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ARTICLE

Rice Deficit Projections for Indonesia's New Capital: A System Dynamics Analysis

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ABSTRACT

The aims of this study are (1) to predict the demand and supply of rice in Ibu Kota Nusantara or IKN and (2) to integrate rice food policy formulation through soil quality assessment and the projection of rice supply and demand. This study presents a novel integration of the system dynamics model with a soil quality model to assess future rice supply and demand, providing a policy-oriented tool for addressing food security in the context of IKN. The data obtained through the Focus Group Discussion process, in-depth interviews and rice field visits. Secondary data comes from the Central Statistics Agency at the national and regional levels, Regional Development Agencies at the provincial and district/city levels. In addition, soil samples in the paddy field were taken and tested in the laboratory to determine the quality of the soil. The results of the model simulation indicate that the IKN region is projected to experience a rice surplus between 2025 and 2032. However, starting in 2033, the region is expected to face a rice deficit. To control rice production, the government needs to control land conversion and illegal mining. The government should implement mitigation policies during the deficit period by improving land quality, expanding rice planting areas, providing water dams, building irrigation, and training as well as educating the farmers.

Keywords: Availability; Deficit; Policy; Rice

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1. Introduction

Indonesia is designing and building a new capital city on the island of Kalimantan. The name of the new capital is Ibu Kota Negara (IKN) Nusantara. It is hoped that the relocation of the capital city will solve social and environmental problems, especially those related to population density, air and environmental pollution in Jakarta. The main source for air pollution is motor vehicle congestion which occurs every day. The economic losses are very large, both in terms of costs and time as well as annual flood subscriptions [1]. On the other hand, one of the major challenges facing East Kalimantan as the proposed location for Indonesia's new capital city is ensuring an adequate supply of rice for the growing population. The population is projected to increase significantly in line with the capital's development, thereby intensifying demand for rice. Low land fertility is a key factor contributing to low agricultural productivity. The soil in the region tends to be acidic, with low levels of essential micronutrients such as calcium (Ca), magnesium (Mg), potassium (K), and organic carbon, all of which limit rice production. Additionally, limited water availability—caused by a short rainy season—affects irrigation and cropping patterns, further reducing productivity. Infrastructure to support water storage and irrigation is also insufficient, resulting in most rice fields being cultivated only once a year. Another major challenge is the government's limited ability to control the conversion of rice fields into plantations and mining areas, which further threatens sustainable rice production.

This challenge is exacerbated by declining local rice production in recent years, largely due to limited water availability. The region experiences fewer than three wet months per year, placing it in the 'dry' agroclimate category (Agroclimate Type C), with rainfall levels typically below 100 mm per month and less than 1,500 mm annually [2,3]. As a result, the cropping index in most areas is limited to only one planting season per year, with a maximum of two. Additionally, the generally low soil fertility across Kalimantan poses further constraints on agricultural productivity [4,5]. Compounding these issues is the volatility of rice prices, which underscores the need for consistent government policy support [6].

However, there is one thing that is still a question in the development of the archipelago's capital, namely food sources, especially rice. According to the work by Supriadi [7], so far rice production in East Kalimantan is only sufficient to meet 1.32 million residents, while the population is 3.7 million. Meanwhile, rice availability is only 66.57 percent, so the estimated deficit is 33.43 percent [8]. The deficit will increase further if residents enter the new capital (Ibu Kota Negara, IKN) after it has been built and inhabited by government officials and the public. For the 2025 projection, East Kalimantan will only be able to supply around 44.8 percent of rice, the rest will be through imports.

On the other hand, East Kalimantan faces serious challenges, namely (1) the productivity of rice fields is still low and (2) the rate of land conversion is high [9,10]. So, how can the East Kalimantan government meet food supplies for the future? The aims of this research are (1) to predict the demand and supply of IKN rice and (2) to formulate a food policy for IKN rice.

In general, the area harvested for paddy (rice) crops increased in 2018 – 2020 but decreased during 2020 – 2022. Furthermore, the production of rice ground dry grain (*Gabah Kering Giling* or GKG) from the last 2 years tended to decline accompanied by a reduction in the area harvested. Moreover, land productivity was relatively decrease in 2022 compared to 2018, namely from 4.05 tonnes/ha to 3.69 tonnes/ha. In detail, the number of harvested areas, GKG production and land productivity in East Kalimantan are presented in **Table 1** [11–14].

Table 1. Number of Harvested Areas, GKG Production and Land Productivity [11–14].

Information	**2018**	**2019**	**2020**	**2021**	**2022**
Harvested area (Ha)	64,961	69,708	73,568	66,269	64,970
Growth		7.31	5.54	(9.92)	(1.96)
GKG tonnes rice production	262,774	253,818	262,435	244,678	239,425

Table 1. *Cont.*

Information	2018	2019	2020	2021	2022
Growth		(3.41)	3.39	(6.77)	(2.15)
Productivity tonnes/ha	4.05	3.64	3.57	3.69	3.69

At the district level, rice productivity in Penajam Paser Utara (PPU) Regency has decreased from 3.4 tonnes per hectare in 2020 to 3.2 tonnes per hectare in 2022. However, the opposite happened in Kutai Kartanegara Regency which experienced an increase in productivity from 3.5 tonnes per hectares in 2020 to 3.8 tonnes per hectare in 2022. In some particular area the productivity even reaches 6 to 7 tonnes in 2023. Meanwhile at the sub-district level, based on the results of interviews with farmers, indicated that lowland rice productivity per hectare was around 3-4 tonnes of dry grain of rice.

