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An Integrated Assessment Model for the German Food-Energy-Water Nexus

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ABSTRACT

The United Nations has defined the food-energy-water nexus as a key issue in the green economy process towards sustainable development. The integrated assessment model is used here to frame and study the heterogeneity of the food-energy-water nexus and to manage the food-energy-water nexus in Germany in a social learning and decision-making process. For the integrated assessment of the German food-energy-water nexus sector, a four-phase approach based on the de Ridder method is used to analyse the food-energy-water nexus against the background of the completely revised German sustainability strategy of 2017. In the first step, the integrated assessment problem analysis, the interconnections of the food-energy-water nexus between the natural resources and the socio-economic system are formulated. The new political values and options needed for the management of the food-energy-water nexus sector are revealed in the second research step and it is stressed that justice is the defining ethical norm of the revised German sustainability strategy of 2017, which is the sustainability framework for the German food-energy-water nexus. Thus, inter- and intragenerational justice is also a central issue of the food-energy-water nexus and is integrated with the social discount rate in the food-energy-water measuring concept (Fisher nexus quantity index) presented in the third step. In the final research step of the integrated assessment approach, it is found that the new food-energy-water nexus policy process also needs a ‘culture of reflected numbers’, as Voßkuhle calls it, to ensure a social discourse as a permanent learning process for both the German government and society.

KEYWORDS

Integrated assessment, Energy-water-food nexus, Fisher index, Culture of reflected numbers.

INTRODUCTION

The discussion about alternative welfare and sustainability measures started in the 1960s when Tobin and Nordhaus developed the Measure of Economic Welfare (MEW)

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[1]. With their pivotal paper "Is Growth Obsolete?" [1] they also laid the foundation for the later development of sustainability indicator measures [2] and for green accounting [3]. This discussion took a new and broader direction in 1992, when the UN Rio de Janeiro Conference adopted Agenda 21 [4]. Furthermore, in 1996 the Bellagio principles [5] [†] for assessing sustainable development were established [6], which serve as fundamental guidelines for carrying out an Integrated Assessment (IA)[‡]. The IA of society defines IA as a "Scientific meta-discipline that integrates knowledge about a problem domain and makes it available for societal learning and decision making processes[§**]".

INEGRATED ASSESSMENT

The IA approach is generally used to frame, study and solve issues such as climate change, water and air quality, land and public health challenges. These issues are also at the heart of the approach. To accomplish these tasks, in the last few decades a wide array of assessment tools has been developed [7]:

- To formulate sustainable development objectives [8];
- To build a decision framework [9];
- To govern sustainable development [10];
- To evaluate sustainable development [11];
- To identify the specific characteristics of sustainability assessment [12];
- To develop sustainability integration assessment models [13].

Based on this preliminary work, de Ridder *et al.* [7] identified seven assessment groups:

- Assessment framework [14];
- Participatory tools [15];
- Scenario analysis tools [16];
- Multicriteria analysis tools [17];
- Cost-benefit analysis [18];
- Accounting tools, indicator sets [19];
- Model tools (climate models, socio-economic models).

In 2014, the Food and Agriculture Organization of the United Nations (FAO) renewed and refocused the duties of an IA for the Food-Energy-Water (FEW) nexus. The FAO stresses that the IA should develop "Nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions" [20], because of the "Growing competition over natural resources" [20] especially between water, energy and food.

The FAO suggestion was taken up and the FEW nexus IA was developed based on the German sustainability strategy [21], which belongs to the 6th assessment group of de Ridder, accounting tools, and the indicator set was chosen as an ex post IA tool [7].

The German Federal Government defined a quantitative sustainable development strategy for Germany [22] in preparation for the Rio+10 Conference in Johannesburg in 2002 [23]. The German sustainability strategy has survived every change of government since 2002 and was renewed in 2017 in order to adapt the strategy in line with the UN-SDGs [24, 25]. The government has also revised its targets [24].

