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# Developing and exploring indicators of water sustainable development

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ABSTRACT

The pressures of rapid economic growth, population increase, and global warming are stretching the availabilities of natural freshwater sources which have implications for economic prosperity and human life. Water resources are entwined in a complex socio-economic system, affected by water demands as well as the environmental implications of pollution and waste discharges. Drawing on existing measures of social and economic wellbeing, this research presents the development of indicators that place economic growth within the context of social and environmental development, presenting a measure that assesses how water resources are used in a manner that is efficient and beneficial to society as a whole. From a study of 37 nations, the findings show that in countries with relatively high (by global standards) economic and social development, there is a discrepancy between social development and the productive use of water resources. This opens up potential applications for policy makers and industry leaders to monitor and measure their progress towards water sustainable practices and enable international comparisons of water sustainable development.

## 1. Introduction

The global economic system is contributing towards an environmental crisis, arising from the pressures of economic growth, rapid population increase and a warming of the global climatic system (UN, 1987; Whiteman et al., 2013; IPCC, 2014; Broman and Robèrt, 2017). These changes have been accompanied by a substantial depletion of natural resources and degradation of ecosystems, manifesting in negative impacts on human-life and implications for the planet as a whole (Rockström et al., 2009; Ridoutt and Pfister, 2010). Many global policy leaders currently recognise the challenges of climate change and declining biodiversity as well as continued poverty and social inequality but are often accused of underestimating the magnitude of these challenges (Broman and Robèrt, 2017). One area where sustainability challenges are overlooked is in freshwater consumption, which is important given that water is a resource which is crucial for supporting human life. Water is also crucial for providing ecological functions and value for economic activities yet many countries around the world are experiencing water stresses and scarcities as the demand for water increases at rates which outstrip traditional sources of supply. It is estimated that by the year 2030, more than 160% of the total available water volume in the world will be required to satisfy global water requirements (Lavrnić et al., 2017) and that 47% of the world's population will be living in high areas of water stress (UNESCO, 2017). Forecasts from organizations such as the European Union project that global water demand is expected to increase by up to 60% by 2025 and possibly double by 2050 (Commission of the European Union, 2012). Indeed, Governments in countries popularly thought to be in water abundance such as the UK are warning that a changing climate is bringing more volatile and extreme weather patterns, including severe droughts, floods, and extremes of rainfall and cold weather (Cabinet Office, 2015) yet there is little focus on how consumption of freshwater impacts on economic and social sustainability (Aznar-Sánchez et al., 2018). This is a crucial point given that the distribution of freshwater is projected to become a prominent issue in sustainability circles. The UN forecasts that water scarcity currently affects 40% of the global population (Xiao et al., 2017), whilst the Intergovernmental Panel on Climate Change (IPCC) note a projected increase in drought affected areas will impact on a number of economic and societal functions including energy production, agriculture, and health (IPCC, 2014). This reveals the integral role of water to most societal institutions – e.g. economic, political, religious, and leisure (Bithas, 2008; Proskuryakova et al., 2018).

At present there lacks a framework for monitoring and measuring the efficient water usage that enables these institutions to operate and

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develop and links to the three pillar idea of sustainable development: ecological (the idea of staying within a biophysical carrying capacity); social (providing a society constructed on the values that people wish to live by), and economic (providing an adequate material standard of living) (Azar et al., 1996; Ostrom, 2009). Defining a sustainability concept to address environmental, economic, and social components of water resource use and providing mechanisms to measure and monitor such a concept is of utmost importance (Hák et al., 2018). The advantages of defining the components of such a concept and providing tools to measure progress against it would aid in gaining acceptance for policy interventions to address water sustainability challenges. Gaining this acceptance as been difficult, particularly in countries and regions that are not traditionally associated with water scarcity. The European Union has implemented policies to safeguard water sources, its key policy being the Water Framework Directive (WFD – EU Directive, 2000/60/EC) which highlights the prime objective of sustainable use and management of water resources, stating that all EU countries must reduce water pollution and implement measures to conform to the WFD objective for water quality protection for the future (Commission of the European Union, 2000, 2012; Bithas, 2008).

The water framework directive includes legally binding provisions in a flexible framework for comparing and assessing policy options based on economic criteria (Bouleau and Pont, 2015) and there exists opportunities to configure environmental policies to create positive social outcomes, as highlighted by the Intergovernmental Panel on Climate Change (IPCC), who state (2014, p. 5):

> “Climate policy intersects with other societal goals creating the possibility of co-benefits or adverse side- effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action”.

These visions however still highlight development by placing emphasis on economic growth, and what is required is the incorporation of social development and sustainability. In addition to concerns of depleted resources and environmental damage resulting from economic growth, there is a growing body of literature that questions whether the pursuit of economic growth is generating the quality of life benefits. The aim of this paper is to quantify the concept of ‘water sustainable development’ which could have applications for policy makers and industry leaders alike to pursue sustainable water policies, drawing on ideas of the original conception of sustainable development and industrial ecology that ensures increased water consumption is accompanied by economic and social development. The remaining paper is structured as follows: firstly, the challenges of defining and measuring sustainability are discussed then in the following sections water consumption in 37 countries is investigated and correlated against social and economic development factors to would help to justify how steps taken to improve the efficient usage of water is of benefit to the economy and to wider society. Finally, the paper concludes by identifying the countries that are efficiently and sustainably consuming water to develop economic and social benefits and comparing the proposed indicators against existing measures of macro-economic sustainability.

