HOW SECURE IS EUROPE'S ENERGY SECTOR, AND HOW IT INTERACTS WITH WATER AND FOOD SECURITY?

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Abstract

This paper develops composite indices for assessing the state of energy security of 17 European countries between 2000 and 2010, and examines the nature of interactions that energy security has on water and food securities. It demonstrates that a simple tool such as a composite security index is an important first-step to develop an in-depth and a comprehensive understanding of energy security in order to deal with this challenge. The results in this paper provide insights into the state of energy security across the select European countries, the factors that contribute to insecurity, and the effect that energy security may have on water and food security. These results can be used to enable monitoring of countries' security performance over time, convey policy messages that can help policy-makers to prioritise security concerns that are specific to their countries, and to support political dialogue aiming to improve energy-water-food security.

1. Introduction

Meeting energy security challenge has lately emerged as a top policy priority for countries around the world, including those in the European Union. However, dealing with this challenge is not an easy task. This is because the concept of 'security' is complex. One of the complexities is that energy security is multidimensional in a sense that it encompasses a range of conflicting policy goals. For example, the current effort of the EU to reduce its reliance on energy imports (Hedberg, 2015) could lead to increased energy prices and thus results in overall deterioration of energy security. Second, the notion of 'security' is dynamic – it differs from country-to-country, and changes over time. This dynamism implies that the importance of each dimension of energy security changes over time, and it is crucial that this changing importance is recognized when conducting analyses of energy security. Third, energy security interacts with 'security' from other domains. This is particular true for water and food owing to increased recognition of energy-water-food nexus (Hoff, 2011). This means that actions to improve energy security are likely to impact water and food security (Rasul & Sharma, 2015).

Designing policies to redress energy security, without causing unintended consequences on water and food security, require holistic and quantitative measures to enable countries to track progress (performance) in response to policy endeavors aiming to improve security. Yet there is no consensus on the precise interpretation and measurement of energy, water and food security. This paper has two overarching objectives: 1) to develop composite indices for assessing the state of energy, water, food security of 12 countries in the EU between 2000 and 2010; and 2) to examine nature of interactions between energy, water, food security.

The paper is organised as follows: Section 2 provides some conceptual discussions on energy, water and food security. Key indicators are also identified for use in developing composite security indices. Section 3 describes the methodology employed to develop composite security indices and examine interactions between these indices. A discussion of results is given in Section 4. Finally, Section 5 presents the main conclusions.

2. Conceptualize Energy-Water-Food Security

This section reviews literature on definitions of energy, water and food security in order to develop a broad contour of security dimensions identified in literature. Based on this review, this paper will then offer a frame of security dimensions to help select, develop and assess security indicators in the following sections.

A great deal of attention has been paid in literature to define energy, water and food security. Early definitions focused on availability of resources, from both physical and geopolitical aspects, where emphases were given to the existence and diversification of resources, and sovereignty associated with resources. For example, Yergin (2006) showed that energy security has always been associated with different types of supply disruptions, including armed conflict (e.g., risk of securing coal to fuel British navy's ships during World War I, oil crises that originated from the conflict in the Middle East during the 1970s and 1980s, the Persian Gulf War), political turmoil and instability (e.g., Russian-Ukrainian dispute that affected natural gas supplies to Europe, tensions over Iran's nuclear program that unleashed the recent oil crisis, attacks on Nigerian oil facilities that has affected exports to the United States), and natural disasters (e.g., Hurricanes Katrina and Rita along the U.S. Gulf Coast in 2005 that caused simultaneous disruptions in energy infrastructure, the earthquake and tsunami in Japan in 2011 that resulted in a shutdown of a series of nuclear power plants). A review of literature on energy security shows that most studies employed a measure that reflect the availability of energy in conceptualizing energy security, including production, access, import-dependence and diversification (Brown et al., 2014; Gnansounou, 2011; Sovacool and Brown, 2010).

Likewise, water security has been defined as closely linked to national security, specifically to provide sufficient access to clean water in order to avoid water-related conflicts and wars (Gleick, 1993). To this end, a number of studies attempted to quantify water availability in various ways. For example, Falkenmark and Widstrand (1992) calculated the amount of annual water available per person to identify the extent to which basic water needs have been met. Raskin et al. (1997) extended the analysis by determine the ratio of annual water consumption to available water resources. This ratio is then used to assess the physical scarcity of water, where countries with high ratio indicate a higher level of water insecurity; the ratio is known as 'water stress'. Seckler et al. (1998) further extended this ratio approach by considering water infrastructure as a nation's storage capacity. It was argued that water infrastructure provides resiliency in terms of access to available water resources, and thus should be counted as a part of the nation's available water resources.

While the concepts of energy and water security are relatively recent, the concept of food security can be traced back to the idea of Thomas Malthus (1789) that questioned the balance between population and food availability. This concept of food security was adopted by the international community at the World Food Conference of 1974, which defined as "ensuring the availability at all times of adequate world supplies of basic foodstuffs to avoid food shortages" (UN, 1974). Food security has also been put side-by-side with food sovereignty in the 1980s as a result of the arrival of food imports from the United States into Latin America that has threatened the existence of peasant and small-scale farmers (Edelman, 1999). From this viewpoint, focusing on domestic food production capabilities is a key to achieve food security.

