gws Discussion Paper 2009/8 ISSN 1867-7290

More Baskets?

Renewable Energy and Energy Security

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Osnabrück, im September 2009

Abstract:

Energy security becomes more and more of an issue in the face of worldwide increasing energy demand and uncertainty about the stability of prices, the availability of resources and delivery conditions. For Europe, the gas troubles between Russia and the Ukraine and more recently suggestions of large energy projects abroad such as Nabucco or Desertec intensified the discussion on energy security. For a long term strategy, diversification is suggested as a possibility to enhance energy security. A mere increase in import countries, however, does not do the trick. Stirling (1998) suggested the use of the Shannon-Wiener index, a simple and robust quantitative index to measure diversity. Other authors have extended the index to include import country stability and resource availability. This paper also includes portfolio cost efficiency. The thus extended index can improve the information on a country's current energy security situation and on a long-term strategy to increase energy security. The index is applied to the historic energy mix in Germany (1995-2007) and two future development paths are compared. The Shannon-Wiener index can serve as a tool to assess long-term energy security strategies, though some aspects of a country's energy mix cannot be included, such as combinability of certain electricity generation sources. Application of the indicator to the German energy mix shows a long term strategy with significant shares of renewable energy is superior to putting "all eggs in fewer baskets".

Keywords: Energy security, diversity index, renewable energy.

CONTENTS

1 INTRODUCTION

Energy security increasingly becomes an issue in the face of rising worldwide energy demand and dwindling resources. Threats to energy security are seen in political instabilities of resource exporting countries, decreasing reserves, geostrategic and geopolitical factors and the structure of the relevant energy markets in terms of market power, monopolies, cartels and trusts. The European Commission has issued two Green Papers on a strategy for the security of energy supply, supporting competitive international energy market (European Commission, 2000 and 2008). The large infrastructure and gas pipeline development project Nabucco through Turkey, Bulgaria, Romania, Hungary and Austria that has recently been launched is motivated by the assumed increase in energy security.

A much discussed hedge against uncertainty is the diversity of energy supply (IEA, 2007 and 2003). However, as intuitively appealing the concept of not putting all the apples in one basket seems, as difficult it has been to quantify diversity. Lately, some work on diversity indices has been published in the literature. Diversity indices especially provide useful measures to distinguish between different energy supply structures either for the future within one country or across countries. Future development of the energy supply structure of a country is an important policy issue; therefore, the development of resilient indicators can provide an important decision tool.

Renewable energy as part of the energy strategy of a country is discussed predominantly in the climate change policy framework. Consideration within the energy security context has been scarce and without any further quantification as of yet, even if it is obvious that domestic renewable energy sources can lessen a country’s import dependence, or diversify the selection of countries from which imports originate. Though decreasing imports as such do not bear any positive message for economy, the shift from risky sources to less risky sources will strengthen the energy security of a country. The following tries to add to literature by supplying a quantitative analysis of the changes in energy security by shifting to a more sustainable fuel mix.

This contribution is organized as follows. The next section (chapter 2) will provide an overview of different measures of energy security suggested in recent literature. Chapter 3 then develops the set of indicators used in the remainder of this contribution. Chapter 4 shows applications to the current energy portfolio in Germany and to different future development paths from literature, which differ with respect to the targets for renewable energy. Chapter 6 concludes.

2 ENERGY SECURITY IN LITERATURE

Literature on energy security falls into several categories, reflecting the different aspects of the energy security theme. These aspects comprise of availability, accessibility, environmental acceptability and affordability (APERC, 2007).

One strand of literature reports on *availability* issues, mostly estimating reserves and resources, the relation between natural resource prices and economical viable reserves, and the development of recovery technologies (cf. Eatherley and Morley, 2008, or Hetherington and Bloodworth, 2008). The large body of literature dealing with peak oil issues also belongs to this category (cf. Tsoskounoglou et al., 2008, Zhao et al., 2009, or de Castro et al., 2009).

Accessibility looks into technical questions of the resource extraction as well but also comprises geopolitical and geostrategic aspects of access to resources, such as ownership, markets, oligopolies and property rights (cf. Eswaran and Lewis, 1985, Mead, 1979). The import/domestic sources distribution is part of the accessibility question, such as technological development within a country and the development of human resources for energy questions.