## 2. Background

Ideas of water sustainability can be conceptualised by drawing on political discourses that reconcile economic growth with environmental conservation (Cini, 1995; Bouleau and Pont, 2015). Linking economic growth to water sustainability is linked to ideas of institutional, market and social reform that leads to the development of a more harmonious and mutually reinforcing relationship between economic development, environmental protection and social development (Korhonen, 2008; Bailey and Caprotti, 2014). This draws on theoretical frameworks of industrial ecology and ecological modernization. Both approaches draw parallels with the Jevon's Paradox (Jevons, 1866). Using the case of coal, Jevons observed that although the coal industry had become more efficient and therefore possible to produce more volume of a product per unit of coal, the total coal consumption increased (Alcott, 2005; Szigeti et al., 2017). Under this paradox, the ‘rebound effect’ arises, whereby the increase of eco-efficiency (by generating more outputs from the same number of inputs) alone is insufficient to increase sustainability (Szigeti et al., 2017). Therefore, measurements of sustainable development should go beyond measuring the eco-efficiency of resource use. Ultimately sustainable development must encompass eco-efficiency but also ensure that improvements in the efficient use of resources are backed up with improvements in economic and social development.

Braungart et al. (2007) rightfully point out that resource efficiency on its own will not produce long term frameworks to alleviate unsustainable economic practices and processes and there is a clear need to add further measures of environmental and social measures to sustainability indicators. For example, the industrial ecology perspective explores the possibilities transforming production processes to reduce the impacts on the environment (York et al., 2003). This takes a focus on six key areas which overall can be applied to sustainable water consumption, often aimed towards business strategies, such as: eco-efficiency, use of technological innovation to solve problems, systems thinking. The concept applies biological analogies in which industrial systems are imagined as complex industrial ecosystems that exist in symbiosis with larger social and biophysical environments (Sullivan et al., 2018). Here it is the ability of business to pursue economic advantages from efficient uses of water resources that can feed into achieving national sustainable development strategies (Sullivan et al., 2018) at a macroeconomic level. Similarly, the Ecological Modernization concept follows similar approach but emphasises the role of technology and innovation in decoupling economic growth from resource depletion environmental degradation (Hovardas, 2016; Bergendahl et al., 2018). Ecological Modernization is therefore more dependent on government and industry identifying and adopting technological innovations to address environmental sustainability concerns (Bergendahl et al., 2018). Under these perspectives, improving the efficiency of water resources will maintain available resource supplies and reduce environmental damage (Gibbs, 2006; Korhonen, 2008) and enables associated governmental and business actors to drive efficient, sustainable resource use alongside the maximisation of social sustainability. There has been a degree of development on water governance regimes around the world that aim to optimize economic and social welfare without compromising the long term functioning and integrity of ecosystems (Azar et al., 1996; Selomane et al., 2015). Ecological Modernization and Industrial Ecology frameworks can be applied to sustainability indicators in a practical sense and overcome a deficiency in sustainability research, a view best highlighted by Bellamy et al. (2001, p. 408), who states:

> “Significantly, no clear evaluative frameworks have emerged to guide continuous program development in the way national resource initiatives contribute to on-going improvement in resource use sustainability and social well-being of communities concerned”.

This research builds upon previous measures of social sustainability such as the Human Development Index (HDI), an annual measure of Human Development for each country first developed by the United Nations Development Programme in 1990 (UNDP, 2014) as am attempt to recognise that ‘development’ is more than just the expansion of income and wealth. The HDI measures the way in which income and wealth are able to improve society (Sagar and Najam, 1998). However there have been mixed responses to the HDI (Sagar and Najam, 1998; Neumayer, 2001; Hezri and Dovers, 2006; Bravo, 2014), particularly as a true alternative to using income measures such as GDP as a measure of a country's progress due to the lack of consideration of environmental sustainability measures (Sagar and Najam, 1998; Neumayer, 2001). It is possible to incorporate sustainability components by modifying the composition of the HDI by adding freely available data such as carbon emissions (Bravo, 2014) or material efficiency (Koh et al., 2016).

### *2.1. Conceptualising water sustainability*

To monitor the sustainable consumption of water it is first crucial to define what is meant by sustainability. The Brundtland Commission on Environment and Development (UN, 1987) defined Sustainable development (SD) as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’, necessitating that the three pillars sustainable development should be assigned equal importance (Tate and Bals, 2016) to address global resource challenges (Togtokh, 2011; Selomane et al., 2015; Koh et al., 2016). In order to develop an indicator which measures water sustainability, Bithas (2008) defines sustainable water use as requiring the satisfaction of two distinct conditions where aggregate water consumption in an economy should follow the ‘optimum use’ as any further consumption would lead to greater social costs than benefits and therefore a sub-optimal result; and that aggregate water consumption should be allocated fairly among users.

Previous attempts at measuring water sustainability have utilised methodological procedures such as Life Cycle Assessment (LCA) of products (Hoekstra, 2016), where environmental (and increasingly social) impacts can be assigned to stages of a products’ lifecycle to identify opportunities for sustainability interventions. For policy-makers there may be difficulties with collecting the necessary data to measure and monitor freshwater consumption; the different types of water (e.g. blue water, green water, grey water); how to combine this with measures of economic and societal well-being; and dealing with the volume of indicators that measure water consumption, and associated factors such as stress and scarcity (Liu et al., 2017).

