Impact of Renewable Energy on the Overall Welfare of a Community/ Region/ Nation

Yarlagadda Karun Kumar, Michael Golba
Carl Von Ossietzky Universität Oldenburg
karun.yarlagadda@uni-oldenburg.de, michael.golba@uni-oldenburg.de

Abstract: Renewable Energy (RE) has a different level of influence at different levels of society, environment and economy. However, the decision makers, especially at the political level, consider investments and economic stability as the most important criteria for implementing and utilizing RE technologies. Conventionally, GDP is referred as an indicator of progress at regional or national level and is considered as the most important parameter to judge the budget allocation. The influence of high investments on installing RE technologies will increase the cost per unit energy produced, which in turn impacts the industry and households. Increase in consumer spending and capital investments due to RE technologies in general will have positive impact on the value of GDP. However, due to provision of subsidies and other benefits for RE technologies, this positive impact on the value of GDP is more or less nullified. Measuring the value of RE only based on capital investments underestimates the overall benefits of RE contributing to the Community, Regional and National welfare. This thesis tries to address this issue and attempts to measure the overall impact of RE. The study has been performed for the whole of Germany. Germany is chosen mainly due to the installation capacity of RE and also availability of data. To measure the overall welfare, the National Welfare Index (NWI) of Germany has been chosen. NWI is an index expressed in monetary terms, which computes the most important and quantifiable parameters of economy, environment and society into a single value.

This thesis studies the impact of RE through selected key parameters of NWI for the period 1991 – 2010. It is found that the overall welfare would reduce gradually over the years if RE technologies were not installed. The primary reason for this result is the high costs of energy security, which increase if RE technologies, are not installed. The high and positive value of energy security negates the external costs (ecosystem damage) due to RE's. Using NWI as the base for this study was crucial which enabled to measure the combined effect of RE on energy security and environment.

1 Introduction

1.1 Measurement of development and welfare

GDP/GNP (Gross National Product) (M C. Urquhart, 1986) is still regarded as a key development indicator assuming that it reflects the overall performance of a national economy. The concept of GNP /GDP (Kuznets S, 1934) was first developed by Simon Kuznets for a US Congress report in 1934. In this report, Kuznets warned against its use as a measure of welfare (in a section titled "Uses and Abuses of National Income Measurements"). It is a fact known to many of the economists in academia and policy advisory boards that GDP per capita cannot alone be considered as a measure of well-being status and development of the people of the country (Diefenbacher H. et al., 2010). However, it is often used as such an indicator, on the notion that all the citizens would benefit from their country's increased economic production. This viewpoint is argued by many politicians and representatives of public life, stating that solving social and economic problems through quantitative growth, and achieving development, has been a successful strategy during many consecutive years in the last few decades (Roland Z. and Diefenbacher H., 2012).

The major advantage of GDP per capita as an indicator is that it is measured frequently, widely, and consistently. It allows trends to be seen and compared frequently. However, there are many flaws in GDP, some of which are (Diefenbacher. H. et al., 2010):

Firstly, the changes in the inequality in income distribution and differences in the levels of consumer expenditure are not reflected well in GDP.

Secondly, GDP does not account for the external and environmental costs (loss in biodiversity, soil erosion, impact on health, depletion of arable land, air pollution, water and noise pollution and etc.) of economic activities.

Thirdly, GDP does not distinguish between the activities based on the negative or positive effect on the society and environment. For example: the investments and expenditure on traffic accidents does not add any development or welfare to the society, but this activity is added to GDP. This should rather be considered as a negative contribution to the economy and rather subtracted from GDP.

Among many other drawbacks, the final one which is worth noticeable is that GDP does not take into account the value of the domestic work (especially the work done by women in the house).

In the last three decades, the fact that there might be economic growth without any improvement in welfare was accepted slowly in some parts of economic theory (Roland Z. and Diefenbacher H., 2012). It is noticeable that the opposite is also possible: that is an improvement in the quality of life without any sync with economic growth pattern.

Numerous attempts in recent decades have been made which resulted in beyond GDP composite indices of progress which try to supplement or act as alternatives to it, including UNDP's Human Development Index (HDI), Environmentally Sustainable National Income (eSNI), Sustainable Development Indicators (SDI), Gross National Happiness (GNH) developed by Bhutan, Social Progress Index (SPI) and many others. However, only few of them are recognized by governments and so far only GNH (Ura K. et al., 2012) is one such indicator which is being successfully used from many years. However, these indicators were only able to cover certain aspects of the overall system and have limitations in the way countries are governed.

Nonetheless, in order to be able to use any alternative index instead of GDP/GNI, it is necessary to sum up the various aspects of a welfare accounting unit values into single unit value. The composite indicators: Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI) and National Welfare Index (NWI) of Germany, were successful in incorporating most important parameters of societal, environmental and economic aspects of development into one single index. These three sustainable indicators differ from each other in certain parameters which are decisively based on certain criteria influenced by new understandings and developments. NWI (Diefenbacher. H. et al., 2010) is the latest among all the three with its base structure adopted from ISEW and GPI. It also incorporates recommendations by several other studies and discussions. Thus, NWI could be considered as refined and upgraded version of ISEW and GPI.