Limited rice production is influenced by two main factors: (1) land conversion and (2) land quality. Detailed information on harvested area, dry grain yield, and land productivity in regions included within the IKN area in East Kalimantan is presented in **Table 2** [15,16].

Table 2. Number of Harvested Areas, GKG, and Land Productivity of Areas Included in the IKN [15,16].

Production			
District/Year	**2020**	**2021**	**2022**
Kutai Kartanegara	110,940.44	104,441.33	105,025.70
Penajam Paser Utara	47,018.03	42,130.12	45,160.69
Harvested Area			
District/Year	**2020**	**2021**	**2022**
Kutai Kartanegara	31,952.96	27,635.02	27,981.31
Penajam Paser Utara	13,924.41	13,501.60	13,531.22
Productivity			
District/Year	**2020**	**2021**	**2022**
Kutai Kartanegara	3.47	3.78	3.75
Penajam Paser Utara	3.38	3.12	3.34

Referring to Pusat Penelitian Tanah Bogor (institutional) based on the results of soil analysis and assessment of soil fertility status, showed that the fertility status of paddy and non-rice paddy fields in the IKN area is classified as low. Thus, it is clear that low rice productivity is also due to inadequate soil fertility [17]. In comparison, rice productivity in East Kalimantan is only around 3-3.8 tonnes per hectare, while on the island of Java it reaches 5.6-5.8 tonnes per hectare of dry grain.

In such conditions, the Government needs to optimize rice fields, especially rain-fed land by building water storage areas (dams) and irrigation system supported along with technology [18]. In this case, water supply is an important factor to support rice production [19]. Low Phosphorus (P) content and low water availability are the limiting factors that affect rice production, so it is necessary to develop technology that save water and P use [20]. Water management and the addition of rice husk ash help provide Silicon (**Si**) which functions to maintain P availability [21].

From a demographic perspective, it is estimated that future population growth and arrivals of people will be greater in IKN. While it is feared that the capacity for food availability of rice will not be able to keep up with supplying the needs. This is why the deficit occurs not only in East Kalimantan but also in the IKN area. In this case, the policy formulation and regulatory system for the provision of rice food should be based on planned future research that is able to maintain the availability and stability of rice food in the long term [22–24].

In general, considerable research has been conducted on land and food systems in East Kalimantan. These include studies on optimizing water management in drylands [25], the management of acid sulfate tidal lands [26], swamp land development [27], agricultural land use dynamics using system dynamics [28], rice production and pricing models [6], rice supply [29], land use change mitigation [30], traditional land expansion using land change simulation [31], food security through livelihood-based actor empowerment [32], land suitability assessments [5], sustainable land management policy framework [33], and spatial-temporal disaggregation of harvest results [34].

Furthermore, the blueprint for the National Capital (IKN) does not provide a comprehensive assessment of land suitability or a detailed projection of future rice availability, raising concerns about long-term food security planning [35]. However, research that integrates specific land characteristics—such as soil conditions—into system dynamics models for the purpose of informing rice-related food policy remains very limited. The objective of this study is (1) to predict the demand and supply of rice in Ibu Kota Nusantara or IKN and (2) to integrate rice food policy formulation through soil quality assessment and the projection of rice supply and demand.

2. Materials and Methods

This study is explanatory research. It described the interconnected elements or variables in a system of supply-demand and availability of rice in the new capital of Indonesia. Primary and secondary data were utilized fully to find for the best solution over time in the system. Primary data were obtained from some Focus Group Discussions (FGD) with the local farmers, government officials and experts from several Non-Governmental Organizations (NGOs). Secondary data were collected from the national dan regional Indonesian Statistics or Badan Pusat Statistik (BPS), Regional Development Boards at the provincial and sub-regional levels, as well as other local governmental offices. Next, conduct a field survey to take soil samples to assess the level of soil fertility and soil Ph levels. Sampling locations as many as 22 points in 2023 as many as 5 points in 2024. This study also uses drones to observe the land cover of agricultural areas, especially rice fields.

The research applied the System Dynamics (SD) model. System dynamics is a methodology based on feedback systems which change over time. It can easily cope with the multi-loop structures, time-delay and non-linearity in a complex system. In modelling the SD, the basic principles of SD are the existence of causal relation, feedback loops and also delay., They are interrelated among variables embedded in the system. There is positive and negative feedback in the feed-back loop, consisting the causal loop diagrams. In addition, the stock and flow diagram can be built from d the flow of incoming flow and stream flow be conceptualized directly without from the causal loop diagram (Maani, 2000).

Following Sterman the modelling process of system dynamics consists of several stages. They are; (1) problem articulation, (2) hypothesis dynamic, (3) model formulation, (4) test and validation and (5) policy and evaluation formulation [36]. This research also took soil samples to be tested in the laboratory. The aim is to determine the quality of IKN rice fields. Based on the field research, the data obtained were used as the basic assumption parameters. Detail stock-flow diagram and causal-loop diagram used in this study is presented the page 8 below. The SD model will be simulated based the 2 models, namely Model 2023 and Model 2024.

Model 2023 used the basic parameters obtained from the IKN first site visit in 2023. Model 2024 refined and updated the data of 2023 with a new information obtained in 2024. Two new assumptions included in Model 2024. The first assumption IKN Authority implements a Moratorium Coal Mining, whether legal and illegal ones, in IKN. The second assumption, IKN Authority also started to implement gradually the provision of 14,000 hectares land for agricultural purposes.