At a policy level, the water component of the European Union's Resource-efficiency Roadmap (Commission of the European Union, 2011) gives a good foundation for the development of a water-efficiency indicator for its member states. Improved water resource productivity and eco-efficiency techniques towards water consumption are not necessarily concerned with consuming less, but with consuming water in a more efficient way, and socially equitable way, placing the risks of future water shortages in the context of a political process to manage natural resources whilst maintaining economic and societal progress (Haughton, 1998). Using natural resources more efficiently is deemed as a necessary step to avoid scarcities and achieve environmental targets such as preserving ecological assets (Huysman et al., 2015). The choice of geographic scales has a significant impact on the assessment, leading to ambiguous conclusions from the quantification of freshwater impacts at local, regional, and national level (Hybel et al., 2015).

Integrating both social and environmental impacts into water sustainability assessments is important as the good living standards is only possible if natural resources can be sustained into the future (Vanhulst and Beling, 2014). Previous studies can be built upon in order to develop the necessary indicators. For example, Togtokh (2011) proposed an environmental dimension to be added to the human development index, arguing that ‘in the current HDI, developed nations and oil-rich countries are placed highly without regard to how much their development paths cost the planet and imperil humanity's future development’ (p269) and introduced the human sustainable development index (HDSI). Developing this further, Bravo (2014)'s study in constructed a modified version of the human development index and concluded that the HSDI remains insufficient in its representation of environmental sustainability and requires a better equilibrium between social, economic and environmental goals. Taking these studies as a starting point, the HSDI can be updated to incorporate water efficiency as opposed to carbon efficiency to provide a baseline understanding of water and social resilience. The intention is that this indicator can be built and refined as further data becomes available.

### *2.2. Measuring and monitoring water-sustainable development*

Previous attempts to identify measures of water sustainability draw on the idea of the ecological footprint. The ecological footprint is expressed in terms of the biologically productive area required to support human activity, an indication of overall general sustainability levels within a country (Wackernagel et al., 1999; Galli et al., 2012). It can be applied to single products, cities and regions, and to the world as a whole (Ewing, 2008). In arrowing the focus, the Water Footprint applies the ecological footprint concept specifically to water consumption and management to highlight the importance of water consumption in good water governance (Galli et al., 2012; Hoekstra and Mekonnen, 2012). At a national level the water footprint (expressed as the sum of green, blue, and grey water consumption)[2] is calculated across agricultural, industrial and domestic consumers and expressed in terms of $m^3$ per capita per year (Hoekstra and Mekonnen, 2012). Whilst this indicator has many uses in sustainability topics, it does not contain a social or economic element embedded within it to assess the productive use of water consumption. I International organisations such as the OECD, World Bank and European Union have been prominent in developing environmental indicators that express water consumption as part of an ‘eco-efficiency’ measure that follows the framework of ecological modernization. For example, the OECD's ‘green growth indicators’ are created from synthesising official statistics of the OECD member states covering the entire economy (OECD, 2014). This provides a large amount of data sources covering four key areas of the economy:

- Resource Productivity – the efficient uses of carbon, energy and material resources
- Maintenance of the Natural Asset Base – the levels of depletion of renewable and natural resources including freshwater, biodiversity, animal and plant species
- Benefit to Society – the benefit to people from improvements in the environment such as waste treatment, water sanitisation, and reductions in air pollution
- Economic Opportunities – the economic benefits from pursuing environmental sustainability, including environmental research and development investment and environmental taxes

The resource productivity statistics are potentially the most useful but are, at the time of writing, not sufficiently developed in terms of water consumption and this paper aims to demonstrate the usefulness of such an indicator. The aim of this paper is to demonstrate a new method for assessing sustainable water consumption that utilises widely available national statistics and through a methodological process which is designed in order to assist policymakers identify how their water efficiency policies impact on wider society. Developing an indicator that fully encompasses water sustainability can help identify and quantify these water sustainability challenges and impacts at a policy and governance level. The simplicity of the indicator could encouraging practices that not only protects water resources but generate a combination of beneficial economic and social outcomes (Fritz and Koch, 2014). The method would remove the need for the collection of large databases of statistics on different types of water footprints and end-users of water, but instead would provide an overview of a country's efficient use of water resources. To achieve this aim, the paper seeks to answer the following questions:

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[2] Water footprinting is split into three categories of water. Green water refers to water from precipitation; Blue water refers to water withdrawn from rivers and aquifers; Gray water refers to the freshwater pollution, defined as the volume of freshwater required to assimilate pollutants based on existing water quality standards (Hoekstra and Mekonnen, 2012).

- What is the relationship between freshwater consumption and societal well-being (as defined by the human development index)?
- What can be inferred from the development of indicators which combine these measures?
- How does a water sustainable development index compare to existing macro-level measures of sustainability?

