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System-Dynamic Simulation Application on Farming Eco-Efficiency Measurement

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Abstract. This paper conducts system-dynamic simulation on farming eco-efficiency measurement completed with social aspects and interrelationship between indicators generated. It applies systemic eco-efficiency measurement methodology built by former research on five selected provinces in Indonesia. As constructed on the methodology, eco-efficiency ratio has been modified and measured not only total cereal production per emission potential, but also take into account the effects of agricultural employment, and the influence of housing, industrial, and infrastructure expansion toward agriculture area. The simulation has been run in year 2004-2025 period for East Java, Central Java, South Sulawesi, South Kalimantan and West Nusa Tenggara. The result shows changes in cereal production and eco-efficiency ranks due to Food Security and Vulnerability Atlas of Indonesia (FSVA) 2015 rankings.

1. Introduction

Eco-efficiency measures sustainability in both economic and environment target achievements [1, 2]. It has been applied prominently in micro level economy for its simplicity, and started to be applied in the larger level. Systemic farming eco-efficiency methodology built by [3] measures not only cereal production per emission potential, but also take into account farming social-aspects contained agricultural employment, and the influence of housing, industrial, and infrastructure expansion toward agriculture area.

Indonesia has 33 provinces that were measured in previous measurement of FSVA[4]. In this model, simulation model has been implemented for selected 5 provinces of Indonesia, which are East Java, Central Java, South Sulawesi, South Kalimantan and West Nusa Tenggara in period 2004-2025. These 5 provinces are chosen for their historical data on cereal production as the main indicator of food availability in previous measurement of FSVA. High cereal production is centralized in sequence of Java and Sumatera islands. Sulawesi and Kalimantan islands for average production and Nusa Tenggara island for low cereal production. According to the result, in this study, East Java and Central Java provinces as two highest cereal productions are chosen to be compared with South Sulawesi South Kalimantan provinces representing two average cereal productions and West Nusa Tenggara province representing low cereal production. In order of cereal production level, these provinces are in 1,2,3,4 and 5 in sequence. Simulation implementation is expected to compares those of provinces and analyses whether any sequence changes are occurred during the simulation measurement. Period of 2004-2025 has been determined based on national strategic planning of Indonesian Ministry of Agriculture.



2. Systemic Farming Eco-efficiency Methodology

Systemic farming eco-efficiency methodology constructed by [3] applies three aspects of sustainable development contained economic, environment, and social simultaneously by conducting system dynamic methodology. This concept allows precise approach of eco-efficiency in macro level, where all aspects are undeniably related and organize a systemic atmosphere. Regarding to its capability of evaluating relationships between these elements of the system, this systemic methodology has been frequently adopted as a method of policy evaluation [5, 6]. Dependencies between indicators are evaluated as relationships between system components which allow acknowledged changes among them. Related applications of systemic eco-efficiency methodology were done by [7-10] for city water system eco-efficiency. Similarly, these studies used system-dynamic methodology to integrate their indicators except for social indicators.

Based on standard eco-efficiency ratio defined by [2] as ratio of product value to its environmental impact, this systemic farming eco-efficiency measurement apply cereal production to its carbon emission potential. Formulation is written as equation 1 below:

$$\text{Eco-efficiency} = \frac{\text{Cereal Production}}{\text{Farming CO}_2 \text{ Emission Potential}} \dots\dots\dots(1)$$

Cereal production represents economic aspect indicators, while farming CO₂ emission potentials represents environment aspect indicators. Cereal production (Kg) formulated as cereal production in one year period, while farming CO₂ emission potential refers to CO₂ emission potential produced in farming process containing fertilizer emission and land used emission. It is provided in Giga gram of CO₂ Equivalent (GgCO₂Eq). For the broader farming system, cereal production are expressed as providing higher cereals that linked to social aspects of agricultural employment and investment, increasing housing, industrial and infrastructure area in system dynamic model as described in Figure 1[3]. Stock-flow diagram is part of system dynamic methodology that illustrates how system elements relate in system dynamic symbols.