The definition of 'security' has evolved over time as a result of increased understanding that assessing security only from a resource availability aspect is not sufficient to capture complexities in the way resources are used and produced in a society (Barrett, 2010; Brown and Matlock, 2011; Sovacool and Brown, 2010). It is increasingly being recognized that ‘security’ is a multifaceted concept. In addition to availability, it also includes other fundamental dimensions, which related to economic accessibility, efficiency in utilizing resources, environmental sustainability, and social acceptability. This expanded conception of ‘security’ has led to the refinement of energy, water and food security definitions, as follows:

- Access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses (UN, 2010);
- Capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN-Water, 2014); and
- All people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2002).

Following the refinement of definitions noted above, a number of studies have devised security indicators that incorporate the multidimensional aspects of security. However, most studies focus on security in a single domain (i.e., energy, water or food). There is only one recent study, to the authors’ knowledge, that developed energy-water-food security index in an integrated manner (Willis et al., 2016).

Based on the review of studies, this paper classifies ‘security’ into three broad dimensions. These dimensions, and their meanings, are as follows.

- Availability: refers to the physical availability and access to energy, water and food, and is determined by the level of domestic production and reserves, and physical capability to obtain these resources.
- Affordability: refers to the economic access to energy, water and food, and is determined by the level of prices, and efficiency in utilizing resources.
- Acceptability: refers to both environmental sustainability (e.g., cleanliness) and social acceptability (e.g., fair and safe) in the way energy, water and food are used and produced in an economy.

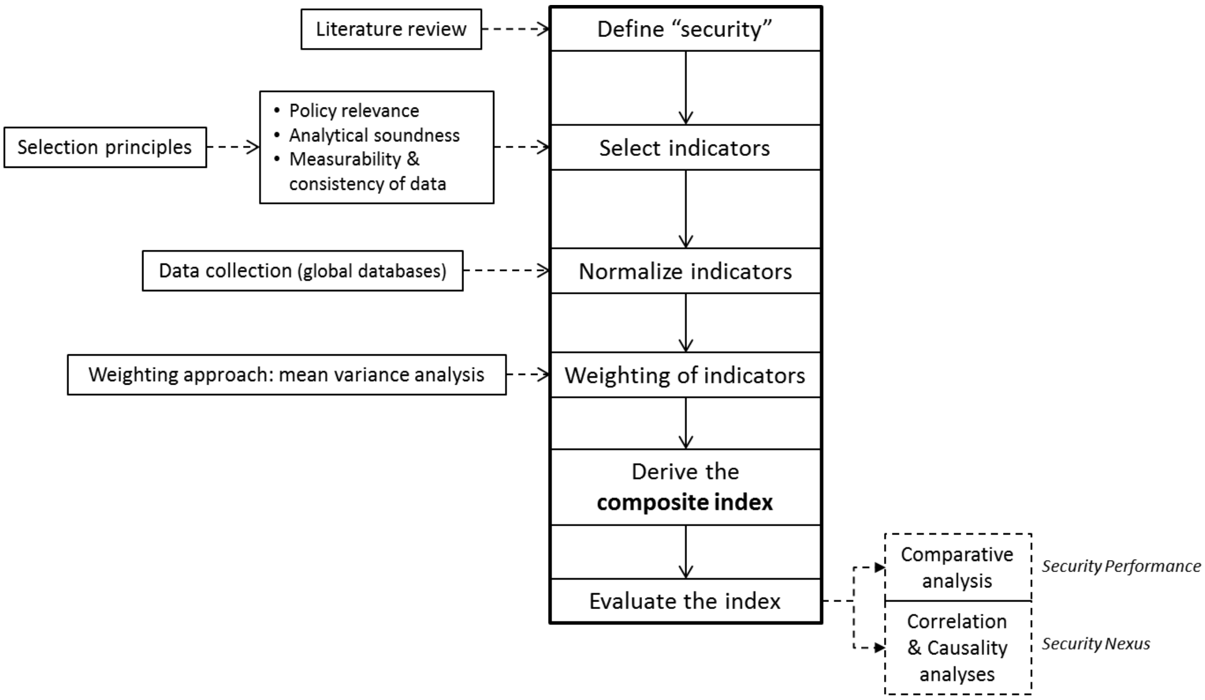
This classification captures all aspects of security dimensions that have been identified in literature in terms of physical, economic, social and environmental aspects. Moreover, it considers a broader dimension than the comparable study (i.e., Willis et al., 2016) in developing energy, water and food security indicators. That is, while Willis et al. (2016) developed energy-water-food security indicators in view of physical and economic aspects, this paper also include social and environmental aspects, through acceptability dimension, in developing security indicators.

In addition to the above noted three dimensions of security considered in this paper, some literature also identified institutional dimension (such as, governance, political and societal capacity) as relevant to the concept of security (e.g., Sovacool, 2013; WEC, 2013; Chavez and Alipaz 2007; Mason and Calow, 2012; FAO, 2016a). This dimension is however not considered in this paper as it is a common denominator for all three domains (energy, water and food). In particular, the improvements in institutional arrangements, or lack thereof, will have direct consequences on all dimensions (availability, affordability and acceptability) of energy, water and food security. As the focus of this paper is to develop security indicators that can be used to inform policy makers about potential tradeoffs that may arise in their domain (i.e., tradeoffs between the three dimensions of security), and how their decision may have consequence on security of other domains, the factors that underpin energy-water-food security altogether (such as, population and economic growth, demographic changes, socio-economic development, and institutional arrangements) is considered to be outside the scope of this paper.

3. Methodology and Data

This section presents the method for developing composite indices that reflect energy, water and food security. It follows the method adopted by Wei et al. (2016) that developed an integrated indicator (comprising of various components) to evaluate the urban carrying capacity of China's mega-cities. The schematic diagram of the overall methodology is shown in Figure 1.