## 3. Materials and methods

This research proposes a new method for quantifying the systemic impacts of water efficiency through measuring the generation of economic and social impacts from water consumption. As this framework focuses on the effective use of key resources, as opposed to prescribing limits on absolute resource consumption, this provides a new approach in quantifying water sustainability of economies. It is embedded in the belief that resource scarcity can be overcome over time through increased efficiency in consumption, and that resource use can be better aligned to meet economic and social objectives. The indicators developed in this research firstly evaluate the sustainable use of environmental resources to create the Water Productivity Index (WPI), and secondly compares this to measures of social well-being, the Social Development Index (SDI) - a modified version of the human development index following the examples of Bravo (2014) and Koh et al. (2016). These two indices can then be combined to create the Water Sustainable Development Index (WSDI).

### 3.1. Water indicators

The WSDI will enable comparisons between water sustainability will enable international comparisons of water consumption performances, the nature of these indicators will also allow for comparisons between the relative social components of that underpin water sustainability, as well as proposing alternative scenarios for environmental and social performance as a result of future trends in resource efficiency – business as usual, converging growth rates, and steady economic growth rates. Unlike previous research by Koh et al. (2016) which follow this framework for assessing macro-economic material productivity which is specifically applied to assessments of supply chains at the micro-economic level, this research focuses exclusively on water consumption at a macro-economic level with applications for policy makers at a macro-economic level. The World Bank (2018) produces contains indicators specifically covering water consumption levels via freshwater[3] abstraction per unit of GDP (expressed in US dollars at 2010 prices), a form of the resource productivity statistics given in the OECD's green growth database for carbon, energy, and material consumption. To demonstrate how indicators could be developed and utilised, this study uses data for the year 2007 as this gave the greatest range of data available (37 countries) and therefore enabled a larger sample for the demonstration of the methodology (World Bank, 2018). In using this indicator, water efficiency (in economic terms) would be demonstrated by increases in the amount of GDP generated from the same volume of water resources and provides a view to which extent water is used for productive purposes. Several limitations exist in this data set, there is sporadic collection of this data by countries, and inconsistencies in the years provided.

### 3.2. Human development index

The Human Development Index was first proposed as a method to assess human development and sustainability that can serve as an alternative measure to economic growth that assesses an economies development. The Human Development index provides a ready-made measure of social sustainability that is widely used and widely recognised (Togtokh, 2011; Bravo, 2014). From 2010, the UNDP began using a new method of calculating the HDI, using measures of income, education, and health of the population of countries. In the case of education and health the same parameters are used as those by the UN in the calculation for the Human Development Index, whilst the income index follows the methodology of Koh et al. (2016), to ensure the GDP component used in the Social Development Index is consistent with the GDP measures embedded within the water productivity statistics:

Eq. (1) Life Expectancy Index (LEI)

$$LEI = \frac{LE - 20}{85 - 20} \tag{1}$$

Where LE = Life Expectancy at birth (years).

Eq. (2) Education Index (EI):

$$EI = 0.5\left(\frac{MYS}{15} + \frac{EYS}{18}\right) \tag{2}$$

Where MYS = Mean years of schooling (Years that a 25-year-old person or older has spent in schools) and EYS= Expected years of schooling (Years that a 5-year-old child will spend with his education in his whole life).

Eq. (3) Income Index (II):

$$II = \frac{\ln(GNIpc) - \ln(100)}{\ln(75,000) - \ln(100)} \tag{3}$$

Where GNIpc: Gross national income at purchasing power parity per capita

Recorded income is capped at $75,000 and a natural logarithmic transformation is applied to reflect diminishing returns to increased income (UNDP, 2014). The Human Development index is then the geometric mean of the above three indices:

Eq. (4) Human Development Index

$$HDI = \sqrt[3]{LEI \cdot EI \cdot II} \tag{4}$$

Attempts to integrate the human development index with environmental indicators have previously been attempted in sustainability research but none has comprehensively addressed the full resource efficiency approach. To create the WSDI, the countries and variables available in the World Bank database for 2007 were selected. Since there is no comprehensive resource for water consumption. The following sections present the methodological followed during the investigation for the construction of the indicator. The development of the indices is structured around the following stages: selection of the variables; the aggregation processes; and the comparison against other variables.

### 3.3. Materials

Data sources covering environmental, social, and economic indicators were collected from sources described in Table.1. Water productivity provides a view to which extent water is used for productive purposes. Increasing values in time series indicate decoupling of the economic growth from water use. It does not necessarily indicate decline in total water use or decline of the (regional) impact of water use.

### 3.4. Building indices

The Water Sustainable Development Index is built from components describing water productivity (the water productivity index based on water productivity statistics) and social development (indices created from life expectancy and education statistics). Economic sustainability is embedded within calculations of water productivity and human sustainable development. Each component index was built using the same formula, as shown in Eq. (5):

Eq. (5) Index Calculation Formula:

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[3] Water productivity is calculated as GDP in constant prices divided by annual total water withdrawal(Eurostat, 2015).