SD has been widely used in various studies. Studies related to the agricultural sector and its development include analyzing the eco-agricultural system in China [37]. Queenan used it to study animal husbandry and food systems in South Africa [38]. The study of complex global food systems is also approached with the SD model [39]. Meanwhile, a study of food security for subsistence farmers in the sub-Saharan region was carried out by Oyo and Kalema using System Dynamics as an analysis tool [40]. Guma Rwashana and Oyo studied the food security of farming households from an SD perspective in Uganda [41]. Other studies that utilize SD include Antle and Stoorvogel who show how a combination of SD and spatial diversity can be integrated in an agricultural production system [42]. Another study related to SD is developing agricultural and rural development [43].

The supply and demand model for food (rice) in IKN is structured in a dynamic systemic form, and is therefore estimated using a System Dynamics approach. This systemic model is composed of three main sub-systems. Each of them is a Rice Demand sub-system, a Rice Supply sub-system and is also accompanied by rice stock availability sub-system. In the Demand sub-system, the rice demanded is closely related to the number of people living in the area and rice consumption per capita. The population in this model is categorized into several groups: local residents; incoming State Civil Apparatus (ASN), including police and military personnel (TNI); and migrant workers involved in the construction of government buildings and other infrastructure projects at IKN.

Meanwhile, in the Supply sub-system, the rice produced is influenced by the size of planted area and productivity of the land as well as the yield of dry grain produced from rice production. The rice availability sub-system is closely related to the balance of demand and supply, the stock of rice by the government and the private sector as well as rice imports and exports. This rice import and export includes the movement of rice commodities, both between regions in East Kalimantan Province and other provinces. East Kalimantan generally imports rice from East Java Province and South Sulawesi Province.

Applying the dynamic Euler equation, the relationship among the element in the systems are formulated in general as the following;

- Population in IKN = growth*(labor + ASN + local – moves out)
- Demand for rice = rice consumption/capita * Population in IKN
- Supply of Rice = yield * Rice production
- Rice production = (rice filed * $productivity_r$) + (non-rice filed * $productivity_{nr}$)
- Stock availability = Supply for rice – Demand for Rice + import+ Export + required Stock

3. Results

3.1. Characteristics of Rice Field Soil in IKN

Soil sampling in this second year of research was carried out to complement the 27 soil samples that had been taken and analyzed in the first year of research, especially for the northern part of the IKN. There were five paddy soil samples taken and given the symbols TS01, TS02, TS03, TS10, and TS11. The spatial distribution of soil samples is in **Figure 1** and administratively the location of sample TS01 is in Loa Janan District and samples TS02, TS03, TS10, TS11 are in Samboja District. According to the Soil Unit Map/SPT, the type of soil in samples TS01, TS02, and TS03 is included in the Typic Hapludults soil type (Ordo Ultisol), while TS10 and TS11 are included in the Fluvaquentic Endoaquepts (Ordo Inceptisol) [44].

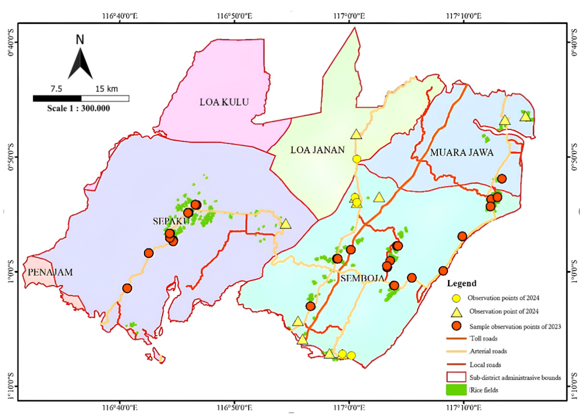

Figure 1. Location of Soil Sampling.

The pH value of the soil from the five samples of paddy soil analyzed ranged from 4.26 to 5.02, so it is classified as acidic to very acidic [45]. The causes of soil acidity are caused by several factors, including parent material, organic material, aluminum hydrolysis, oxidation reactions to minerals, and leaching of base cations in the soil [46]. In the pH analysis, samples TS01 and TS10 have very acidic pH values of 4.48 and 4.26. Thus, paddy soil in the IKN area, especially in Samboja District, has a relatively low level of fertility.

When viewed in the micronutrients section such as Ca, Mg, K, and Na, the values are also relatively low, indicating that the availability of nutrients needed by plants is also relatively low. The results of the analysis of C-organic levels show that the soil samples are in the very low to low category [47]. Even for the TS02 soil sample, the C-organic content is very low, which is below 1% with the total N content in the paddy field soil sample only ranging from 0.13 - 0.18. This value is included in the low category [45]. This low C-organic content will have an impact on soil fertility, because soil with low C-organic generally has a poor soil structure, as a result the soil's ability to retain water becomes low and increases the risk of drought in plants. Low C-organic also causes a decrease in the cation exchange capacity (KTK/CEC). The results of the KTK analysis show that the cation exchange capacity in the five samples is generally in the low to high category [45]. KTK is an aspect that describes the amount of cations absorbed and exchanged by the soil. Clay and C-organic elements are materials that contribute to soil KTK. The higher the level of organic C in the soil, the higher the KTK value of the soil [48].

The results of soil analysis, samples TS01 and TS03 have high KTK values of 26.27 cmol/kg and 27.35 cmol/kg. This can be because the C-organic and clay values are relatively high, respectively TS01 has 1.33% C-org, 64.13% clay and TS03 has 1.32% C-org, 64.64% clay. Meanwhile, the lowest CEC value is owned by soil sample TS02, which is 11.82 cmol/Kg because it only has 0.77% C-org and 19.55% clay. Soil with low CEC like this cannot retain important nutrients such as potassium, calcium, and magnesium, which causes these nutrients to be easily washed out and unavailable to plants in the long term. This is in accordance with the analysis data which shows that the levels of micronutrients (Ca, Mg, K, and Na) in the five samples are relatively low. The detailed results of the soil nutrient content analysis are presented in **Table 3**.