Figure 1 Methodology to develop and evaluate security indicators



There have been several attempts to devise 'security' indicators over the years. A comprehensive review of literature suggests that the term 'security' has been expressed by certain measurable indicators that capture various dimensions reflecting the security of energy, water and food resources. These dimensions capture aspects related to availability (including, reliability and physical accessibility of resources), affordability (including economic accessibility of resources and efficiency of how resources are utilized), and acceptability (i.e., safety and cleanliness associated with resources). The consideration of these dimensions facilitates the development of composite indices that capture the complexities embedded in the definition of security.

To allow empirical estimates of 'security', certain criteria are used for the selection of indicators, based on the guiding principles suggested by OECD (2011). First is the policy relevance of indicators with respect to emerging security challenges. In particular, the selected indicators should adequately reflect changes in the area where policy-makers can influence security outcomes that are of public concern. Second is the analytical soundness of indicators in a sense that they are a reasonably good representative, and provide a balanced coverage, of the security conditions in question. Finally is the measurability and consistency of data that allows comparisons to be made across countries and/or over time. Also, the data should be publicly available, regularly updated, and of a reasonably good quality.

Based on the selection principles, Table 1 presents an overview of 47 indicators selected for developing composite security indices in this paper. Each indicator ties to a particular dimension of security and have different measurement units. They are distributed as evenly as possible, both across different security domains (i.e., 21, 12 and 14 indicators for energy, water and food) and across dimensions (i.e., 19, 14 and 14 indicators for availability, affordability and acceptability). From databases that include information for more than 200 countries, composite indices are developed for a wide-range of countries where data are available for all 47 indicators over the period 1990 to 2010. In particular, composite indices of energy, water and food security are developed for 85, 51 and 78 countries, respectively. In terms of time coverage, the composite energy and water security indices are developed for the period between 1990 and 2010, while the composite food security index covers the period between 2000 and 2010 due to unavailability of data on food prices and fertilizer consumption prior to 2000. However, as the datasets chosen in this paper are published regularly by reputable organizations, it is expected that the country-level data for the selected indicators will expand into the future, and thus allows countries to monitor progress over time.

Table 1 Overview of energy, water and food security indicators included in this paper

Indicator	Measurement unit	Attributes	Literature cited	Country coverage	Data source	Weights (%) 1990	2000	2010
Energy Security Index				**85**		**100**	**100**	**100**
Availability				*110-113*		*35*	*26*	*38*
Access to electricity	% of population	+	i, l, q, t	211	WB 2016	19.4	11.0	14.1
Diversity of electricity supply	index (Herfindahl)	-	j, s	137-140	IEA 2016*	1.5	0.8	9.6
Dependent on traditional energy	% of final energy use	-	i, q, t	173-181	IEA 2016	2.8	4.8	6.4
Diversity of primary energy supply	index (Herfindahl)	-	j	136-140	IEA 2016*	1.5	2.2	4.1
Energy import dependency	% of primary energy use	-	b, h, i, j, l	138-141	IEA 2016	0.6	0.8	1.4
Diversity of end-use energy consumption	index (Herfindahl)	-	i	138-142	IEA 2016*	9.3	5.8	1.3
Value of energy reserves	% of national income	+	i, j, l, q	128	WB 2016	0.3	0.4	0.4
Domestic energy production	tonne-of-oil-equivalent per person	+	l, q, s	135-139	IEA 2016*	0.1	0.2	0.2
Affordability				*115-128*		*36*	*45*	*38*
Energy prices	$ per liter	-	b, i, j, q, s	159-176	IEA 2016	7.8	5.9	14.2
Primary energy intensity	MJ/$GDP	-	i, s	183-190	IEA 2016	9.1	4.9	8.8
Economy-wide energy efficiency	final-to-primary energy ratio (%)	+	i, l	135-137	IEA 2016	0.9	4.7	7.7
Network losses	% of output	-	l, q, s	136-140	IEA 2016	1.1	7.6	4.6
Value of energy imports	% of total imports	-	i, s	164-182	WB 2016	7.3	13.8	1.4
End-use energy intensity	MJ/$GDP	-	b, i, j, l	184-190	IEA 2016	8.3	7.2	0.9
Thermal efficiency	percent	+	i	134-136	IEA 2016	1.5	0.4	0.5
Acceptability				*122-132*		*29*	*29*	*24*
Greenhouse-gas emissions	metric tons per person	-	b, i, l, q	197-204	WB 2016	12.6	3.9	9.8
Renewable-based electricity production	% of total electricity output	+	i, j, l	159-162	IEA 2016	1.9	6.9	4.9
Indoor air pollution	particulate emission damage (% GNI)	-	b, i, q, s	160-167	WB 2016	2.0	7.2	3.7
Carbon intensity of GDP	kg per $GDP	-	i, l, s	177-188	WB 2016	3.7	3.6	3.3
Renewable energy consumption	% of final energy use	+	i, j, l	181-188	IEA 2016	1.0	4.7	1.6
Carbon intensity of fuel	kg per kg of oil equivalent energy use	-	i, s	159-169	WB 2016	7.3	3.1	0.8
Water Security Index				**51**		**100**	**100**	**100**
Availability				*118-173*		*42*	*46*	*60*
Water stress ratio	ratio of use from internal resources	-	d, m, o, r	95-178	FAO 2016b	9.1	9.9	30.3
Access to clean drinking water	% of population	+	g, k, r, t	170-202	WB 2016	6.5	20.2	13.5
Importance of sectoral water withdrawals	index (Herfindahl)	-	k, r	94-180	FAO 2016b*	0.6	7.0	12.5
Access to improved sanitation facilities	% of population	+	g, k, r, t	163-201	WB 2016	23.3	8.4	3.7
Internal freshwater resources	thousand cubic meters per person	+	d, f, m, r, t	174-180	FAO 2016b	2.0	1.0	0.1
Affordability				*77-142*		*0*	*1*	*1*
Irrigated agricultural water productivity	$value-added per m^3	+	a, m, r	67-162	WB/FAO 2016*	0.2	0.5	0.1
Industrial water productivity	$value-added per m^3	+	a, m, r	66-159	WB/FAO 2016*	0.0	0.0	0.0
Economy-wide water productivity	$GDP per m^3 of water withdrawal	+		85-170	WB 2016	0.1	0.3	0.5
Acceptability				*122-130*		*58*	*53*	*39*
Vulnerability of waterflows due to dam	% electricity production from hydro	-	a, d	138-140	IEA 2016	17.5	3.2	13.4
Inequality in access to sanitation facilities	% diff. between urban-rural access	-	a, k	174-201	WB 2016*	1.8	13.0	12.7
Inequality in access to clean water	% diff. between urban-rural access	-	a, k	181-202	WB 2016*	10.8	23.5	12.5
Discharges of hot cooling water	ratio :nonrenewable power & thermal	-	a, d	134-136	IEA 2016*	28.0	13.0	0.8
Food Security Index				**78**			**100**	**100**
Availability				*143-145*			*26*	*33*
Depth of food deficit	Calories per person per day	-	g, t	169	FAO 2016a		16.5	22.6
Irrigated land area	% of arable land	+	g	166-176	FAO 2016a		2.2	5.8
Value of food production	$ per person	+	e, g	178-185	FAO 2016a		2.7	1.9
Cereal production	metric tons per person	+	e	172-178	WB 2016		1.2	1.7
Arable land	hectares per person	+	p	202-207	WB 2016		2.1	1.0
Aquaculture production	metric tons per person	+	e	155-178	WB 2016		0.8	0.1
Affordability				*116-125*			*32*	*22*
Value of food imports	% of total imports	-	g	99-158	WB 2016		15.1	14.5
Food prices	index	-	c, g, t	148	FAO 2016a	n.a.	12.7	6.6
Agricultural productivity	value-added per worker ($'000)	+		149-178	WB 2016		3.8	0.8
Cereal yield	tons per hectare	+		171-178	WB 2016		0.0	0.1
Acceptability				*114-120*			*43*	*45*
Agricultural nitrous-oxide emissions	tons of CO_2-equivalent per person	-		199-200	WB 2016		25.7	20.8
Agricultural methane emissions	tons of CO_2-equivalent per person	-		199-200	WB 2016		14.7	20.0
Use of chemical fertilizer	kg per hectare of arable land	-		158-162	WB 2016	n.a.	1.3	2.7
Diversification of food consumption	% of starchy food	-	c, e, n, t	160-164	FAO 2016a		1.0	1.2

