*
5. Current and projected size of *intermittent renewable generation.*
6. Current and projected *distributed generation*, competing with large-scale generation by e.g. nuclear power plants.

In many countries worldwide much emphasis tends to be given to fast market development of renewable generation, especially intermittent wind and solar PV power. This bags the question how large penetration of intermittent renewable generation will affect the economics of nuclear. In fact, the economics of nuclear are negatively affected on several counts:

1. The short-run marginal cost of intermittent renewables are very low. Hence, electricity from intermittent renewables tends to be first in line for dispatch. This will displace high marginal cost generation first, but in the end also base load sources such as coal-based power and lastly nuclear power as well. Apart from technical capabilities to ramp down power output, it is economically quite onerous to part-load nuclear power plants.
2. It might be less loss-making for the nuclear power plant to generate temporarily at negative power prices instead of ramping down, when the power trading platforms allow for that. Yet in that case fixed preferential tariffs or premiums as a market support mechanism for renewable generators will further depress power prices in situations of high intermittent renewable power injections at low demand hours.
3. Given the less flexible generation profile of nuclear, this option warrants availability of balancing services by flexible generators. Intermittent generators raise the need for such services, which will be reflected by higher imbalance penalties.

Public acceptance can play an important role in the future scope for the nuclear option to affect ESS. The track record of the nuclear industry regarding operational safety and proliferation of dangerous weapon-grade materials helps to shape the level of public acceptance, especially in countries with western-type of political democracies.

Short-term ESS

In the absence of adequate regulation and remedial actions by the transmission system operator, enhanced needs for generation/demand flexibility providers to provide balancing services to the TSO may reduce the robustness of system reliability. Remedial actions include transmission network reinforcement as well. As already stated in the previous section, notably for the smaller nuclear countries the latter includes investment in good interconnections and close collaboration between the system operators concerned. Moreover, in keeping with the n - 1 criterion the contracting of adequate additional secondary and tertiary frequency reserve capacity is in order.

Concluding remark

In conclusion, in countries meeting key general pre-conditions for the introduction of nuclear power with an adequately large power demand volume and a relatively well-developed transmission network nuclear power can make a positive contribution to long-term energy services security. To ensure no deterioration in the robustness of system reliability and consequently of short-term energy services security materialises after commissioning of new nuclear build, a well-designed *policy and regulatory framework for the power sector* is of paramount importance.

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Appendix A Overview of ESS indicators

In the table below, we enumerate a long-list selection of mainly simple ESS indicators. Selected ESS indicators are presented for each of the proposed four ESS dimensions - *reliability*, *energy costs*, *policy framework* and *public acceptance* - and their pertinent components. Attribute values (labels) of contextual attributes *timescale* and *location* are listed in the respective rows for each selected indicator.

Table A.1 *Dimensions, components and indicators of energy services security*

Dimension *Component* *Sub-component*	Indicator #	Indicator	*Contextual attributes*		Indicator parameters	Remarks/references
			Time scale	*Location*		
Reliability *Adequacy* *Generation*	I.1.1	Total electricity demand	*S* *M* *(L)*	*HC* *HR*	Gross in-land energy consumption (TWh/yr)	
	I.1.2	Peak demand	*S* *M* *(L)*	*HC* *HR*	- Peak demand on the in-land power system in a certain period e.g. year (GW)	
	I.1.3	Base load demand	*S* *M* *(L)*	*HC* *HR*	- Minimum demand on the in-land power system for a certain year considering a set number of hours during that year, e.g. 8000 hours, with the highest demand (GW)	
	I.1.4	Total installed capacity	*S* *M* *(L)*	*HC* *HR*	- Total nameplate capacity of all available generation units connected to the in-land power system per ultimo of a certain year (GW)	
	I.1.5	Generation capacity margin	*S* *M* *(L)*	*HC* *HR*	- Peak demand - Total installed (and available) capacity	Difference between installed capacity and the peak load (peak demand) for a particular year as % of peak load. Applicable to notably generation, T&D, pipeline fuel transport. *Several variants exists, e.g. the surplus margin, de-rated for expected availability by generating technology, 'N-1' capacity allowing for loss of the largest system capacity component, etc.* (Percebois, 2006; DTI, 2006)
	I.1.6	Secondary frequency control reserve	*N* *S* *M*	*HC* *HR*		Secondary (frequency) control by a TSO seeks to maintain a balance between generation and demand within his control area as well as the system frequency within the (wider) synchronous area, taking into account the control program, without impairing the parallel primary control in the