[†] The Bellagio project was undertaken by IISD staff and a group of experts and collaborators. Overall direction came from Peter Hardi, Program Director, Measurement and Indicator Program, IISD, Terrence Zdan was responsible for editorial work and case study coordination

[‡] http://www.tias-web.info/integrated-assessment/

[§] http://cms.tias-web.de/index.php?page=integrated-assessment

[**] http://www.tias-web.info/integrated-assessment/

Phases of Integrated Assessment

For the IA approach, based on the work of de Ridder [7] and the EU SEA framework, four phases were identified [26]:

- Problem analysis: definition of the assessment situation;
- Finding options: identification of the objectives;
- Analysis: impact assessment;
- Follow-up: monitoring.

INTEGRATED ASSESSMENT OF FOOD-ENERGY-WATER NEXUS

The UN identified the interconnections between water, energy and food in two UN nexus conferences [27] in Bonn. The 2011 Bonn conference "The Water, Energy and Food Security Nexus – Solutions for the Green Economy[††]" aimed to develop a visionary method of achieving sustainability and in 2014[‡‡] the conference issued a call to action and demands for responsible governance of natural resources, broad involvement of stakeholders, and an expansion of financial, institutional, technical and intellectual resources for nexus research and applications. The nexus ideas of the two conferences form the first keystone of our IA FEW nexus approach. The second keystone is the idea expressed in the Stiglitz-Sen-Fitoussi Commission report [28] that the way the socio-economic and ecological systems are measured influences how social organizations and public policies are governed. The "Statistics… reflect our aspirations, the values that we assign things" [29].

The ideas of the Sen-Stiglitz Commission will be taken up to reveal the values behind the selected indicators and the chosen sustainability metrics to comply with the demand of the Bonn conference for responsible governance of natural resources by a model of a culture of reflected numbers.

Integrated Assessment problem analysis: Food-Energy-Water nexus

Our approach is expressed in the following Figure 1. The figure visualizes the interconnections between the natural resources and the socio-economic system, which have to be considered by the IA FEW nexus.

The socio-economic system is part of the FEW nexus, a subsystem of the overall ecosystem, which provides the water supply, energy resources and food for the socio-economic system. Since 2000, the German socio-economic system has been engaged in a social discourse about the sustainability path for Germany [30]. In 2002, the German government developed a sustainability concept for Germany based on aggregated and disaggregated data for Germany [22]. In 2014, the German government set up its new research agenda for the transformation process of the green economy in Germany [31], which led to a completely revised sustainability strategy in 2017 [25] that is in line with the UN SDGs [32] as Table 1 shows. With its new sustainability strategy, the government also revised its sustainability goals and targets for a sustainable development of Germany [24] and in its green economy process the government outlined the political action fields to achieve these goals [33]. The indicators of the 2017 sustainability strategy represent important aspects for a sustainable society in the view of the government. The selection of the indicators also structures the social discourse about a sustainable development of Germany and reveals to the public the values the government associates with its strategy.

[††] https://www.water-energy-food.org/about/bonn2011-conference/
[‡‡] https://www.water-energy-food.org/news/2014-05-21-bonn-2014-nexus-conference-call-to-action-for-implementing-the-water-energy-food-nexus-from-bonn-2014/

