Energy services security: some metrics and policy issues

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Jaap C. Jansen [a),]
a) Energy research Centre of the Netherlands (ECN), Petten, Netherlands.
E-mail address: j.jansen@ecn.nl

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Abstract

After introducing concept of energy security and energy services security, the paper reviews some composite indicators that have been proposed to quantify long-term energy security. Special attention is paid to two of these approaches, i.e. diversity-based indices and the S/D Index. Next an overview is given of simple indicators of energy services security. The concept of energy services security is proposed with a demand-side focus, enabling an integrated approach to security issues.

Key words: energy services, energy services security, energy services security indicators

1 Introduction

This paper is about the availability of useful energy to meet a population's needs for energy services. 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) 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.

Yet Walt 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 (Patterson, 2007). Ambient energy includes sources such as windpower, 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, and biomass. Furthermore, Patterson refers to the First Law of Thermodynamics which implies that no single joule of energy gets lost. 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. *Useful* energy rather than energy *per* sé, is in short supply.[1]

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.[2] 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 ("energy losses"). Note furthermore that energy services include outputs from non-energy industrial feedstocks.[3]

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.[4] Hereafter ESS refers to the certainty level at which the population in a defined 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 this multi-facetted issue.

Evidently, the pricing of energy services is of key energy policy relevance. Energy services priced at supra-competitive levels as a result of the use of monopolistic market power by suppliers of energy carriers result in welfare loss. In turn, this may

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

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

[3] 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.

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

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. 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 the price of useful energy input requirements, this is a key energy policy issue as well.

This paper is structured as follows. First two approaches are briefly explained towards quantifying supply security using composite indicators that ECN helped to develop (section 2). Next we seek to somewhat elaborate the energy supply security concept and present a preliminary overview of single ESS indicators covering aspects of the proposed three dimensions of energy services security (section 3). Concluding remarks wind up this paper (section 4).

2 Some recent approaches to measure supply security

Multi-fossil-fuels energy security measurement[5]

In the 1990s the world-wide use of natural gas, most notably in many OECD member states, has expanded rapidly. The disparate geographical distribution of natural gas resources and the specific risks pertinent to cross-border pipe-line natural gas supply chains brought home the message that energy security is not only a matter of the vagaries of the world petroleum market. As from 2004, it became clear that coal-based energy services are also liable to serious risks in the coal supply chain. An additional factor prompting multi-fuel supply approaches to the 'energy security' issue is climate change. Advocates of fast policy action to address climate change sought to strengthen their case by invoking the potentially significant energy security co-benefits of climate change mitigation measures. This aroused interest in interactions of climate change and energy security policy measures.

Let us consider the perhaps most well-known recent document of a multi-fossil-fuels approach to the design of energy security indicators, i.e. the one proposed by the IEA (Lefèvre, 2007).[6] It adheres to the rather confined welfare economics perspective and postulates that energy insecurity stems from the welfare impact of either the physical unavailability of energy, or prices that are not competitive or overly volatile. The IEA proposes:

A composite multi-fossil-fuels index of energy security, composed of single energy security indicators based on market concentration in the international markets

[5] This section draws on (Jansen and Seebregts, forthcoming)

[6] This publication was the second major one in a multi-annual IEA research programme on energy security indicators which included five country case studies. It builds on the first major publication in this programme, (Blyth and Lefèvre, 2004), which in turn was partly based on (Stirling, 1999) and (Jansen et al., 2004).

(ESI_{price}): for oil and gas with oil-linked pricing; gas with gas-based pricing; and coal respectively;[7]

A second energy security indicator based on physical unavailability (ESI_{volume}): for gas imported through pipelines with oil-linked pricing.[8]

The two indicators permit relative (ranking) comparisons. These enable to investigate in which direction the level of energy security of a specific country or region is projected to evolve relative to a base year under a certain scenario or whether energy security in country (region) A is less/higher than in country (region) B in a certain year. Measured (projected) values for ESI_{price} or ESI_{volume} or - provided resulting ranking information with the two indicators being mutually consistent - both would provide clues.

The following observations can be made on the two IEA-proposed energy security indicators. As demonstrated in the country case studies, the IEA-proposed indicators of energy security can be applied in a forward-looking way indeed. This requires projections of international trade in (imports of the country/region considered of) fossil fuels, broken down by trading (export) regions or countries. Moreover, taken together the two indicators broaden the scope of energy security measurement from one to three fossil fuels. Yet the indicators still have some major flaws. Their most important limitation is that they only refer to international fossil fuel markets. By implication, they neglect other sources in the energy mix and key resilience aspects of a country's energy system, i.e. the performance of the country (region) considered itself in mitigating the potential impact of (latent) energy insecurity. Furthermore, a certain non-extreme numerical outcome as such of the Herfindhal-Hirschman Index (HHI) of market concentration, and by implication the IEA-proposed energy security index, cannot be readily interpreted by less informed policy makers and other users. Besides, outcomes for both proposed indicators taken together and their mutual relationship in defining an overall energy security level is also puzzling for external observers. One index instead of two indicators makes comparisons easier and more readily communicable. Finally, in the review of indicator approaches in Annex I of (Lefèvre, 2007) just one other approach is singled out for questioning the subjective arbitrariness in defining the relative importance of the different components or parameters to construct supply security indices. Yet every approach to design meaningful energy security indicators faces this problem.[9] The IEA-proposed ESI_{price}

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7 Broadly similar to a procedure proposed by (von Hirschhausen and Neumann, 2003) and (Jansen et al., 2004), the initial indicators are adjusted to account for political stability in the export countries. (Lefèvre, 2007) assumes that the future level of political stability will remain the same as the last measured level, which makes sense because of its lack of predictability. The adjustment for political stability in supplying export countries changes the range of possible outcomes from [0,10000] for a simple HHI index with 10,000 as the least energy-secure outcome (one supplying country to the importing country considered) to [0, 30000]. The level of 30,000 would obtain for the case with not only extreme market concentration, i.e. one supplier; the single supplying country would also be characterised by the highest level of political instability with a value 3 on a [1,3] scale.

