Jurnal Teknologi

Full paper

# System Dynamics Model to Support Rice Production and Distribution for Food Security

Erma Suryani[a*], Rully Agus Hendrawan[a], Totok Mulyono[a], Lily Puspa Dewi[a,b]

[a]*Information Systems Department–Faculty of Information Technology (FTIF), Institut Teknologi Sepuluh Nopember (ITS)–Kampus ITS Keputih, Sukolilo, Surabaya 60111*

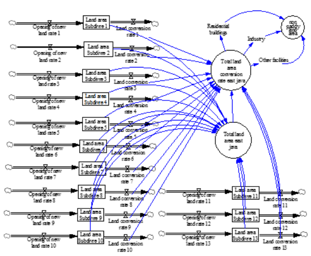
[b]*Informatics Department–Faculty of Industrial Technology, Petra Christian University, Surabaya, Indonesia*

*Corresponding author: erma.suryani@gmail.com

**Article history**

Received :1 January 2014
Received in revised form :
15 February 2014
Accepted :18 March 2014

**Graphical abstract**



**Abstract**

Food security is a national issue as the impact of food insecurity in several regions in Indonesia. The number of Indonesia's large population requires a full attention by the government to meet people's welfare, especially relating to food. A comprehensive study is therefore required to solve this problem. In this research, we utilized System Dynamics based on consideration that this framework offers the ability to incorporate expert knowledge in the model and the ability to model highly non-linear behavior. This pilot study seek developed a System Dynamics model to improve food security by considering regional condition changes to evaluate several policies for strategic decision making; and help government in improving food security through several policy scenarios development such as land intensification, land expansion, and distribution from other region (subdivre) which has surplus stock and import. This study could be considered as a pilot study to improve food security through some scenarios such as land intensification, land expansion, distribution from other regional district, and import.

*Keywords*: System dynamics; modeling; food security; simulation



## ■1.0 INTRODUCTION

Food security is an issue that has become a national concern as the result of the scarcity of crops traditionally consumed as staple food in several regions in Indonesia, as an impact of post-crisis macroeconomic issues. Indonesia's large population and its vastness pose challenges in ensuring the welfare of the people in all areas, especially regarding food.

System dynamics model for Food Security has been developed in development countries which used a systemic perspective as means of understanding the complexity of a phenomenon as well as the (interrelation) linkage and interdependency of its factors. The approach will empower the planners of local regions to foresee future threats, to alleviate partly the scarcity of food, and to handle the mismanagement of food resources [1].

A modelling approach based on System Dynamics can be used to represent relationships between the main agricultural and food system drivers and their consequences for food security, environment, and livelihoods; to represent the quantified outcomes through some regional scenarios, and to indicate how policy and technical interventions can be implemented to the system [2].

Therefore, in this research we propose a System Dynamics (SD) approach based on consideration that this framework offers the ability to model highly nonlinear behavior and to incorporate expert knowledge into the model. Using System Dynamics Framework, we can enhance our understanding of food security issues, especially in the context of local and regional availability of food, severity level of food insecurity in each location, and related changes that occur. Identification and understanding of these issues are crucial, especially for the government and related decision makers, as this would enable them to develop more effective strategic decision making in ensuring food security.

This paper is organized as follows. Section 1 demonstrates introduction. Section 2 provides literature review and previous related work. Section 3 describes the base model development, Section 4 provides model validation, and Section 5 shows the scenario development for the next future. Finally in Section 6, the conclusion is presented.

## ■2.0 LITERATURE REVIEW AND PREVIOUS RELATED WORK

System dynamics enable us to develop scenarios based on different assumptions, or by issuing different values to the parameters and initial variables. By issuing different values to the parameters, alternatives forecasts, or scenarios can be easily obtained [3]. A detailed description of the system dynamics modeling process has been offered; it reinforces many of Ford's perspectives and he offers his own insights [4]. It points out that modeling is a creative process in which each modeler approaches a problem differently [5]. In the beginning, the system dynamics model will demonstrate the existing condition of rice supply, demand, and distribution by considering the external factors such as regional change to check the food security. Causal Loop Diagram (CLD) can be used as a framework in developing the integrated system dynamics model; thus it is very important to ensure its thoroughness. Therefore, understanding the system is essential for the model development. Such understanding can be achieved by a combination of references, data, information, and direct observation of the system. This CLD is the starting hypothesis in developing the model, and it needs to be validated as the proof of its correctness. At this stage, we need to identify some variables which have significant impact to the model output.