Notes

Attributes: '+' indicates that indicator with a higher value has a more favourable outcome; '-' indicates that indicator with a lower value has a more favourable

Literature cited: a) ADB 2013; b) Brown et al. 2014; c) Burchi & Muro 2016; d) Chavez & Alipaz 2007; e) EIU 2016; f) Falkenmark & Widstrand1992; g) FAO 2016a; h) Gnansounou 2011; i) IAEA 2005; j) Kruyt et al 2009; k) Lautze & Manthrithilake 2012; l) Martchamadol & Kumar 2013; m) Mason & Calow 2012; n) Maxwell et al. 2014; o) Raskin et al 1997; p) Rasul & Sharma 2016; q) Sovacool 2013; r) UN-Water 2009; s) WEC 2013; t) Willis et al 2016.

Data source: * indicates that the indicator is estimated by author, using data obtained from this source.

Since all indicators shown in Table 1 are in different measurement units, they need to be first normalized into a dimensionless index, and then scaled from 0-100, where 100 represents most favourable outcome, and zero, least favourable. Indicators where a higher value indicates a more favourable outcome are normalized as follows:

$$x_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]} \quad (1),$$

where $\min(x_{ij})$ and $\max(x_{ij})$ are the lowest and highest values for any given indicator i in the entire data j (for all countries and years). These indicators are considered as having a positive attribute, and accordingly shown as a positive sign (e.g., access to electricity, availability of internal freshwater resources, and availability of irrigated land area).

For indicators where a high values indicate unfavourable outcomes, the normalization function takes the form:

$$x_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]} \quad (2).$$

These indicators are considered as having a negative attribute, and accordingly shown as a negative sign (e.g., network losses, water stress, and value of food imports).

Once each indicator is normalized using equations 1 and 2, they can be combined into a composite index. Each composite index indicates the overall outcome of a particular security dimension. For example, a composite energy security index comprises of composite indices that reflect availability, affordability and acceptability of energy resources. Further, a composite index that represents energy availability is the combination of 8 indicators, including access to electricity, diversity of electricity supply, dependent on traditional energy, diversity of primary energy supply, energy import dependency, diversity of end-use energy consumption, value of energy reserves, and domestic energy production.

Each composite index (CI) is calculated as the weighted-mean of individual indicators, as below:

$$CI = \sum_i \omega_i x_i \quad (3).$$

Most studies (e.g., EIU, 2016; Sovacool, 2013; UN-Water, 2009; Willis et al. 2016) assume an equal-weight method to determine a composite security index where all indicators are treated as equally important (i.e., $\omega_1 = \omega_2 = \cdots = \omega_n$). This implies that increasing access to electricity, for example, is as important as reducing reliant on energy imports in order to make energy available for a country. Similarly, increasing energy availability is as important as making it affordable and clean (acceptable) in order to improve energy security condition.