8 This indicator has a [0,100] scale, where 100 is reached when 100% of a country's total primary energy supply is met by gas imported through pipelines under long-term oil-price-indexed contracts. Gas traded "on gas-based terms" at natural gas exchanges is treated like LNG.

9 Perhaps Stirling's most advanced diversity approach as expounded in, among others, (Stirling, 1999) forms an exception.

index is no exemption. Why using, as the IEA does, the share in total primary energy supply and not, for example, share in total value of primary energy supply as weight of a component indicator in the overall index? And why using an adjustment factor for the political stability of an export country on a [1,3] scale and not on, for instance, a [1,10] scale? Even the IEA accounting of for quantities of energy from different sources in total primary energy supply suffers from a serious "apples and oranges" aggregation problem.[10] All in all, doubts remain as to whether the energy security indicators proposed in (Lefèvre, 2007) are indeed capable of meeting the set objective, i.e. to "focus on measuring the cause of energy insecurity".[11]

Diversity-based indices

One of the first attempts to design composite indices of energy supply security was in (Jansen et al.; 2004), i.e. a small pre-study to a larger one on four long-term global environmental sustainability scenarios.[12] This pre-study addresses the key research question as to whether it is possible to design a composite index for long-run energy supply security and if so how. Available scenario information on the projected evolution of 17 world regions and scanty previous work on this issue formed its ingredients. The approach chosen to address the key question is prompted by work of Andrew Stirling on diversity analysis (Stirling, 1999). The basic presumption is that large blind spots of ignorance mark one's perspective of long-term future socio-economic developments. If this holds true indeed, well-designed diversity strategies hold out the best promise for energy supply security.

Four composite diversity indices of long-term energy security are introduced, allowing for successive additional integration of different supply security aspects on a stepwise basis. The indices are based on the Shannon-Wiener diversity index for application to multi-fuel energy supply security. In the last two indices the basic "total ignorance" diversity concept is merged with distinct geopolitical (indices I_3, I_4) and exhaustibility (I_4) elements for which the total ignorance assumption is departed from and prior knowledge is presumed. The four diversity-based indices are:
Diversification of energy sources in energy supply (I_1)
Diversification of imports with respect of imported energy sources (I_2)
Long-term political stability in regions of origin (I_3)
The fuel resource base in regions of origin, including the home region (I_4).
These indicators are normalised into a [0,100] scale, with a lower value indicating an inferior supply security situation. See Annex 2 for more details.

When reliance has to be had on pre-set sustainability scenarios and a long-term time horizon, in the face of huge uncertainties Stirling's diversity approach has strong merits. Moreover, this approach is simple in principle and can be readily communicated. A weak point, though, of the pure diversity approach as such is the equal treatment of all sources, assuming complete ignorance. Yet for certain aspects we do have meaningful prior knowledge. For example, we know that certain sources

10 Segers shows that from a climate change mitigation perspective the IEA accounting rules for energy volume seriously underrate the contribution of ambient energy flow resources such as notably wind power to total energy supply (Segers, 2008).
11 (Lefêvre, 2007): p.13. Italics mode inserted by the present author.
12 The credit for the first attempt to design a multi-fuel index goes to Thomas Neff (Neff, 1997). Through a simple HHI index (Neff, 1997) proposed to measure energy security by the level of diversification of the energy mix, comparable to index I_1 of (Jansen et al., 2004).

are exhaustible whereas others are not. Index I_4 addresses this issue to a certain extent. A second major weak point is the absence of any feedback mechanism on the demand side. It can be expected that once the message gets across of increasing risks that events of major supply vulnerabilities will become manifest, actors in the home region will go for remedial public measures and private actions to mitigate such risks. Demand-side resilience is not accounted for in any of the aforementioned diversity-based indices.

Supply/Demand Index

The resilience of a certain society against shocks in the supply of energy resources driving the provision of societal needs for energy services is not only determined by diversification of - notably external - supply and other non-domestic supply considerations. The structure and intensity of national (regional) demand for energy services, supply elasticity for distinct categories of energy services, the inland supply chain and conversion infrastructure and the physical environment affecting societal needs for fuels and electricity are part and parcel of the supply security equation as well. Few of the recent approaches towards designing supply security indicators include inland infrastructural and demand-oriented aspects as well. Hereafter we explain one such approach, the Supply/Demand Index (S/D Index), proposed by Energy research Centre of the Netherlands, ECN, and the Clingendael International Energy Programme, CIEP, (Scheepers et al., 2006 and 2007).

The S/D Index is a supply security indicator for a defined region in the medium and long run that sets out to integrate major underlying supply-side and demand-side factors. This index is normalised to range from 0 (extremely low security) to 100 (extremely high security). It covers final energy demand, energy conversion and transport and primary energy sources (PES) supply and, hence, in principle the entire energy system. The S/D Index uses four types of inputs, two objective types and another two of a more subjective nature. The more or less objective inputs concern the shares of different supply and demand categories (i.e. for supply: oil, gas, coal, nuclear, RES and other; for demand: industrial use, residential use, tertiary use and transport use) and the values characterizing efficiency, adequacy and reliability in conversion and transport based on the secondary energy carriers (electricity, gas[13], heat and transport fuels). Figure 1 displays the conceptual model of the elements considered in the overall S/D Index.

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[13] The updated S/D Index model (Scheepers *et al*., 2007) has a separate branch for the secondary energy carrier Gas.