						synchronous area. TSO uses automatic generation control to control designated generation sets and controllable load in the time-frame of seconds up to typically 15 minutes after an incident. The sizing of secondary control reserve is done by reference to deterministic and/or probabilistic approaches. The size of the total required reserve must match the size of the largest possible generation incident. Under certain conditions and up to a maximum extent, border-crossing reserves can be counted towards the reserves of a TSO concerned. See further: (ENTSO-E, 2009b)
	I.1.7	Tertiary frequency control reserve	*N* *S* *M*	*HC* *HR*		Tertiary control by a TSO uses tertiary reserve that is usually activated manually in case of observed or expected sustained activation of secondary control, typically within 15 minutes after a (large) incident. Under certain conditions a TSO can contract tertiary control reserve capacity cross-border. Conditions include adequate ICT connections between reserve receiving TSO, reserve connecting TSO, and contracted cross-border generating facilities. See further: (ENTSO-E, 2009b)
	I.1.8	Critical electricity surplus	*N*	*HA*	- Scheduled generation - Available export capacity - De facto demand	Surplus electricity generation which cannot be sold in a particular area and which cannot be exported from the area. Can e.g. happen when variable renewable generation (wind power) suddenly peaks at low demand hours. In countries with priority excess for renewable generation the TSO may order base load capacity to ramp down when no flexible capacity is running. (EnergiNet DK, 2007)
Reliability Adequacy Transmission	I.1.9	Interconnection rate	*S* *M* *L*	*HC* *HR*	- Capacity of interconnections with neighbouring countries - Total installed in-land capacity	(Percebois, 2006)
	I.1.10	Nomination Rate (NR)	*S*	*HC*	$\mathrm{NR}_{\mathrm{Y}} = \frac{\sum_{h \in \mathrm{Y}} \frac{\text{Net Schedule}_h}{\mathrm{NTC}_{NetSchedule,h}}}{Count(h \in \mathrm{Y})}$	Yearly average indicator for cross-border bottlenecks retrospect analysis. Y stands for the year for which this analysis is conducted and h an index covering every hour during that year. Net schedule is the netting of import and export

						commercial schedules. NTC is the Net Transmission Capacity offered to the market in the direction of the Net Schedule. See further: (ENTSO-E, 2009d: pp. 66-68)
Reliability Delivery security	I.2.1	SAIDI: sum of customer interruption durations in minutes per year	*N* *S* *M*	*HC* *HR*	- Sum of customer interruption durations in minutes per year - Total # customers served	System average duration index (minutes / year)
	I.2.2	SAIFI	*N* *S* *M*	*HC* *HR*	- Total # customer interruptions per year - Total # customers served	System average interruption frequency index (# interruptions / year)
	I.2.3	CAIDI	*N* *S* *M*	*HC* *HR*	- Sum of customer interruption durations in minutes per year - Total # customers served	Customer average duration index, i.e. the average time required to restore service to the average customer per sustained interruption (minutes / year). CAIDI = SAIDI / SAIFI
	I.2.4	% non-fossil in electricity generation			- Total installed (and available) non-fossil generating capacity (GW); total annual non-fossil generation (TWh) - Total installed (and available) capacity); total annual generation (TWh)	Indicator for monitoring the de-carbonisation of the electricity system
	I.2.5	Thermal power capacity	*S* *M* *(L)*	*HC* *HR*	- Total installed capacity of fossil-fuel based generation units (GW)	Indicates the potential base for substitution by low carbon generating technology
	I.2.6	Share multi-fuel plant capacity in total thermal power capacity	*S* *M* *(L)*	*HC* *HR*	- Installed capacity of all multi-fuel thermal plants - Total installed capacity of thermal plants	One form of supply flexibility in case of serious supply contingencies with one kind of fuel, e.g. natural gas or coal.
	I.2.7	Rate of contractually flexible demand (interruptible contracts, fuel switch on government order)	*N* *S* *M*	*HC* *HR*	- Total flexible demand - Total peak demand	(Mandil, 2008)
	I.2.8	Strategic fuel stock ratio	*S*	*HC* *HR*	- Stocks per critical fuel - Corresponding fuel consumption	(IAEA et al.,2005:ECO16) (Mandil, 2008)
	I.2.9	Import dependency (fossil fuels)	*S* *M*	*HC* *HR*	- Net energy import, by fuel and total	(IAEA et al.,2005:ECO15) (WEC, 2008)