Environmental acceptability connects the energy security issues with the broader concepts of sustainability. Different fuels interfere with sustainability concepts differently. While coal, and to a lesser extend oil and gas, combustion is in conflict with climate change policies on green house gas (GHG) emission targets due to large CO_2-emissions, nuclear, and all fossil fuel extraction is associated with environmental damages such as toxic contamination to land and water resources or hazards during the mining process. Biogenic resources impact land use and compete with food production, which is more related to social acceptability as an extended concept of environmental acceptability.

Affordability, as the last aspect mentioned, is related to the price risk of resources as well as the costs of exploring alternative sources.

A rather recent comprehensive treatment of the energy security issue has been published by the Asia Pacific Energy Research Center (APERC, 2007) for the APEC region. The countries in this region are facing growing energy demand due to economic and population growth and heavily rely on energy imports because of resource scarcity in their own countries. Energy Policy (forthcoming) publishes a special issue on energy security this year. The contributions in this issue range from a theoretical discussion on the economics of energy security (Markandaya and Pemberton, 2009) to an analysis of the policy process in the United States that thus far has led to very little policy results on improving energy security (Bang, 2009).

Bohi and Toman analyzed in 1993 energy security using the notion of economic externalities in oil markets. From their view point, governmental action could be justifiable if there was an externality, i.e. if certain aspects were not reflected in the market prices of, say, a barrel of crude oil. Although the effects of high oil prices on the trade balance and then on the dollar exchange rate sit well in theory, the authors find little empirical evidence for these effects. Equally little supportable by the numbers is an effect on inflation. Cross country comparisons of the effect of the 1970s oil price shocks on employment showed mixed results.

15 years after this discussion the interest in energy security is unbroken. More empirical research goes into indicators, such as Löschel et al. (2009), Stirling (2009) or Jansen et al. (2004). More and more additional fuels are taken into consideration and the publications on energy security do not focus on the oil market alone. On the contrary: a diverse energy mix seems to come in first regarding energy security.

3 Energy security indicators

The discussion on energy security stays arbitrary without concepts for its quantification. The literature knows different suggestions of indicators for energy security, which cover different aspects of the problem, such as import dependence (Turton and Barreto, 2006, APERC, 2007, Constantini et al., 2007) market concentration or resource availability (IEA, 2007) and diversity (Stirling (1998, 2007, 2009), Awerbuch, 2006, Frondel and Schmidt, 2008). If the focus is on diversity, two measures are used in the literature: The Shannon-Wiener Index (1) and the Herfindahl-Hirschmann Indicator (2). The latter is easily normalized, the former is additive, i.e. new possibilities actually increase the indicator – a rather useful property for the issue of energy security.

Shannon-Wiener: $S1 = -\sum_i p_i \ln(p_i)$ **p_i = share of fuel i** **1**

Herfindal-Hirschmann: $HHI = \sum_i p_i^2$ **2**

Hill (1973) showed that the indicators can be transformed into each other with few straightforward assumptions. Stirling (1998) suggested the use of the Shannon-Wiener index, a simple and robust quantitative index to measure diversity. Application and extension to include import country stability, resource availability and portfolio cost efficiency can improve the information on a country's current energy security situation and on a long-term strategy to increase energy security.

3.1 Basic Indicator

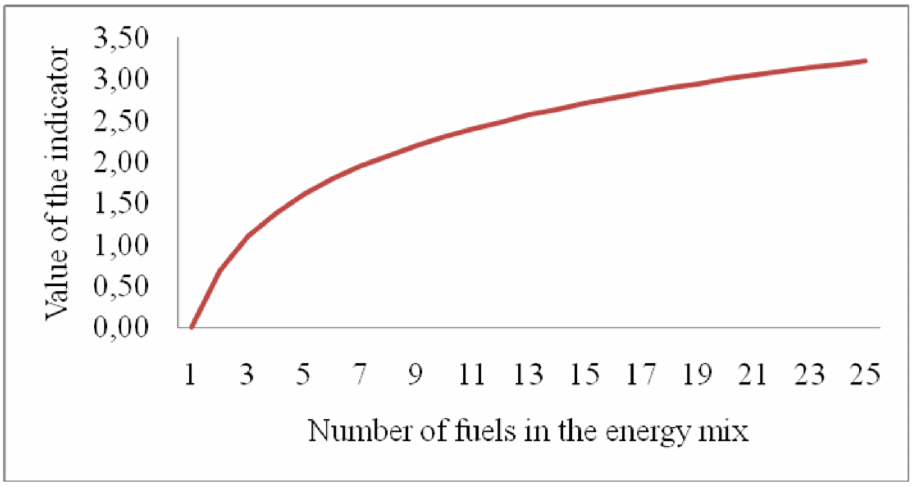
Stirling (1998) provides an identification of the three relevant aspects of diversity and derives measures for the first and the second of these aspects:

- Variety: "number of baskets", i.e. number of categories
- Balance: "size of the baskets" or apportionment across the relevant categories.
- Disparity: measure for the qualitative difference of the "baskets"

They incorporate the categories of energy security in several ways. The variety aspect of diversity can be mapped to the availability of resources and the accessibility (see section 2). Both will be increased with increasing variety. Affordability, however, can be affected in a positive or a negative direction, the sign is not a priori obvious. Similar considerations hold for the balance aspect of diversity. A balanced energy portfolio can compensate for access loss, but if the balance tended towards an increase of the lost resource, the overall performance will be worsened. The same holds for the availability. Jansen's et al. (2004) approach accounts for this risk. It does not, however, account for the affordability aspect. Our approach developed below tries to include this aspect, too.

The basic indicator S1, as defined in equation 1, sums the logs of all shares p weighted by the respective shares. It increases with more fuels and towards an even distribution of all shares (Figure 1).

Figure 1: Increase of S1 with number of fuels



This basic indicator (S1) is improved and extended to allow for import dependence, long term country stability and affordability of alternative energy sources.

3.2 Import Dependence (S 2)

The spread over different import sources and the respective shares of each exporting country in the import mix contribute to energy security. If an important country of origin fails, or cuts the trade with the importing country, the effects on the importing country are much larger if the alternatives are lacking as opposed to a rather even distribution. Therefore, two quantities matter and should be included in the respective indicator. Firstly, m_i denotes the share of total imports per fuel and m_{ij} denotes the share of this share stemming from country j. The story of S_2 is as follows: the indicator is determined by the shares of the different fuels in the total energy mix. Per fuel, one looks at the distribution of domestic production and imports. For instance, Germany imports m_i = 97% of its crude oil. Out of these 97%, roughly one third originates from Russia, leading to $m_{\text{crude oil, Russia}}$. A Shannon type indicator is constructed for each fuel, with a maximum at an even distribution of countries of origin per fuel and increasing in the number of exporting countries. The weights constructed from this analysis should be strictly smaller than 1. Therefore, we normalize the indicator S_{i2} with its maximal attainable value, i.e. its value with an even distribution at a given number M of countries.

$$S_2 = \sum_{i=1}^{N} c_{2i}\, p_i\, ln(p_i), \text{with } c_{2i} = \left(1 - m_i\left(1 - \frac{S_{i2}^m}{S_{i2}^{max}}\right)\right)$$

$$S_{i2}^m = -\sum_{j=1}^{M} m_{ij} \ln(m_{ij}) \text{ and } S_{i2}^{max} = -M\,\frac{1}{M}\ln M$$

From this construction it is easily seen that $S_1 > S_2$.

3.3 Long term country stability (S3)

In energy security, not only the number of "baskets" matter, but also the quality. In terms of our indicator, we need to include some kind of risk measurement or indicator for political stability. Since we modified S2 to include the shares of the countries of origin per fuel and within the import countries' composition, this very point is included in the next modification.

$$S_3 = -\sum_{i=1}^{N} c_{3i}\, p_i\, ln(p_i), with\ c_{3i} = \left(1 - m_i\left(1 - \frac{S_{i3}^m}{S_{i3}^{max}}\right)\right)$$

$$S_{i3} = -\sum_{j=1}^{M} A_j * m_{ij} \ln(m_{ij}) \text{ and } S_{i3}^{max} = -M\,\frac{1}{M}\ln M \text{ and } A = \left(1 - \frac{risk\ indicator}{\max risk\ indicator}\right)$$

Again, A has to be normalized to one. The structure given is based upon risk indicators larger than 1. A frequently suggested value set for the risk indicators are the Hermes indicators (see chapter 4), which are regularly updated and indicate a countries credit rating. However, long-term political stability could also be measured with other indicators. The World Bank publishes the Worldwide Governance Indicators which are composed of different indicators on "Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption". The aggregate or single elements of this indicator could also be used for long term country stability. They are documented comprehensively for 1996 until 2008 (Kaufmann et. al., 2009). Another option is the Human Development Indicator, published by United Nations. In the following, we use the Hermes indicator, because it has been used several times in the energy security literature and therefore it is easier to compare our work with others'.