**Table 1**
Data sources used in study.

| Original Data Source | Published Variables | Description | Year(s) | Frequency of Update |
|---|---|---|---|---|
| World Bank (2018) | Water Productivity | Water productivity is gross domestic product (GDP) divided by the total annual fresh water abstraction. | 2007 | Annual |
| | GDP Per Capita ($ 2010 Prices) | GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2010 U.S. dollars | 2007 | Annual |
| Barro and Lee (2013) | Mean Education Attainment | Average number of years of education received by people ages 25 and older, converted from education attainment levels using official durations of each level. | 2005, 2010 | 5-Yearly |
| UNESCO (2013) | Expected Education Attainment | Number of years of schooling that a child of school entrance age can expect to receive if prevailing patterns of age-specific enrolment rates persist throughout the child's life. | 2005–2009 | Sporadic |
| UNDESA (2013) | Life Expectancy at Birth | Number of years a newborn infant could expect to live if prevailing patterns of age-specific mortality rates at the time of birth stay the same throughout the infant's life. | 2005–2009 | Annual |

$$x\ index = \frac{x - \min(x)}{\max(x) - \min(x)} \tag{5}$$

Where x = the component of resource efficiency being measured, min(x) = minimum value of x over the observed period, max(x) = maximum value of x over the observed period

### 3.5. *Integrating indices*

To ensure consistency in the economic data used throughout the generation of the WSDI is to use the income index methodology from the pre-2010 human development index. The Water Sustainable Development Index is shown in Eq. (6):

Eq. (6) Water Sustainable Development Index

$$WSDI = \sqrt[4]{WPI \cdot LEI \cdot EI \cdot II} \tag{6}$$

Where WSDI = Water Sustainable Development Index; WPI = Water Productivity Index; LEI = Life Expectancy Index; EI = Education Index; II = Income Index

This analysis follows the examples of Togtokh (2011) and Bravo (2014) which apply equal weight to the environmental components to each of the sub-components of the human development index and take a geometric mean of each of the components. The social component (the Social Development Index - SDI) can be calculated by taking the geometric mean of LEI, EI and II.

### 3.6. *Cluster analysis*

Cluster analysis was carried out to test whether countries could be classified into groups based on their relative levels of economic and social prosperity and levels of sustainable water development. Cluster analysis is a statistical method used to classify elements (countries) according to similar characteristics for which information is provided - quantitative measures of economic, social, and levels of water sustainability development. By calculating the similarity of each element to the others, homogenous groups of elements can be identified. These so-called 'clusters' share similar characteristics and differ significantly from the other clusters. A hierarchical cluster analysis, which is a bottom up approach was run, using the Ward's method (Ward, 1963). The optimal level of clusters was chosen after examining the agglomeration schedule and identifying where the kink in the graph occurs.

## 4. Results

### 4.1. *Measuring policy successes in countries*

Table 2 orders the countries according to their Water Sustainable Development Index in 2007. The results show a marked decline in WSDI values, dropping from 0.94 of Denmark in first place to 0.68 of Norway in $5^{th}$ place. The bottom 25% of countries have a value of less than 0.3 for the WSDI and highlights a low level of performance in water productivity in all countries. The figures for the WPI show steep decline from Denmark's high score of 1, with only Ireland having a WPI score greater than 0.5, closely followed by the UK (WPI of 0.49). The value of the WSDI is influenced by the water productivity measures given that the lowest score for the SDI outside of Zimbabwe in last place is that of Armenia which scores 0.61.

As seen in Fig. 1, the majority of countries are clustered to the right of the graph, indicating greater levels of social development compared to water sustainability. What this framework indicates is that effective sustainable uses of water can be framed in a wider 'triple bottom line' sense of sustainability that incorporates economic, environmental (in the case of water), and social development, and should provoke a rethink to development strategies that incorporate a response to concerns over future water availability and scarcity. The developed indicator proposes that the efficient use of water is not just concerned with water consumption but is a function of economic growth and the productive use of water in order to attain such a level of economic growth, and how the effective use of natural resources is essential to the survival of human society.

### 4.2. *Cluster analysis*

A hierarchical cluster analysis was conducted using Ward's method with a squared Euclidean distance measure on the standardised visual control variables. Plotting the agglomeration schedule (see Fig. 2) identified six clusters as the optimum number and therefore analysis proceeded with a six-cluster solution with the results shown in Table.3.

Group 1 is composed of 12 countries across 4 continents, these countries have relatively lower incomes, as well as having lower levels of water productivity, and life expectancy, which in turn gives these

**Table 2**
Water sustainability ranking of nations 2007.

| | | WSI | SDI | WSDI | | | WSI | SDI | WSDI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Denmark | 1.00 | 0.93 | 0.94 | 20 | Poland | 0.06 | 0.76 | 0.40 |
| 2 | Ireland | 0.54 | 0.94 | 0.82 | 21 | Portugal | 0.04 | 0.82 | 0.39 |
| 3 | United Kingdom | 0.49 | 0.91 | 0.78 | 22 | Hungary | 0.04 | 0.77 | 0.36 |
| 4 | Sweden | 0.31 | 0.92 | 0.70 | 23 | Romania | 0.04 | 0.70 | 0.33 |
| 5 | Norway | 0.23 | 0.97 | 0.68 | 24 | Lithuania | 0.03 | 0.77 | 0.33 |
| 6 | Malta | 0.42 | 0.80 | 0.68 | 25 | Estonia | 0.02 | 0.81 | 0.31 |
| 7 | Cyprus | 0.25 | 0.82 | 0.61 | 26 | Jordan | 0.04 | 0.61 | 0.30 |
| 8 | Germany | 0.17 | 0.90 | 0.60 | 27 | Venezuela | 0.02 | 0.70 | 0.30 |
| 9 | Latvia | 0.24 | 0.77 | 0.58 | 28 | Jamaica | 0.02 | 0.63 | 0.28 |
| 10 | France | 0.14 | 0.90 | 0.56 | 29 | Mexico | 0.02 | 0.70 | 0.28 |
| 11 | Netherlands | 0.12 | 0.92 | 0.56 | 30 | Cuba | 0.02 | 0.73 | 0.28 |
| 12 | Slovak Republic | 0.20 | 0.78 | 0.56 | 31 | Serbia | 0.01 | 0.67 | 0.24 |
| 13 | Czech Republic | 0.17 | 0.82 | 0.55 | 32 | Bulgaria | 0.01 | 0.67 | 0.23 |
| 14 | Belgium | 0.12 | 0.89 | 0.55 | 33 | Kazakhstan | 0.01 | 0.67 | 0.21 |
| 15 | Japan | 0.11 | 0.89 | 0.53 | 34 | China | 0.01 | 0.56 | 0.20 |
| 16 | Slovenia | 0.08 | 0.86 | 0.48 | 35 | Thailand | 0.00 | 0.62 | 0.18 |
| 17 | Spain | 0.07 | 0.88 | 0.46 | 36 | Armenia | 0.00 | 0.61 | 0.13 |
| 18 | Canada | 0.06 | 0.91 | 0.46 | 37 | Zimbabwe | 0.00 | 0.00 | 0.00 |
| 19 | Greece | 0.05 | 0.87 | 0.43 | | | | | |