## ■3.0 BASE MODEL DEVELOPMENT

Figure 1 represents the CLD of supply, demand, and rice distribution to support rice production and distribution for food security. As we can see from Figure 1, the production of crops is influenced by the productivity of the land, the yield area, impact of pest and the processing technology. Land productivity depends on fertilization, revitalization of land, rainfall, and food processing technology. The ratio of demand fulfillment depends on the quantity of production and demand. This ratio can be increased by both the expanding and the intensification of land area.

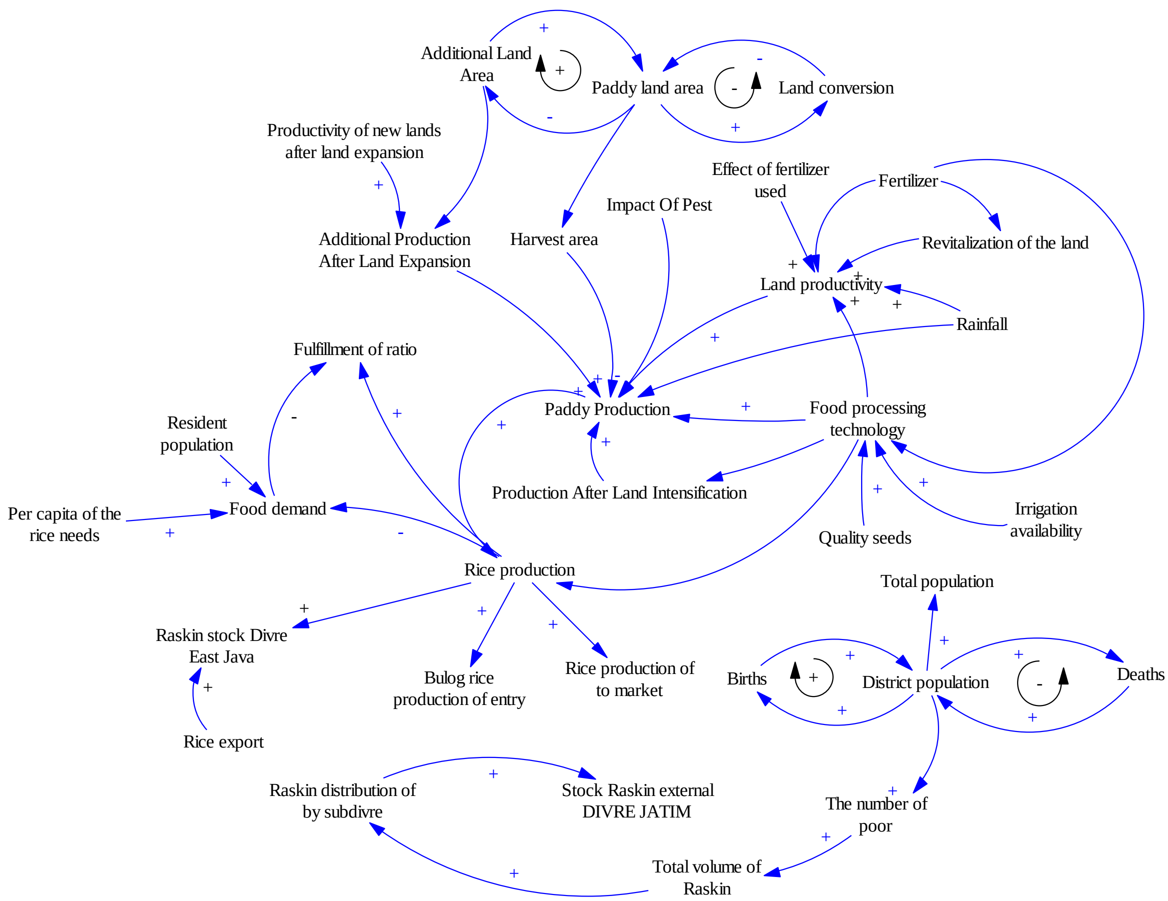



**Figure 1** Causal loop diagram of supply, demand, and rice distribution

### 3.1 Population and Demand Sub-model

The number of population depends on the birth and death rates. The number of population will determine the rice demand. In this research we treated East Java, Indonesia as the case study. As the rice distribution area in East Java is divided into 13 sub-regional divisions, we set the sub-models in accordance with the area division as depicted in Table 1. Rice demand depends on the number of population and consumption per capita. The total East Java population in 2011 was around 37.814.890 people. Based on 2011 statistics, subdivre 1 has the greatest population; it was 5.8 million people, while sudivre 6 has the smallest population of 1.4 million. With this number of population, East Java's demand was approximately 4.73 million ton of rice in 2011.