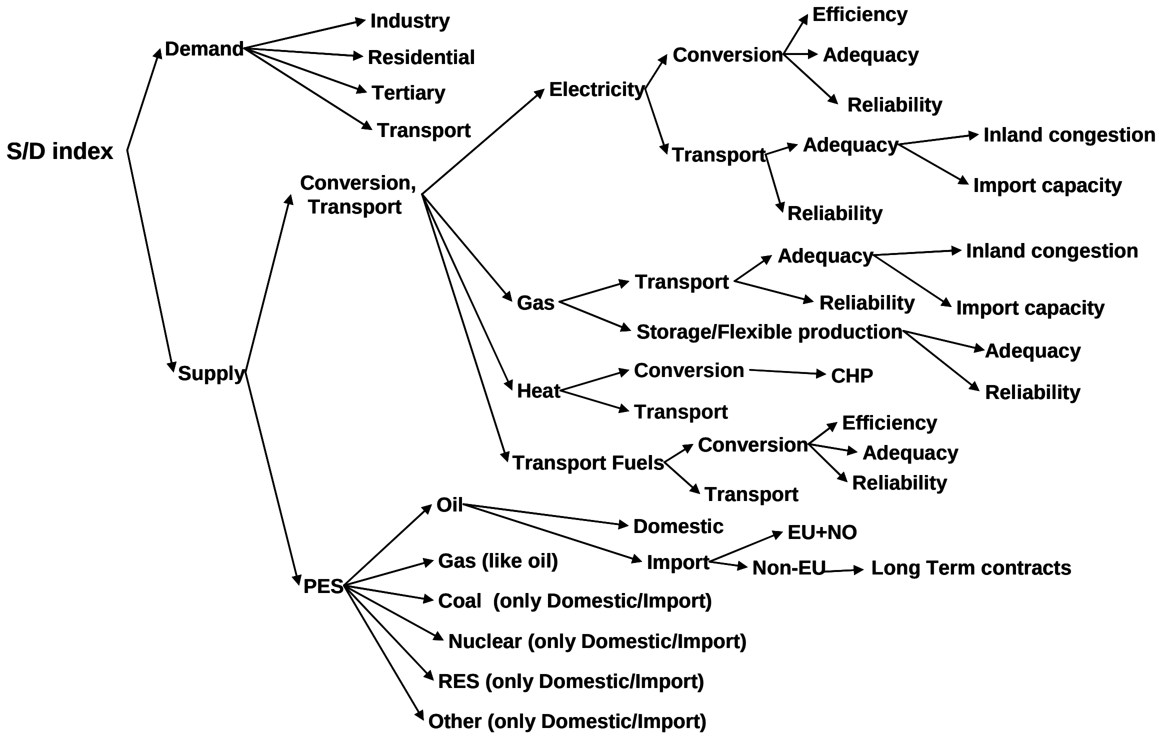

Figure 1 *The Supply/Demand Index Model Structure*

Subjective inputs include the weights that determine the relative contribution of the different components in the S/D Index and the scoring rules for determining various S/D Index values reflecting different degrees of perceived vulnerabilities. These inputs are integrated in a transparent framework and can be changed in a user-defined way. Currently, the S/D Index is officially adopted by Ireland (SEI, 2006 and 2007) and the Netherlands. Recently, the IEA Clean Coal Centre used the S/D Index to assess the role of coal and energy security (Kessels et al., 2008).

The use of the S/D Index can be illustrated with examples for the EU-27 and its member states for the years 2005 and 2020. The examples are based largely on information contained in energy balances, derived from mainly Eurostat (Eurostat, 2006) and IEA statistics (IEA, 2006) and the 'EU Trends to 2030 - update 2005' baseline scenario (EC, 2006a). The S/D Index model combines that information with certain default weighing factors and scoring rules. S/D Index values for some EU member states in year 2005 (realised) and year 2020 (projected) are displayed in Figure 2

The un-weighted average of the S/D Index values for the 27 EU member states in 2005 is about 56. The range is from 25 (Cyprus) to 82 (Denmark). The primary underlying factor accounting for the differences in scores between EU member states consists of differences in the PES (Primary Energy Sources) sub-index.[14] Member states with high import dependencies for oil and gas, combined with high shares of these imports originating from outside the EU/Norway, have a relatively low score.

[14] See for example (Scheepers *et al*., 2007) for details on sub-indices such as the PES sub-index.

Such member states include: Cyprus, Luxembourg, Malta, Latvia, Greece, Lithuania and Portugal. On the other hand, member states that are net exporters of gas and/or oil mark a relatively high score, i.e. an S/D Index of 60 or higher, for example the United Kingdom anno 2005 (80). Member states that import oil and natural gas mainly from within EU/Norway and/or deploy renewables and/or combined heat and power abundantly also achieve relatively high S/D Index values. Examples are Denmark (82), Ireland (75), and to a lesser extent Sweden (70). As most of the larger member states (Germany, France, United Kingdom) exhibit relatively high scores, the score for the whole EU-27 region is also relatively high (65).

Projections of S/D Index values in year 2020 for EU member states suggest some noteworthy upcoming developments.[15] The overall supply security level in the EU is poised to decrease. For example, for Ireland and the UK a quite large decrease in energy supply security as captured by the S/D Index is projected, as a surge in sourcing of primary energy sources outside the EU/Norway is envisaged for these countries.