1.2 National Welfare Index (NWI)

Firstly, it is important to know that NWI is not intended to replace GDP/GNI but rather to integrate it as an informational counterpart (Roland Z. and Diefenbacher H., 2012). The work is rather to be seen in the context of the research project of the German Federal Environmental Office and of the Federal Ministry for the Environment, Environmental Protection and Reactor Security. Secondly, it is required to be aware that NWI is an open system and its parameters and data is subject to change based on new developments and methodological improvements.

NWI uses an ordinal scale and not a cardinal scale. This means: from a numeric value, if one year NWI value is double the previous year's value (for the same set of parameters and given the data is from same sources and methodologies used is same), it should not be inferred that the welfare of an individual or a society is exactly twice as high from the previous year. NWI values are directionally stable, which means that a higher value always expresses a welfare enhancement (Roland Z. and Diefenbacher H., 2012). NWI is a monetary quantity, i.e. all included variables are provided in monetary form as yearly flux quantities, or could theoretically be provided in such form. In its current form, NWI 2.0 includes 20 variables (Diefenbacher. H. et al., Jan. 2013). Table 1 presents the list of 20 variables.

Table 1: National Welfare Index Variables

S. No	Variable	+/-
1	Index of income distribution (Gini Index)	
2	Weighted consumption expenses	+
3	Value of household production	+
4	Value of voluntary work	+
5	Public expenditure on health care and education	+
6	Costs and benefits of durable consumer goods.	+/-
7	Traveling between home and workplace	-
8	Costs of traffic accidents	-
9	Costs of crime	-
10	Costs of alcohol, tobacco and drug abuse	-
11	Compensatory social expenses due to environmental impact	-
12	Damage from water pollution	-
13	Damage from soil pollution	-
14	Damage from air pollution	-
15	Damage from noise	-
16	Loss and gain of biodiversity	+/-
17	Loss and gain of agricultural areas	+/-
18	Replacement costs due to the use of non-renewable resources	-
19	Damage from GHG emissions	-
20	Costs of use of Nuclear Power	-

Source: NWI 2.0, 2013

Following is a brief explanation of the categories of NWI 2.0, which are referred from the NWI report (Roland Z. and Diefenbacher H., 2012). NWI 2.0 refers the version of NWI published by the authors in the year 2013 which has time series values for the years 1991-2010.

- ➔ NWI starts from the basic quantity "weighted private consumption". This starting point is based on the assumption that private consumption, i.e. the consumption of goods and services on the part of households, generates positive utility contributing to welfare. On account of the reflections based on the theory of welfare, according to which the same supplementary income in a poor household generates a greater supplementary welfare than in a rich household, private consumption is weighted with income distribution. The more unequal income distribution is in a given society, the lower is the NWI, if all other conditions are equivalent.

- ➔ Value creation through housework and voluntary work, unpaid in the market, is included and computed in NWI. Both parameters are welfare enhancing and thus contribute positively to the overall NWI.

- ➔ Six indicators reproduce supplementary social factors: on one hand, the welfare creating public expenditure on health care and education is added while, on the other hand, the cost of crime and the cost of traffic accidents are subtracted.

- ➔ Ecological factors are represented by variables 11 to 19: expenses for the compensation of environmental damage, damage costs on account of different environmental impacts and replacement costs for the use of non-renewable resources.

- ➔ The 20th variable is the nuclear liability costs. It basically comprises of, costs of insurance in case of accidents, costs for searching location of disposal, costs for decommissioning and dismantling and costs for disposal of nuclear waste.

- ➔ The positive symbol in table1 indicates that any contribution of this variable increases the welfare of the society, thus this value will take positive symbol so as to be added in the computation process. On the other hand a growth of the variable with negative value will lead to reduction of welfare and thus this value is subtracted from the overall index. In addition, there are variables with both positive and negative symbols. If the values of these variables impact positively and grow they will benefit the society and if the growth has negative impacts, the variable will reduce the welfare of the society (it takes either positive or negative value based on the year on year (YoY) performance).

1.3 Research Task/Question

The main research task is "To quantify the impact on NWI due to the implementation/integration of RE in the energy mix of Germany (1991 – 2010)".

2 Assumptions, Facts and Figures:

To carry out the analysis certain assumptions have to be made, some methodological limits and standards have to be set and some facts have to be known. It is to be noted that detail calculations and tables are not enclosed in this paper[1].