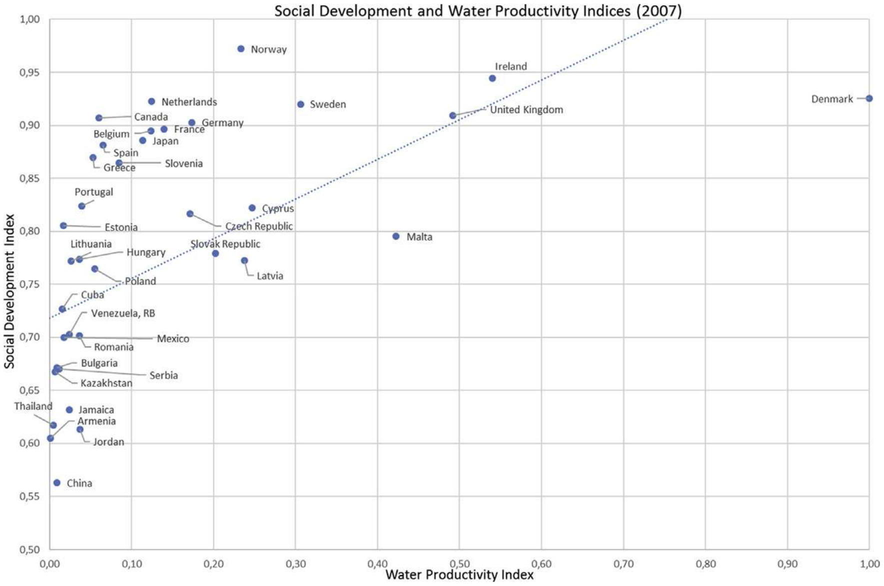

**Fig. 1.** Correlation of water productivity and social development.

countries the lower Water Sustainable Development Index. The majority of these countries also have histories of planned economies which may be a factor in the water infrastructure of the countries. Group 2 is comprised of European Nations, Japan and Canada. These represent wealthy nations and high levels of social development. Cluster 4 contains the British Influenced European nations of the United Kingdom itself, plus Ireland and Malta. What distinguishes these countries from the other European nations is a much higher level of water productivity. Cluster 4 contains former Eastern Bloc countries plus Portugal, characterised by lower than average incomes by European standards and a lower level of water productivity. The final two clusters place Zimbabwe and Denmark out on their own, as the country with the highest and lowest level of water productivity, as well as polarised on social scores. From the ANOVA analysis (See Tables 4 and 5), the water productivity, GDP per capita, life expectancy, WPI, SDI and WSDI have statistically significant differences between the clusters at the 0.05 level. Whilst these clusters may intuitively offer insights into potential ways of classifying water driven sustainable development across these nations, there is a need to include a greater sample of countries and a number of time periods to be able to draw any firm conclusions.

### *4.3. Comparisons with other indicators*

Assessing how the WSDI compares with other measures of environmental dimensions of sustainability was achieved by comparing it with a number of indicators commonly estimated at country level, using the most recent estimates available.

- The Water Footprint, available from Hoekstra and Mekonnen (2012), was compared to the WSDI using the per capita water footprint for nations, of which all 20 nations had available data. Correlations were run between the SWDI and other measures of sustainability
- The Human Social Development index (Togtokh, 2011; Bravo, 2014) attempts to modify the Human Development Index by incorporating country environmental performance into the calculations
- Data for the Ecological Footprint is calculated by the Global Footprint Network (Ewing, 2008), containing data for 18 of the countries used to create the Sustainable Water Development Index. The two countries that lack figures for the ecological footprint are Malta and Cyprus, due to the small sizes of these countries.