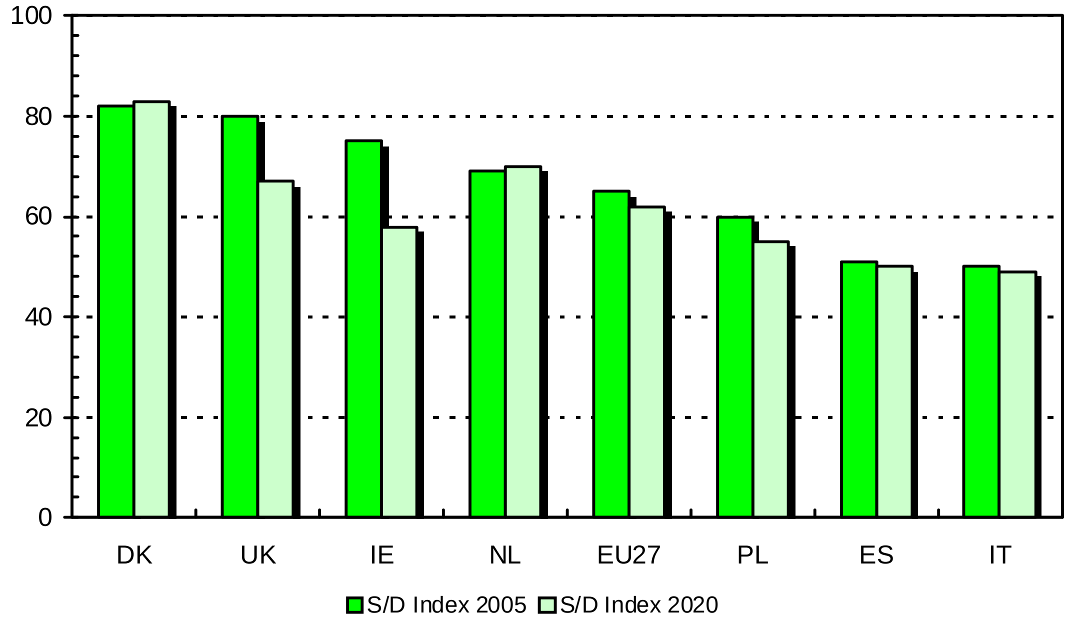

Figure 2 *S/D Index, EU-27 and selected Member States, years 2005 (actuals) and 2020 (projections)*

A major advantage of the S/D Index compared to most alternative measures would seem to be its relative comprehensiveness with the inclusion of some important demand-side aspects. The necessary corollary of comprehensiveness is reduced simplicity. On the other hand, for long term security purposes in the Primary Energy Supply the geopolitical-political dimension is captured less well, compared to e.g. the diversity-based indices set out above. Furthermore, aggregation of the various components - by means of a fully transparent framework - entails some subjective value assignments. These can be set in consultation with, and allowing for preferences of, users including policy makers.

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15 See Scheepers *et al.*, 2007 for more details.

3 ESS dimensions and preliminary listing of simple indicators

In this section we initiate the elaboration of the notion energy services security (ESS). We propose three main dimensions of ESS and report on preliminary results of ongoing work to categorise many quantitative and qualitative ESS indicators along these dimensions, based on a brief scan of literature. Ultimately, this activity is intended to provide some more insights into the complex interrelationships between the manifold aspects of ESS and to support future composite ESS indicator work.

3.1 ESS dimensions for indicator classification

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., Alhaji, 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).

Seriously underexposed in most recent work on 'energy security' is the resilience of a defined region (e.g., a country) to cope with adverse 'energy security' 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 further elaboration. The magnitude of risks to ESS security, or for that matter ‘energy security’, is not only determined by exposure to supply-side vulnerabilities. The measure of resilience of a recipient society of averse supply-side vulnerability events works as a cushion that dampens the impacts of supply-side vulnerability. This is depicted by Figure 3

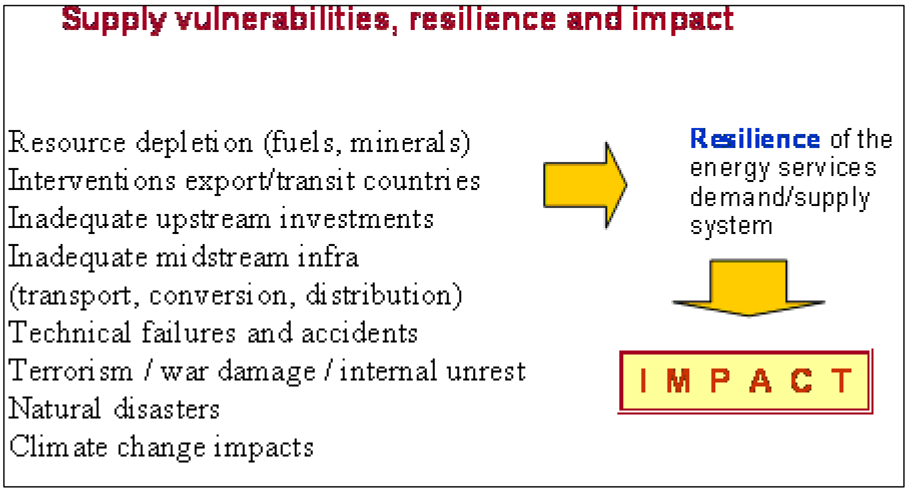

Figure 3 *Supply vulnerabilities, resilience and impact*

Energy services security (EES) is a more holistic concept than ‘energy security’ starting out the analysis of the topic under review from the demand side. We propose following three key dimensions to energy supply security:

1. *Exposure to supply-side vulnerabilities*. Low (high) exposure to risks regarding the supply of energy inputs (fuels, electricity) positively (negatively) affects the level of ESS.
2. *Resilience on the demand side*. High (low) demand-side resilience positively (negatively) affects the level of ESS.
3. *Resilience on the supply side*. High (low) supply-side resilience positively (negatively) affects the level of ESS.

In the remainder of this section we briefly explain a *preliminary* listing of simple indicators of energy services security, which is presented in Annex 1. This list of simple quantitative and qualitative ESS indicators is categorised into the proposed three main ESS dimensions.

Furthermore, a separate listing is made for the electricity sector for two major reasons: its special character and its importance. The electricity sector is special in that supply has to match realised demand instantaneously for technical reasons (to avoid brown-outs that are harmful for electrical appliances and outright black-outs). On the other hand electricity stands out as a secondary energy carrier that can be generated from a multitude of primary and secondary energy sources. The latter feature, its delivery convenience and continuous technical progress bringing down conversion costs including physical “conversion losses” make electricity the end-use energy carrier of choice for most important energy services in all end-use energy sectors. The major remaining exception is transportation. Yet it appears that we are on the verge of witnessing the take-off of plug-in hybrid electric vehicles in the light duty road vehicles market segment. Moreover, along with the world’s burgeoning mega-cities electricity-driven mass transit systems appear starting to command higher shares in road passenger transport market. All in all, a separate ESS treatment of the electricity sector is warranted.

The time horizon 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. Notably for short and medium-term timescales the functioning of international fuel markets and the political economy of international resource rent transfers are major topics of attention. In the overview in the Annex for each indicator the timeframes are indicated for which the indicator can be used. The following time periods are discerned:

N(near real-time):	$t < 1$ minute
S(short run):	$t < 2$ years
M (medium run):	$2 \leq t \leq 20$ years
L (long run)	$t > 20$ years
V (very long term)	$t > 50$ years

The timeframe indications can be used as a first screening of short-term and long-term ESS indicators. Indicators for which the applicable time frame indications include N and S may qualify for use as short-term ESS indicators, whilst the ones which exclude the N and S indications may qualify for use as long-term ESS indicators.