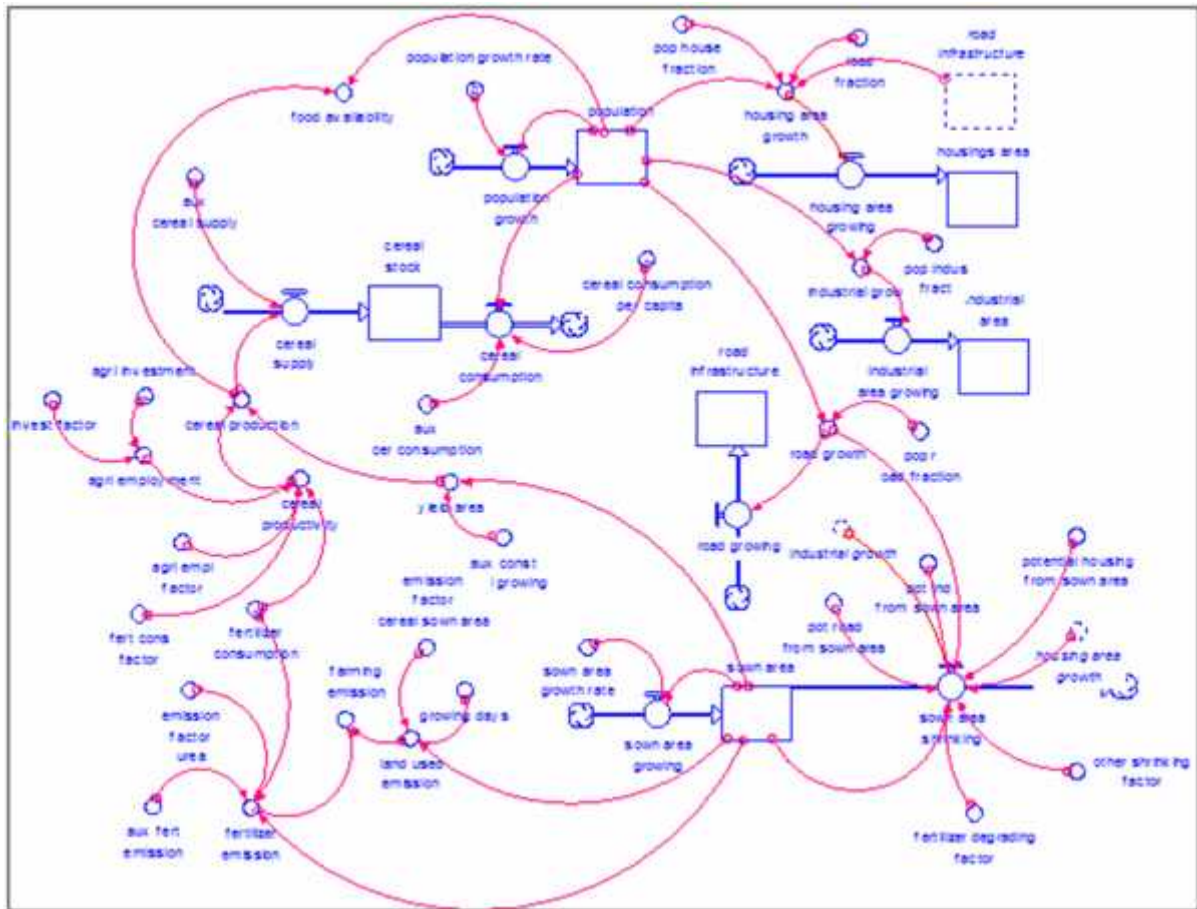


Figure 1. Stock Flow Diagram of Systemic Farming Eco-efficiency Measurement[3]

3. Simulation of Farming Eco-efficiency Measurement

Based on systemic farming eco-efficiency methodology, system dynamic simulation model has been built and run for selected 5 provinces in Indonesia. Since significant political changing in Indonesian farming, the simulation was run only for 22 years of 2004 until 2025 based on national strategic planning of agricultural ministry. Indonesia has 33 provinces that were measured in previous measurement of FSVA. In this phase, basic simulation model has been implemented for East Java, Central Java, South Sulawesi, South Kalimantan and West Nusa Tenggara. These 5 provinces are chosen for their historical data on cereal production as the main indicator of food availability in previous measurement of FSVA. High cereal production is centralized in sequence of Java and Sumatera islands. Sulawesi and Kalimantan islands for average production and Nusa Tenggara island for low cereal production. According to the result, in this study, East Java and Central Java provinces as two highest cereal productions are chosen to be compared with South Sulawesi South Kalimantan provinces representing two average cereal productions and West Nusa Tenggara province representing low cereal production. In order of cereal production level, these provinces are in 1,2,3,4 and 5 in sequence. Simulation implementation is expected to compares those of provinces and analyses whether any sequence changes are occurred during the simulation measurement. Period of 2004-2025 has been determined based on national strategic planning of Indonesian Ministry of Agriculture. Initial values of those provinces are listed in Table 1 below:

Table 1. Initial Values and Rates of 5 Provinces In Year 2004

Variables/Provinces	East Java	Central Java	South Sulawesi	South Kalimantan	West Nusa Tenggara
Cereal production (Kg)	22,061,776	19,469,590	8,924,776	3,753,518	3,698,734

Housing area (Ha)	10,064	8,414	1,966	853	1132
Industrial area (Ha)	2,185	1,445	703	546	0
Population (person)	32,189,177	35,301,302	4,200,213	3,230,052	8,443,489
Road infrastructure (Ha)	20,270	13,900	17,220	8,660.9	6,321.7
Sown area (Ha)	1,115,239	995,469	512,510	420,086	226,627
Sown area growth rate (Ha/yr)	0.0011	0.00435	0.005393	0.00196	0.11191

Equation 2 until 6 list several system dynamic formulations used in the simulation:

Cereal production = Cereal productivity x yield area..... (2)

Yield area = aux const growing x sown area..... (3)

Cereal supply = cereal production x cereal supply..... (4)

Cereal consumption = (cereal consumption per capita x population) x cereal consumption..... (5)

Sown area growing = sown area x sown area growth rate..... (6)

Eco-efficiency ratio result of simulation running then indexed based on equation 7 as constructed by [11]. It is completed by normalising values of those indicators at base year of 2002-2025 in value between 1 to 5 using interpolation. This paper has used values between '1 and 5' rather than '0 and 1' to avoid zero indexes which would be a denominator in eco-efficiency ratio. Values 1 to 5 mean that the maximum value in those indicators has index of 5 and the minimum value has index of 1

$$\text{Index of Value } k\text{th} = 5 - (5 - 1) \frac{\text{Value}_k - \text{Min Value}}{\text{Max Value} - \text{Min Value}} \dots\dots\dots(7)$$

Where k is numbers of data series from 1 to 110 (22 year in 5 provinces). 'Min value' means minimum value in series of 110 data, while 'max value' means maximum value in series of 110 data.

Provinces	East Java	Central Java	South Sulawesi	South Kalimantan	West Nusa Tenggara
Year					
2004	0.41	0.49	1.68	2.00	1.00
2005	0.44	0.46	1.72	2.03	1.03
2006	0.48	0.52	1.75	2.05	1.05
2007	0.55	0.52	1.77	2.06	1.08
2008	0.60	0.55	1.77	2.04	1.08
2009	0.64	0.57	1.70	1.92	1.07
2010	0.66	0.60	1.64	1.86	1.06
2011	0.72	0.64	1.64	1.81	1.07
2012	0.75	0.67	1.60	1.75	1.06
2013	0.76	0.70	1.53	1.66	1.06
2014	0.85	0.74	1.51	1.62	1.06
2015	0.88	0.77	1.47	1.56	1.05
2016	0.89	0.80	1.42	1.50	1.05

Year	Eco-efficiency Index					Efficiency provinces
	2017	2018	2019	2020	2021	
2017	0.90	0.82	1.38	1.44	1.04	efficiency provinces
2018	0.90	0.84	1.34	1.39	1.04	
2019	0.91	0.86	1.30	1.34	1.03	
2020	0.94	0.88	1.26	1.30	1.03	
2021	0.95	0.90	1.23	1.26	1.02	
2022	0.97	0.92	1.20	1.22	1.02	
2023	0.98	0.93	1.17	1.19	1.01	
2024	1.00	0.94	1.14	1.16	1.01	
2025	1.02	0.95	1.12	1.14	1.00	