Tabel 3. The Results of the Nutrient Content Analysis Test of the IPB University Land Resources Laboratory.

No.Lab	No. Field	IKM-ITSL-22	IKM-ITSL-24	IKM-ITSL-25	IKM-ITSL-03	IKM-ITSL-02		IKM-ITSL-05				
		pH 1:5	Walkley & Black	Kjedldahl	Bray I	HCl35%		N NH_4Oac pH 7.0				
		H_2O	C-org	N-Total	P	P	K^+	Ca	Mg	K	Na	KTK
			..(%)..	..(%)..	.(ppm).	..(ppm)..		..(cmol$^{(+)}$/kg)..				
HI 0020	TS 01	4.48	1.33	0.15	5.40	285.4	109.3	6.00	4.47	0.41	0.18	26.27
HI 0021	TS 02	5.02	0.77	0.13	4.01	257.5	87.1	6.00	5.31	0.25	0.16	11.82
HI 0022	TS 03	4.61	1.32	0.18	4.96	231.4	101.8	2.26	2.27	0.23	0.11	27.35
HI 0023	TS 10	4.26	1.95	0.14	4.12	109.0	47.3	0.68	0.32	0.12	0.08	18.31
HI 0024	TS 11	4.67	1.92	0.18	5.31	75.7	78.1	1.17	0.95	0.18	0.15	23.11

description:
TS01 is located in Loa Janan District and TS02, TS03, TS10, TS11 are located in Semboja District
TS01 to TS03 have soil types based on Soil Map Unit namely Typic Hapludults (Ordo Ultisol) while TS10 and TS11 are Fluvaquentic Endoaquepts (Ordo Inceptisol)
Soil sampling was carried out using the composite method where at one location 3 soil drilling points were carried out as a representation of soil conditions with a depth of 0-20 cm then combined and composited.
N-Total affect s plant (growth and productivity)

Based on laboratory tests of samples TS01, TS03, TS11, they appear to have a clay texture (clay fraction >60%), sample TS02 has a dusty clay texture (dust fraction >60%), and sample TS10 has a dusty clay texture (the percentage of dust and clay is not much different) based on the texture triangle, Samboja District is dominated by clay fractions. This texture condition is in accordance with the characteristics of the Ultisol (Typic Hapludults) and Inceptisol (Fluvaquentic endoaquepts) soils spread across this district [49]. Soil with the Ultisol order has the following characteristics, namely it is formed from intense weathering and washing processes resulting in clay-like soil with a high clay mineral content so that the amount of water available to plants is reduced. The Ultisol order is acidic soil that has low nutrient content and high Al content, causing low CEC, and Ultisol soil has a low or slow permeability or infiltration rate [50,51]. The widest distribution of ultisol soil is found in Kalimantan [52]. In terms of its nature, Inceptisol soil is actually not much different from Ultisol soil which is old soil (weathered), where both types of soil have similarities, namely having low fertility due to the continuous washing process that causes the soil to become acidic. The detailed analysis results are presented in **Table 4**.

Table 4. Result of Soil Texture Analysis of the IPB University Land Resources Laboratory.

No. Lab	No. Field	KB	IKM-ITSL-09		IKM-ITSL-11		
			DTPA		Texsture (Pipet Method)		
			Fe	Mn	sand	silt	clay
		..(%)..	..(ppm)..		..(%)..		
HI 0020	TS 01	42.08	45	56.59	0.22	35.65	64.13
HI 0021	TS 02	99.16	23	86.90	1.40	79.05	19.55
HI 0022	TS 03	19.43	45	65.52	0.94	34.42	64.64
HI 0023	TS 10	6.48	93	9.46	11.78	42.33	45.89
HI 0024	TS 11	10.56	15	8.72	1.67	20.98	77.35

3.2. Rice Stock Projection

The number population of IKN in Sepaku, West Samboja, Samboja and Muara Jawa districts in 2023 is around 147,529 people [53–55]. With a growth of around 1.2 percent, this number will increase to about 150 thousand in 2024, along with the start incoming of the ASN relocation to the IKN. The ASN relocation will bring about 4,000 people (discussion with director of IKN), plus the workers who are currently completing the physical construction of the IKN, which number around 27,000 people, it is estimated that the population in the IKN will reach 180 thousand people by 2024.

Using per capita rice consumption data of 110 kg per person per year and with the arrival of ASN and construction workers to the IKN area, the need for rice in this area is estimated to be 19.5 thousand tons per year. Meanwhile, based on a field survey conducted in 2024, it is estimated that rice production in the IKN area (Sepaku, West Samboja, Samboja and Muara Jawa Districts) amounted to approximately 40 thousand tonnes per year. Thus, until 2024, rice production in the IKN area will still experience a surplus compared to the need to meet the food needs of the population in this area.