However, the notion of security is dynamic in a sense that the importance of each security dimension (and accompanying indicators) changes over time. This changing importance can be captured by assigning different weights to individual indicator. Wei et al. (2016) showed that there are two approaches to assign weights for each individual indicator: subjective- and objective-based approach.

The subjective-based approach (including, Delphi and Analytical Hieratical Process methods) uses the experience of experts or key decision-makers in assigning weights to individual indicators. This approach however produces the estimates that are highly subjective to their opinion, which may be biased or influenced by their ideological viewpoints. In contrast, an objective-based approach is free from such biasedness, and therefore leads to objective estimation outcomes. One such approach is based on statistical method in order to assign different weights to individual indicators; this method is called mean-variance analysis. The weight-coefficient (ω) of each indicator is determined by:

$$\omega_i = \frac{\sigma_i}{\sum_i \sigma_i} \quad (4),$$

where σ is the root-mean-squared-deviation of a normalized index of each country (x_{ij}) around the average of all countries (μ_i), and is calculated as:

$$\sigma_i = \sqrt{\sum_i (x_{ij} - \mu_i)^2} \quad (5).$$

Equation 5 represents the variability of the dataset for each individual indicator. An indicator that has a high σ means that the values of that indicator for most countries are spread-out around the average value, and therefore attracts more weight, compared with dataset of an indicator that has values of most countries closer to the average value. The implication of using this method in weighting indicators is that if data for all countries on a particular indicator converge, that indicator will become less important in determining the composite index. The weights of individual indicators can be added to derive aggregate weights of each dimension in order to derive composite index.

The weights of individual indicators can be added to derive aggregate weights of each dimension in order to derive composite index. The weights of energy, water and food security indicators included in this paper is shown in Table 1. Among the three dimensions of energy security, for example, availability and affordability attract equal weights of 38% in 2010, while acceptability attracts 24%. Within the availability dimension, access to electricity is considered to be the most important indicator, contributing 14% to the composite energy security index, which is equal in importance to energy prices from the affordability dimension.

The composite security indices are used in two ways. First, it is used to evaluate energy, water and food security condition across countries, and assess their performance over time. This is simply conducted by comparing composite indices, with some reasoning supported by assessment of individual indicators.

Second, it is used to analyse the nature of nexus between different dimensions (i.e., availability, affordability and acceptability) of security in each domain (i.e., energy, water or food), and the nature of nexus between energy security, water security and food security. For this purpose, the Spearman's rank correlation coefficient (ρ) is estimated to measure the direction and strength of association between the two composite security indices. This method has increasingly been used to examine the nature of various bivariate relationships in the area of energy, water and food, including food security indicators (Maxwell et al., 2014), energy security dimensions (Brown et al., 2014), and energy-water nexus (Ruddell and Dixon, 2014).

A positive value of ρ indicates that the two composite security indices move in the same direction (either increase or decrease), which implies that the nature of their association is 'coupling'. In contrast, a negative value of ρ indicates that the two composite security indices move in the opposite direction, which suggests the existence of 'tradeoff'. Further, the strength of coupling/tradeoff is determined from the absolute value of ρ as follows: strong when $|\rho| \geq 0.6$; moderate when $0.4 < |\rho| < 0.6$; and weak when $|\rho| \leq 0.4$.

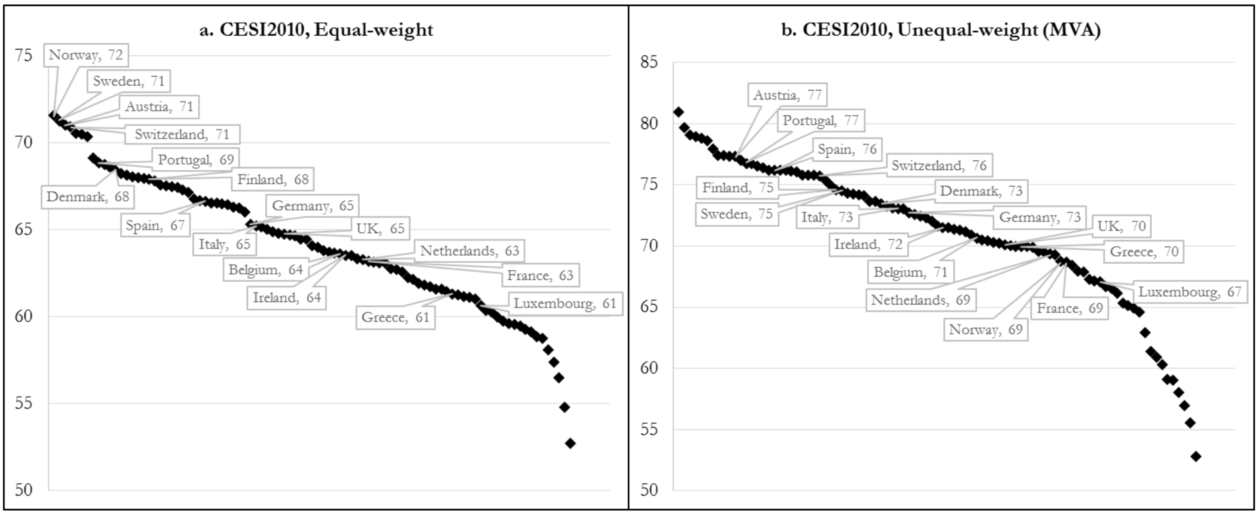
4. Key Results

This section assesses the overall energy security (composite energy security index) in terms of the relative performance across countries, and over time (Section 4.1). It then applies the composite energy security index with water and food security indices to examine the nature of nexus between energy, water and food security; whether the security nexus presents a coupling effect, or exhibits a tradeoff (Section 4.2).