			L	*W*	- Corresponding PES, TPES	
	I.2.10	Oil import dependency	*S* *M* *L*	*HC* *HR* *W*	- Net oil import - Inland oil demand (primary oil-based energy supply) - TPES	(IAEA et al.,2005:ECO15) (APERC, 2007: ESIIV)
	I.2.11	Middle East oil import dependency	*S* *M* *L*	*HC* *HR* *W*	- Net Middle East oil import - Inland oil demand (primary oil-based energy supply)	(APERC, 2007: ESIV)
	I.2.12	Reserves-to-production ratio	*S* *M* *L* *V*	*HC* *HR* *W*	- Proven recoverable reserves - Total energy production	(Jansen et al., 2005a) (IAEA et al.,2005:ECO4) (British Petroleum, various editions) Low and declining trend in estimates for subsequent past years may herald acceleration in positive real price escalation
	I.2.13	Resources-to-production ratio	*S* *M* *L* *V*	*HC* *HR* *W*	- Total estimated reserves - Total energy production	(IAEA et al.,2005:ECO5) Low and declining trend in estimates for subsequent past years may herald acceleration in positive real price escalation
	I.2.14	Average field recovery rate	*S* *M* *L*	*HC* *HR* *W*	- Cumulative fuel volume extracted from a field up to development completion - Initial field resources	Increasing recovery rates through technology development raise proven reserves and postpone resource depletion
	I.2.15	Fuel shares in energy	*S* *M* *L*	*HC* *HR* *W*	- PES, FC by fuel - TPES, TFC	TPES: total primary energy supply TFC: total final consumption (IAEA et al.,2005:ECO11)
	I.2.16	Share of non-carbon energy in energy	*S* *M* *L* *V*	*HC* *HR* *W*	- PES, FC covered by non-carbon sources - TPES, TFC	(IAEA et al.,2005:ECO12) (APERC, 2007: ESIIII) (WEC, 2008)
	I.2.17	Share of renewables in energy	*S* *M* *L* *V*	*HC* *HR* *W*	- PES, FC covered by renewables - TPES, TFC	(IAEA et al.,2005:ECO13)
	I.2.18	Fuel concentration	*S* *M* *L*	*HC* *HR* *W*	- HHI index of fuel shares in TPES - PES by fuel - TPES	(Neff, 1997)
	I.2.19	Fuel diversification	*S* *M*	*HC* *HR*	- Shannon-Wiener index - G, PES by fuel	(Stirling, 1994 and 1999) (Jansen et al, 2004)

			L	*W*	- TG, TPES	(APERC, 2007: ESII)
	I.2.20	Supplier concentration	*S* *M*	*HC* *HR* *W*	- HHI index of supplier (independent countries or regions) shares in total net imports / apparent demand - PES by fuel and supplier - PES by fuel	Supplier concentration as for exhaustible fuels, especially import concentration may render fuel importing countries/regions susceptible to supra-competitive fuel prices and geopolitical tensions (Neff, 1997), (Karl, 1997) (Lefèvre, 2007) (WEC, 2008)
	I.2.21	(Foreign) Supplier diversification	*S* *M*	*HC* *HR* *W*	- Shannon-Wiener index - Net energy import by fuel and supplier - Corresponding PES	For low supplier diversification broadly the same holds as for high supplier concentration. Yet in contrast to latter measure no underrepresentation bias of suppliers with a small share. (Hirschhausen…, 2003) (Jansen et al, 2004) (WEC, 2008)
	I.2.22	Diversification of PES, adjusted for import dependency	*S* *M* *L*	*HC* *HR* *W*	- Shannon-Wiener index - Net energy import by fuel - Corresponding PES - TPES	(APERC, 2007: ESIII)
	I.2.23	Value of lost load (VoLL)	*N* *S* *M*	*HC* *HR*	- Total; Per end-use category: - Aggreggate value of lost load ($;€) - Lost load because of power supply interruptions (kWh)	(van der Welle and van der Zwaan, 2007) Indicates cost of electricity services forgone because of electricity supply disruptions
	I.2.24	Rate of distributed generation	*S* *M* *L*	*HC* *HR*	- Installed DG capacity; DG-based generation - Total installed capacity; total generation	DG increases complexity of system operations and risks when conventional. DG may compete with large-scale generators on power markets. Flexible distributed generation (DG) may compete with flexible large-scale power plants for system services. Yet flexible DG may accommodate less flexible large-scale generation such as nuclear.
	I.2.25	Intermittent renewable power capacity	*S* *M*	*HC* *HR*	- Total installed capacity of intermittent renewable generation (GW)	High penetration of intermittent renewable generation may adversely affect the economic feasibility of the nuclear option (See main text: Section 5)
	I.2.26	‘Must run’ base load generation capacity	*S* *M* *(L)*	*HC* *HR*	- Total capacity of less flexible ‘full load’ generating units for which part-loading or switching off except for planned outages has	Projected prospective values for indicators I.1.3 and I.2.32 are key for assessing the need for additional nuclear power.