2.1 Following are general assumptions and facts:

- ➔ Only Biomass, Solar and Wind categories among all the RE categories used in Germany are considered for evaluating external and environmental costs.
- ➔ Pollution through Hydro Power stations is not considered/ included in this evaluation. Wherever it is mentioned regarding damage, loss/gain, emissions and pollution of/from RE, it is without considering Hydro Power.
- ➔ Pollution for using waste resources to produce energy is not considered, since waste already exists and is not specifically grown for energy production.
- ➔ Wind energy: Reliable data of external costs and quantity of pollution from only off-shore wind energy was available. In this report, the same sets of values are used for all offshore, onshore or inland wind farms.
- ➔ Years under analysis: 1991 to 2010.
- ➔ All the prices are converted to the year 2005.
- ➔ Consumer price index (CPI) value of the year 2005 = 100.[2]
- ➔ To measure the impact of RE, virtually it is assumed that during the period 1991 – 2010, there was no installation and usage of RE technologies. Thus all the energy which was previously produced from RE, will now have to be produced from fossil fuels. This assumption will lead to scenario where the energy production from fossil fuels would contribute to emissions, air pollution and other external costs. In

[1] Information can be provided upon request from the author.
2 Data from world bank(http://data.okfn.org/data/core/cpi)

addition, it contributes negatively on the energy security of the country. However, the original value of NWI consists of values when RE was being already used in Germany during the years 1991-2010. Thus, the value of external costs (air pollution and others) due to usage of RE must be subtracted from the original values of NWI.

2.2 Quantity of primary energy for analysis

RE primary energy, RE share (wind, bio-energy and solar) and energy assumed to be generated from fossil fuels is shown in Figure 1 (TWh = Tera Watt hour). The share of energy produced by respective fuel sources (lignite, hard coal, nuclear, gas and other RE resources) in the Primary Energy consumption is obtained from the document "Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland" (AGEB): Published in the years 2008 and 2011.

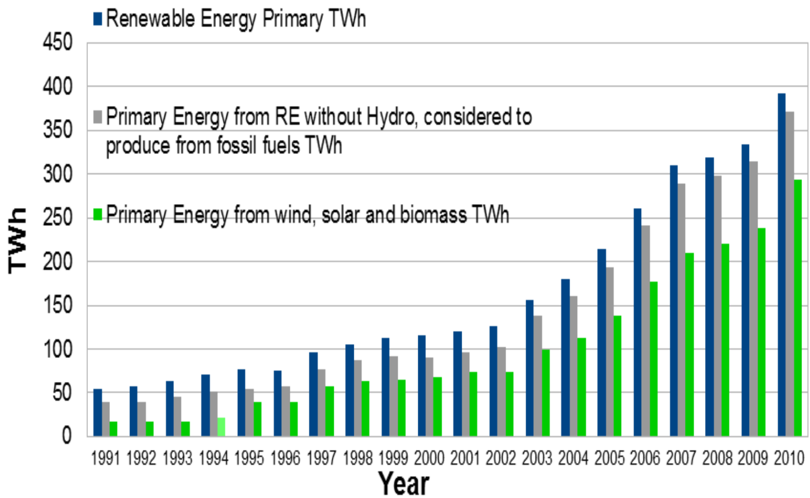

Figure 1: Quantity of energy under analysis

Source: AGEB, 2008 & 2011

Under assumption of this study, the amount of energy to be produced through fossil fuels is obtained after subtracting the hydro energy from the energy produced by all RE technologies. From Fig.1 it can be seen that, the amount of energy to be produced through fossil fuels is higher than that from wind, biomass and solar energy (as mentioned earlier, under the present study, energy produced from only these three RE technologies will be evaluated for environmental costs). From here on, wherever, it is mentioned RE (it refers to energy produced from solar, wind and biomass resources).

The difference between energy produced from fossil fuels and RE is very high during the period 1990 to 1994, where fossil fuels consumed is more than twice the amount of RE. This may lead to higher emissions and external costs during these years. During the period 1991-2010, the cumulative energy production from fossil fuels is approximately 40% more than that from RE. The difference is mainly because of energy production from waste and other RE technologies (like: geothermal), which are part of the total primary RE, but are not considered to be part of RE, as waste is already available and not developed to produce energy and share of energy from geothermal and others is very small.

2.3 Composition of RE (biomass, wind and solar)

Fig.2 shows the distribution of biomass, wind and solar in the total of their individual contributions to RE primary energy production. It can be seen that, bio-energy is dominating throughout the years and it's contributing more than 80% of energy in the total energy supply of RE mix. Wind energy starts in the year 1995 and increases its share gradually. However, its contribution falls after solar energy is added and with slight increase in percentage share of energy from biomass. Energy production from solar has started in the year 2000. However, its contribution is small and has a gradual growth rate.