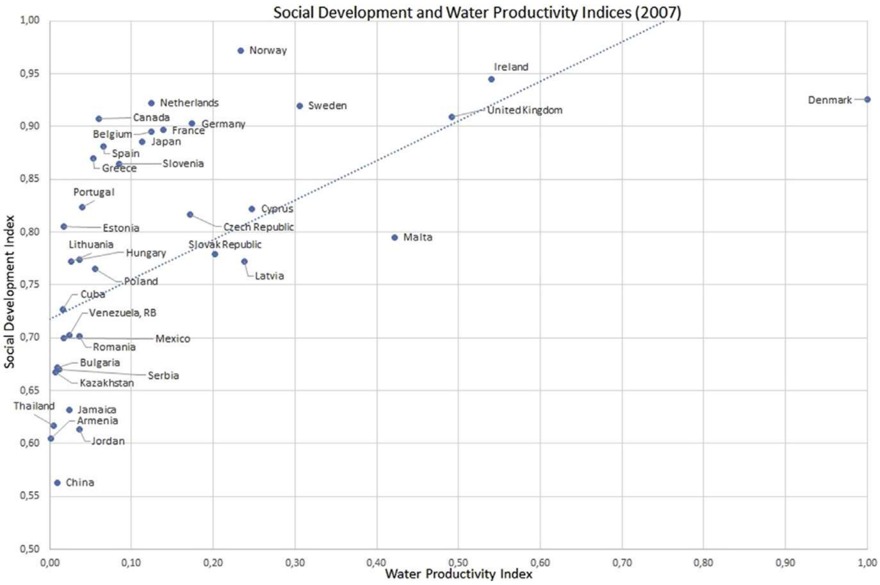

**Fig. 2.** Plot of Co-efficient against number of clusters.

**Table 3**
Cluster Groupings of the 37 countries.

| Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 |
|---|---|---|---|---|---|
| Armenia | Belgium | Estonia | Ireland | Zimbabwe | Denmark |
| Bulgaria | Canada | Hungary | Malta | | |
| China | Cyprus | Lithuania | United Kingdom | | |
| Cuba | Czech Republic | Poland | | | |
| Jamaica | France | Portugal | | | |
| Jordan | Germany | | | | |
| Kazakhstan | Greece | | | | |
| Mexico | Japan | | | | |
| Romania | Latvia | | | | |
| Serbia | Netherlands | | | | |
| Thailand | Norway | | | | |
| Venezuela | Slovak Republic | | | | |
| | Slovenia | | | | |
| | Spain | | | | |
| | Sweden | | | | |

**Table 4**
ANOVA statistics for mean differences between clusters.

| | F | P |
|---|---|---|
| Water Productivity ($m^3$ per GDP) | 90.627 | $<0.001$ |
| GDP Per Capita | 10.179 | $<0.001$ |
| Life Expectancy | 29.614 | $<0.001$ |
| Expected Education | 11.289 | $<0.001$ |
| Mean Education | 10.966 | $<0.001$ |
| Water Sustainability Index | 90.627 | $<0.001$ |
| Social Development Index | 71.747 | $<0.001$ |
| Water Sustainable Development Index | 64.966 | $<0.001$ |

- Table 6 gives an approximation indication of the correlation between these indicators, however due to data deficiencies these indicators were only available for specific years. In this analysis the WSDI, the WPI and SDI's figures for 2007 were used; the ecological footprint used 2008 data; whilst the HSDI used data from 2012. Whilst this does not give a precise figure for the relationship between the indices constructed in this paper and existing sustainability indicator, it does give a rough indication as to whether the indicators are measuring concepts with already developed quantitative measures. What the results reveal is that there is no statistically significant correlation between the water indicators (with and without the social component) and existing indicators that measure sustainability.

There is positive correlation between the water sustainable development index and the ecological footprint ($r = 0.728$) as well as with the HSDI ($r = 0.792$). The high positive correlation between the EF and HSDI ($r = 0.699$), and the EF and SDI ($r = 0.724$) suggests that countries with higher levels of human development have higher ecological footprints and future work should consider a time series to see how the relationship between the WSDI and EF changes and develops over time. Also of note is the weak correlation between the water footprint and the WPI and WSDI, driven by the relating of water consumption to GDP. This provides an opportunity for the development of indices and indications that assess the performance of a country's economy that does not place too much emphasis on economic growth, or conserving water resources, but instead focuses on how best an economy is organised to make the most effective and efficient use of natural resources to generate benefits for society.

## 5. Discussion

The aim of this paper was to demonstrate a new method for assessing sustainable water consumption through a methodological process which

**Table 5**

Mean comparisons for water sustainability and social development.

| | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 |
|---|---|---|---|---|---|---|
| Water Productivity ($m^3$ per GDP) | 12,54 | 95,96 | 23.65 | 292.75 | 601.12 | 2.80 |
| GDP Per Capita (Euro) | 5315 | 36643 | 14656 | 40358 | 58734 | 473 |
| Life Expectancy | 73.24 | 79.01 | 74.52 | 79.20 | 78.40 | 46.80 |
| Expected Education | 13.50 | 15.88 | 15.80 | 15.90 | 16.80 | 9.30 |
| Mean Education | 11.51 | 13.58 | 13.17 | 13.58 | 14.00 | 8.42 |
| WSI | 0.02 | 0.16 | 0.03 | 0.48 | 1.00 | 0.00 |
| SDI | 0.66 | 0.87 | 0.79 | 0.88 | 0.93 | 0.00 |
| WSDI | 0.25 | 0.55 | 0.36 | 0.76 | 0.94 | 0.00 |

**Table 6**

Comparison of the Sustainable Water Development Index against existing indicators of sustainability.