3.1 Supply-side vulnerabilities

High exposure to supply-side risks negatively affects levels of ESS of a country. A wide variety of disruptions in supply of fuels and electricity can occur. This, in turn, can lead to outright physical fuel/electricity shortages, substantial changes of real prices or high price volatility with consequential loss in economic welfare. Main categories of supply-side disruptions include:

- Depletion of fuel resources and minerals used in energy conversion appliances
- Restrictions to fuel extraction rates and fuel exports by governments of fuel export and transit countries
- Inadequate investments in certain components of fuel supply chains because of interventions by governments of fuel-abundant countries
- Inadequate regulatory frameworks, e.g. frameworks without a mandate for the regulator to oversee compliance with investment adequacy criteria e.g. for inland generators, network operators, interconnection capacity or (other) market failures
- Congestion on transit routes or in fuel conversion (electricity generation) plants because of inadequate investment
- Acts of war or terrorism
- Technical failures
- Human errors
- Natural disasters: adverse weather events, volcanic eruptions
- Adverse impacts of climate change

3.2Demand-side resilience

The size and composition of demand for energy end-use services is mainly driven by:

- consumer income levels
- lifestyles and associated consumer preferences
- climate conditions (in-doors climate conditioning)
- spatial human settlement patterns, public transportation and building infrastructures shaping living, working, travel and freight haulage conditions of consuming and producing agents.

In the absence of energy policy, significant autonomous changes impact on the size and composition of a region (country)'s demand for energy end-use services. For example, structural changes in the economy of economically-advanced countries tend to unfold from energy-intensive basic industry activities into the direction of less energy-intensive services. On the other hand, penetration rates of fuel-guzzling cars and electric gadgets including personal computers in the household and services sectors seem to rise relentlessly.

Demand-side resilience policies and demand-side resilience indicators concern the following main aspects:

- End-use efficiency of fuel or electricity-using appliances
- Waste reduction (adoption of energy-resources-saving *lifestyle changes* by consumers; good housekeeping measures by the public and private business sector)
- Flexibilisation of energy services demand (interruptible contracts; substitution capabilities through multi-fuel drive train; time-of-day and locational pricing + end user-ICT-based metering and control e.g. domotica and virtual power plant applications)
- Demand substitution towards energy services that are less energy-resources-intensive
- Further advancement of electrification of energy services
- Focusing on biomass options in niche categories of energy services (maritime, air, freight transportation)
- Sustainable spatial planning
- Effective public transportation infrastructure.

3.3 Supply-side resilience

Low supply-side resilience negatively affects the level of ESS. Main aspects of (high) supply-side resilience include:

- Assessment of the *full* energy (electricity, fuels) supply chains on supply risks and risk mitigation opportunities and scope for improving the efficiency of energy resources e.g. through reduction of transmission and distribution losses
- Reducing fossil-fuel intensities (life cycle basis) of electricity, heat, transport fuels and fossil-fuel-based non-energy industrial feedstocks
- Diversification of energy/electricity mix away from fossil fuels (renewables, nuclear, CHP)

- Level-playing-field competition between large-scale centralised and small-scale production of end-use energy carriers close to demand centres (reform of regulatory frameworks)
- Within each fossil fuel supply chain: diversification of suppliers, supply modes (e.g. penetration of LNG with respect to pipeline gas), and supply routes
- Strategic supplies, both public and commercial
- Access to other forms of storage (e.g. interconnections with countries with large-scale hydro)
- Mandate for regulators of network services providers to supervise investment adequacy.

Furthermore, the implications of advanced energy-related technology on fossil-fuel intensities on a life-cycle basis (e.g. synfuels production, hydrogen production and use, carbon capture and storage) need to be considered seriously. The energy services security implications of these technologies should be due part of the equation in the assessments of public support for these technologies.

Trade-offs exist between decentralised, localised provision of energy services based on renewable energy sources and centralised provision of energy services based on fossil fuels and nuclear energy. In the advanced economies technological development has capitalised on the economics of scale that can be achieved in extracting and using high-density but exhaustible fuels for a range of applications, including importantly centralised high-voltage electricity generation. However, supply chains to demand centres tend to get longer and market concentration on the supply side stronger. This implies that from a certain point onwards increasing supply chain vulnerabilities emerge. Likewise, centralised power grid management gets disproportionately more complex by the ascent of decentralised generation. Unless properly managed at high cost, risks of deteriorating service levels rise up to levels where the risk of black-outs cascading across large areas can not be fully discounted.[16]

Amply available ambient energy resources are as such free-of-charge. For a range of direct thermal applications the costs to harness ambient energy are already competitively low (e.g. passive solar space heating and cooling). The cost of typically quite expensive decentralised generation equipment harnessing ambient energy sources tend to come down and technical performance improves through rapid technological learning. Moreover, efficient use of small-scale distributed energy resources warrants active network management, involving all system components including notably the end-users. This, in turn, tends to render demand appreciably more price elastic.

All in all, a gradual shift in the economics from centralised, large-scale towards decentralised, small-scale provision of energy services might be unfolding. Acceleration of this trend in a socio-economically efficient way appears might enhance EES at (very) long timescales.

[16] See (Patterson, 2007). For instance, in August 2003 a large cascading blackout happened in the U.S. Northeast and Midwest and Canada with an immediate shut down of 21 nuclear reactors. This blackout affected at least some 50 million people.

4 Concluding remarks

This paper has made the case that a comprehensive approach is warranted to design effective long-term supply security policies. To that effect, the notion of energy services security was introduced. A first step towards the design of new long-term composite ESS indicators was made by a preliminary categorisation of simple ESS indicators by main ESS dimension.