4.1. Energy Security Performance

Based on data availability, as shown in Table 1, energy security performance is determined for 85 countries. The composite energy security index (CESI) for 2010 is shown in Figure 2; the results are presented for both weighting methods, equal-weight (i.e., simple average) and unequal-weight using mean variance analysis (MVA).

Figure 2 Comparisons of composite energy security indices, 2010



The results in Figure 2 reveal the following key points:

- Based on an equal-weight method (Figure 2a), the European countries are among the most energy secure in the world. In particular, four of the top five most energy secure countries are Norway, Sweden, Austria and Switzerland. This result is consistent with the rankings by other reputable organizations, such as USCC (2016) and WEC (2016).

- However, based on an MVA-weight method, the position of ranking changes substantially. While most of the European countries are relatively energy-secure, compared with other countries in the world, they are no longer in the top list. This is because of an unequal importance of individual indicators that made up the composite index.

- Norway is a good example to illustrate the difference between the use of equal-weight and MVA-weight method; the CESI score for Norway changed from being in the top rank (Figure 2a), to the level of world average (Figure 2b). Norway is an energy-abundant country that exports significant amount of crude oil and natural gas, while relies almost entirely on hydro to produce its electricity. However the weights that reflect these attributes have low values; energy import dependency, value of energy reserves, and amount of domestic energy production attract weights of 1.4%, 0.4% and 0.2%, respectively. On the other hand, energy prices in Norway, compared with may other European countries, are relatively high, and economy-wide energy efficiency is relatively low. These two indicators however attract higher weights – 14.2% and 7.7%, relatively.

Table 2 presents the detail results of energy security performance. The results show that, in 2010, Austria, Portugal, Spain and Switzerland are among the most energy-secure countries in Europe where the CESI values are higher than 75 in 2010). On the other hand, Luxembourg, France, Norway and the Netherlands are relatively less secure where the CESI values are less than 70. Some key findings from this table are discussed below:

- The European energy sector has a distinct feature in that they have sufficient access to energy resources to fulfill demand. This attribute is reflected in the energy availability index where the index values for all countries, except Luxembourg, are greater than the world average. For example, the energy availability index for Finland, for 2010, is 90 (highest in the sample), compared with the world average of 69. While the population of Finland have a universal access to electricity and no reliant on traditional energy (same as all European countries), their energy supply sources are diverse (the Herfindahl indices for energy diversity are low), compared with other countries. In contrast, the energy availability index for Luxembourg is lower (66) than the world average; they are overly dependent on oil to meet its energy needs, with the Herfindahl index of 0.8.

- While the energy availability index for the European countries are almost exclusively higher than the world average, the case for energy affordability index is the opposite – they are all lower than 70 in 2010. This implies that the access to energy in Europe is relatively costly compared with the rest of the world. In particular, energy prices for all European countries are higher than the world average of $1.2 per litre. While the values of other indicators under energy affordability (such as, energy intensities, network losses) for European countries are more favourable than the world average, a relatively higher weight of energy prices in the composite index in 2010 (14.2%, see Table 1) means that the value of this indicator dominated the energy affordability index.

Table 2 Energy security performance indicators

		Austria		Portugal		Spain		Switzerland		Finland		Sweden		Denmark		Italy		Germany		Ireland	
		2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Composite indices																					
Energy Security (CESI)		86	77	80	77	78	76	84	76	81	75	84	75	80	73	78	73	78	73	78	72
	Availability	91	84	85	86	87	88	87	82	92	90	89	84	88	85	88	84	89	87	86	81
	Affordability	88	67	85	64	83	65	88	65	82	61	84	59	86	61	84	62	84	60	88	63
	Acceptability	79	83	68	82	62	76	75	82	70	73	78	83	62	75	62	74	58	70	58	70
Raw data on individual indicators*																					
Availability	Access to electricity (+)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Diversity of electricity supply (-)	0.5	0.4	0.2	0.2	0.2	0.2	0.5	0.5	0.2	0.2	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4
	Dependent on traditional energy (-)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Diversity of primary energy supply (-)	0.2	0.2	0.4	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.3	0.4
	Energy import dependency (-)	65.7	64.5	84.4	75.3	74.1	73.0	51.9	51.8	53.9	52.2	35.8	35.0	-48.8	-19.9	83.6	82.7	59.8	60.7	84.4	87.2
	Diversity of end-use energy consumption (-)	0.3	0.3	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.5	0.4
	Value of energy reserves (+)	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	1.8	0.2	0.1	0.1	0.1	0.1	0.0
	Domestic energy production (+)	1.2	1.4	0.4	0.5	0.8	0.7	1.7	1.6	2.9	3.3	3.4	3.5	5.2	4.2	0.5	0.6	1.6	1.6	0.6	0.4
Affordability	Energy prices (-)	0.8	1.6	0.7	1.7	0.7	1.5	0.8	1.7	1.0	1.8	0.9	1.8	1.0	1.9	0.9	1.8	0.8	1.8	0.7	1.7
	Primary energy intensity (-)	4.0	4.1	4.0	3.6	4.2	3.6	3.1	2.8	7.9	7.6	6.4	5.6	3.6	3.5	3.6	3.5	4.8	4.2	3.8	3.1
	Economy-wide energy efficiency (+)	82.4	81.7	78.8	80.5	70.1	73.3	78.3	80.3	76.2	73.3	74.2	68.7	76.4	77.7	75.1	76.2	68.7	69.3	77.1	78.1
	Network losses (-)	5.3	4.9	8.4	8.0	8.7	9.2	6.2	6.6	3.8	3.4	7.4	7.1	5.8	6.8	7.1	6.9	6.0	3.8	8.5	7.4
	Value of energy imports (-)	5.5	11.0	10.4	14.1	12.2	18.5	4.6	7.5	11.9	18.4	9.1	13.4	5.7	7.8	9.8	18.6	8.6	11.5	4.1	12.2
	End-use energy intensity (-)	3.0	3.2	2.8	2.6	2.6	2.4	2.4	2.2	5.8	5.2	4.5	3.6	2.7	2.7	2.6	2.5	2.9	2.7	2.8	2.4
	Thermal efficiency (+)	49.9	58.1	43.6	50.3	41.2	49.0	82.3	80.2	65.3	59.9	74.4	84.0	64.8	68.1	42.2	50.1	42.0	44.5	40.7	47.1
Acceptability	Greenhouse-gas emissions (-)	7.8	8.1	6.1	4.6	7.3	5.8	5.4	5.0	10.1	11.5	5.6	5.5	9.6	8.4	7.9	6.8	10.1	9.3	10.8	8.8
	Renewable-based electricity production (+)	72.5	66.2	29.7	52.8	15.6	32.8	57.0	56.7	33.4	30.0	57.2	55.3	15.5	32.0	18.9	25.8	6.1	16.7	5.0	13.1
	Indoor air pollution (-)	0.2	0.1	0.2	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.1	0.3	0.2	0.3	0.2	0.1	0.1
	Carbon intensity of GDP (-)	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.3	0.3	0.2	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2
	Renewable energy consumption (+)	26.5	31.4	20.1	27.8	7.9	14.4	18.4	21.2	31.6	33.5	40.0	46.0	10.7	21.3	5.1	10.1	3.7	10.6	2.0	5.3
	Carbon intensity of fuel (-)	2.2	2.0	2.6	2.0	2.4	2.1	1.6	1.5	1.6	1.7	1.0	1.0	2.8	2.4	2.6	2.4	2.5	2.3	3.0	2.8