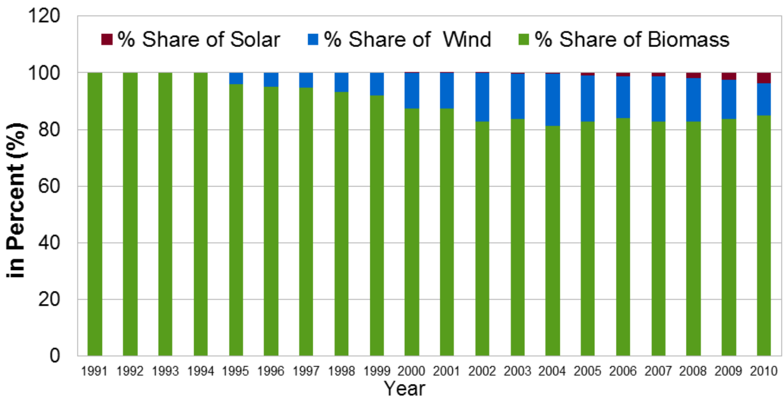

Figure 2: Composition of RE mix (biomass, wind and solar)

Source: AGEB, 2008 & 2011

2.4 Composition of fossil fuels

Fig.3 shows the distribution of lignite, nuclear, hard coal and natural gas in total of their individual contributions to the primary energy production. It can be seen that the share of natural gas is increasing over the years and reached an approximate value of 40% by the year 2010. The share of lignite and hard coal has fallen over these years, whereas the share of energy production from nuclear has more or less remained stable. The share of energy produced from different fossil fuels is an approximation, it may not be accurately said that this would have been the same share if fossil fuels were used when RE were not utilized.

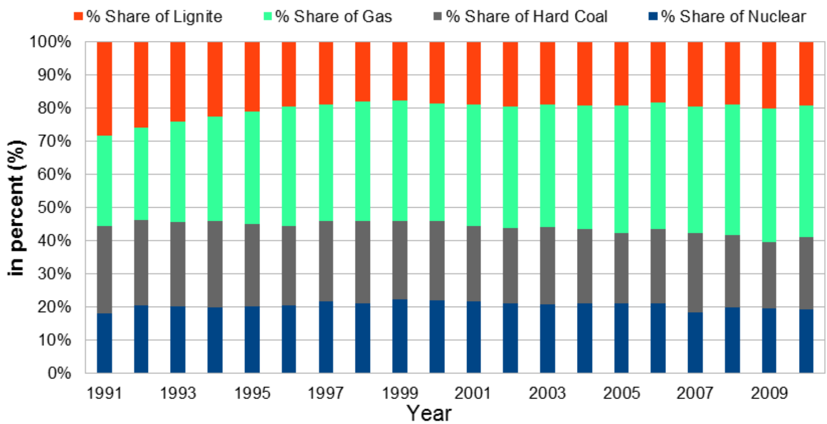

Figure 3: Fossil Fuel composition in Primary Energy

Source: AGEB, 2008 & 2011

3 Selection of Variables of NWI

Table- 2 shows the selected variables of NWI for carrying out the study of "impact of RE on the national welfare". In this study, five variables which are impacted and influenced by RE and fossil fuels have been chosen. In NWI 2.0, there are additional parameters which are also influenced by fossil fuels and RE, like water pollution, soil pollution and health impacts. However, they are not considered in the present study. The values of the selected five parameters would be determined and they would be computed with existing values of NWI 2.0 for each respective year from 1991 to 2010. This computation would result in a new value of NWI.

Table 2: Selected Variables of NWI

S. No	S. No in NWI	Variable
1	14	Damage from air pollution
2	16	Loss and gain of biodiversity
3	17	Loss and gain of agricultural areas
4	18	Replacement costs due to the use of non-renewable resources
5	19	Damage from GHG emissions

For developing countries, additional variables of NWI can be used. An example: Identify the aftereffects of installing biogas plants to energize lamps/stoves in the municipality (or a community) which has replaced the old wood and kerosene stove and lamps. To measure the overall welfare, it would be suggested to consider, parameters like: increased household production value for not collecting wood (variable 3 of NWI 2.0), reduced expenditure on healthcare (Variable 5), reduced expenditure towards restoration of environment (variable 11), etc.

4 Methodology:

This section presents the methodology and data used to find the values of selected variables of NWI.

4.1 Damage from Air Pollution

The procedure to find the damage from air pollution is explained in the methodology document of NWI 2.0 (which was provided by the research team of NWI). In this study, a similar process is followed and same data sources are used to determine the damage costs. The air pollution due to energy production from wind, biomass and solar (which are expected to emit pollution in their overall Life Cycle) have to be subtracted from the original air pollution values of NWI 2.0.

Firstly, the cost in Euro per ton of each pollutant is obtained from the excel sheet created by the project's NEEDS (New Energy Externalities Developments for Sustainability) and CASES (Cost Assessment for Sustainable Energy Systems). Table.3 shows the cost of air pollutants per ton in the year 2010. The prices are converted to the year 2005. These costs are similar to the costs used in the air pollution evaluation in NWI 2.0.