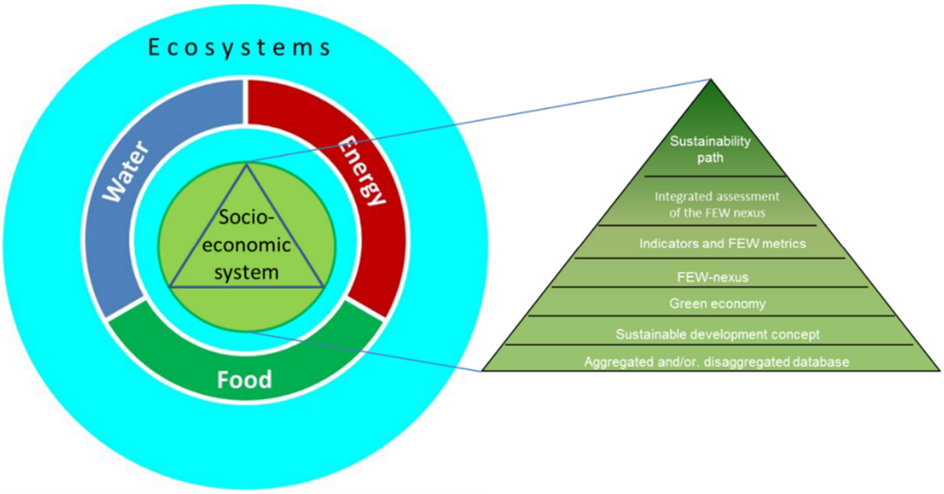

Figure 1. The IA model for the FEW nexus
(source: UNEP 2016 and Authors 2017 based on http://www.unep.org/esm/Waterecosystems/Thematicareas/Water-Energy-Foodnexus/tabid/131727/Default.aspx, 2016)

In the following, the FEW nexus issues are analysed with selected FEW-nexus-related sustainability indicators of the German strategy (Table 1) and the new FEW metrics [Fisher Nexus Index (FNI)]. The IA of the FEW nexus sketches the methodological framework for analysing the sustainability path of the German FEW nexus and reveals the values connected with the sustainability strategy.

Table 1. 17 UN SDGs and 28 German FEW indicators

Number of SDGs	UN SDGs	German SDGs based FEW indicators*	Indicators
1	No poverty		
2	Zero hunger	Nitrogen surplus of agriculture, organic farming	2
3	Good health and well-being	Emissions of air pollutants, share of the population with increased exposure to PM10 in Germany	2
4	Quality education		
5	Gender equality		
6	Clean water and sanitation	Water quality (nitrate, phosphorus)	2
7	Affordable and clean energy	Energy productivity, Primary energy consumption, Share of renewables in gross final energy consumption, in gross electricity consumption	4
8	Decent work and economic growth	Raw material productivity Gross fixed capital formation in FEW sector	1
9	Industry, innovation and infrastructure	Private and public spending on research and development in FEW sector	2
10	Reduced inequalities		
11	Sustainable cities and communities	Built-up area and transport infrastructure expansion, loss of open space, settlement density, Final energy consumption of passenger and freight transport, average travel time with public transport	6
12	Responsible consumption and production	Energy consumption and CO_2 emissions of consumption	2
13	Climate action	GHG emissions	1
14	Life below water	Nutrient contamination in North Sea and Baltic Sea, sustainable fishery	3
15	Life on land	Diversity of species, eutrophication, reforestation in developing countries	3
16	Peace, justice and strong institutions		
17	Partnership for the goals		
		Total	28

Source: Authors 2017 based on German Federal Government and German Federal Statistical Office, 2017
* The indicators are explained in Annex 1 glossary

Integrated Assessment finding new political options and values

On 25 September 2015, the United Nations adopted the "2030 Agenda for Sustainable Development" and thereby also 17 sustainable development goals (UN SDGs) to assess global development [32], and in 2017 the German government published its revised sustainability strategy [24], which implemented the UN goals in Germany and selected 36 sustainability measures to analyse the sustainable development of Germany. The government uses its targets to define its understanding of the sustainable development of German society and its nexus systems.

The German FEW sector can be described by 10 of the 17 UN SDGs and by 28 indicators of the 36 German sustainability measures (Table 1). This disaggregated indicator set for the FEW nexus demonstrates that it is possible to operationalize the UN goals in the analysis of the German FEW nexus, as the following table shows [25].

The government set up its 36 indicators and sustainability targets for these key issues to avoid the impression that its sustainable development strategy is merely a list of good intensions [25], and in this way it renewed its vision of a sustainable pathway for Germany of 2002 [22] and enabled a description of the sustainable development path for the FEW nexus sector. The goals and targets are new revised criteria for quality of life and well-being in Germany.

