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Integration of artificial intelligence methods and life cycle assessment to predict energy output and environmental impacts of paddy production

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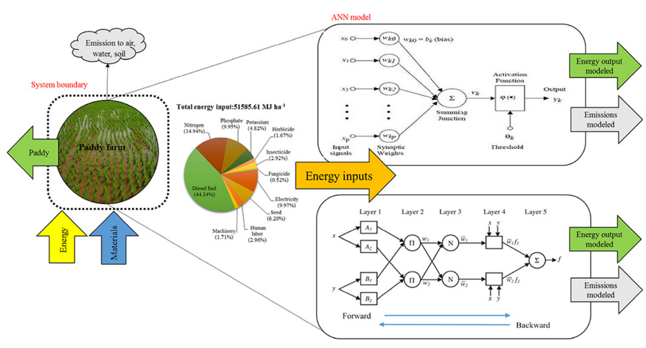
HIGHLIGHTS

- Energy output paddy production modeled by Artificial intelligence.
- Environmental impacts from paddy farm modeled by Artificial intelligence
- Artificial Neural Network predicted the data with high precision.
- Adaptive Neuro Fuzzy Inference System predicted data with high speed and accuracy.

GRAPHICAL ABSTRACT



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ABSTRACT

Prediction of agricultural energy output and environmental impacts play important role in energy management and conservation of environment as it can help us to evaluate agricultural energy efficiency, conduct crops production system commissioning, and detect and diagnose faults of crop production system. Agricultural energy output and environmental impacts can be readily predicted by artificial intelligence (AI), owing to the ease of use and adaptability to seek optimal solutions in a rapid manner as well as the use of historical data to predict future agricultural energy use pattern under constraints. This paper conducts energy output and environmental impact prediction of paddy production in Guilan province, Iran based on two AI methods, artificial neural networks (ANNs), and adaptive neuro fuzzy inference system (ANFIS). The amounts of energy input and output are 51,585.61 MJ kg^{-1} and 66,112.94 MJ kg^{-1}, respectively, in paddy production. Life Cycle Assessment (LCA) is used to evaluate environmental impacts of paddy production. Results show that, in paddy production, in-farm emission is a hotspot in global warming, acidification and eutrophication impact categories. ANN model with 12-6-8-1 structure is selected as the best one for predicting energy output. The correlation coefficient (R) varies from 0.524 to 0.999 in training for energy input and environmental impacts in ANN models. ANFIS model is developed based on a hybrid learning algorithm, with R for predicting output energy being 0.860 and, for environmental impacts, varying from 0.944 to 0.997. Results indicate that the multi-level ANFIS is a useful

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tool to managers for large-scale planning in forecasting energy output and environmental indices of agricultural production systems owing to its higher speed of computation processes compared to ANN model, despite ANN's higher accuracy.

1. Introduction

The second most produced grain worldwide is paddy (*Oryza sativa*) that is one of the main foods and the most relevant food for human nutrition. It is eaten by more than three billion people in the world, especially in Asia and South America (Nunes et al., 2016). Paddy in the form of rice kernels are used as an essential energy source for human (human caloric intake provided by rice is more than 70% in some countries (Pishgar-Komleh et al., 2011) and 21% all over the world (Nunes et al., 2016)), as well is an important protein source for human nutrition. According to Walter et al. (2008), depending on genotypic characteristics, temperature, nitrogen fertilization and solar radiation, rice kernels vary from 4.3% to 18.2% out of the total mass of paddy.

In Iran, paddy is an important production because rice is typically consumed at least once daily as part of the main meal. According to FAO (2016), approximately 2,386,492 tons of paddy are produced each year at an average yield of 42,862 hg ha^{-1} in Iran's paddy farm. Guilan province, with 44.94% share of total paddy production, is among the main paddy production areas in Iran. Paddy production share of this province was 1,072,666 tons in 2016 (Ministry of Jihad-e-Agriculture of Iran, 2016) but this amount of production is not sufficient to satisfy food demand, and to make it up, the government needs to import about 1,000,000 tons annually. Therefore, policy makers and managers are looking for ways to attain self-sufficiency in paddy production in Iran. Statistics indicate that the annual paddy production increases from 600,000 tons in 1961 to 2,386,492 tons in 2016 (FAO, 2016). However, it is still necessary to take efforts to increase production of paddy. Since the crop yields and food supplies are directly linked to energy (Pishgar-Komleh et al., 2011), the change in energy consumption can lead to improved amount and yield of paddy production.