In designing ESS policy strategies, interactions with other policy domains have to be taken into account. We give some examples:

- Non-fuel supply constraints can matter a great deal:
    - Complex reactor vessel components (nuclear power plants)
    - Silicium (Si-based PV)
    - Copper (wind turbines, PV equipment)
    - Lithium (batteries of electric vehicles)
    - Platinum (fuel cells for hydrogen applications)
- ESS enhancing fuel substitution may narrow (weaken) a country's fiscal revenues base
- Interactions with climate change policies
    - CCS raises fuel resource requirements
    - Climate change impacts may aversely affect, notably large-scale centralised, energy supply infrastructures.

The ESS approach is a generic approach. It is both applicable to fuel-exporting and fuel-importing countries. Let us consider the case of a fuel-exporting country. Also the population in this country faces security risks regarding its energy services requirements. Furthermore, also this country will face sooner or later resource depletion issues. A great economic concern for its fuel export revenues is the instability of world fuel prices and hence potential exposure to steeply declining fuel export revenues. Moreover, many fuel exporting countries face growing non-competitiveness of their non-fuel economy on account of an appreciating real exchange rate ('Dutch disease'). Effective demand-side resilience policies can substantially mitigate the aforementioned vulnerabilities. Yet in practice, elites in many fuel exporting countries indulge in political rent-seeking behaviour reducing demand-side resilience in the process (Karl, 1997). In a bid to acquiescence urban populations such behaviour includes subsidisation of fuel prices and other macro-economically unsound policies. Economic research has found positive indications of the existence of the 'resource curse' finding *cet. par.* significantly better economic performance of countries devoid of abundant fuel resources that their fuel-abundant counterparts (Sachs et al., 1995; Collier, 2008). It is noted though, that these findings are not unanimously accepted (Brunnschweiler, 2008).

We subscribe to the view that good relations between fuel importing and exporting countries are a goal worthwhile to aspire when realistic. Yet we do not agree with Alhaji (Alhaji, 2008) that it is in the interest of the world at large when fuel importing countries would concede to the elites in fuel exporting countries stable import volumes as a general policy principle. 'Energy' (i.e. fuel) demand, not unlike other economic goods, is insecure by the very nature of economic transformation as time goes by. Entering into a sort of barter trade agreements with fixed market volumes for certain exporting countries creates inefficient rigidities. It is quite another issue, that there might be an economic justification for the initiation of mega-investment projects in the field of gas or oil field development or pipeline projects, to engage in long-term commercial take or pay contracts between stakeholders from both fuel importing and exporting countries.

Our final remark concerns future work on composite long-term ESS indicators. We see two main approaches for composite long-term ESS indicators. One is to develop an improved update of the Supply/Demand Index, or perhaps rather a Demand/Supply Index. Alternatively, a branch structure by ESS dimension can be developed by theme (and possibly sub-theme), each theme with its own indicator(s). Indicators might either be of quantitative but also of qualitative nature: qualitative information might provide valuable complementary information. At the very least scores for each theme might be attributed, normalised to the extent possible, with the best and worse scores defining the normalised range. Information on scores per ESS theme already provides interesting information to assist ESS policymakers. Any aggregation of scores warrants attribution of subjective score weights. To do this, close consultations with stakeholders from public-sector agencies responsible for energy services security policy strategies are indispensable.

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Annex 1 Preliminary listing of simple ESS indicators

This annex provides an overview of a preliminary listing of indicators. This list is due to be further elaborated.

Dimensions and indicators of energy services security: all energy services/ energy services directly driven by (all/specific) fuels

#	**Dimension** **Indicator**	**Time scale**	**Components**	**Remarks/references**
	Supply-side vulnerability			
ESS(EN).I.1	Accident fatalities per energy produced by fuel chain	S M L	- Annual fatalities by fuel chain - Annual energy produced	(IAEA et al.,2005:SOC4)
ESS(EN).I.2	Reserves-to-production ratio	S M L V	- Proven recoverable reserves - Total energy production	(Jansen et al., 2004) (IAEA et al.,2005:ECO4)
ESS(EN).I.3	Resources-to-production ratio	S M L V	- Total estimated reserves - Total energy production	(IAEA et al.,2005:ECO5)
ESS(EN).I.4	Exchange rate (volatility)	S M	- Local currency units - US$	(Percebois, 2006) (WEC, 2008)
ESS(EN).I.5	Fuel price	S M L	- Marker prices for oil, gas, coal, uranium - End-use energy prices by fuel and by sector	(IAEA et al.,2005:ECO14)
ESS(EN).I.6	Fuel price volatility	S M	- Standard deviation of (average or ultimo) fuel price per period (week, month, quarter, year)	(Awerbuch and Berger, 2003) (Jansen et al., 2006a) (WEC, 2008)
ESS(EN)I.7	Carbon price	S M L	- Marker price (e.g. EU ETS price)	(Jansen et al., 2006a)
ESS(EN).I.8	Carbon price	S	- Standard	(Jansen et al., 2006a)

	volatility	M	deviation of (average or ultimo) carbon price per period (week, month, quarter, year)	
ESS(EN).I.9	CO_2 covered by CCS, % of CO_2 emissions	M L	- CO_2 covered by CCS (t) - Total CO_2 emissions (t)	CCS raises primary energy requirements and consequently raises supply-side vulnerabilities
	Resilience on the demand side			
ESS(EN).II.1	Share of household income spent on fuel and electricity	S M	- Household income spent on fuel and electricity - Household income	All households and poorest 20% (IAEA et al.,2005:SOC2)
ESS(EN).II.2	Energy use per capita	S M L V	- TPES, TFC - Population	(IAEA et al.,2005:ECO1)
ESS(EN).II.3	Energy use per unit of GDP	S M	- TPES, TFC - GDP	(IAEA et al.,2005:ECO2) (WEC, 2008)
ESS(EN).II.4	Sectoral energy intensities	S M	- Energy use in (sub-)sector - Corresponding value added	(IAEA et al.,2005:ECO6/7/8)
ESS(EN).II.5	Household energy intensities	S M	- Energy use in households by key end use - # households, floor area, persons per household, appliance ownership	(IAEA et al.,2005:ECO9)
ESS(EN).II.6	Transport energy intensities	S M L	- Energy use in passenger travel and freight sectors, by mode - Passenger-km travel and tonne-km freight, by	(IAEA et al.,2005:ECO10)