Table 3: Costs of air pollutants

S. No	Pollutant	Cost in Euro per ton
1	NH3	21.111
2	NMVOC	1.327
3	NOX	12.172
4	PM10 (0.25-10)	2.264
5	PM2.5	43.712
6	SO2	10.373
7	CO	1.117

Source: NEEDs and CASES, 2009 and 2008

Then, the quantity of each pollutant which would be released in generation of energy per KWh from different fossil fuel power plants and RE are retrieved from the document of the project NEEDS (Project no: 502687): (2009). Deliverable n 6.1 – RS1a: "External costs from emerging electricity generation technologies". The pollution emitted has to be considered for Primary Energy production, since pollution has to be considered for the actual energy generated. Using the amount of primary energy produced from each resource presented in section 2.2, the amount of each air pollutant in ton per annum from respective resource is computed.

Finally, the annual costs of damage due to each air pollutant due to energy production from individual energy resource is obtained by multiplying the quantity of air pollutant in ton with cost in Euro per ton of that pollutant.

4.2 Loss and gain of Biodiversity

The gain and loss of biodiversity costs would not be computed with the values of NWI. This is mainly because firstly, NWI only permits to analyze this data from the year 2000. The value of biodiversity in NWI may not reflect the actual values since the data availability was still poor when NWI 2.0 was evaluated. In NWI 2.0 evaluation, a nominal memory value for loss and gain in biodiversity is considered, which will be kept the same in this study. Nevertheless, the damage to biodiversity when energy is produced through renewable energies (the present situation) and if the same energy was produced through fossil fuels can be evaluated and compared using the values in table. 4.

Table 4: Costs of Biodiversity per KWh from various energy

cents Per KWh in prices of year 2005						
Nuclear	Lignite	Hard Coal	Natural Gas	Biomass	Solar	Offshore Wind
0.004	0.076	0.097	0.032	0.205	0.022	0

Source: NEEDs, 2009

4.3 Loss and gain of agricultural area

In this analysis, damage of area due to conversion of land area (arable/agricultural or forest area) into energy crops is evaluated. The damage from installation of fossil fuel plants, solar plants or wind turbines in agricultural areas is not evaluated. If the conversion to energy crops was not done, then the land could either be used for organic/natural farming or left naturally. Conversion of land to energy crops increases indirectly the cost of food and secondly intensive farming practices of energy crops, increases the external costs on national welfare. In consideration to a general criterion that the emission reductions of a country were generally set to reach below the levels of the year 1990[3], it is assumed that the land area used for production of bioenergy should remain either the same or less than the 1990 values in all future years. This is because energy crops add more damage to the welfare of the society and any addition of land area for production of feedstock for generation of energy should be considered negative. Thus, any addition of land for production of energy from year 1990 is considered as negative and it will be deduced from the NWI value.

The loss and gain of agricultural area is determined in NWI 2.0 as follows:

(Agricultural area in ha in t+1 - agricultural area in ha in t) * (price per ha in t+1) (where t, is time in years)

The data of land area of energy crops is processed by the federal ministry of food and agriculture[4]. The online document is updated annually and the previous year documents are removed from the website, hence historical data is always missing. The data for the duration 1997 to 2010 is obtained from various sources[5] (Steven J, Fehrenbach H and Fritsche U (2013).

Some assumptions and points considered for evaluation:

1. In the years when there is a reduction of area for bio energy production, the land is considered to be left free. Since intensive farming is practiced for energy crops, it would/may not be suitable for production of sustainable food

---

[3]Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety., Accessed in November 2014. http://www.bmub.bund.de /en/topics/climate-energy/climate/general-information/

[4] Fachagentur Nachwachsende Rohstoffe e.v. “Energy Crops”. Accessed in December 2014. http://international.fnr.de/renewable-resources/bioenergy/ energy-crops/

[5] Fachagentur Nachwachsende Rohstoffe e.v.. “Bioenergy in Germany: Facts and Figures.” Accessed in December 2014. https://mediathek.fnr.de/ bioenergy-in-germany-facts-and-figures.html

crops the very same year. Hence this gain of land would not mean any gain or benefit in the loss/gain of agricultural land area. Since, cumulatively from 1991 to 2010, there is a continuous growth in the amount of land area used for energy crops, a reduction in land area in some years is compensated by increase in land area in the following years. Thus for the years when there is a reduction in the energy crop area, the values are not computed with the NWI value.

2. Land area used for production of bio-energy for the years 1990 to 1996 was not available. Hence the values are estimated by taking reference land area value of the year 1997 and using the ratio of bio-energy consumed in the years 1990 to 1996 with respect to the year 1997. Table 5 shows the bioenergy production per year and the ratio of bioenergy produced in the year 1990 to 1996 over the year 1997. The data of annual energy production from biomass resources is taken from the time series published in AGEE – Stat (Feb 2014): Zeitreihen zur Entwicklung der Erneuerbaren Energien in Deutschland (table 10 to 17). The approximate land area of bioenergy crops for the years 1990 to 1996 is obtained by multiplying the corresponding ratio of each year with the land area of the year 1997.