However, there are several issues that can affect the production and supply of rice from the local districts. These issues include changes in the conversion of rice commodities to oil palm plantations and conversion to buildings. Discussion with stakeholders of the Penajam Paser Utara Regency, the officials of local government, indicated that the conversion of rice field commodities to oil palm plantation was around 100 ha, out of 600 ha of land in Rawa Mulia, Babulu District. The causes of the conversion among others include (1) better income prospects for oil palm plantations accompanied by small farming business risks, (2) rice farming has a risk of crop failure due to flooding and high tides, (3) low productivity and production which affects low farming business income and profitability [56], (4) additional costs of farming to reduce soil acidity, (5) risk of drought in farming land due to climate change and natural conditions [57], (6) often there is an increase in the cost of fertilizer farming to be large because the availability of subsidized fertilizer is limited [58,59], (7) attacks by brown planthoppers (*Nilaparvata lugens*) and, (8) seed quality. The increasing rate of land use change in the IKN area has a significant impact on rice harvests and rice supply in this.

Changes of agricultural land in the area also occur due to increased coal mining activities (**Figure 2**). Mining activities, both legal and illegal, have also caused environmental damages. These coal mining activities will eventually cause land depletion and left a hole with stagnant waste water and repairing the environmental damages will take a very long time. As an illustration of the change function of agricultural land, especially rice fields, with damage of the natural environment is shown in **Figure 2(a)** and **(b)**.

(a) **(b)**

Figure 2. Environmental Damages Due to Coal Mining in the Agricultural Area **(a)** Former Pit Turned into Artificial Waterbody; no Sign of Rehabilitation **(b)** Expansion.

Data from the Ministry of Agriculture (2020) and satellite imagery from 2021 and 2024 (sourced from https://goto.arcgisonline.com/maps/World_Imagery) show a decline in rice field area in the IKN region. The area decreased from 1,800 hectares in 2021 to 1,700 hectares, and further to 1,500 hectares in 2024. Mining activities have significantly contributed to this reduction.

In addition to land conversion factors, the availability of water for rice fields also plays an important role in rice production in East Kalimantan, including the IKN. Generally, rice fields in this area are highly dependent on rainwater in addition to the rivers that flow in this area. Rainfall in Samboja and Muara Jawa Districts ranges from 104 - 190 mm per month with an average rainfall of between 130-150 days per year [54,55]. Meanwhile, for Sepaku District in PPU Regency, the rainfall recorded in 2019 was very varied, namely a minimum of 1 mm per month in September and a maximum of 268 mm per month in March [53]. Reduced rainfall during the planting season will greatly reduce the harvest. Likewise, if rainfall is very abundant, it will submerge agricultural land which will result in crop failure. Almost the same findings regarding the role of water and rain in food crop farming were also obtained in other studies.

To estimate and simulate the system dynamics model, the parameters shown in **Table 5** below are used for the 2023 and 2024 model.

Table 5. Basic Assumption Parameters.

Basic Assumptions Parameters			
Descriptions	**Model 2023**	**Model 2024**	**Unit**
State Civil Apparatus (ASN)	16990	4925	Person
ASN growth	10	10	Percentage
Population of IKN	175000	180000	Person
Local population growth	1.2	1.2	Percentage
Workers move-in	17000	27000	Person
Rice consumption per capita	110	110	Kilogram/year
Land potential	29199.63	14000	Hectare
Rice fields	1725.16	1500	Hectare
Non-rice fields	27373.37	1700	Hectare
Land productivity	3 – 3.5	5	Ton/Hectare
Dry grain yield	60	65	Percentage

Source: Field data and National and Regional BPS publications

The selection of parameters is based on research objectives and supported by previous studies. Each parameter includes operational definitions and clearly defined scopes to highlight their respective distinctions. The parameters used in this study are as follows:

1. **State Civil Apparatus Growth**: Refers to the increase in the number of civil servants, including during the entire development period of the IKN. This growth directly affects rice demand [8]. Parameter used in the study was obtained from discussion with the Authority of IKN (OIKN)
2. **Population of IKN**: Represents the total number of residents living in the IKN, which serves as a key determinant of future rice demand [6,8,60–63]. The data obtained from local and regional statistics offices in the region under study and focus group discussions with stakeholders in Tenggarong, Penajam and Samarinda.
3. **Local Population Growth**: Refers to population growth originating from surrounding local areas. This contributes to changes in total rice consumption. Discussion with authorities IKN indicated that the incoming labor as well as the out-going one were higher than previously estimated.
4. **Worker move-in**: Captures the influx of workers into the IKN for infrastructure and industrial development, thereby increasing rice demand. Parameter on rice consumption were estimated based on the data available at the Ministry of Agriculture and other official publications.
5. **Rice Consumption per Capita**: The average amount of rice consumed by each individual, serving as a key factor in estimating total rice demand in the IKN [6,60–63]. Estimates used was collected during discussion with OIKN, who planned gradually to set aside area for agricultural purposes.
6. **Land Potential**: The extent and quality of land available for rice and non-rice agriculture, influencing future production capacity [61]. Parameter estimates used was collected from the Regional Statistical Offices.
7. **Paddy Field**: The total area designated for rice cultivation, which directly determines the volume of rice supply [8,28]. Parameter estimates used was collected from the Regional Statistical Offices.
8. **Non-Paddy Field**: Land not used for rice cultivation, but potentially allocated for other agricultural activities or infrastructure development. Data obtained from local and national official publications.
9. **Land Productivity**: The yield per unit area of rice farmland, which significantly affects annual rice production [6,8,28,60,62,64]. Data obtained from local and national official publications.
10. **Dry Milled Paddy (GKG) Yield**: The amount of harvested unmilled paddy (Gabah Kering Giling) ready for processing, representing potential rice supply and stock levels [61,63]. Data obtained from local and national official publications.
11. The following is the system dynamics model developed for the study. It shows the relationship among elements or variables, in the system of demand and supply of rice in IKN. The dynamic system model is structured into three main subsystems: (1) the rice demand subsystem, (2) the rice supply subsystem, and (3) the stock availability subsystem. The rice demand subsystem includes parameters such as per capita rice con-

sumption, growth of the State Civil Apparatus (ASN), regional population growth, and worker move-in. The rice supply subsystem consists of land potential, paddy field area, non-paddy field area, and land productivity. The stock availability subsystem is determined by the equation: rice supply – rice demand + imports – exports ± required stock adjustments. The model shown is used to estimate the two parameter assumptions shown in **Table 3** above.