		Belgium		UK		Greece		Netherlands		Norway		France		Luxembourg		WORLD	
		2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Composite indices																	
Energy Security (CESI)		77	71	77	70	75	70	77	69	88	69	78	69	80	67	76	71
	Availability	88	83	89	85	82	82	87	80	87	70	88	78	83	66	74	69
	Affordability	84	61	83	57	81	58	84	60	86	55	82	57	89	72	82	70
	Acceptability	56	67	57	69	59	71	58	67	91	88	63	72	66	61	70	77
Raw data on individual indicators*																	
Availability	Access to electricity (+)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	71.1	74.5
	Diversity of electricity supply (-)	0.4	0.4	0.3	0.3	0.5	0.3	0.4	0.5	1.0	0.9	0.6	0.6	0.4	0.8	0.6	0.6
	Dependent on traditional energy (-)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.2	18.7
	Diversity of primary energy supply (-)	0.3	0.3	0.3	0.3	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.7	0.7	0.3	0.3
	Energy import dependency (-)	76.6	74.5	-22.2	26.7	63.1	65.8	21.4	16.3	-771.5	-511.9	48.1	48.1	98.1	97.1	-26.1	-18.8
	Diversity of end-use energy consumption (-)	0.4	0.3	0.3	0.3	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.5	0.3	0.3
	Value of energy reserves (+)	0.0	0.0	1.8	1.3	0.0	0.0	1.2	0.9	15.7	10.3	0.0	0.0	0.0	0.0	4.1	3.8
	Domestic energy production (+)	1.3	1.4	4.6	2.4	0.9	0.8	3.6	4.2	50.8	42.5	2.1	2.1	0.1	0.2	3.0	2.8
Affordability	Energy prices (-)	0.9	1.7	1.2	2.0	0.7	1.9	0.9	1.9	1.2	2.1	0.9	1.9	0.7	1.5	0.6	1.2
	Primary energy intensity (-)	6.5	5.9	5.0	3.9	4.3	3.6	4.9	4.9	4.2	4.5	5.1	4.7	4.0	3.9	7.3	6.4
	Economy-wide energy efficiency (+)	70.7	68.5	67.5	68.1	68.1	70.5	77.4	77.6	75.9	65.9	64.7	62.1	97.0	92.0	45.0	45.0
	Network losses (-)	4.6	4.6	8.3	7.0	8.0	6.6	4.6	3.8	8.2	7.7	5.7	6.3	9.7	3.8	9.8	9.1
	Value of energy imports (-)	8.8	13.8	4.1	10.2	13.5	24.5	9.8	15.7	3.5	6.6	10.0	14.0	6.7	10.0	10.6	13.3
	End-use energy intensity (-)	3.9	3.4	3.1	2.5	2.8	2.4	3.1	2.9	2.8	2.6	3.0	2.7	3.8	3.6	4.6	3.8
	Thermal efficiency (+)	46.8	55.7	0.0	0.0	36.7	36.3	59.6	59.7	66.4	54.1	44.9	42.6	45.5	57.1	23.4	24.9
Acceptability	Greenhouse-gas emissions (-)	11.2	9.9	9.2	7.9	8.5	7.5	10.4	10.9	8.8	12.3	5.9	5.4	18.9	21.6	4.4	4.8
	Renewable-based electricity production (+)	1.3	6.9	2.7	6.8	7.8	18.3	3.3	9.5	99.7	95.7	13.1	13.8	41.0	8.3	28.1	27.6
	Indoor air pollution (-)	0.3	0.2	0.2	0.1	0.3	0.3	0.2	0.2	0.1	0.0	0.2	0.2	0.3	0.2	0.6	0.4
	Carbon intensity of GDP (-)	0.3	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.3	0.2
	Renewable energy consumption (+)	1.4	5.2	1.0	3.2	7.5	11.1	1.5	3.6	60.2	56.3	9.2	12.2	6.9	3.7	30.1	28.0
	Carbon intensity of fuel (-)	2.0	1.8	2.4	2.4	3.4	3.0	2.3	2.2	1.5	1.8	1.4	1.3	2.5	2.6	2.0	2.1