Both the UN and the German government are driven by the conception expressed in the definition of sustainable development in the Brundtland Report: "A development that meets the needs of the present without compromising the ability of future generations to meet their own needs [34]". The UN committed itself again in 2015 to intergenerational justice by stating: "We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations" [32]. Hence, justice between the present generation (intragenerational justice) and justice between different generations (intergenerational justice) are still central guidelines for any sustainable development concept [35]. Thus, justice is the defining ethical norm for sustainable development.

The "Ideas of justice are the core normative guidelines with regard to the sustainable use and conservation of the services provided by ecosystems, such as food and fresh water production, flood protection and erosion control" [35], as Glotzbach und Baumgärtner wrote thereby stressing the necessity of justice for the FEW nexus and its central institutional framework. Because as Rawls put it: "Natural distribution is neither just nor unjust, nor is it unjust that persons are born into society at some particular position. These are simply natural facts. What is just and unjust is the way that institutions deal with these facts" [36]. According to Rawls' reasoning, institutions are thus responsible for enabling a fair society. For Rawls "Justice is the first virtue of social institutions" [36] and of sustainable development and has to be reflected in the way development is measured.

In the next assessment step, the FEW Nexus Index is derived in order to calculate the degree to which sustainability has been achieved in the FEW nexus sectors on the basis of the German sustainability strategy and against the background of the UN SDGs.

Integrated Assessment analysis of German Food-Energy-Water system by sustainability indicators

Thus, inter- and intragenerational justice also represents a central issue for the development of the FEW nexus and this aspect is integrated in our FEW measuring concept by operationalization of the social discount rate.

Introduction – social discount rate. The social discount rate expresses the preferences of the current generation for the future (time preference) [37], i.e. the view of current society of the needs of future generations and the willingness of the current generation to consider future needs in their current decisions [38]. In our measuring concept, the discount rate based on the neo-Austrian capital theory [39] is interpreted as the difference in the price of a good at different points in time [40]:

$$\frac{p_1^0(1)}{p_1^0(2)} = 1 + r^0 = \mathrm{MRS} \tag{1}$$

where p is the price of good G1 in period 1 and 2 and r^0 is the discount rate. The discount rate expresses the Marginal Rate of Substitution (MRS) of contemporary for future consumption [40, 41]. Hence, the price difference is considered in our measuring concept in order to engage with intergenerational justice issues as shown in the SDGs of Table 1.

The Fisher Index

The Fisher Quantity Index (FQI). The Laspeyres Quantity (LAQ) Index assesses the current (U^0) and future household utility (U^k) with the current (x^0) and future consumption (x^k) of goods at current prices (p^0), as the following equation shows [42]:

$$\mathrm{LAQ}_{0,k} = \frac{p^0 \cdot x^k}{p^0 \cdot x^0} \qquad \mathrm{LAQ}_{0,k} \leq 1 \Rightarrow \mathrm{U}\left(x^k\right) \leq U\left(x^0\right) \tag{2}$$

In contrast, the Paasche Quantity (PAQ) Index assesses the current and future consumption of goods represented by the sustainability indicators at future prices:

$$\mathrm{PAQ}_{0,k} = \frac{p^k \cdot x^k}{p^k \cdot x^0}, \mathrm{PAQ}_{0,k} \geq 1,\ U\left(x^k\right) \geq U\left(x^0\right) \tag{3}$$

The FQI [43-45] is the geometric mean of the Laspeyres Price Index and the PAQ Index [46]:

$$\mathrm{FQI}_{0,k} = \sqrt{\left(\frac{p^0 \cdot x^k}{p^0 \cdot x^0}\right) \cdot \left(\frac{p^k \cdot x^k}{p^k \cdot x^0}\right)} \qquad \mathrm{FQI} = \sqrt{\mathrm{LAQ}_{0,k} \cdot \mathrm{PAQ}_{0,k}} \tag{4}$$

Hence, an index is needed that will assess the current and future consumption of the goods represented by the sustainability indicators at both current and future prices.