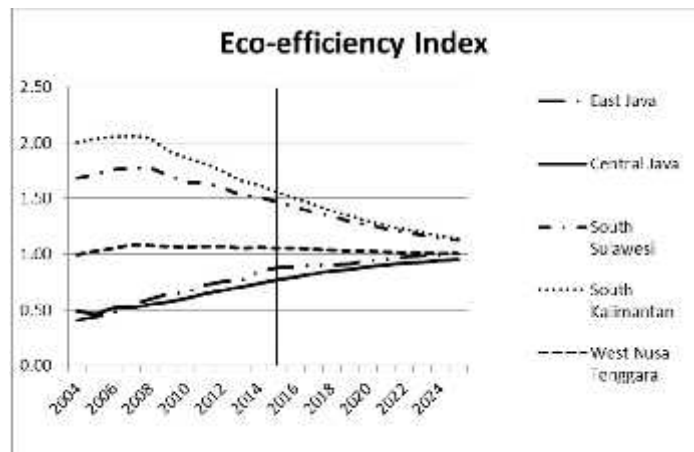


Figure 2. Graph of Eco-efficiency Index

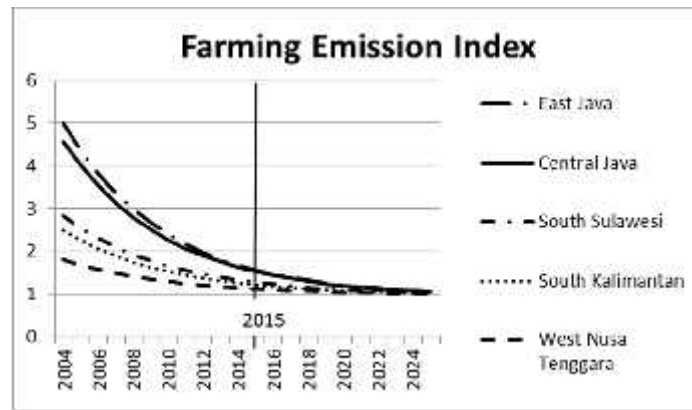


Figure 3. Graph of CO₂ Farming Emission Potential Index

The simulation result of farming eco-efficiency is listed in Table 2 and depicted in Fig.2 as an index number. Higher index value represents better eco-efficiency which means more eco-efficient. By the year 2015, South Kalimantan is the highest index. Figure 3 shows result of CO₂ farming emission potential index.

4. Result and Discussion

This study applied systemic farming eco-efficiency methodology constructed by [3]. Three aspects of sustainable development of economic, environment and social indicators were integrated and simulated to calculate eco-efficiency ratio of cereal production per CO₂ farming emission potential. The integration formed a system dynamic model that consists of those indicators as its elements and eco-efficiency ratio as its goal. Fig. 1 is the simulation model in stock-flow diagram of system dynamic and has been run in period of year 2004 until 2025 for Indonesian five provinces. It results in eco-efficiency index as showed in Table 2 and Fig.2. By analysing these results at year 2015, South Kalimantan reaches the highest index of eco-efficiency which also explains by Figure 3 that South Kalimantan has low index of CO₂ farming emission potential.

Rank of cereal production released by [4] states that East Java, Central Java, South Sulawesi, South Kalimantan And West Nusa Tenggara have cereal production level in a sequence ranking of 1,2,3,4,5. However, for farming eco-efficiency index 2015, South Kalimantan reaches the highest index instead of in rank-4 position. This change proves that evaluating environment aspect in evaluating farming situation reveals significant point of view about how environment aspect influences farming situation.

The simulation model also showed social aspect relationship that housing area, industrial area and road infrastructure area that represents land conversions problem influencing cereal production. Agri-employment affects cereal productivity that also affects cereal production and eco-efficiency.

These privileges are only can be obtained when social aspect indicators are integrated in system dynamic simulation. These also noted as arguments of different analysis with previous studies done by [12-14] which including social aspect indicators as background indicators.

5. Conclusion

This methodology also occupies complex relationship between indicators by exposed them in system dynamic simulation. Measurement model has been implemented to selected 5 provinces of Indonesia. These 5 provinces of East Java, Central Java, South Sulawesi, South Kalimantan And West Nusa Tenggara have cereal production level in a sequence ranking of 1,2,3,4,5. On previous measurement done Food Security and Vulnerability Atlas of Indonesia (FSVA)[4] in 2015,. In comparison with simulation result sequence of eco-efficiency index 3,5,2,1,4 as mentioned has proved that consideration of farming emission as environmental consideration affects to eco-efficiency measurement sequences .

In this study, general model of macro level eco-efficiency has been developed with integrated economic, environment and social indicators. Future research in measuring eco-efficiency of ASEAN

countries is high-possibly done by inputting initial values of each country and several assumptions of similar developing and cereal producer countries would be required.

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