			mode	
ESS(EN).II.7	Rate of contractually flexible demand (interruptible contracts, fuel switch on government order)	N S M	- Total flexible demand - Total peak demand	(Mandil, 2008)
	<u>*Resilience on the supply side*</u>			
ESS(EN).III.1	Extraction efficiency	S M L	- Quantity of extracted fuel from a certain field - Quantity of proven fuel before field development	
ESS(EN).III.2	Efficiency of conversion and distribution	S M	- Losses in conversion, transport and distribution - Fuel dispatched at well, port of embarcation	(IAEA et al.,2005: ECO3)
ESS(EN).III.3	Fuel shares in energy	S M L V	- PES, FC by fuel - TPES, TFC	(IAEA et al.,2005: ECO11)
ESS(EN).III.4	Share of non-carbon energy in energy	S M L V	- PES, FC covered by non-carbon sources - TPES, TFC	(IAEA et al.,2005: ECO12) (APERC, 2007: ESI_{III}) (WEC, 2008)
ESS(EN).III.5	Share of renewables in energy	S M L V	- PES, FC covered by renewables - TPES, TFC	(IAEA et al.,2005:ECO13)
ESS(EN).III.6	Import dependency	S M L	- Net energy import, by fuel and total - Corresponding PES, TPES	(IAEA et al.,2005: ECO15) (WEC, 2008)
ESS(EN).III.7	Ratio of net energy import bill to GDP	S M	- Value of net energy imports (in local	(Percebois, 2006) (WEC, 2008) Macroeconomic vulnerability. Can

			currency) - GDP	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.
ESS(EN).III.8	Average supply cost of imported energy	S M	- Value of net energy imports (in US$) - Total net energy import	(WEC, 2008)
ESS(EN).III.9	Oil import dependency	S M L	- Net oil import - Inland oil demand (primary oil-based energy supply) - TPES	(IAEA et al.,2005: ECO15) (APERC, 2007: ESI_{IV})
ESS(EN).III.10	Middle East oil import dependency	S M L	- Net Middle East oil import - Inland oil demand (primary oil-based energy supply)	(APERC, 2007: ESI_{V})
ESS(EN).III.11	Strategic fuel stock ratio	S	- Stocks per critical fuel - Corresponding fuel consumption	(IAEA et al.,2005: ECO16) (Mandil, 2008)
ESS(EN).III.12	Fuel concentration	S M L	- PES by fuel - TPES	(Neff, 1997)
ESS(EN).III.13	Fuel diversification	S M L	- PES by fuel - TPES	(Jansen et al, 2004) (APERC, 2007: ESI_{I})
ESS(EN).III.14	Supplier concentration	S M	- PES by fuel and supplier - PES by fuel	(Neff, 1997) (Lefèvre, 2007) (WEC, 2008)
ESS(EN).III.15	(Foreign) Supplier diversification	S M	- Net energy import by fuel and supplier - Corresponding PES	(Hirschhausen and Neumann, 2003) (Jansen et al, 2004) (WEC, 2008)
ESS(EN).III.16	Diversification of PES, adjusted for	S M	- Net energy import by fuel - Corresponding	(Jansen et al, 2004) (APERC, 2007: ESI_{II})

	import dependency		PES - TPES	
ESS(EN).III.17	Weekly publication of stocks	S	- Yes/No	(Mandil, 2008)
ESS(EN).III.18	Regulator has mandate to ensure adequate T&D infrastructure capacity (along with mandate to ensure fair prices/tariffs)	S M	- Yes/No	(Mandil, 2008)
ESS(EN).III.19	Periodic publication of official medium-term demand/supply planning document	S M	- Yes/No	(Mandil, 2008)
ESS(EN).III.20	CO_2 covered by CCS, % of CO_2 emissions	M L	- CO_2 covered by CCS (t) - Total CO_2 emissions (t)	CCS raises primary energy requirements and consequently raises supply-side vulnerabilities

<u>Legend</u>
Timescale:

N(near real-time): $t < 1$ minute
S(short run): $t < 2$ years
M (medium run): $2 \leq t \leq 20$ years
L (long run) $t > 20$ years
V (very long term) $t > 50$ years

Dimensions and indicators of energy services security: electricity-driven services

#	**Dimension** Aspect/Theme	Time scale	Components	Remarks/references
	Supply vulnerabilities			
ESS(EL).I.1	SAIFI	N S M	- Total # customer interruptions per year - Total # customers served	System average interruption frequency index (# interruptions / year)
ESS(EL).I.2	SAIDI	N S M	- Sum of customer interruption durations in minutes per year - Total # customers served	System average duration index (minutes / year)
ESS(EL).I.3	CAIDI	N S M	- 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
ESS(EL).I.4	Fuel price	S M L	- Marker prices for oil, gas, coal, uranium - End-use electricity prices by sector	(IAEA et al.,2005:ECO14)
ESS(EL).I.5	Fuel price volatility	S M	- Standard deviation of (average or ultimo) fuel price per period (week, month, quarter, year)	(Awerbuch and Berger, 2003) (Jansen et al., 2006a) (WEC, 2008)
ESS(EL).I.6	Carbon price	S M L	- Marker price (e.g. EU ETS price)	(Jansen et al., 2006a)