**Table 1** The list of subregional division in East Java

| SUB-REGIONAL DIVISION | COVERAGE AREA |
|---|---|
| 1 | Surabaya, Sidoarjo, and Gresik |
| 2 | Mojokerto City, Mojokerto, and Jombang |
| 3 | Bojonegoro, Lamongan, and Tuban, |
| 4 | Madiun City, Madiun, and Ngawi |
| 5 | Kediri City, Kediri, and Nganjuk, |
| 6 | Bondowoso and Situbondo |
| 7 | Malang City, Malang, Batu, Pasuruan City, Pasuruan |
| 8 | Probolinggo City, Probolinggo, and Lumajang |
| 9 | Banyuwangi |
| 10 | Blitar City, Blitar, and Tulungagung |
| 11 | Jember |
| 12 | Bangkalan, Sampang, Pamekasan, and Sumenep |
| 13 | Ponorogo, Magetan, and Pacitan |

## 3.2 Land Area Sub-model

The total area of all sub-regional division is the combination of the land area in each respective sub-regional division, as described in Figure 2. The land area of each sub-regional division has a tendency to decrease from time to time as the result of the changes in land utilization, due to housing development, industry, and other facilities.

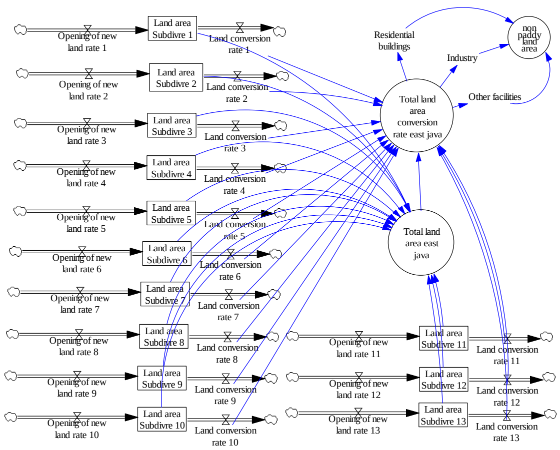



**Figure 2** Land area sub-model

## 3.3 Land Productivity and Paddy Production Sub-model

Land productivity depends on temperature, humidity, sunshine, land surface height, rainfall, fertilizer, seeds volume, and the availability of irrigation. Land productivity is also influenced by the geographical conditions. Geographically, rice plants can grow well in the area between 35 degrees South latitude and 50 degrees North latitude and scattered in the area of height of 2,000 meters above sea level with rainfall between 200 mm / month or 600-1200 ml per year with temperatures of 15-30 degree C, humidity 50-90 percent, 10-11 hours of sunshine per day, land surface height 0-1300, fertilizer, high quality rice seeds and irrigation [6].

The impact of several variables in determining the land productivity can be explained as follows:

- Temperature: Temperature is a very important factor since it has direct impact on crop growth, as it influences almost every stage of the growth process. Every plant has its own specifications in terms of minimum, optimum, and maximum environment temperature, and these values may also vary during different levels of growth. The span of temperature for rice crop growth is between 15-30 C [7].
- Humidity: Humidity is closely related to the rate of transpiration through leaves. Transpiration itself has impacts on the distribution of water and dissolved nutrition. If a humid condition can be maintained, more water will be absorbed by the plant and less will be evaporated. This condition supports the increase in cell size, thus enabling the cells to achieve their maximum size more quickly. The humidity for rice crop is ideally around 60% [8].
- The exposure of sunlight: The radiation from the sun which is captured by chlorophyll in green-leaved plants is the source of energy needed for photosynthesis process. The result of photosynthesis is the main ingredients for plant growth, thus sunlight exposure influence the production of food-producing crops. The sunlight need for rice crops ranges between 10-11 hours per day [9].
- Influence of Rainfall: Rainfall has a very important role in the growth and productivity of food crops. The ideal rainfall for rice plant is about 200 mm per month or more. Assuming that such level of rainfall is necessary for around 4 month period, the desired overall rainfall is around 600-1200 mm [10].
- Seed Quality Factor: The superior quality of seed used the second most important factor in contributing to production system, or around 25% [11].
- Irrigation: Irrigation provides sufficient and stable water supply to guarantee the productivity of rice plants. In order for rice productivity to stay effective in every unit of land area, adequate water supply through irrigation is very important. In average, 2500 liters of water is needed [12].