4. Discussion

Results of the system dynamics model simulation in this study predicts that the population in the IKN area in 2040 will be around 1.775 million people. This number is slightly lower than that the one estimated by the IKN Authority (OIKN). OIKN plans that the total population in the IKN area at the end of 2045 not to exceed 1.9 million people.

Figure 3 presents the projected rice supply (*pasokan beras*) and demand (*permintaan beras*) based on the 2023 model, which serves as the base model. The model parameters are detailed in **Table 5.** The blue line represents rice supply, while the red line represents rice demand. **Figure 4** shows an interesting pattern of increasing trends in both demand and supply of rice in IKN. In the first two years, the IKN region still experienced a rice surplus because production exceeded demand. In this case, in 2025 the rice supply is estimated to be 16,755 tons while the demand for rice will be 15,625 tons.

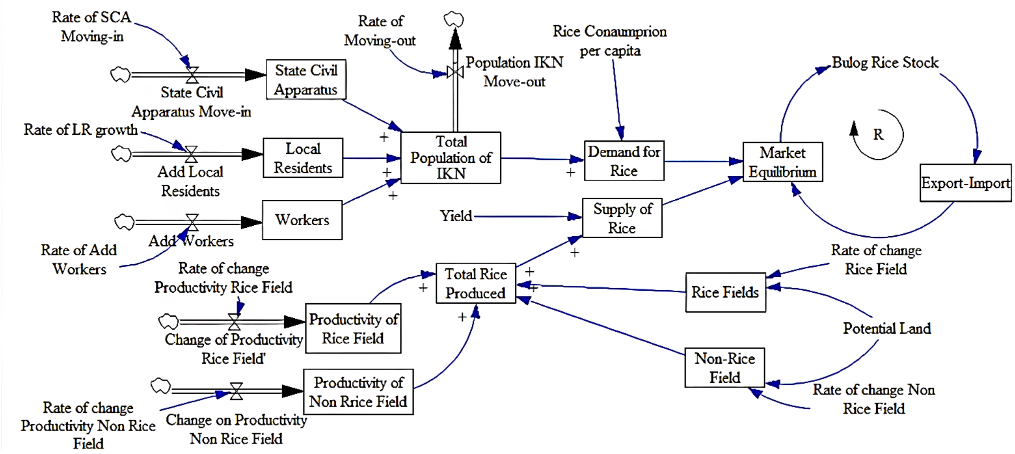

Figure 3. System Dynamics Model for Demand and Supply of Rice in IKN.

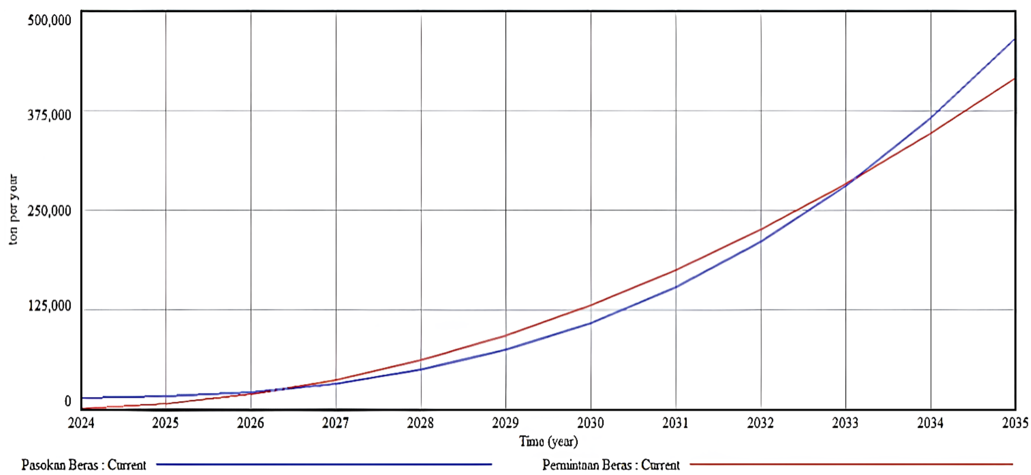

Figure 4. Demand and Supply of Rice in IKN, Base Model.

However, in the following years there was a rice deficit situation because demand for rice was greater than supply. This increase in demand is mainly due to the increasing number of residents who are expected to inhabit the IKN area. Because the population increases from year to year, the demand for rice will also increase. This population increase (starting in the third year) appears to be no longer fully met by local rice production.

