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System dynamics model of gasoline supply and demand for bioethanol production analysis in Indonesia

Abstract: Bioethanol is an alternative solution that fulfills the gasoline demand and directly reduces imports. It has similar characteristics to gasoline and is more sustainable because it is derived from biomass and has lower emissions. The research aims to assess bioethanol production to meet Indonesia's mandatory bioethanol utilization and to reduce imports until 2030 by accomplishing a system dynamic model of gasoline supply and demand in Indonesia. Using system dynamics software STELLA, the model will help us to understand the trend of supply-demand of gasoline in Indonesia with related variables, and with some scenarios, the simulation will be conducted to achieve particular goals. If no intervention exists in the modeled system, the gasoline import trend tends to grow yearly, reaching more than 70% of the total supply. The bioethanol mandate will be achieved when the Mandatory Scenario is used, which will be 20% blended with gasoline in 2025. The scenario will reduce gasoline imports to 4.13–10.39 million kL during the simulation period. Meanwhile, the Zero Gasoline Import Scenario will need 31.54–43.91 million kL of bioethanol, and the blending rate of bioethanol will be 71–76%. Therefore, the government should set an

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E75–E80 mandate if gasoline imports are to be abolished. Several policies that can support the scenario and be proposed to the government are also given, such as incentives for feedstock and bioethanol producers, price regulation for gasoline and bioethanol, and incentives for the customer and automotive manufacturers.

KEYWORDS: bioethanol production, blending rate, gasoline gmport, gasoline supply demand, system dynamics

Introduction

The increasing population and economy have led to an increase in energy needs. Oil demand in Asia Pacific countries has grown yearly, making the supply-demand balance increasingly tight by the day (Nakanishi and Komiyama 2006). As well as Indonesia, which has been categorized as a developed country, it tends to have positive economic and population growth; it also has similar trends to balance the supply and demand of oil. Energy consumption in Indonesia for the last decade has increased by 6–7% per year as the population and economy grew (Akhmad and Amir 2018).

Most energy utilization in Indonesia is dominated by petroleum products (crude-derived products) since most technologies are also based on fossil fuels. The Handbook of Energy and Economic Statistics of Indonesia (HEESI) 2023 shows that petroleum products account for 29.91% of the total primary energy supply, and there was an increase in energy consumption, reaching 6.29%, making the year 2023 the highest in the last six years. The industrial sector dominated oil consumption at 45.6% of total final energy consumption, followed by the transportation sector (36.74%), the household sector (12.35%), and the remaining commercial and other sectors (MEMR 2023).

The main problem in utilizing petroleum products is the unsustainability of the product; it cannot be renewed and will vanish in a few decades. Outlook Energy of BPPT (Indonesia Research and Development Technology Bureau) stated that no new oil reserves have been found, and based on the ratio R/P (Reserve/Production), crude oil reserves in Indonesia will vanish in the next seven years (per 2019) (CTERC 2016). Other problems regarding oil utilization are declining production, fluctuating prices, and non-environment-friendly emissions. These things caused the imbalance of petroleum products supply and demand in Indonesia, making Indonesia a net oil importer since 2004 (PwC Indonesia 2016).

Gasoline, as one of the petroleum products, has been widely used as one of the leading end products in the transportation sector in Indonesia. 14.24 million kL of gasoline was produced, and 21.05 million kL of gasoline was imported in 2023 (MEMR 2023). This indicates that gasoline imports were higher than national production to fulfill the demand, and this trend has been occurring for decades. Gasoline imports have affected the national budget and energy security. Therefore, another solution is needed to solve this problem.

Bioethanol is an alternative solution to fulfill the gasoline demand and directly reduce imports. Bioethanol has similar characteristics to gasoline and is more sustainable because it is derived from biomass and has lower emissions. Several studies have been conducted on bioethanol utilization and its ability to substitute for the gasoline demand. Mgeni et al. (2025) reviewed bioethanol production from agricultural and fruit waste and blended it with gasoline as a vehicle fuel. They concluded that the process would boost the gasoline octane rating, thus enhancing fuel quality and lowering the cost and emissions (Mgeni et al. 2025). Sabet et al. (2025) wrote about bioethanol production from biomass as a solution to mitigate greenhouse gas emissions by reducing gasoline consumption. The article introduced bioethanol as a biofuel, the conversion technology, and the latest advancements, challenges, and limitations (Sabet et al. 2025).

This research aims to assess bioethanol production to meet Indonesia's mandatory bioethanol utilization and to reduce imports until 2030 by accomplishing a system dynamics model of gasoline supply and demand in Indonesia. The model will help us understand the trend of gasoline supply and demand in Indonesia with related variables, such as crude oil production and imports, petroleum production, gasoline demand, and imports. The simulation will use the model with some scenarios to achieve particular goals.