The total paddy production in East Java is the summation of the paddy production in all Subdivre(s). The total paddy production in East Java was around 6 million to 8 million ton [13].

## 3.4 Rice Stock and Distribution Sub-model

Rice stock will determine the rice distribution. Rice distribution can be delivered from Subdivre which has surplus to Subdivre which has deficit stock. The purpose of this distribution is to provide rice to meet demand and to improve food security. The rice distribution will be allocated to market and targeted household (RTS = Rumah Tangga Miskin). Food security can be determined by three indicators such as Food Availability, Food Access, and Fulfillment Ratio. Figure 3 represents the flow diagram of rice stock and distribution (Note: sb means subdivre).

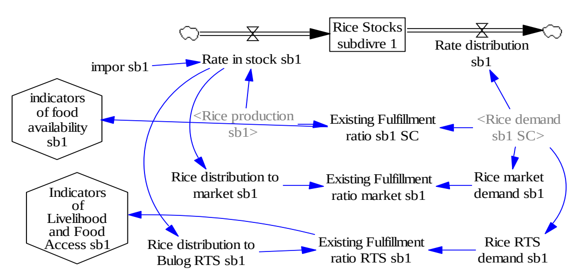



**Figure 3** The flow diagram of rice stock and distribution

Existing fulfillment ratio in the year of 2011 for each Subdivre is shown in Table 2.

**Table 2** Existing fulfillment ratio

| SUB-REGIONAL DIVISION | Fulfillment Ratio |
|---|---|
| 1 | 0.19 |
| 2 | 0.62 |
| 3 | 1.20 |
| 4 | 1.40 |
| 5 | 0.60 |
| 6 | 1.18 |
| 7 | 0.55 |
| 8 | 0.73 |
| 9 | 1.08 |
| 10 | 0.60 |
| 11 | 0.60 |
| 12 | 0.46 |
| 13 | 0.76 |

## 4.0 MODEL VALIDATION

Model validation is required to check the model accuracy. A model will be valid if the error rate is less than 5% and error variance is less than 30% [14]. Until now we have validate the population and rice demand. Error rate and error variance are defined in Eqs. (1)-(2):

$$ErrrorRate = \frac{\left[\bar{S} - \bar{A}\right]}{\bar{A}} \quad (1)$$

$$ErrorVariance = \frac{|Ss - Sa|}{Sa} \quad (2)$$

Where :
$\bar{S}$= the average rate of simulation
$\bar{A}$= the average rate of data
$S_s$= the standard deviation of simulation
$S_a$= the standard deviation of data

Error rate of Population, Demand, and Production are depicted as follows:

1) Error rate of Population

$$= \frac{[36{,}314{,}889.6166667 - 36{,}266{,}334.1666667\,]}{36{,}314{,}889.6166667} = 0.001$$

2) Error rate of demand

$$= \frac{[4{,}539{,}361.20208333 - 4{,}529{,}479.07291667\,]}{4{,}539{,}361.20208333} = 0.002$$

3) Error rate of production

$$= \frac{[6{,}940{,}316 - 6{,}846{,}652\,]}{6{,}846{,}652} = 0.01$$

Error Variance of Population, Demand, and Production are determined as follows:

1) Error variance of Population

$$= \frac{[1{,}042{,}123.3901551 - 1{,}026{,}604.06033097\,]}{1{,}042{,}123.3901551} = 0.015$$

2) Error variance of Demand

$$= \frac{[4{,}539{,}361.20208333 - 4{,}529{,}479.07291667\,]}{4{,}539{,}361.20208333} = 0.002$$

3) Error variance of Production

$$= \frac{[733{,}041 - 653{,}025\,]}{733{,}041} = 0.11$$

## 5.0 SCENARIO DEVELOPMENT

Scenario Development is required to improve the food security by considering three indicators of food security such as food availability, food access, and fulfillment ratio. This scenario can be done by improving land productivity to increase the production and fulfillment ratio. Subdivre which has surplus stock may deliver rice to Subdivre which has deficit stock.