3.4 Affordability (S4)

While the risks of importing fuels from – potentially – risky countries can be mitigated by more concentration on domestic sources, these domestic sources may come with a higher price component. This will be the case with most domestic fuels, since the price difference has been the motive for imports to begin with. Currently, it is the case especially with the much discussed renewable energy option, though the overall expectation is that this price difference will vanish on the long run. The affordability aspect is usually not included in the energy security indicator, but it is an important aspect in the discussion of the benefits of renewable energy. Supporters of an increase of renewable energy claim an improvement of energy security due to an increase of domestic production. Skeptics claim the additional costs were too high. Including these additional costs in a sensible way into the energy security indicator gives us a new tool for evaluating and comparing different future paths. Obviously, the energy security indicator has to decrease with increasing additional costs.

$$S_4 = \sum_{i=1}^{N} c_{3i} \left(1 - \frac{D_i}{TC}\right) p_i \, ln(p_i) \text{ , with } D_i\text{: additional cost of technology } i, TC\text{: total cost}$$

For large additional costs and large shares of the respective technology, the indicator will decrease. If, however, the respective technology becomes less expensive than the average energy costs, the “additional costs” turn negative and the indicator turns to a larger value.

The indicators suggested above are tested using data on the past for Germany to illustrate their properties and the overall performance. The more interesting exercise will be to apply the indicators to different future scenarios and to show which path might be the more preferable considering energy security.

4 Applications

4.1 Ex post analysis

4.1.1 Data

Germany’s primary energy supply is dominated by oil and gas, followed by coal and nuclear energy (Table 1). Traditionally, electricity production was based to a large extend on the use of (domestic) coal, hard coal and some lignite in the western part of the country, predominantly lignite in the eastern parts of the country. While lignite mining is continued, hard coal mining will be phased out by 2018 (in North-Rhine Westphalia by 2014) (Hard Coal Ordinance 2007). Today’s electricity production is based on coal, gas and increasingly on renewable sources. In 2008, more than 15% of electricity generation came from renewable sources.

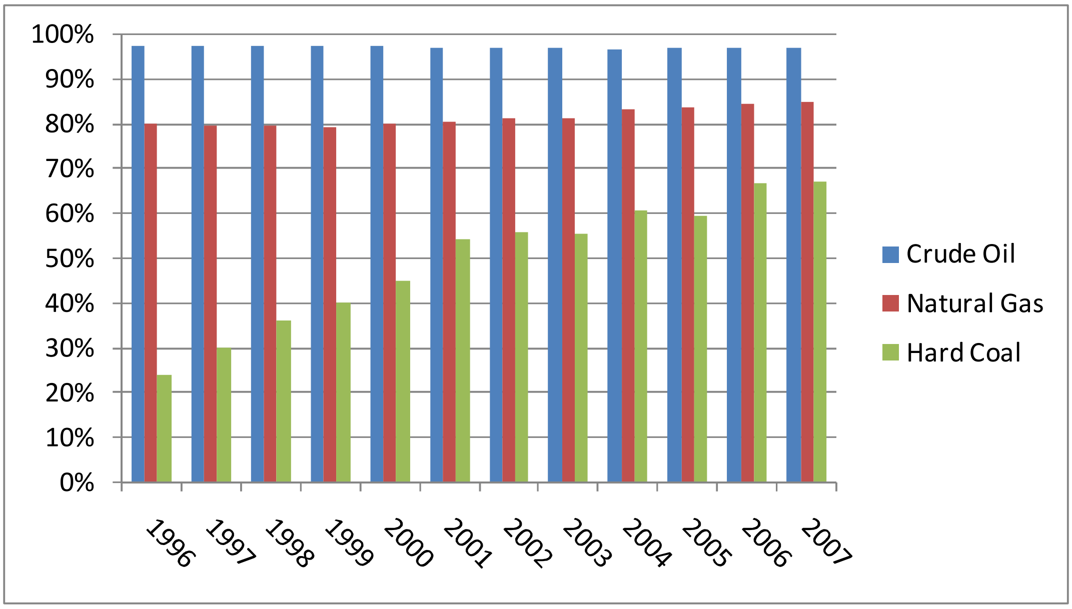
Table 1: Energy balances of Germany, primary energy selected years (PJ)