					economic disadvantages or sheer technical limitations, notably nuclear and coal-fired power plants (GW)	
Energy costs						
Affordability						
	II.1.1	Fuel price	*S* *M* *L*	*HC* *HR* *W*	- End-use energy prices by fuel and by sector - Marker/wholesale prices for oil, gas, coal, uranium	This indicator reflects the final price paid by consumers for energy services. Final consumer prices for enrgy products are driven by marker/wholesale prices. (IAEA et al.,2005:ECO14)
	II.1.2	Carbon price	*S* *M* *L*	*HC* *HR*	- Marker price (e.g. EU ETS price)	(Jansen et al., 2005b) Carbon price can be a major component of fuel/power prices
	II.1.3	Share of household income spent on fuel and electricity	*S* *M*	*HC* *HR*	- Household income spent on fuel and electricity - Household income	All households and poorest 20% (IAEA et al.,2005:SOC2)
	II.1.4	Ratio of net fuel import bill to GDP	*S* *M*	*HC* *HR*	- Value of net energy imports (in local currency) - GDP	(Percebois, 2006) (WEC, 2008) Macroeconomic vulnerability. Can also be applied per fuel, e.g. oil. Can be decomposed into other indicators: = III.6 * II.2 * III.8 * I.4 Has opposite sign for net exporters.
	II.1.5	Average supply cost of imported energy	*S* *M*	*HC* *HR*	- Value of net energy imports (in US$) - Total net energy import	(WEC, 2008)
Fuel price trend						
	II.2.1	Fuel price trend (after inflation)	*S* *M* *L* *V*	*HC* *HR* *W*	- Marker prices for oil, gas, coal, uranium, power, carbon - End-use energy prices by fuel and by sector - GDP price index	Analysing different timescales back from most recent data may indicate changes in trend (deceleration, reversal, acceleration)
Fuel price volatility						
	II.3.1	Fuel price volatility	*S*	*HC*	- Standard deviation of (average or	(Awerbuch and Berger, 2003)

			M	*HR* *W*	ultimo) fuel price per period (week, month, quarter, year)	(Jansen et al., 2005a) (WEC, 2008) Taking different timescales
	II.3.2	Carbon price volatility	*S* *M*	*HC* *HR*	- Standard deviation of (average or ultimo) carbon price per period (week, month, quarter, year)	(Jansen et al., 2005b)
	II.3.3	Exchange rate (volatility)	*S* *M*	*HC* *HR*	- Local currency units - US$	(Percebois, 2006) (WEC, 2008)
Energy intensity						
	II.4.1	Energy use per capita	*S* *M* *L* *V*	*HC* *HR* *W*	- TPES, TFC, Electricity use - Population	(IAEA et al.,2005:ECO1)
	II.4.2	Energy use per unit of GDP	*S* *M*	*HC* *HR* *W*	- TPES, TFC, electricity use - GDP	(IAEA et al.,2005:ECO2) (WEC, 2008)
	II.4.3	Sectoral energy intensities	*S* *M*	*HC* *HR* *W*	- Energy, fuel, electricity use in (sub-)sector - Corresponding value added	(IAEA et al.,2005:ECO6/7/8)
	II.4.4	Household energy intensities	*S* *M*	*HC* *HR* *W*	- Energy, fuel, electricity use in households by key end use - # households, floor area, persons per household, appliance ownership	(IAEA et al.,2005:ECO9)
	II.4.5	Heating degree days	*S* *M*	*HC* *HR*		
	II.4.6	Cooling degree days	*S* *M*	*HC* *HR*		
	II.4.7	Transport energy intensities	*S* *M* *L*	*HC* *HR* *W*	- Energy, fuel, electricity use in passenger travel and freight sectors, by mode - Passenger-km travel and tonne-km freight, by mode	(IAEA et al.,2005:ECO10)
	II.4.8	Fuel chain efficiency of conversion and distribution	*S* *M*	*HC* *HR* *W*	- Losses in conversion, transport and distribution - Fuel dispatched at well, port of embarkation	(IAEA et al.,2005:ECO3)