Notes: * Measurement units for the indicators are provided in Table 2. Signs in the bracket represents the attributes of indicators, where '+' indicates that indicator with a higher value has a more favourable outcome, and '-' indicates that indicator with a lower value has a more favourable outcome.

Sources: The sources of raw data are provided in Table 2; composite indices are based on authors' estimates.

- In terms of energy acceptability index, just five (out of 17) European countries scored higher than the world average of 77 in 2010. These are Austria, Portugal, Switzerland, Sweden and Norway. This implies that the energy systems in most European countries are relatively less clean. Despite having relatively lesser indoor air pollution that arise from fossil fuel combustion, the amount of per-capita greenhouse-gas emissions from most European countries are higher than the world average (4.8 tonnes per person); Portugal is the only exception. Further, the above noted five countries have a greater share of renewables in total energy consumption (more than 28%), compared with the world average.

- Over the period between 2000 and 2010, all European countries experienced deterioration in energy security. That is, the composite energy security index declined in all countries included in this paper. Most of the decline was experienced by Norway where energy security decreased from 88 in 2000 (the most energy-secure in the world), to 69 in 2010. Decreased energy affordability is the main reason for reduced energy security in Norway (in fact, in all European countries). Norway and Luxembourg are the only two countries that experienced reduced energy security in all dimensions (availability, affordability and acceptability) over the period between 2000 and 2010.

- The country that was least affected by reduced energy security is Spain where energy security decreased from 78 in 2000, to 76 in 2010. While it has experienced significant gains in energy acceptability (from 62, to 76) due to the significant increase in the share of renewables in total electricity generation (from 15.6% in 2000, to 32.8% in 2010), this was totally offset by decreased in energy affordability, specifically as a result of doubling petrol prices and increased in the value of oil imports.

4.2. Energy-Water-Food Security Nexus

This subsection applies the composite energy security index with composite water and food security indices to further examine the nature of nexus between energy, water and food security; whether the security nexus presents a coupling effect, or exhibits a tradeoff.

At the macro-level, the estimated pairwise-correlation coefficients, which are used to inform energy-water-food security nexus, are as follows.

- Energy-Water security nexus: +0.19
- Energy-Food security nexus: +0.81
- Water-Food security nexus: +0.42

The magnitude of the estimated correlation coefficients (ρ) is diverse, but has positive signs. This suggests that the overall interactions between energy, water and food security are all positive, and thus presence some coupling effects in the nexus. That is, improving security in one area is likely to be associated with improved security in other areas. In particular, the coupling effect in the energy-food security nexus is quite strong (i.e., $\rho \geq 0.6$). The coupling effect in the water-food nexus is moderate (i.e., $0.4<\rho<0.6$), while that in energy-water security nexus is weak (i.e., $\rho<0.4$).

The granger causality test, which is typical used to show the direction of the relationship between two variables, is summarized in Table 3.

Table 3 Energy-water-food security nexus in European countries: Causality test results

Test cases	Observation	Null Hypothesis:	F-statistics	Causality decision
Energy-Water security nexus	40	ES does not cause WS	0.26	WS → ES
		WS does not cause ES	7.55*	
Energy-Food security nexus	17	ES does not cause FS	0.12	FS → ES
		FS does not cause ES	5.51*	
Water-Food security nexus	17	WS does not cause FS	0.19	WS — FS
		FS does not cause WS	0.83	

*Notes: * indicates the hypotheses are rejected at 5% significance level, → and ← indicate unidirectional causality, ↔ indicates bidirectional/feedback causality, — indicates no causality.*

The results presented in this table suggest the following:

- Improvement in energy security is conditioned upon an improvement in water security. However, increased energy security may not always lead to increased water security.
- Increased food security is likely to result in increased energy security, but not the opposite.
- No clear causal relationship can be determined between water security and food security. However the correlation between this pair is moderate (+0.42), implying a possibility of two-way causal interactions.

However, the number of observations undertaken in this analysis is limited. Therefore there is a need to increase the observation in order to obtain meaningful results. Further, the analysis undertaken in this subsection suggests that further refinement and grouping of countries may be needed to check the robustness of these interactions.

5. Conclusions

This paper employs the mean-variance analysis method to develop composite indices for assessing the state of energy security of 17 European countries between 2000 and 2010. The indices are classified into three broad dimensions of energy security – availability, affordability and acceptability. These indices are then used to examine the nature of interactions that energy security has on water and food securities.

This paper demonstrates that a simple tool such as a composite security index is an important first-step to develop an in-depth and a comprehensive understanding of energy security in order to deal with this challenge. The results in this paper provide insights into the state of energy security across the select European countries, the factors that contribute to insecurity, and the effect that energy security may have on water and food security. These results can be used to enable monitoring of countries' security performance over time, convey policy messages that can help policy-makers to prioritise security concerns that are specific to their countries, and to support policy dialogue aiming to improve energy-water-food security.

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