	1995	1998	2000	2004	2006
Hard coal	1,955	1,934	1,848	1,798	1,837
Lignite	1,711	1,485	1,528	1,659	1,589
Crude Oil	4,400	4,631	4,569	4,800	4,801
Gasoline	251	209	92	120	259
Kerosine	117	119	122	115	175
Diesel	212	151	129	136	240
Oil (heat)	504	478	373	375	434
Natural Gas	2,799	3,019	2,985	3,250	3,337
Hydro, Wind, PV	77	63	127	166	190
Biomass	6	17	280	481	731
Other RES	185	291	9	15	19
Waste	7	8	56	169	132
Nuclear	1,682	1,764	1,851	1,822	1,826
Sum	14,269	14,521	14,401	14,656	14,827

Source: BMWi 2009

Apart from lignite and renewable sources, all other energy carriers rely heavily on imports. With the Hard Coal Ordinance mentioned above, latest 2018 all hard coal will be imported, too. Today the share of imported coal is around 70%, whereas oil and gas are imported by almost 100% (oil) and around 80% (gas) (cf. Figure 2).

Figure 2: Shares of imports in total energy supply (BMWi 2009)



Oil, gas and coal imports have differing structures concerning the respective countries of origin (BMWi 2009). Coal imports shifted from EU countries to overseas; while in 1995 almost one third of coal imports came from the EU in 2007 it is only one fifth, though the absolute quantities rose during the same time. Increasing amounts and shares are imported from South Africa, Columbia and Australia.

Russia covers the largest import share for oil and gas. In 2007 nearly 32% of all oil imports to Germany came from the Russian Federation. The natural gas imports rely with 42% on the Russian Federation. In chapter 3 we discussed the use of the Hermes Indicator as a risk indicator. It is taken from the country classification of the Official Export Guarantee Scheme of the Federal Republic of Germany. The indicator runs from 0 to 7, with 0 as the best rating and 7 as the worst. All EU-countries and most industrial countries have a 0. Figure 3 shows this indicator and its development for the 5 dominant countries of origin for German coal imports. China has been ranked quite high and constant over the period 1999 – 2007. Venezuela's rating went down during 2002 and 2003, and stabilized at a very low level. The rating of the Russian Federation improved considerably from a very low position.

Figure 3: **Country Risk Classifications of the Participants to the Arrangement on Officially Supported Export Credits for the 5 most important countries of origin for German coal imports**