Table 5: bio-energy production from 1990 to 1998 and the ratio of values of each year with respect to the year 1997

Year	BIOENERGY for the years 1990 to 1998	Ratio of land as compared to the year 1997
	PJoules	
1990	101,772	0,605
1991	102,143	0,607
1992	102,352	0,608
1993	102,442	0,609
1994	103,396	0,614
1995	103,867	0,617
1996	104,378	0,620
1997	168,278	1,000
1998	183,963	1,093

Source: AGEE – Stat, Feb 2014

3. Actual land area to be considered for production of bio-energy: Approximately 90% of the land area considered as energy crops only goes into direct use as energy source and the remaining 10% or less goes into other industrial use (Steven J, Fehrenbach H and Fritsche U (2013). Accurate data is not available to find the exact amount of bio-energy crops going into

production of vegetable oils or other purposes. However, for this study, 90% energy crop area is considered to be used as feedstock for producing energy, which is more on the lower side for prediction of the damage costs.

The avoided damage on the value of agricultural area would be calculated using the formula:

(Energy crops area in ha in t - energy crops area in ha in t+1) * price per ha in t+1 = avoided costs (t, time in years)

4.4 Replacement costs due to the use of non-renewable resources

The authors of the NWI report describe replacement costs as the costs which the future generations will have to incur in order to build an energy production capacity on the basis of renewable resources, aimed at maintaining those goods and services that are now being produced through the present day consumption of energy from non-renewable resources.

4.4.1 Determining the amount of energy to be replaced:

In the present analysis, it is assumed that all the energy including that energy which was earlier supplied from RE sources (except for hydro power) will be supplied through fossil fuels. The yearly quantity of end energy supplied from non-renewable and also from RE sources, is retrieved from the time series data of the AGEB 2008 and AGEB 2011 documents. Here only end energy consumption is considered as the user already pays the cost for overall energy production through their end energy consumption. In the actual analysis of this parameter in NWI 2.0, the energy consumed by the transport industry is not considered (except for mobility of car sector and electric power used). At present the energy required for cars is assumed as: 20 KWh per 100 KM. The kilometers of travel were obtained from the tables: 152 and 153 (Personenkraftwagen und Kombi) of the publication Verkehr in Zahlen 2014, DIW. Transmission losses of 6% have been considered in the analysis of NWI 2.0. The energy including the transmission losses gives the total energy that has to be replaced by RE technologies.

4.4.2 Replacement costs per unit KWh:

From the previous section 4.4.1, we obtain the energy required to be replaced by RE resources. From the NWI 2.0 report, the cost for replacement of this energy per year is retrieved from the table in the Annex II. Using the following formula, the replacement costs per KWh for each year is obtained:

Total costs from NWI (Euro cents) / Total energy to be replaced (KWh)

4.4.3 Process to find new replacement costs

Now the assumption is made, that the energy which previously produced from all RE (except for hydro power) technologies, is now produced from fossil fuels. Thus, this assumed additional energy from fossil fuels, is to be added to the previously obtained value of energy to be replaced in step 5.4.1. This will give new energy to be replaced due to use of non-renewable sources under the scenario assumed.

The replacement cost per year for the new total energy is obtained using the formula:

New energy to be replaced in KWh * replacement cost per unit (Euro cents/Kwh)

The replacement cost per unit (Euro cents/Kwh) is obtained in step 4.4.2

4.5 Greenhouse gas (GHG) emissions

The GHG emissions are represented in tons equivalence of CO_2. In NWI 2.0 the damage cost due to CO_2 is taken as 80€ per ton (in price of the year 2005). Justification for considering this value is well explained in the NWI document and it is mentioned that this value is also used by official statistical office in Germany. This value is considered as a memory item and the same value is used for all the years.

The GHG emissions which were avoided earlier due to usage of RE will now be considered and added to the overall GHG emissions. The GHG emissions avoided due to the use of RE in Germany from 1990 – 2010 is obtained from the time series published in AGEE – Stat (Feb 2014): Zeitreihen zur Entwicklung der Erneuerbaren Energien in Deutschland (table 10 to 30).

The damage cost due to GHG is determined as:

GHG emissions avoided due to use of RE in tons of CO_2 equivalence (each year) * 80 €/ton

4.6 Final computation of NWI:

The obtained values of the four variables of NWI would be finally integrated with the final value of NWI. The costs due to gain or losses in biodiversity are not computed as explained earlier. Table 6 shows the final computation sample data table. The second column shows the initial and original NWI values and the last column shows the final NWI value after computation.