The Fisher Nexus Quantity Index (FNQI). The FNI is now based on 28 measurable indicators covering the key issue of sustainable development of the FEW sectors, where x^0 represents the value of the indicator (i) at the starting period of time 0, x^k represents the value of the sustainability target of the sustainability indicator at period k.

The discount rate is included in parts of the Fisher Index to obtain the FNI and consider intergenerational issues in measuring sustainability.

Hence, the FNI is constructed in three major steps:

- The Laspeyres Nexus Quantity Index (LANQ):

$$\mathrm{LAQ}_{0,k,i,n} = \frac{p_{i,n}^0 - x_{i,n}^k}{p_{i,n}^0 - x_{i,n}^0}, \tag{5}$$

where 0, k is point in time, i is indicator 1... 28 and n is nexus sector 1… 3. By introducing the discount rate:

$$\mathrm{LANQ}_{0,k,i,n} = \frac{\left(p_{i,n}^{k} \cdot (1+r)\right) - x_{i,n}^{k}}{\left(p_{i,n}^{k} \cdot (1+r)\right) - x_{i,n}^{0}} \tag{6}$$

where 0, k is point in time, i is indicator 1… 28 and n is nexus sector 1… 3.

- Paasche Quantity Index:

$$\mathrm{PAQ}_{0,k,i,j,n} = \frac{p_{i,j,n}^{k} - x_{i,j,n}^{k}}{p_{i,j,n}^{k} - x_{i,j,n}^{0}} \tag{7}$$

where 0, k is point in time, i is indicator 1… 28 and n is nexus sector 1… 3.

By introducing the discount rate in the Paasche Index, the Paasche Nexus Index (PANQ) is obtained:

$$\mathrm{PANQ}_{0,k,i,j,n} = \frac{\left(\frac{p_{i,j,n}^{0}}{1+r}\right) - x_{i,j,n}^{k}}{\left(\frac{p_{i,j,n}^{0}}{1+r}\right) - x_{i,j,n}^{0}} \tag{8}$$

where 0, k is point in time, i is indicator 1… 28 and n is nexus sector 1… 3.

- FNI: The FNI is the result of combining the Paasche and the Laspeyres Index:

$$\mathrm{FQNI}_{0,k,\mathrm{i},n} = \sqrt{\left(\frac{\left(p_{i,n}^{k} \cdot (1+r)\right) - x_{i,n}^{k}}{\left(p_{i,n}^{k} \cdot (1+r)\right) - x_{i,n}^{0}}\right) \cdot \left(\frac{\left(\frac{p_{i,n}^{0}}{1+r}\right) - x_{i,n}^{k}}{\left(\frac{p_{i,n}^{0}}{1+r}\right) - x_{i,n}^{0}}\right)} \tag{9}$$

$$\mathrm{FQNI}_{0,k,i,n} = \sqrt{\mathrm{LANQ}_{0,k,i,n} \cdot \mathrm{PANQ}_{0,k,\mathrm{i},n}} \tag{10}$$

Integrated Assessment follow-up – The culture of reflected numbers for institutions

The analysis of the FEW nexus sector represents a new scientific research area [47] and a new local, national [48] and international governance field which needs quantitative data to develop new political options in a political discourse [48]. The democratic institutions are at the centre of this discourse process, because for far-reaching political decisions the political decision makers need sufficient political legitimation based on democratic approval by the citizens [49]. This legitimation can only be effected by elected parliaments, which are the institutional centre of the political life of a country [50]. Voßkuhle stresses that the political decisions of parliament need statistical data and a ‘culture of reflected numbers’ [50], which uses the quantitative research results as a starting point for political reasoning and debate. The research results are not simply to be executed by the political institutions [50]. Especially the sustainability indicators [51] are an important tool for initiating a political debate and social learning process.

We have to consider that no matter how well the indicators are calculated, they cannot replace a democratic political decision-making process. In particular, the target values of the numerical sustainability indicators are simply the outcome of a social discussion process resulting in political targets approved by parliament [52]. Hence, also the new FEW nexus policy process needs a 'culture of reflected numbers' as Voßkuhle puts it [50] to discuss the policy options and values behind the measurement concept.