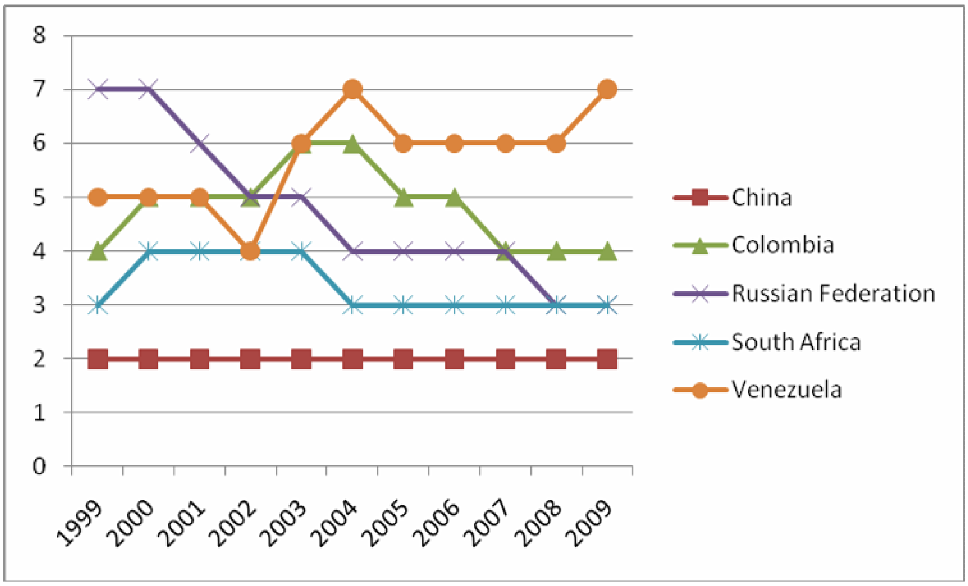
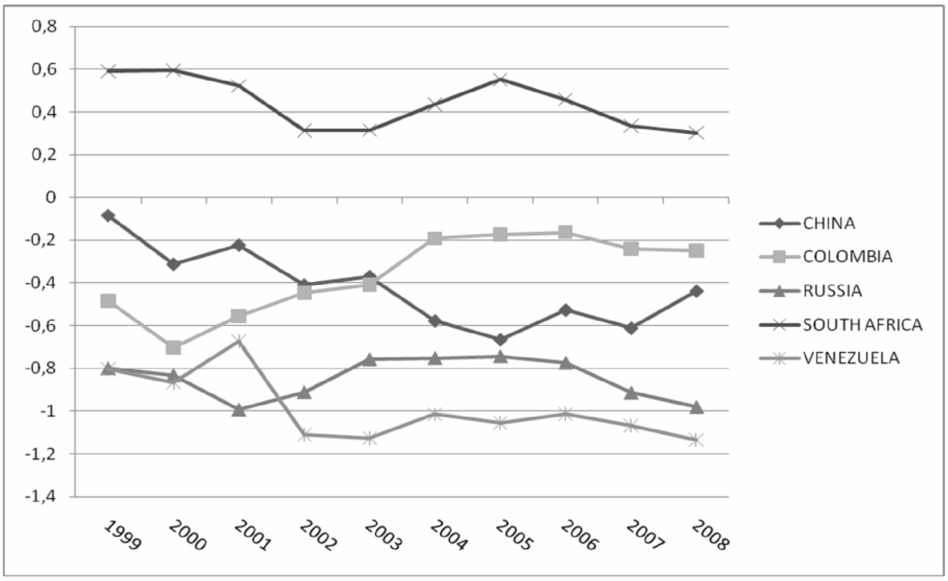


Figure 4 shows one of the alternative indicators for the same countries – the World Bank's corruption indicator, which is part of the World Bank's governance indicators. Here, South Africa is way ahead of all other countries (the indicator ranges from -2.5 to 2.5) and the Russian Federation comes out second worst. For application in the Shannon-Index, this indicator needs re-scaling, since the risk indicator has been defined positively in the equations above.

Figure 4: World Bank corruption indicator for the 5 most important countries of origin for German coal imports



4.1.2 Results

The ex-post analysis shows that energy security has slightly improved over the last years, due to a more balanced mix in the fuels and in the countries of origin (cf. Table 2).

S4 can only be calculated from 2000 on, since there have been no significant contributions of renewable energy (except for large hydro) to the energy mix before that time.

Table 2: Shannon indicators 1995 – 2006 for Germany (Own calculations)

	1995	1998	2000	2002	2004	2006
S1	1,55	1,56	1,57	1,60	1,63	1,70
S2	1,42	1,41	1,44	1,46	1,51	1,53
S3	1,21	1,21	1,25	1,28	1,37	1,40
S4	-	-	1,24	1,28	1,36	1,39

Own calculation.

More interesting than the mere considerations of the past is the comparison between different future scenarios.

4.2 Ex ante analysis

4.2.1 Scenarios

Scenarios provide a structured description of possible future development paths, depending on current and future framework conditions. For the analysis of the future development of energy security in Germany two different scenarios are compared to each other:

- a German *reference scenario (REF)*, based on the energy economic reference forecast by EWI/Prognos (EWI/Prognos05)

- a German *target oriented scenario* (TOS) that comes close to reach the national target of a 40% (2030) or 80% CO_2 reduction by 2050, respectively, Nitsch (2008)

Energy consumption already declines in the *reference scenario* (Figure 5, below) after 2010: in 2030, primary energy supply is down to 85% and final energy consumption to 90% of their 2004 values. Electricity consumption increases until 2020 and decreases in the following decades back to its level today.

Energy intensity decreases by 40% and renewable energy contributes 10% to primary energy use. The *reference scenario* assumes a continuation of current German policies, i.e. the German feed-in tariffs will be continued and nuclear energy will be phased out by 2022. The reference scenario reaches a 30% (44%) CO_2 reduction by 2030 (2050) and misses the national targets.

