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An adaptive neuro-fuzzy inference system (ANFIS) approach for measuring country sustainability performance

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ABSTRACT

With the increasing demand for sustainable development, many international institutions and governments are seeking a balance between the environment, society and economy. With the aim of understanding and monitoring sustainability performance, various sustainability assessment methods have been developed. Fuzzy logic theory has been widely used for sustainability assessment. Good as these approaches are, there are criticisms that most studies use pre-defined simple linear membership functions (triangular or trapezoidal) and fuzzy rules, which are largely derived from experts' knowledge. However, sustainability is a very complex, multi-criteria issue, which contains various complex non-linear relationships. Moreover, it is time-consuming to find out the optimal membership functions and rules based on the expert knowledge. Therefore, it becomes necessary to explore a new approach for induction of membership functions and fuzzy rules. This paper introduces the adaptive neuro-fuzzy inference system (ANFIS) approach for country level sustainability assessment. The membership functions and fuzzy rules are generated from 128 training samples. The assessment results are close to the SAFE, *Sustainability Assessment by Fuzzy Evaluation*, model. Furthermore, three different types of non-linear membership functions, including Gaussian, bell-shaped and sigmoidal, are tested. The Gaussian membership function is the best one for country sustainability assessment. This study explores sustainability assessment, and results show that, by using appropriate training data, the ANFIS method is effective to measure the countries' sustainability performance. Using ANFIS, assessment accuracy can be further improved through appropriate selection of training samples using alternative data from UN-Habitat, or World Bank, or even new data sets.

1. Introduction

Over the past few decades, the world has experienced substantial economic and social development. The statistics show that the GDP has increased from 1423.6 billion US dollars in 1961 to 77,696 billion dollars in 2014, or approximately 54.5 times with an annual average growth rate of 8.1%. Over the same time period, the total population has also increased from 3.076 billion (1961) to 7.259 billion (2014), accounting for nearly 2.4 times. However, the economic and social development has also caused a number of environmental problems, such as global warming, habitat destruction, desertification and source depletion (Bond and Morrison-Saunders, 2011; Chen and Lu, 2017; Lu et al., 2016; Retief et al., 2016; Shen et al., 2012; Shuai et al., 2017; Wende et al., 2012). Therefore, the recognition of these problems caused by rapid development has led to the promotion of sustainable development (Zhou et al., 2015a).

Sustainable development was defined as "…*meeting the needs of the present without compromising the ability of future generations to meet their own needs*" by a key pioneer, Brundtland (1987). Since then, sustainable development has become a global issue. Since the turn of the century, many intergovernmental programs and private initiatives have been implemented to promote global sustainable development, such as the New Urban Agenda by UN-Habitat (2016), Sustainable Development Goals by United Nations (2016), and Istanbul Declaration by North Atlantic Treaty Organization (NATO) (2004), the HK2030 Study by Hong Kong Planning Department (2007), City plan 2010 by Melbourne City Council (2001), and Plan Verde by Government of Mexico City (2007). With the implementation of various sustainable development programs, it is considered that the recognition of sustainable development performance is important in the pursuit of effective sustainable development, since it has been invested with a great many resources (Tan et al., 2016).

In line with the sustainable developments, many research efforts have been focused on sustainability assessment (Jiao et al., 2016; Lu

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et al., 2015; Peng, 2015; Shen et al., 2016, 2017; Shen et al., 2015; Tan et al., 2015; Tan et al., 2014; Tan et al., 2011; Zhou et al., 2015b). Among them, fuzzy-set theory has also been applied for sustainability performance assessment. For example, Houshyar et al. (2014) used fuzzy-set theory to measure the sustainability performance of agriculture development. Cavallaro (2015) proposed an application of Takagi-Sugeno fuzzy inference modelling to build a synthetic index for monitoring the sustainability performance of energy production. Zhao and Li (2016) established the hybrid stochastic AHP and fuzzy TOPSIS model to evaluate the sustainability performance of smart grids. However, in most of these existing studies, pre-defined linear membership functions (triangular or trapezoidal) and fuzzy rules are commonly applied, which are based on experts' knowledge. These have led to criticism that the sustainability is a very complex, multi-criteria and dynamic issue, which contains various complicated non-linear relationships between variables such as measures of the economy, environment and resources etc. (Hjorth and Bagheri, 2006). Furthermore, Singh et al. (2012) argued that it is time-consuming to find out the correct membership functions and rules that result in a reliable solution, because it requires time to process the expert knowledge.

Therefore, there is a need to explore a new approach for induction of fuzzy membership function and fuzzy rules. This paper aims to: (1) review the existing studies on country sustainability assessment; (2) introduce ANFIS, a new approach; (3) apply the ANFIS approach to re-assess country sustainability based on the work by Phillis et al. (2011); and (4) test different membership functions. The main contribution of this paper is to introduce a new approach, ANFIS, for country sustainability assessment, which makes the assessment process independent of expert knowledge and close to human reasoning. Furthermore, a framework for optimal membership function selection was proposed. The proposed ANFIS approach has been shown here to be feasible and effective for country sustainability assessment, and can be further improved by integrating new training data.