### 5.1 Distribution Scenario

This scenario is developed to meet the fulfillment ratio by providing supply from other Subdivre which has excess stock (the fulfillment ratio is greater than 1) and import. So that the ratio of fulfillment after obtaining supply from other Subdivre and import can be close to 1, which means the supply can meet the demand as described in Table 3:

**Table 3** Fulfillment ratio and scenario plan for distribution and import

| Subdivre | Fulfillment (2011) | Scenario Plan |
|---|---|---|
| Subdivre 1 | 0.19 | After obtain additional supply from Subdivre 3, the fulfillment ratio can be increased through the additional supply and the rest will be fulfilled through import. |
| Subdivre 2 | 0.60 | The fulfillment ratio can be increased through import |
| Subdivre 3 | 1.20 | Distribute to Subdivre 1 of around 20% of its production |
| Subdivre 4 | 1.40 | Distribute to Subdivre 5 of around 40% of its production |
| Subdivre 5 | 0.60 | After obtain additional supply from Subdivre 4, the fulfillment ratio can be increased through the additional supply and the rest will be fulfilled through import. |
| Subdivre 6 | 1.18 | Distribute to Subdivre 7 of around 18% of its production |
| Subdivre 7 | 0.55 | After obtain additional supply from Subdivre 6, the fulfillment ratio can be increased through the additional supply and the rest will be fulfilled through import. |
| Subdivre 8 | 0.73 | The fulfillment ratio can be increased through import |
| Subdivre 9 | 1.08 | Distribute to Subdivre 11 of around 10% of its production |
| Subdivre 10 | 0.60 | The fulfillment ratio can be increased through import |
| Subdivre 11 | 0.60 | After obtain additional supply from Subdivre 9, the fulfillment ratio can be increased through the additional supply and the rest will be fulfilled through import. |
| Subdivre 12 | 0.46 | The fulfillment ratio can be increased through import |
| Subdivre 13 | 0.76 | The fulfillment ratio can be increased through import |

From this scenario plan, we can determine the import volume for each Subdivre based on the Demand, Expected Supply (Production + Additional Supply) to make the fulfillment ratio close to 1. The detail of this process can be seen in Table 4. Subdivre 1 for example, its fulfillment ratio will increase from 0.19 to 1.02 by importing of around 50% of its demand, and obtaining additional supply from Subdivre 3 of around 20% of its (Subdivre 3) production.

**Table 4** Distribution scenario for import and additional supply from other subdivre

| Subdivre | Year 2012-2025 | | | | |
|---|---|---|---|---|---|
| | Average Demand (Ton) | Expected Supply (Ton) | Distribution (Import and Additional Supply Scenario) | | Fulfillment Ratio |
| Subdivre 1 | 791.722.39 | 804.357.71 | Import = 50% of Demand | Additional Supply from Subdivre 3 of around 20% of its production | 1.02 |
| Subdivre 2 | 316.503.30 | 346.034.77 | Import = 10% of Demand | 0 | 1.10 |
| Subdivre 3 | 474.742.10 | 721.318.07 | 0 | 0 | 1.52 |
| Subdivre 4 | 213.659.22 | 237.035.90 | 0 | 0 | 1.11 |
| Subdivre 5 | 360.098.11 | 578.126.24 | Import = 10% of Demand | Additional Supply from Subdivre 4 of around 40% of its production | 1.61 |
| Subdivre 6 | 187.299.84 | 284.920.06 | 0 | 0 | 1.53 |
| Subdivre 7 | 675.606.12 | 669.551.48 | Import = 80% of Demand | Additional Supply from Subdivre 6 of around 18% of its production | 0.99 |
| Subdivre 8 | 313.315.19 | 311.804.04 | Import = 80% of Demand | 0 | 1.00 |
| Subdivre 9 | 204.128.39 | 283.136.84 | 0 | 0 | 1.39 |
| Subdivre 10 | 386.006.42 | 375.711.56 | Import = 80% of Demand | 0 | 0.97 |
| Subdivre 11 | 305.547.55 | 305.941.22 | Import = 70% of Demand | Additional Supply from Subdivre 9 of around 10% of its production | 1.00 |
| Subdivre 12 | 504.074.00 | 475.291.15 | Import = 80% of Demand | 0 | 0.94 |
| Subdivre 13 | 276.887.47 | 289.269.13 | Import = 80% of Demand | 0 | 1.05 |