1. Literature review

1.1. Gasoline production

Indonesia has been producing crude oil since 1885, but the production tended to decrease, with a declining rate of up to 3% per year, while the demand is 3.3%, increasing the average rate (Devold 2013). The refining process will convert Crude oil or petroleum into petroleum products. The petroleum supply chain starts from the wellhead to the pump, mainly moving and storing it, such as crude oil being lifted from the ground and then moved to storage facilities and refined. Converting crude oil to rich energy fuel, which contains 84% volume of hydrocarbon refining, adds value. Its primary objective is to maximize the value added to finishing products (ICCT 2011). Simple refineries use a distillation column to separate crude into fractions; the relative quantities directly depend on the crude used. Therefore, it is necessary to obtain a range of crudes to be blended into a suitable feedstock to produce the required quantity and quality of end products. Petroleum refineries are large, capital-intensive manufacturing facilities with highly complex processing schemes. They convert crude oils into many refined products, such as gasoline, diesel oil, kerosene, jet fuel, liquid petroleum gases (LPG), petrochemical feedstock, asphalt, lubricating oils and waxes, and other products (ICCT 2011).

Gasoline is one of the petroleum products that is used as fuel for combustion engines. It is a complex mixture of light hydrocarbons containing carbon atoms of 5 to 11 and a boiling range of 15–19°C (Abbas et al. 2014). One of the most essential properties of gasoline is the octane number. The higher the octane number, the greater the fuel's resistance to combustion, pressure, and heat. Therefore, the octane number is a measure to indicate gasoline's resistance to heat, pressure, and the start of spontaneous combustion with no spark (Samimi et al. 2020). There are also some essential properties of gasoline, such as the chemical composition of the blended gasoline, fractional composition during the atmospheric distillation, Sulfur, resins, and the ratio of lead. Table 1 gives gasoline specification properties based on its octane.

Table 1. Specification properties based on its RON number

Tabela 1. Właściwości specyfikacji oparte na liczbie RON

Properties	Normal	Regular	Premium	Super
RON	85	90	95	98
Lead content [g/L]	0.01	0.01	0.01	0.01
Sulfur content [%]	0.05	0.05	0.05	0.05
Benzol content [%]	5	5	5	5
MBTE content [%]	≤ 8	12	15	15
Appearance	Net and transparent	Net and transparent	Net and transparent	Net and transparent

Source: Abbas et al. 2014.

Indonesia has been selling various types of gasoline with specific octane numbers. There are RON 88, RON 90, RON 92, and RON 95. The government subsidizes most of the gasoline sold with RON 88, which burdens the national budget. Therefore, purchasing RON 88 gasoline is limited, and the government promotes other kinds of gasoline, such as RON 90, 92, and 95, as it is one way to increase the output power of a car's engine (Samimi et al. 2020).

Gasoline production in Indonesia reached 89.58 million barrels or 14.24 million kL in 2019. Meanwhile, gasoline demand in transportation was 36.022 million kL (MEMR 2023). There must be an unbalanced supply and demand for gasoline because national production could afford 39.53% of the national demand. The gap between production and demand will be solved by importing gasoline. This indicates that imports make a higher contribution than national production.

1.2. Bioethanol production

Bioethanol is renewable energy in the form of biomass based on carbon cycles. It is a liquid biofuel derived from a living organism that contains sufficient sugar, such as sugar cane and sugar beets, or any feedstock that can be converted into sugar, such as wheat, potato, corn, cassava, and many more. There is also biomass called lignocellulose, which contains lignin, cellulose, and hemicellulose, bioethanol's second-generation feedstock (Rutz and Janssen 2007). Bioethanol can replace gasoline or be blended with gasoline in several percentages since it has similar properties. Table 2 shows a physical comparison between gasoline and bioethanol. Bioethanol has some superior properties to gasoline. It has a higher-octane number, which will result in stable combustion in the engine.

Table 2. Physical comparison of gasoline and bioethanol

Tabela 2. Porównanie fizyczne benzyny i bioetanolu

Properties	Units	Gasoline	Bioethanol
Density	Kg/J	0.75	0.79
Viscosity	mm^2/s	0.6	1.5
Flash point	ºC	< 21	< 21
Calory value at 20ºC	MJ/Kg	42.7	26.8
Calory value	MJ/I	32.45	21.17
Octane number	RON	92	> 100
Fuel equivalence	1	1	0.65

Source: Rutz and Janssen 2007.