However, Voßkuhle also stresses [50] that for such a culture of reflected numbers an open political and social discourse in the sense of Karl Popper [53] is needed because democracy lives first and foremost from and in a climate of functioning public opinion [53], which discusses the measured numbers [54]. This culture can help to avoid "short-term and 'common-sense' solutions (which) often bear unintended consequences that may produce worse situations over the long term than if no action had been taken at all" [55].

The result of the culture of reflected numbers can be that the targets of the indicators will be readjusted or new indicators selected to engage more effectively with German social reality. The goal of the culture of reflected numbers is to avoid the automatism that the measuring results have a self-executing character, which can no longer be questioned by society. The validity of the results has to be scrutinized and the meaningfulness of the indicators has to be analysed in an ongoing monitoring process [52].

CONCLUSIONS

The IA model shows that it is possible to make an IA of the German FEW sector based on a four-step research concept. The model enables us to deliver data for the political discourse and social learning process in Germany about the future sustainable development of the FEW sectors in the green economy process. The data captured by quantitative indicators [50] are used for a portrayal of reality which will be discussed in parliament and society [52].

Our new nexus measuring concept (FQNI) enables us to assess the energy, water and food subsystems and the FEW nexus system itself by considering intertemporal justice issues with the discount rate. Our indices allow decision makers to reduce the complexity of the presentation of the analysed system without reducing the complexity of the analysed system itself, because the indices are based on a broad database set up by the German Federal Statistical Office [33]. Against the background of the new UN sustainability concept, the German sustainability strategy, and the discount rate (intertemporal time preference), the FNI permits us to develop a measuring framework for monitoring, in the sense of the culture of reflected numbers, the transformation process of German society in an indicator-based ex post IA approach. With the discount rate, intergenerational issues, which are a central element of sustainable development, are also integrated into the discourse of the culture of reflected numbers.

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ANNEX 1. GLOSSARY OF THE INDICATORS

	Indicator glossary based on Eurostat
Energy productivity	Energy productivity = Gross domestic product divided by primary energy consumption, the energy productivity expresses how gross domestic product can be generated per unit primary energy consumption (in petajoule)
Eutrophication	Eutrophication is a process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. It may occur naturally but can also be the result of human activity (fertilizer run-off, sewage discharge)
Final energy consumption	Final energy consumption is the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself
Greenhouse gas emissions	Greenhouse gases constitute a group of gases contributing to global warming and climate change: non-fluorinated gases; Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Flourinated gases; Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), Nitrogen trifluoride (NF_3)
Gross Fixed Capital Formation (GFCF)	Gross fixed capital formation, abbreviated as GFCF,consists of resident producers' investments, deducting disposals, in fixed assets during a given period. It also includes certain additions to the value of non-produced assets realized by producers or institutional units. Fixed assets are tangible or intangible assets produced as outputs from production processes that are used repeatedly, or continuously, for more than one year
Gross electricity consumption	Gross national electricity consumption includes the total gross national electricity generation from all fuels (including auto-production), plus electricity imports, minus exports. Auto-production is defined as a natural or legal person generating electricity essentially for his/her own use. Gross electricity generation is measured at the outlet of the main transformers, i.e. it includes consumption in the plant auxiliaries and in transformers
PM10	Atmospheric particulate matter, which is particles with a diameter between 2.5 and 10 micrometers
Primary energy consumption	Primary energy consumption measures the total energy demand of a country. It covers consumption of the energy sector itself, losses during transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum not used not for combustion but for producing plastics)
Raw material productivity	Gross domestic product divided by raw material consumption: A commodity, also called primary product or primary good, is a good sold for production or consumption just as found in nature. Commodities include crude oil, coal, copper or iron ore, rough diamonds, and agricultural products such as wheat, coffee beans or cotton; they are often traded on commodity exchanges

Source: Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Thematic_glossaries, 2017