ESS(EL).I.7	Carbon price volatility	S M	- Standard deviation of (average or ultimo) carbon price per period (week, month, quarter, year)	(Jansen et al., 2006a)
	<u>*Resilience on the demand side*</u>			
ESS(EL).II.1	Share of household income spent on fuel and electricity	S M	- Household income spent on fuel and electricity - -Household income	All households and poorest 20% (IAEA et al.,2005: SOC2)
ESS(EL).II.2	Energy use per capita	S M L V	- Electricity use - Population	(IAEA et al.,2005: ECO1)
ESS(EL).II.3	Energy use per unit of GDP	S M L V	- Electricity use - GDP	(IAEA et al.,2005: ECO2)
ESS(EL).II.4	Efficiency of generation, transmission and distribution	S M	- Generation energy input - Final electricity use	(IAEA et al.,2005: SOC3)
ESS(EL).II.5	Sectoral energy intensities	S M	- Electricity use in (sub-)sector - Corresponding value added	(IAEA et al.,2005: ECO6/7/8)
ESS(EL).II.6	Household energy intensities	S M	- Electricity use in households by key end use - # households, persons per household, appliance ownership	(IAEA et al.,2005: ECO9)
ESS(EL).II.7	Transport energy intensities	S M L	- Electricity use in passenger travel and freight sectors, by mode - Passenger-km travel and	(IAEA et al.,2005: ECO10)

			tonne-km freight, by mode	
ESS(EL).II.8	Value of lost load (VoLL)	N S M	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, forthcoming)
	<u>Resilience on the supply side</u>		-	
ESS(EL).III.1	Efficiency of generation, transmission and distribution	S M	- Generation energy input - Final electricity use	(IAEA et al.,2005: SOC3)
ESS(EL).III.2	Fuel shares in energy	S M L V	- Electricity generation and generating capacity by fuel - Total electricity generation and generating capacity	(IAEA et al.,2005: ECO11)
ESS(EL).III.3	Share of non-carbon energy in energy	S M L V	- Electricity generation and generating capacity from non-carbon sources - Total electricity generation and generating capacity	(IAEA et al.,2005: ECO12)
ESS(EL).III.4	Share of renewables in energy	S M L V	- Renewable electricity generation and generating capacity - Total electricity generation and generating	(IAEA et al.,2005: ECO13)

			capacity	
ESS(EL).III.5	Installed reserve factor	S M L	- Peak demand - Total installed (and available) capacity	Difference between the installed capacity and the peak load for a particular year as % of peak load (Percebois, 2006)
ESS(EL).III.6	Interconnection rate	S M L	- Capacity of interconnections with neighbouring countries - Total installed capacity	(Percebois, 2006)
ESS(EL).III.7	Rate of distributed generation	S M L	- Installed DG capacity; DG-based generation - Total installed capacity; total generation	
ESS(EL).III.8	Regulator has mandate to ensure adequate generation, T&D infrastructure capacity (along with mandate to ensure competitive markets/ fair tariffs)	S M	- Yes/No	(Mandil, 2008)
ESS(EL).III.9	Periodic publication of official medium-term demand/supply planning document	S M	- Yes/No	(Mandil, 2008)

<u>Legend</u>
Timescale:

N(near real-time): t < 1 minute
S(short run): t < 2 years
M (medium run): 2 ≤ t ≤ 20 years
L (long run) t > 20 years
V (very long term) t > 50 years

Annex 2 Diversity-based indicators

This annex provides an overview of diversity based supply security indicators, proposed by (Jansen et al., 2004).

$$I_{1} = -\sum_i c_i^1 p_i \ln p_i \qquad (1)$$

Where:
I_1 = indicator no. 1
p_i = share of primary energy source i in total primary energy supply
i = 1…….M: primary energy source index
c_i^1 = correction factor to p_i for indicator I_1; equal to unity in case of the first indicator.

- 8 categories of PES (Coal, Oil, Gas, Modern Biofuels, Traditional Biofuels, Nuclear, Renewables n.e.s., Hydro power)
- the maximum value that non-normalised I_1 can take on indicating maximum dual diversity is approximately 2.079 (-ln1/M; M=8).
- The minimum value if all energy services would be driven by only one primary source is 0.

$$I_{2} = -\sum_i c_i^2 p_i \ln p_i \qquad (2)$$

Subject to:

$$c_i^2 = 1 - m_i\left(1 - S_i^m / S_i^{m,\max}\right) \qquad (3)$$

where:
I_2 = energy supply security indicator no. 2 accounting for import of energy resources
c_i^2 = correction factor to p_i for indicator I_2
m_i = share of net import in primary energy supply of source i

S_i^m = Shannon index of import flows of resource i

$$S_i^m = -\sum_j m_{ij} \ln m_{ij} \qquad (4)$$

m_{ij} = share of imports of energy resource i from import region j in total import of source i

j=1….N: index for import regions. A total number of N import regions are distinguished.

$S_i^{m,max}$ = Maximum value of Shannon index of import flows of resource i (equal to 2.77 for 16 import regions)

$$I_3 = -\sum_i c_i^3 p_i \ln p_i \qquad (5)$$

where:
I_3 = energy supply security indicator 3 accounting for energy imports and the extent of long-term socio-political stability in exporting regions

$$c_i^3 = 1 - m_i\left(1 - S_i^{m*} / S_i^{m*,\max}\right) \qquad (6)$$

$$S_i^{m*} = -\sum_j h_j m_{ij} \ln m_{ij} \qquad (7)$$

h_j = extent of political stability in import region j
.
S_i^{m*} = Shannon index of import flows of resource I, adjusted for political stability in the import regions

$S_i^{m*,max}$ = Maximum value of aforementioned Shannon index (equal to value 2.77 for 16 import regions)

$$I_4 = -\sum_i \{1 - (1 - r_{ik})(1 - m_i)\} c_i^4 p_i \ln p_i \qquad (8)$$

Where:
I_4 = indicator 4 accounting for energy imports, political stability in producing regions and for the proven regional reserves with respect to the annual production in the region concerned.

$$r_{ij} = Min\left\{\left[\frac{(\mathrm{R/P})_{ij}}{50}\right]^{a};1\right\} \qquad (a<1) \qquad (9)$$

$$c_i^4 = 1 - m_i\left(1 - S_i^{m\bullet\bullet} / S_i^{m**,\max}\right) \qquad (10)$$

$$S_i^{m**} = -\sum_j r_{ij} h_j m_{ij} \ln m_{ij} \qquad (11)$$

r_{ij} = depletion index for resource i in import region j
r_{ik} = depletion index for resource i in home region k, for which the indicators are determined (that is, OECD Europe in our applications in Chapter 5 of this report)
$(R/P)_{ij}$ = proven reserve-production ratio for resource i in region j