The *target oriented scenario* is characterized by a faster decrease in energy intensity and a much more rapid increase of the share of renewable energy. Primary energy consumption decreases until 2020 by 17%. The average increase of energy efficiency is 3% and therefore fulfills governmental targets. The increase of renewable energy is after 2010 roughly twice as fast and by 2020, 18% are of final energy consumption (Figure 5, above) from renewable energy. The scenario extends to 2050 and aims for a 50% share of renewable energy in primary energy supply by this time. The aspired 80% reduction of CO_2-emissions will be reached just so. An important feature of the scenario is an increase in CHP heat. Under the aspect of energy security, this feature is important, too, since it replaces imported oil and gas for heating purposes by domestic CHP heat.

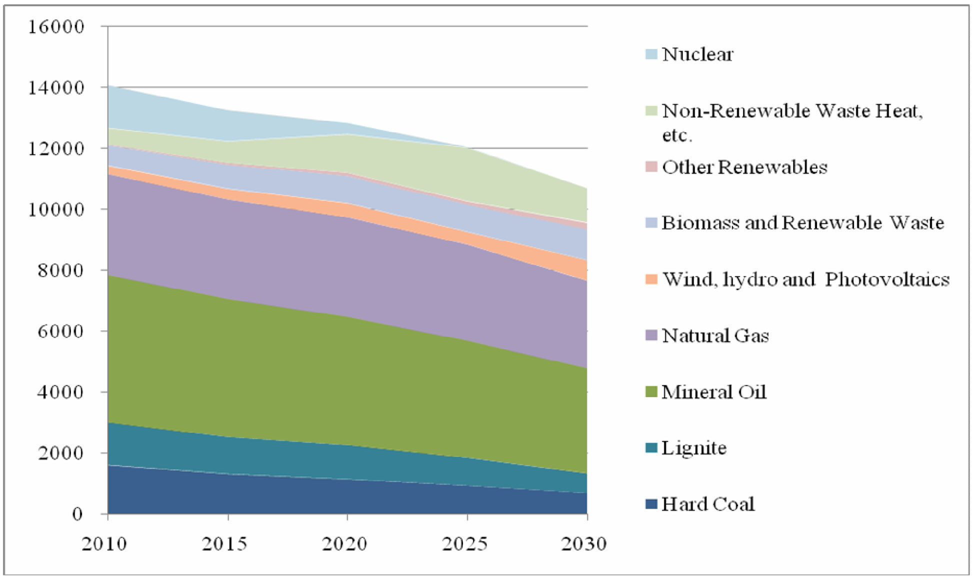
Table 3: Shares of Renewable Energy, comparison of reference TOS

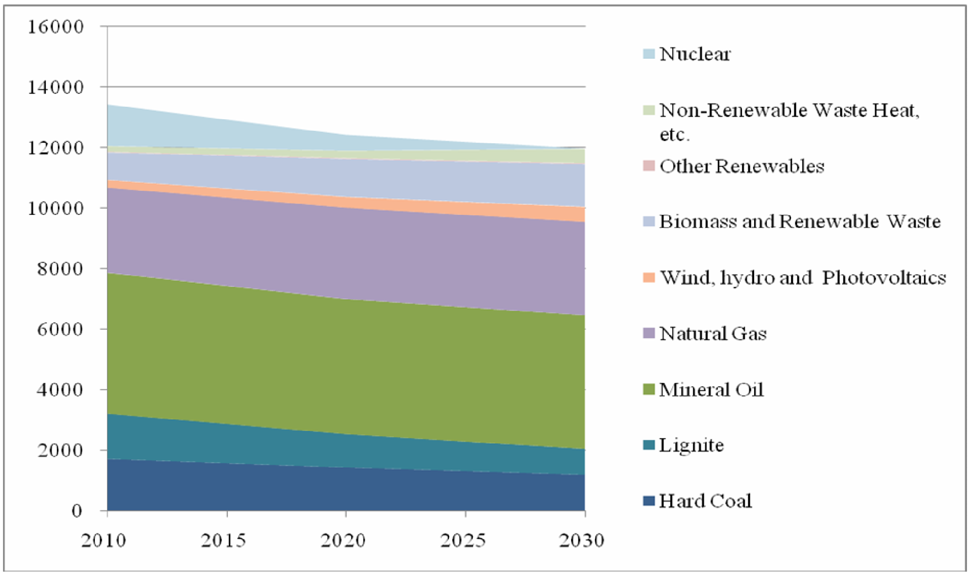
	Reference Scenario				Target Oriented Scenario		
	2004	2010	2030	2050	2010	2030	2050
Share RES PE (%)	3.6	5.7	10.7	16.0	9.5	25.4	47.6
Share RES END (%)	5.1	6.9	12.4	18.6	19.3	53.9	87.0
Share RES ELEC (%)	9.3	13.4	25.0	34.9	16.9	50.1	80.9

Source: Nitsch 2008

All other indicators such as population, GDP or households are identical across the scenarios.