Based on newest information obtained from the second field visit in 2024 in the same area, the 2023 parameters are updated with the 2024 parameters. Then based on these new parameters, estimates and simulations are carried out on the system dynamics model. The results are shown in **Figures 5** and **6.**

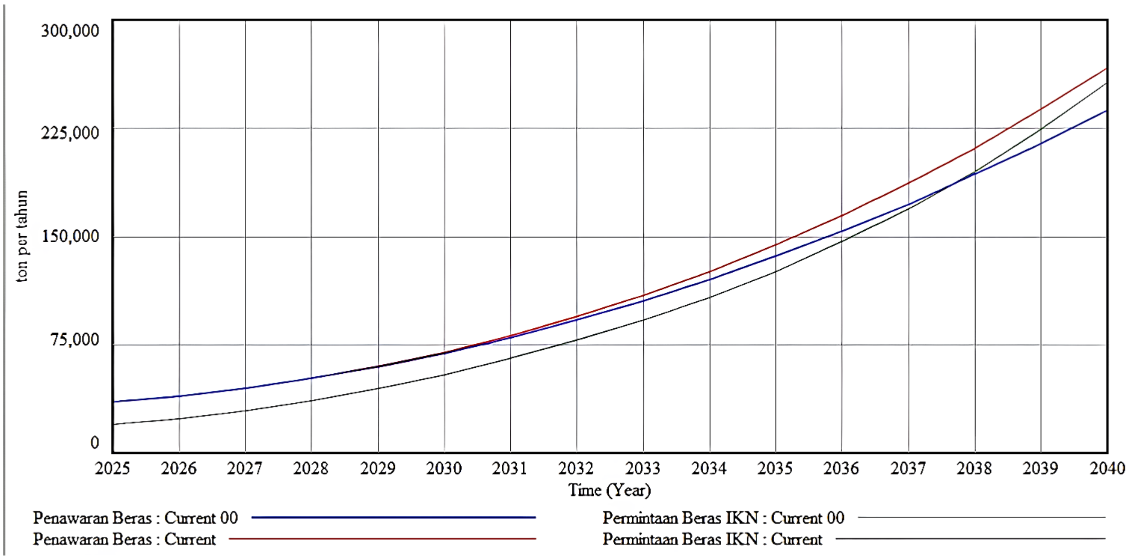

Figure 5. Demand and Supply Rice in IKN (Model 2024a).

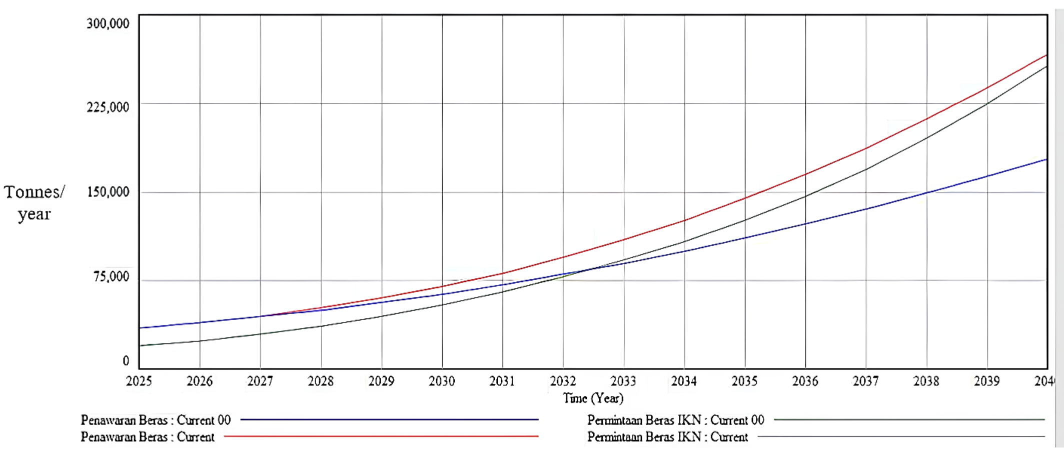

Figure 6. Demand and Supply Rice in IKN (Model 2024b).

Figure 5 is estimated based on the assumption that rice field area is about 1500 hectare as the initial number in model 2024b. Blue line indicates rice supply while the green line indicates the demand for rice. Red and grey line are indicating the supply and demand for rice in the base model 2024a with initially 1700 ha area of the rice field.

Following the scenario of rice field reduction due to palm oil plantations and mining, the projected supply and demand for rice are shown by the blue and green lines. **Figure 5** shows that a surplus of rice supply occurs from 2025 to 2037. Starting in 2038, the demand for rice will be greater than what can be supplied by rice production in the IKN. In that year, demand amounted to 194.8 thousand tonnes and the supply of rice amounted to 192.7 thousand tonnes. Without any measures to stop the decreasing area of rice field the gap between supply and demand for rice will be wider in the years after 2037.

Applying parameter of Model 2024b, with the available rice paddy reduced to 1500 ha, the equilibrium between demand and supply happens in mid of 2032 as presented in **Figure 6**.

Blue line indicates the supply of rice, while the green one represents the demand for rice. Intersection of both lines occurs in the mid-year of 2032. By 2033 demand for rice is larger than the supply. It amounted to be 89.5 thousand tonnes, while the demand for rice will be 91.9 thousand tonnes.

Responsiveness of the dynamic simulation or sensitivity was performed by estimating the supply and demnd for rice on the two different cases. One with the initial total area of 1700 Ha and without coal mining and palm oil land reduction and the other with initial area or 1500 Ha and declining area due to coal mining and palm encroachment. Other contributing factors on the supply of rice is the significant increase of productivity due to better farming practices. During the second site of field visit in 2024, some regions in IKN have demonstrated the increase of rice productivity per hectare in Samboja. In addition, change of taste and rice consumption of the younger generation were also considered. Reduction in demand and increase in supply produced the projection result as shown in **Figure 6**. In other study, Bhandari and Mishra stated that the decline in rice supply was partly due to a demographic transformation which was marked by a reduction in the farmer population from 20.84 percent to 19.21 percent [65,66]. On the other hand, population growth increases the demand for rice [67–69]. Furthermore, the future outlook for global rice consumption is slightly higher (influenced by rice demand, GDP per capita and world rice price) [70].