2. Literature review

Sustainability assessment is defined as"*...a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable*" (Devuyst et al., 2001). Currently, various methods, techniques and tools have been developed for country sustainability assessment. These methods can be summarized into 5 categories including: (1) ecological footprint (Strezov et al., 2016); (2) data envelopment analysis (Iribarren et al., 2016; Santana et al., 2014); (3) comprehensive evaluation (Coteur et al., 2016; Dor and Kissinger, 2017; Veldhuizen et al., 2015); (4) system dynamics (Karami et al., 2017; Onat et al., 2016); and (5) Fuzzy-set theory (Phillis and Andriantiatsaholiniaina, 2001; Phillis et al., 2011). These methods are either efficiency-oriented or output-oriented. For example, DEA is a typical efficiency-oriented assessment method (Yu and Wen, 2010). This efficiency-oriented approach has been widely applied in ecological footprint studies (Yan et al., 2002). However, Li and Li (2009) pointed out that the results obtained from the DEA method only present the relevant efficiency of individual indicators. Taking the environmental dimension in the sustainable development as an example, the energy efficiency for reducing carbon emission in USA is quite high, which indicates good environmental performance. However, USA is the second largest carbon emitter in the world when considering the total carbon emission (Guan et al., 2008). The output-orientated principle has been widely used for comprehensive analysis (Yigitcanlar et al., 2015). Nevertheless, Shen et al. (2015) emphasized that the output-orientated principle only focuses on outcomes rather than the process, which presents difficulties for city decision-makers when selecting a suitable development strategy.

Sustainability assessment is a complex problem, which considers multi-criteria simultaneously (Ness et al., 2007). Cornelissen et al. (2001) commented that uncertainty related to sustainable development must be considered in sustainability assessment. Furthermore, some soft (qualitative) indicators such as corruption and poverty are also significant to reflect a sustainable performance. These soft indicators cannot be quantified by selecting a crisp number. Instead, discrete variables, using linguistic terms, such as "Good", "Normal", "Bad", can be used for representing these indicators (Phillis and Andriantiatsaholiniaina, 2001). Mendoza and Prabhu (2003) also stressed that sustainability assessment requires both qualitative and quantitative criteria rather than only using simple qualitative criteria. These features make fuzzy-set theory more appropriate for sustainability assessment than other methods. This point has also been echoed by other researchers. For example, Ratnayake (2014) suggested that fuzzy-set theory enables connecting and handling both qualitative and quantitative criteria. Zhou et al. (2015c) pointed out that fuzzy-set theory can deal with systematic uncertainties. Andriantiatsaholiniaina et al. (2004) asserted that fuzzy logic is a systematic tool for sustainability assessment, which can deal with those imperfect data. Phillis and Andriantiatsaholiniaina (2001) concluded that fuzzy logic is a natural technical method for sustainability assessment because fuzzy logic can emulate the behavior of skilled humans and handle vague situations.

Fuzzy-set theory has therefore been widely applied in country sustainability assessment by many researchers (Grigoroudis et al., 2014; Jayaraman et al., 2015; Kouikoglou and Phillis, 2011; Kouloumpis et al., 2008; Liu et al., 2014; Phillis et al., 2011; Phillis and Kouikoglou, 2009). However, *pre-defined linear membership functions* (triangular or trapezoidal) and fuzzy rules that basically depend on expert knowledge are commonly used in existing studies, which cannot reflect the non-linear relationships between variables (Hjorth and Bagheri (2006)and it is time-consuming to define the correct membership functions and rules (Singh et al. (2012).

In searching for a better possible solution, the use of an artificial neural networks (ANN) is considered as an intelligence technique which specifies the relationship between input and output from training samples to determine distribution of membership functions (Naderloo et al., 2012). However, it is not easy to determine the proper size and optimal structure of the network, which is a main disadvantage of neural network (Singh et al., 2012). Combining the ANN and fuzzy-set theory can overcome the disadvantages of both techniques. An adaptive neural fuzzy inference system (ANFIS) method for fuzzy membership function and fuzzy rules induction was introduced by Jang (1993). The ANFIS has combined the advantages of fuzzy systems for dealing with explicit knowledge, which can be explained and understood (such as fuzzy inference system), with neural networks for dealing with implicit knowledge, which can be acquired by learning (such as membership function) (Singh et al., 2012).

Since then, the ANFIS method has been widely applied in different research areas, such as knowledge discovery (Inyang and Akinyokun, 2014), prediction (Abdulshahed et al., 2015; Hegde and Raju, 2015) and decision-making (Hashemi et al., 2013; Özkan and Inal, 2014). Further, and even more relevant to this paper's study, the ANFIS method has also been used for assessment. For example, Mohandes et al. (2011) used the ANFIS method to estimate the wind speed profile, and concluded that it provided high accuracy and reliability for assessing the wind speed. Sangaiah et al. (2015) innovatively integrated the ANFIS approach with a Taguchi-genetic learning algorithm to evaluate outcomes of global software development. This study is the first attempt to apply the ANFIS approach to country sustainability assessment.

3. The principle of ANFIS

Adaptive Neural Fuzzy Inference System (ANFIS) was first proposed by Jang (1993). ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are derived from training examples. Assume a FIS under consideration has two inputs x and y with two