Figure 5: Above: Target oriented Scenario (Nitsch 2008); below: Reference Scenario (EWI/Prognos 05)





The scenarios come with detailed information about the necessary investment into RES, the resulting development of additional costs based on technology specific databases of cost curves as well as a scenario for the development of fossil fuel prices and the CO_2-emission costs.

4.2.2 Results

The four indicators that have been developed in section 2 are applied to the two scenarios for the future energy mix in Germany. The main difference between these scenarios lies in the importance of renewable energy and the share thereof in the overall energy supply. TOS performs better with all indicators. This is not surprising, since it firstly increases the number of baskets, secondly attempts a more even distribution of fuel sources, and thirdly replaces imported fuels by domestic technology. The more surprising result lies in the results for the indicator S4, which represents the fact that renewable energy will be more expensive, at least at first. This is reflected in Table 4 by the lower value for S4 compared to S3. But this effect is turned around already in 2020, when some technologies overcome the profitability threshold. These technologies compensate for the higher costs of the remaining technologies, at least within the framework of the security indicator. This effect comes fully through in 2030. S4 actually increases if we include the additional costs for the new technologies.

Table 4: Energy security indicators: Comparison of two scenarios.

	2010		2020		2030	
	REF	TOS	REF	TOS	REF	TOS
S1	1.70	1.78	1.55	1.79	1.61	1.91
S2	1.52	1.60	1.34	1.61	1.41	1.73
S3	1.41	1.49	1.22	1.49	1.29	1.61
S4	1.41	1.47	1.22	1.49	1.28	1.64

Own calculations.

5 CONCLUSIONS

Energy security is a concern to many governments in the face of worldwide increasing energy demand, and uncertainty about the stability of prices, the availability of resources and delivery conditions. Though the economic externalities are hard to quantify, decision makers vindicate several actions and projects with improvements of energy security. A quantifiable indicator can contribute to better policy choices.

The Shannon-Wiener index can serve as a tool to assess long-term energy security strategies. In its most simplistic form, this indicator is a measure of diversity, i.e. the number of energy sources and the distribution of the fuel mix. Since energy security strongly hinges on the performance of energy imports, the indicator has been extended to include the number of exporting countries and the political stability of these exporting countries.

Renewable energy is rather new to the debate on energy security. Since the use of more renewable energy sources means tapping more strongly into domestic potentials, supporters of RES claim, they will enhance energy security. However, the use of renewable energy will be coming at greater cost for some foreseeable time. To include this trade off, the additional cost component is included in the construction of the indicator.

The thus developed set of indicators is applied to the historic data of Germany's energy consumption pattern to show the properties of the indicators. Since the boundaries on the indicators are increasing by moving from the simple indicator S1 to S2 (inclusion of import structure), S3 (inclusion of risk factors) and S4 (inclusion of additional costs), S1>S2>S3>S4 has to hold. As the energy mix in Germany diversified in terms of sources and in terms of countries of origin, energy security improved over the last years since 1996.

The application to future scenarios is even more interesting. Given two different scenarios for a possible future development, the set of indicators has been applied to judge these scenarios in terms of energy security. The scenarios differ by their assumptions on the increases of energy efficiency and renewable energy shares. The diversity measures reward the increase in energy resources by design, but the added cost factor could take some of this reward. It does so, but to a lesser extent than expected. Once renewable energy becomes less expensive than fossil fuels, energy security is actually increased taking the cost component into account.

Though some aspects of a countries energy mix cannot be included, such as combinability of certain electricity generation sources, the application of the indicator to the German energy mix shows a long term strategy with significant shares of renewable energy is superior to putting “all eggs in fewer baskets”. Future research, however, should include increasing dependence on importing resources for the production of renewable energy facilities such as photovoltaic cells and modules.

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