	II.4.9	Efficiency of generation, transmission and distribution	*S* *M*	*HC* *HR* *W*	- Generation energy input - Final electricity use	(IAEA et al.,2005:SOC3)
Policy framework						
Regulation						
	III.1.1	Rate of contractually flexible demand (interruptible contracts, fuel switch on government order)	*N* *S* *M*	*HC* *HR*	- Total flexible demand - Total peak demand	(Mandil, 2008)
	III.1.2	Establishment independent energy sector regulator	*S* *M*	*HC* *HR*	- Yes/No	
	III.1.3	Regulator has mandate to ensure adequate T&D infrastructure capacity (along with mandate to ensure competitive prices/tariffs)	*S* *M*	*HC* *HR*	- Yes/No	(Mandil, 2008)
	III.1.4	Periodic publication of official medium-term demand/supply planning document	*S* *M*	*HC* *HR*	- Yes/No	(Mandil, 2008)
	III.1.5	Strategic fuel stock ratio	*S*	*HC* *HR*	- Stocks per critical fuel - Corresponding fuel consumption	(IAEA et al.,2005:ECO16) (Mandil, 2008)
	III.1.6	Weekly publication of stocks	*S*	*HC* *HR*	- Yes/No	(Mandil, 2008)
	III.1.8	Adoption energy-efficiency building code	*S* *M*	*HC* *HR*	- Yes/No	
	III.1.9	Adoption low-energy/carbon vehicle standards	*S* *M*	*HC* *HR*	- Yes/No	
	III.1.10	Adoption EE standards for	*S* *M*	*HC* *HR*	- Yes/No	

		major energy end-use appliances				
	III.1.11	Adoption mandatory emergency preparedness plan	*S* *M*	*HC* *HR*	- Yes/No	
Market functioning						
	III.2.1	Size of the spot market	*S* *M*	*HC* *HR*	- Annual spot / DA market volume - Annual total market volume/ demand for fuel c.q. electricity	
	III.2.2	Market concentration	*S* *M*	*HC* *HR*	- Market concentration - Share largest 3 suppliers - HHI index	
	III.2.3	Unbundling of transmission network	*S* *M*	*HC* *HR*	- Yes/No	
PUBLIC ACCEPTANCE						
Operation safety						
	IV.1.1	Accident fatalities per energy produced by fuel chain	*S* *M* *L*	*HC* *HR* *W*	- Annual fatalities by fuel chain - Annual energy produced	(IAEA et al.,2005:SOC4)
Proliferation of dangerous materials						
	IV.2.1	Proliferation events	*S* *M* *L*	*HC* *HR* *W*	- Events per period	
Waste production						
	IV.3.1	Radioactive waste produced per unit of electricity	*S* *M* *L*	*HC* *HR* *W*	- High/medium radioactive waste from nuclear electricity - Nuclear power generation	
	IV.3.2	Non/low radioactive solid/liquid waste produced per unit of electricity	*S* *M* *L*	*HC* *HR* *W*	- Non/low radioactive solid/liquid (including thermal) waste from electricity generated from a source - Electricity generated from a source	
Emissions	IV.3.3	GHG emissions per	*S*	*HC*	- GHG emissions from electricity	

		unit of electricity	*M* *L*	*HR* *W*	generated from a source - Electricity generated from a source	

<u>Legend</u>

Timescale:

- N(near real-time): t < 1 minute
- S(short run): t < 2 years
- M (medium run): 2 ≤ t ≤ 15 years
- L (long run) t > 15 years
- V (very long term) t > 50 years

Location:

- HA (home area; within home country or home region)
- HC (home country)
- HR (multi-country home region)
- W (world)