Indonesia produced bioethanol in 2007 to 2010 from molasses (sugar cane by-product). The production stopped due to lower price regulation and limited feedstock; it competes with food. Therefore, bioethanol producers produced industrial bioethanol rather than gasoline bioethanol (gasohol) (Mayasari and Dalimi 2018).

Despite all the problems regarding bioethanol production, Indonesia has set a mandatory bioethanol utilization target until 2025, which is E20 for Micro, Fishing, Farming Entrepreneur, Transportation and Public Services (PSO); Transportation (Non PSO); and Industrial and Commercial (MEMR 2015). E20 means 20% of bioethanol will be blended with 80% of gasoline. In other words, by 2025, bioethanol is expected to supply 20% of the gasoline demand in Indonesia.

Many researchers have conducted studies regarding bioethanol production in Indonesia, but most studies are about finding the proper feedstock for bioethanol. Pabendon et al. (2017) studied sweet sorghum varieties as bioethanol feedstock and how to increase the yield (Pabendon et al. 2017). Meanwhile, Harsono et al. (2014) chose arabica coffee waste as the second bioethanol feedstock and planted it in East Java (Harsono et al. 2014). Wahyuono et al. (2014) also used tapioca solid waste and simulated the possible contribution to bioethanol demand in Indonesia (Wahyuono et al. 2014).

Besides feedstock, other assessments of bioethanol are also conducted by several researchers, such as Jupesta (2010), who concluded that biofuel in the transportation sector, both bioethanol and biodiesel, have many positive impacts on Indonesia (Jupesta 2010), Hasibuan and Nazir

(2017) analyzed feasibility of bioethanol production in Sumba Island using Bayes method with financial and SWOT analysis to propose the development strategy of sustainable bioethanol industry (Hasibuan and Nazir 2017). In addition, Khatiwada et al. (2016) performed an LCA analysis of sugarcane-based bioethanol production in Indonesia and evaluated energy and GHG balances in the entire production chain (Khatiwada et al. 2016).

1.3. System dynamics

System dynamics is a method used to model a complex system. This method combines analysis and synthesis to establish and formalize the relation between different information flows and structures in a complex system that facilitates distinguishing feedback mechanisms (Jupesta 2010). Through system dynamics modeling, it is possible to understand how organizational structures, policies, and delays for decision-maker interaction influence the success or failure of a system or a company (Forrester 1961).

System dynamics is based on engineering control and management. Its approach used a fundamental perspective of feedback and delayed information to understand the dynamic behavior of complex physical, biological, and social systems. The dynamics of system behavior are defined by its structure and interaction. The main goal of system dynamics is to understand how these behaviors result from applying qualitative and quantitative models and use this knowledge to predict the consequences of policy changes to a system within a specific time frame. System dynamics has been applied to more comprehensive applications, such as economy, management policy and public health and biology, energy and environment, science and social, decision-making, software engineering, and supply chain management (Sterman 2000).

Due to several factors that affect energy policy, such as system complexity, a system dynamic approach is needed to review the consequences of policies and scenarios (Repele et al. 2017). Many researchers have been using the system dynamics approach to assess energy policy in general and biofuel analysis in particular. Azadeh and Arani (2016) have applied hybrid system dynamics and mathematical programming to design and plan the biofuel supply chain from biomass farm to the customer market with some constraints in their analysis (Azadeh and Ariani 2016). Repele et al. (2015) created a model that helps to provide biomethane production growth and stability using system dynamics (Repele et al. 2017). Meanwhile, Bautista et al. (2019) used system dynamics modeling to analyze biodiesel production in a specific context. They established and applied system dynamics to assess the sustainability of the baseline scenario in Colombia and concluded that strong support of government policies is needed to promote biodiesel blending and increase capacity (Bautista et al. 2019). Mayasari et al. (2019) observed how to increase bioethanol production from molasses and cassava to fulfill Indonesia's mandate using system dynamic modeling (Mayasari et al. 2019).

System dynamics methodology has four general steps divided into activities, allowing decision-makers to understand the process: Problem formulation or model conceptualization; Model development; Model validation and verification; and Scenario simulation (Mayasari et al. 2019).

2. Research design

2.1. Model conceptualization

The first stage of the system is setting a conceptual model for the whole system. The model goal is to reach the mandatory target of bioethanol utilization and reduce gasoline imports. Therefore, output variables are gasoline production, imports, and bioethanol production. It is also assumed that there is no constraint or obstacle to bioethanol development in Indonesia.