Table 6: Methodology: Final Computation of NWI

Year	NWI 2.0 (RE)	Air Pollution (-)	Loss/Gain of agriculture land (+/-)	Replacement Cost (-)	GHG Emissions (-)	NWI new (only Fossil)
	Billion. €	Billion. €	Billion. €	Billion €	Billion €	Billion. €
1991	1174	-0,08	-0,011	4,25	0,87	1169
1992	1195	-0,09	-0,005	4,54	0,89	1190

5 Results and Evaluation

5.1 NWI with and without RE implementation

Fig. 4 shows the time series curves of NWI with and without RE during the period 1991 to 2010. As mentioned earlier, biodiversity costs are not computed in this analysis. It is observed that the NWI value is less without RE, i.e. when all the energy is produced from fossil fuels. The difference between the two curves is increasing with increasing share of RE. The maximum impact is ~ 28.5 Mrd.(Billion) Euro in the year 2010. The increasing gap in the later years is mainly because of increase in absolute volumes of wind and solar energy, which increase the replacement costs per KWh.

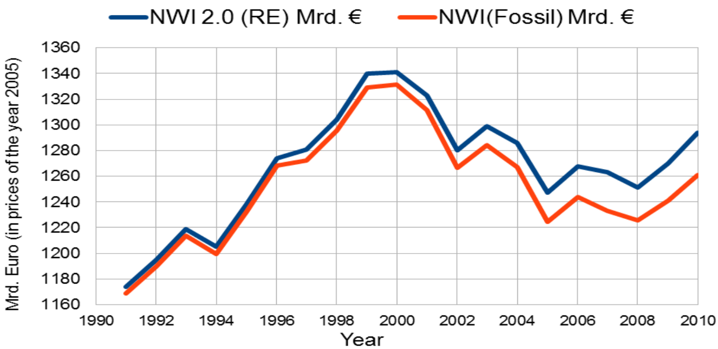

Figure 4: NWI with RE and without RE (i.e. with fossil fuels)

5.2 Loss and gain of environmental costs in NWI:

Fig. 5 shows the NWI curves before and after computing the values of three selected environmental variables of NWI (i.e. costs of air pollution, loss and gain of agricultural area and cost of GHG emissions). From Fig. 5, it is observed that, during the period 1991 – 2010, significant impact on

NWI due to environmental cost benefits of RE is not reflected. This is mainly because of the high weight of economical parameters in NWI and low values of environmental cost benefits of using RE. It is noted that, RE shows positive impact on welfare by avoiding GHG emissions, whereas it shows negative impact due to higher amount of air pollution and loss of agricultural area. The computation of the positive and negative values, nullifies the overall environmental benefits due to RE.

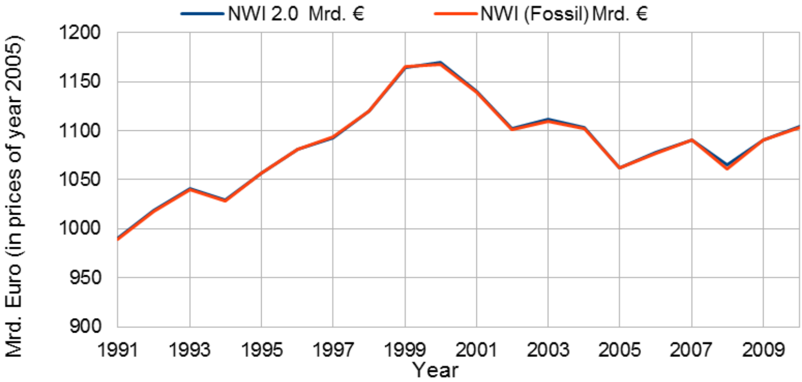

Figure 5: NWI 2.0 (RE) and NWI New (Fossil) (Without replacement costs)

6 Results significance

The results can be mainly interpreted at two levels. One is the impact of RE on the economy and the other one is the impact of RE on environmental costs. The social costs are not significant in this study as the social variables of NWI are not considered in this study.

The increased energy security due to the installation and usage of RE will benefit the present as well as future economy. The utilization of RE has contributed positively to the NWI, which was reflected in terms of reduced value in replacement costs (or in other terms, the replacement costs were higher when fossil fuels were used).

It is clear that RE has similar or more environmental costs than fossil fuels during the period 1991 – 2010. Even if we assume that some environmental costs of fossil fuels are not considered (for example, high water pollution values due to energy production from nuclear power plants), they cannot overcome the higher environmental costs from RE. This is due to the fact that the cumulative production of energy considered in this study (i.e. from 1991-2010) from RE resources is 40% lower than that produced from fossil fuels (see Fig. 1). Furthermore, the external costs due to wind energy seem to be underestimated (with respect to the data used in this study). On the other hand, the external costs of nuclear waste and de-commissioning may be balanced out the external costs due to biodiversity damage caused by feedstock production for bio based energy plants.

Finally, the higher weight of the economical variable, i.e. replacement costs of using non-renewable resources, completely overshadows the negative environmental impacts of RE. The negative environmental impacts of RE are mainly due to high share of energy from bio based sources.