| | WSI | SDI | WSDI | WF | HSDI | EF |
|---|---|---|---|---|---|---|
| WPI | 1 | 0.439** | 0.846** | -0.193 | 0.442** | 0.543** |
| SDI | 0.439** | 1 | 0.778** | 0.164 | 0.976** | 0.724** |
| WSDI | 0.846** | 0.778** | 1 | -0.096 | 0.792** | 0.728** |
| WF | -0.193 | 0.164 | -0.096 | 1 | 0.128 | 0.116 |
| HSDI | 0.442** | 0.976** | 0.792** | 0.128 | 1 | 0.699** |
| EF | 0.543** | 0.724** | 0.728** | 0.116 | 0.699** | 1 |

Where WPI = Water Productivity Index; SDI = Social Development Index; WSDI = Water Sustainable Development Index; WF = Water Footprint;; HSDI = Human Sustainable Development Index; EF = Ecological Footprint.

** Correlation is significant at the 0.01 level (2-tailed).

uses widely available data and simplifies the computational and data requirements to provide overviews of sustainable water consumption. Drawing on the approaches of Togtokh (2011) and Bravo (2014) which expand upon the relatively simple method underpinning the HDI, and using freely available data from the World Bank, as well as the underlying data for the HDI itself to develop the WSDI meets the methodological requirement. The WSDI itself provides an overview of countries where policy-makers might intervene in order to ensure water consumption maximises the social and economic well-being of its citizens, which would be indicated by an increase in the WSDI value, recognising the idea of water sustainable development as following the Brundtland Commission definition of sustainability to meet the needs of the present generation without compromising the needs of the future (i.e. not to exhaust global water supplies) whilst also accounting for development in a way that improves society overall (Sagar and Najam, 1998). Industrial ecology and ecological modernization approaches suggest that this can be achieved through encouraging greater eco-efficiency practices and technological innovations, rewarding water consumers that are able to demonstrate improved water productivity for their economic and social activities.

In assessing the relationship between freshwater consumption and societal well-being, the results suggest that the efficient use of water resources and that for all countries their water productivity is below their social development level and there is therefore a need for greater emphasis on water sustainability as part of a social development strategy. The comparison of the social and water efficiencies of the 37 countries sampled in this study revealed that social and water resource efficiencies have a statistically significant positive relationship, but the correlation co-efficient is short of what might be regarded as practical significance for policy makers (where $|r|>0$) (Morris et al., 2012). This follows a similar finding of Koh et al. (2016) comparing material productivity and social sustainability.

From the cluster groupings based on water productivity and social development, a split between high and low water productive countries can be inferred, splitting Europe almost between East, West and British influenced. For policy makers, the study demonstrates through the WSDI the potential impact of water resource policy decisions on national well-being, going beyond the focus on water availability and economic growth. The positive correlation between the WSDI and the ecological footprint, as well as with the HSDI does suggest that the WSI is providing a credible measure of sustainable development, but as the correlation co-efficient between the WSI and the EF and HSDI is approximately 0.73 and therefore an $r^2$ value of approximately 0.53 indicates that 47% of the variance in the WSDI is not accounted for by these indicators and gives scope for the WSDI to focus on water-related measures of sustainable development. A key test however remains on examining how the WSDI and its component indicators vary over time and how measures for countries can be assessed as part of a longitudinal study.

## 6. Conclusions

The proposed WSDI can be used as a simple to understand, and relatively easy to calculate indicator which can assess the development of a national economy towards one which is sustainable, able to use water resources efficiently and effectively to maximise benefits to wider society. The WSDI developed here is the is one which fits within the framework of measuring a sustainable economy and specifically, measuring water sustainability as part of a triple pillar of sustainability framework by adapting indicators from existing research that are currently focused on reducing environmental impacts such as carbon emissions and measuring societal wellbeing.

The analysis presented in this paper demonstrates that the majority of the countries in the sample set have water consumption levels currently inefficient in comparison with their social development levels and the WSDI has the potential to measure the effectiveness of pathways taken towards the sustainable use of water resources which fills a gap in contemporary research which has focused on measuring impacts from economic activities as the primary focus and highlights issues with focusing on each component of sustainability in isolation. Further refinement of this approach can aid policy makers, but also business leaders wishing to assess the water sustainability credentials of national economies to identify areas of strong water sustainability performance.

The main limitations of this approach concerns the applicability for distinguishing between industrial and residential water consumption, which may be a priority for policy-makers as the water consumption statistics used focus on the abstraction of freshwater resources, as opposed to the nature of its consumption. Whilst the WSDI provides a starting point towards an explicit approach on water sustainability, further work is needed to develop a wider sample size of countries beyond the nations in the World Bank database. In addition, there is a need to expand the focus of analysis and incorporate other measures of environmental and social sustainability factors. The methodology could also be enhanced to provide accompanying sub-national level water statistics in order to reveal the variations in water productivity at regional, local, and catchment scale. Crucially, the paper uses freshwater resources as a ‘catch-all’ approach and does not distinguish between the end-users of water, and further research should focus on the distinction between industrial and domestic water uses, in order to better tailor policy decisions. These future research activities would enhance the potential applications for policy makers and industry leaders to monitor and measure their progress towards water sustainable practices.

## Declarations

### Author contribution statement

Jon Morris: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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