## 5.2 Land Intensification, Land Expansion, Distribution, And Import Scenario

Land intensification can be conducted through improving agricultural irrigation, the use of high quality seeds and fertilizer volume in accordance with the requirements of rice growth. Land intensification might increase production by 18.1% from the existing condition. Here we assume that, the use of high quality seeds might increase agricultural output by 10%, improve agricultural irrigation can increase production by 5%, and the use of fertilizers might increase production by 3%. Land expansion policies can be carried out by agricultural expansion into untapped areas. Imports for some subdivres might still be required to improve the fulfillment of a minimum ratio of 0.6.

For example, the fulfillment ratio of subdivre 1 will increase from 0.19 to 0.91 by conducting land intensification and land expansion of around 3000 Ha (so that its production would be around 717,634.57 Ton), import of around 10% of Subdivre 1 demand, and additional supply around 45% of Subdivre 3 production. All the possible options for the other Subdivres can be seen in Table 5.

**Table 5** Scenario results of land intensification, land expansion, production, import, additional supply, and new fulfillment ratio

| Subdivre | Year 2012-2025 (Scenario Results) | | | | | |
|---|---|---|---|---|---|---|
| | Land Productivity Scenario (Ton/Ha) | Land Expansion Scenario (Ha) | Production Scenario (Ton) | Import and Additional Supply from Other Subdivre (Ton) | | New Fulfillment Ratio |
| Subdivre 1 | 4.4 → 4.73 | 3000 | 717,634.57 | Import = 10% of demand | Additional Supply from Subdivre 3 = 45% of Sb3 Production | 0.91 |
| Subdivre 2 | 4.87 | 3000 | 349,649.53 | Import = 10% of demand | 0 | 1.11 |
| Subdivre 3 | 6.66 | 0 | 500,112.79 | 0 | 0 | 1.06 |
| Subdivre 4 | 6.93 | 0 | 316,792.76 | 0 | 0 | 1.49 |
| Subdivre 5 | 5.57 | 0 | 380,290.27 | 0 | 0 | 1.06 |
| Subdivre 6 | 7 | 0 | 284,080.63 | 0 | 0 | 1.52 |
| Subdivre 7 | 6.9 → 8.0 | 5000 | 269,003.54 | Import 40% | Additional Supply from Subdivre 6 = 18% of Subdivre 6 Production | 0.60 |
| Subdivre 8 | 5.1 → 5.89 | 3000 | 126,814.92 | Import 40% | 0 | 0.60 |
| Subdivre 9 | 5.7 | 0 | 284,407.60 | 0 | 0 | 1.40 |
| Subdivre 10 | 5.1 → 5.5 | 5000 | 228,305.90 | Import 40% | Additional Supply from Subdivre 4 = 20% of Subdivre 4 Production | 0.80 |
| Subdivre 11 | 4.2 → 4.5 | 3000 | 156,308.64 | Import 40% | Additional Supply from Subdivre 9 = 10% of Subdivre 9 Production | 0.71 |
| Subdivre 12 | 4.6 → 5 | 5000 | 228,254.15 | Import 45% | 0 | 0.60 |
| Subdivre 13 | 4.5 → 5 | 5000 | 128,136.64 | Import 40% | 0 | 0.67 |

## 6.0 CONCLUSION

The system dynamics model may provide insight for decision maker in improving food security through some indicators such as *food availability and fulfillment ratio*. In this article, rice production is used as a model.

Rice demand depends on the number of population and consumption per capita. Meanwhile, land productivity depends on temperature, humidity, sunshine, land surface height, rainfall, fertilizer, seeds volume, and the availability of irrigation.

This study could be considered as a pilot study to improve food security through the use of some scenarios such as land intensification, land expansion, distribution from other regional district, and import. Further research is required to integrate national food logistics based on several key factors such as commodities; agent and logistics service provider, transportation, information and communication technology, human resources, as well as regulation and policy.

## Acknowledgement

We would like to express our deepest appreciation to our research partners that have provided data and information regarding food production.

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