According to Kizilaslan (2009), energy use in agriculture is increasing due to the population growth, and changes in technology to satisfy food demand. On the other hand, for attaining sustainable agricultural production, energy efficiency is essential since higher energy efficiency leads to saving in cost, preservation of fossil resources and reduction of environmental disturbance (Demircan et al., 2006). For this purpose, it is necessary to recognize and study common patterns of agriculture in order to select a suitable energy use pattern for recommendation to farmers.

As already mentioned, paddy production plays a key role in food security in Iran and other Asian countries and South America so that changes in energy consumption help to provide food security. Yet, there are concerns about Greenhouse Gas (GHG) emissions (about 10–12% of global anthropogenic GHG emissions is related to agricultural sector (Smith et al., 2007) and especially paddy cultivation (Brodt et al., 2014)) and more energy use in these farms (Nabavi-Pelesaraei et al., 2017). Based on Linquist et al. (2012)'s report on total global warming potential (GWP) of paddy fields, CH_4 emissions, followed by N_2O emissions, have key role. Methane (CH_4) and nitrous oxide (N_2O) emissions for paddy farm depend on the cultivation system, including irrigated or flooded cultures, or uplands cultivation as well GHG emissions caused by anaerobic conditions of flooded areas (Brodt et al., 2014). It is expected that, due to the increase of population growth and demand, GHG emissions caused by paddy farms will increase day-by-day (Cai et al., 2007). Therefore, it is indispensable to estimate environmental impacts and identify appropriate means of reduction of energy use and environmental impacts (Safa and Samarasinghe, 2011).

Life cycle assessment (LCA) is a holistic approach that is widely used to evaluate environmental impacts of agri-food products. Its use in agricultural systems (Goossens et al., 2017) is mainly in an attempt to estimate and assess all GHG emissions and other environmental impacts of production systems such as crops. LCA provides a complete environmental assessment of the production chain of life cycle (ISO, 2006). LCA is considered as the best environmental management tool that can be used to obtain an appropriate understanding and quantification of environmental impacts related to different methods of crop production for comparative and improvement purposes (Biswas et al., 2008). Moreover, LCA helps determine the “hot spots” in the system that have the most significant environmental impacts and thus can identify sustainable and eco-friendly production options (Azapagic et al., 2006). Accordingly, LCA studies can be employed as a decision support implementation in the selection of the best method of crop production (in terms of environmental considerations).

Another analytic tool that is important to this study is Cumulative Exergy Demand (CExD) Analysis. CExD is the total amount of renewable and non-renewable primary exergy demanded for product or service. According to Peters et al. (2014), CExD analysis aims to create an efficient process or system of to minimize degradation or loss of exergy.

The most important factor for good management of paddy farm is a right decision. Decision-making process can be undertaken by studying current conditions and expected future conditions. Hence there exists a need for a model to predict various factors of paddy farm. Given the fact that the paddy produced as well as environmental impacts caused by paddy production are the most important factors in long-term decisions in the selection and replacement of paddy production methods, the model should be able to predict these factors. Several models may be available for this type of prediction. However, since there is not a clear and specific relationship between inputs and outputs in the paddy production, the applied model should ideally have high precision, be fast and computationally inexpensive, and have the ability to solve these issues.

Artificial neural networks (ANNs) are well-known computational systems and methods to predict output of complex systems and solve multifaceted nonlinear problems (even without prior information) (Tohidi et al., 2012) with high accuracy, which is based on biological neuron activities (Taki et al., 2018). ANN models are comprised of architectures or structures of interconnected computational elements) neurons). With these architectures, ANNs are enable to learn from examples (Zhang et al., 1998). Their learning process is similar to human brain. Given a training set of data, the neural network can learn the behaviors behind with a training algorithm. ANN training includes discovering a set of weights of links between nodes such that the network produces a favorable output signals. The process of training is considered by regulating the amount of these weights by using a series of training samples showing desirable ANN demeanor (Czarnowski and Je, 2006).

The first fuzzy-rule introduced by Zedeh (1965), based on fuzzy logic and fuzzy set theory, is known as one of the most popular and powerful methods for modeling. According to Sugeno and Yasukawa (1993), modeling by fuzzy-rule is a qualitative modeling scheme that describes the system behavior by using a natural language. In recent years, the integration of neural networks and fuzzy logic has given birth to a new research termed Adaptive Neuro Fuzzy Inference System (ANFIS). This intelligent computational method is based on self-learning capability