Combining the effects of replacement costs and environmental costs along with other aspects of welfare development was possible only due to the availability of the index “NWI”. The results showed that by utilizing RE, NWI was higher than if they were not used. Thus it can be inferred that RE has an overall positive impact on the welfare of the society. However, the results can also be contradicted, as replacement costs (economical impact) should make sense only when the energy produced from RE has less environmental impact than energy produced from fossil fuels.

Some parameters which would influence the results:

- ➔ As compared to the analysis done in this study with five variables of NWI, different results will be obtained if all the variables of NWI on which RE and fossil fuels have impacts are included for analysis.
- ➔ The environmental costs are assumed to be constant for all years. However, they may be different in reality which would depend on the policy and regulation in those years.
- ➔ There will definitely be a difference in pollution emitted per KWh between older and newer power plants.
- ➔ As per the NEEDS report the real total external costs would be higher than the quantifiable costs used at present. With improvements in methodologies and availability of data, external costs certainly would be higher than the present values.
- ➔ It has to be realized that the data used and methodology followed are based on the resources obtained and current knowledge level of the author. With the development of statistical data and improvement in knowledge levels, a similar analysis will definitely yield different results.

7 Conclusions

On a National, Regional or a Municipality level, NWI can be used to measure the overall impact which otherwise is not possible through GDP. NWI includes and also allows analyzing the most important parameters of welfare of society (i.e. societal, environmental and economic).

During the analyzed period 1991 – 2010, the impact of RE on NWI was found to be positive. Replacement costs have played a major role in influencing the results. The environmental costs due to usage of RE is found to be higher than that from fossil fuels. During the observed period, a higher share of biomass has led to higher damage costs from the RE mix and a higher share of natural gas has led to lower damage costs from fossil fuels. Thus even though RE has contributed positively in increasing the value of NWI, it is still questionable to consider if it is a sustainable solution to meet the energy needs due to high share of bioenergy (which has very high environmental costs) in German RE mix.

The future does not look bright for Germany, because the cost of energy production from biomass based sources is lower as compared to energy production from wind and solar energy systems. This will compel the government and the industry to invest in the installations of biomass based energy production systems. Furthermore, shutting down of nuclear power plants in Germany may also result in installation of new biomass based energy systems due to its advantages of constant and predetermined energy production as compared to wind and solar energy systems (Dena-Netzstudie II, 2010). Clearly it seems to be a very tough challenge for Germany to establish sustainable energy systems in the near future.

Finally this study provides one method “to measure the impact of RE on the overall welfare of a region/nation using tools like NWI”. It can be concluded from the study that in order to truly build sustainable energy systems in the context of overall welfare of Germany, it is advisable to increase the share of wind and solar in the RE mix and increase the share of natural gas in the fossil fuel mix. Apart from efficiency measures and reduction in absolute energy consumption, it is highly advisable and desirable to reduce the share of energy production from biomass based resources.

8 References

Urquhart M C (1986). New Estimates of Gross National Product, Canada, 1870-1926: Some Implications for Canadian. http://www.nber.org/chapters/c9678.pdf, printed in 1986

Kuznets S (1934). National Income, 1929-32. 73rd Congress, 2nd Session. Document No. 124

Diefenbacher H et al. (2010). Measuring Welfare in Germany- A Suggestion for a New Welfare Index). Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety. Project No. (FKZ), 3707 11, 101/01. Report No. (UBA-FB) 001328/E

Roland Z and Diefenbacher H (2012). The National Welfare Index as a Contribution to the Debate on a More Sustainable Economy. FFU report.

Ura K, Alkire S, Zangmo T and Wangdi K (2012). An extensive analysis of GNH index

Diefenbacher H et al. (2013). NWI 2.0 – Weiterentwicklung und Aktualisierung des Nationalen Wohlfahrtsindex. Endbericht zum Vorhaben UM 10 17 907, Heidelberg/ Berlin: FEST/FFU

New Energy Externalities Developments for Sustainability Project (NEEDS) (March 2009). Deliverable n 6.1 – RS1a “External costs from emerging electricity generation technologies” (Project no: 502687)

Cost Assessment of Sustainable Energy Systems CASES (Sept. 2008). Deliverable D.6.1. [WP6 report] Development of a set of full cost estimates of the use of different energy sources and its comparative assessment in EU countries. Project No 518294 SES6

Steven J, Fehrenbach H and Fritsche U (2013). Implementing the GBEP indicators in Germany. Report presented at the event: 4th meeting of the Global Bioenergy Partnership (GBEP) working group on capacity building (WGCB), Berlin

Deutsche Energie- Agentur (Dena). dena-Netzstudie II – Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015 – 2020mit Ausblick 2025. http://www.dena.de/fileadmin/user_upload/Publikationen/Erneuerbare/Dokumente/Endbericht_dena-Netzstudie_II.PDF, printed in 11/2010