Another influencing factor, based on soil laboratory results, shows that soil fertility in East Kalimantan is classified as very low. Most of the rice fields in IKN have low P, high Fe content and low soil pH. On the other hand, P has an important role in producing better rice grains [71]. Furthermore, the very high clay content of 57 percent affects water loss and water efficiency in paddy fields. This is what affects the relatively low productivity of rice fields around IKN. The solution to overcome the problem of high Al, low P, K and C-organic content is to return the straw to the rice field plots [72–74].

During the deficit period, the IKN authority needs to implement policies to overcome the deficit in the long term by providing more agricultural areas, building infrastructure, research development and human resources. Research efforts include producing varieties with higher yield potential and grain quality [75].

In addition, the government is implementing stricter regulations related to coal mining. Rice fields and fertile land cannot be converted into mining areas. Rice fields converted into coal mining areas must be replaced with similar land with a larger area and better land quality, in addition to financing incentives and the provision of new rice fields. Rice field productivity of 3-4 tons per hectare must increase by 5-8 tons per hectare by building dams and irrigation to ensure water availability. Meanwhile, to maintain resilience and production, incentives are provided for fertilizer, superior seeds and technology. Furthermore, improving the welfare and resources of farmers is supported by price stability and farmer skill. This plan is an important part of controlling and mitigating the estimated rice deficit in 2033 or 2038.

The implementation of this policy is part of a model simulation that shows that in 2033 there will be an increase in rice production, dry harvested grain and rice so that it is estimated that it can overcome the rice deficit problem. The government implements mitigation policies during the deficit process by improving land quality, expanding rice planting areas, providing dams, building irrigation networks, protecting food land, and training and educating farmers.

Another affirmative policy is to protect rice fields through the implementation of Law (UU No 41 2009, 2009). This law can be implemented through planning and establishing sustainable food farming areas. The designation of the IKN rice food area is an effort to protect rice fields so that their use is not converted. This law is the basis for developing consistent IKN spatial planning.

5. Conclusion

Results of the system dynamic model simulations show that the IKN at the beginning is still experiencing a rice surplus because production exceeded demand in the first year. In 2026, rice supply is estimated to be 39.2 thousand tonnes, while rice demand will be 23.7 tonnes. Entering 2037, IKN will start experiencing a rice deficit because demand for rice is greater than supply. The rice deficit comes sooner in 2033 if the rice field depletion is not being checked.

The increasing population—comprising State Civil Apparatus (ASN), military and police personnel (TNI and Polri), their families, construction workers, and other laborers—has led to a rise in rice demand. To meet this demand, IKN relies on rice supplies from Babuluh District in Penajam Paser Utara Regency, as well as from several districts in Kutai Kartanegara Regency and areas beyond East Kalimantan. These regions are expected to play a key role in addressing the projected rice deficit in the new capital

The government's policy framework in this context focuses on two main objectives: (1) preventing rice deficits and ensuring food availability, and (2) improving soil quality. Efforts to ensure rice availability include expanding planting areas, constructing dams, developing irrigation networks, and providing training and education for farmers. Additionally, the government has implemented a moratorium on the opening of new coal mining areas, particularly on rice fields, as a measure to protect agricultural land. The use of rice fields for mining has caused environmental degradation, leading to a decline in both rice production and productivity.

Although rice imports may serve as a short-term solution to meet supply shortages, they are not a sustainable strategy for strengthening rice self-sufficiency in the long term. As an agricultural country located in a tropical region, Indonesia—especially its capital city—should ideally be capable of fulfilling its food needs independently. Moreover, reliance on imports can disrupt local food price stability and negatively affect farmer welfare. Therefore, the minimum supply of rice should originate from within the capital city area and its surrounding regions, or at least from other parts of Indonesia. This reflects the ideal of a capital city that is resilient and self-reliant in rice production. Such an approach also ensures that capital city development does not come at the expense of the agricultural sector, but instead contributes to its strengthening.

Furthermore, improving land quality through adding organic material to the land to increase the availability of P elements so that the productivity of rice fields can increase to 5-8 ton per hectare. The next long-term effort is to improve soil properties through applying lime or applying organic fertilizer or inorganic synthetic fertilizer wisely according to the dosage. Next is embedding straw into the paddy soil to increase organic C levels. Land protection through the implementation of the policy of Law (UU) Number 41 of 2009 concerning Protection of Sustainable Food Agricultural Land. This policy is an effort to protect rice fields so that their use will not be converted.

This policy aligns with the Sustainable Development Goals (SDGs), particularly Goal 2: Zero Hunger, and Goal 12: Responsible Consumption and Production. These goals emphasize not only ensuring food availability, but also encouraging dietary diversification through increased protein and fat consumption, and reducing food loss across the production and supply chain, including post-harvest stages. Furthermore, achieving sustainable development requires collaboration with coal mining companies to adopt environmentally responsible practices. Public awareness and access to information about sustainable living and harmony with nature are also critical.

Finally, this study acknowledges limitations, particularly the exclusion of climate change scenarios and global rice price volatility. Future research should address these factors to improve the relevance and robustness of rice policy planning.

Author Contributions

Methodology, A., and B.P.; investigation, A., B.P., B.T., G.S.P.H., H.A., and P.S.L.; formal analysis, A., B.P., B.T., G.S.P.H., and H.A.; writing original draft preparation, A., and B.P.; writing review and editing, B.P., and H.A.; visualization, B.T., and G.S.P.H. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data was obtained through field surveys, soil sampling, interviews with farmers and government and official sources from the government.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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