Figure 1 shows the Causal Loop Diagram (CLD) of the model, which is constructed from several variables and their interaction. It can be seen from the model that the Gasoline Production is driven by refinery production, which is the derived product of crude oil supply. Meanwhile,

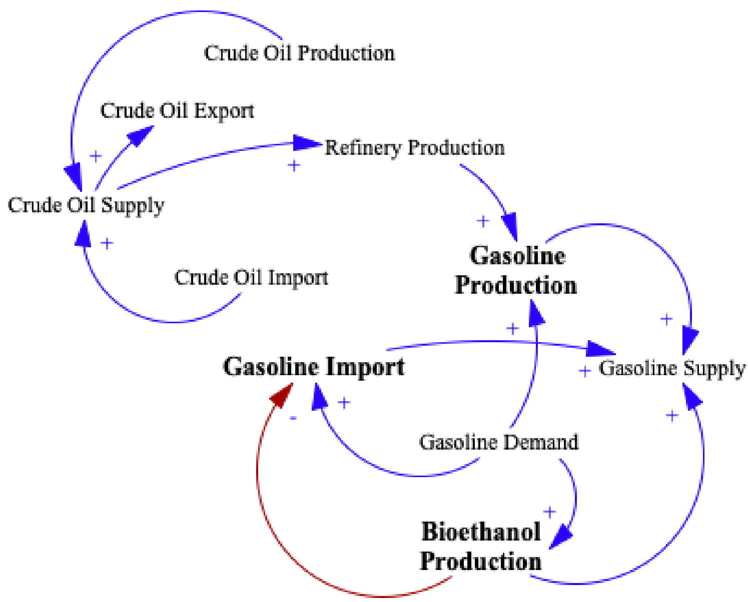

Fig. 1. Causal loop diagram of gasoline supply demand with bioethanol production

Rys. 1. Schemat pętli przyczynowo-skutkowej popytu na benzynę i produkcji bioetanolu bioethanol production is influenced by the demand for gasoline. Therefore, some scenarios could be run through the model. Bioethanol production has a balancing connection with gasoline imports, meaning the more bioethanol is produced, the less gasoline is imported.

2.2. Model development

After model conceptualization, the next step is developing the concept. A Stock Flow Diagram (SFD) is constructed at this stage using STELLA software. STELLA, or Systems Thinking, Experimental Learning Laboratory with Animation, is a visual programming language for system dynamics modeling that allows users to create graphical representations of a system using fundamental building blocks. It has been used in various research and business applications and is famous for its simplicity and fascinating GUI.

Figure 2 illustrates the gasoline supply-demand system in Indonesia, which is modeled with the SFD of system dynamic modeling using STELLA. It can be seen from the SFD model that gasoline production is influenced by refinery production and the shared percentage of gasoline

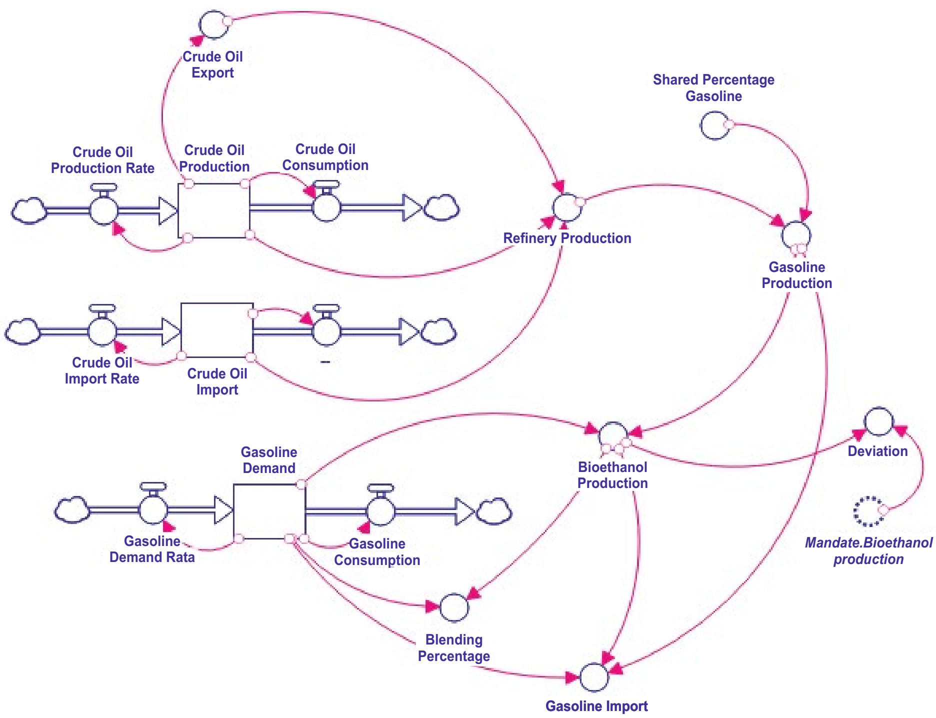

Fig. 2. Stock flow diagram of gasoline supply demand with bioethanol production in Indonesia

Rys. 2. Schemat przepływów zapasów benzyny w kontekście popytu i podaży oraz produkcji bioetanolu w Indonezji from petroleum products. Meanwhile, bioethanol production is affected by gasoline demand and supply (gasoline production and import) to achieve the mandatory goal. Refinery production is a product of crude oil production, crude oil imports, and crude oil exports. Meanwhile, crude oil production is a stock variable and can be expressed in Equation 1.

$$\text{Crude Oil Production } (t) = \text{Crude Oil Production } (t - dt) + [\text{Production Rate } (t) \cdot dt] \tag{1}$$

Bioethanol production substitutes for gasoline demand and production to achieve no gasoline imports. Meanwhile, gasoline demand is also a stock variable expressed in Equation 2.

$$\text{Gasoline Demand } (t) = \text{Gasoline Demand } (t - dt) + [\text{Demand Rate } (t) \cdot dt] \tag{2}$$

Crude oil production rate, gasoline demand rate, and other input variables are attained from historical data trends. Table 3 shows Indonesia's crude oil supply and demand during 2010–2023. Table 3 shows that crude oil production declined while crude oil imports increased to fulfill the demand. Crude oil is also exported abroad because some of its production cannot meet the national refiner's requirements.

Table 3. Data of crude oil parameters in Indonesia

Tabela 3. Dane dotyczące parametrów ropy naftowej w Indonezji

Year	Crude oil parameters [million kL]		
	production	export	import
2010	54.837	21.381	16.074
2011	52.353	21.556	15.401
2012	50.032	18.339	15.259
2013	47.832	18.663	18.815
2014	45.776	17.479	19.397
2015	45.603	18.288	21.730
2016	48.230	19.957	23.589
2017	46.328	16.326	22.517
2018	44.803	11.841	20.047
2019	43.093	4.089	14.201
2020	41.220	5.000	12.670
2021	38.218	6.959	16.600
2022	35.542	2.464	16.651
2023	35.153	3.402	21.049

Source: MEMR 2023.

Table 4 shows gasoline production in Indonesia during the 2010–2023 period. Refinery production produced 26.37% gasoline of its total production. These gasoline products consist of Ron 88 and Ron 90, commercially known as premium and Pertalite, respectively, Ron 92 as Pertamax, and gasoline with a Ron number above 95. It can be seen from Table 4 that Ron 88+90 is the highest share of gasoline production, followed by Ron 92 and Ron > 95. The higher the octane number (RON), the more expensive the price per liter of gasoline; thus, the demand for lower octane numbers is also greater, and it still meets the engine requirements. Furthermore, the Indonesian government subsidizes the gasoline of Ron 88+90 to its citizens.

Table 4. Data of gasoline production in Indonesia

Tabela 4. Dane dotyczące produkcji benzyny w Indonezji

Year	Refinery production [million kL]	Gasoline production				Total [million kL]
		Ron 88+90 [million barrel]	Ron > 95 [million barrel]	Ron 92 [million barrel]	total [million barrel]	
2010	47.56	66.820	0.668	3.301	70.789	11.26
2011	51.04	64.460	0.736	2.446	67.642	10.76
2012	47.58	67.684	0.514	2.487	70.685	11.24
2013	47.72	68.174	0.566	2.651	71.391	11.35
2014	49.20	70.829	0.545	3.629	75.003	11.93
2015	43.15	71.733	0.672	8.725	81.130	12.90
2016	63.85	68.878	0.592	24.432	93.902	14.93
2017	51.38	53.712	0.604	39.085	93.401	14.85
2018	53.15	56.313	0.779	36.877	93.969	14.94
2019	53.26	51.378	1.051	42.424	94.853	15.08
2020	48.07	41.830	1.625	48.294	91.749	14.59
2021	47.76	62.216	2.469	28.572	93.257	14.83
2022	51.28	78.229	1.303	7.495	87.027	13.84
2023	52.64	83.104	0.606	5.870	89.580	14.24

Source: MEMR 2023.

Meanwhile, Table 5 gives gasoline import data in Indonesia during the same period as the previous data. Both Table 4 and Table 5 confirm that gasoline products with octane numbers 88 and 90 are the most consumed products in Indonesia. Table 5 also indicates an increasing trend in gasoline Ron 92 imports for the last 8 years (since 2017), the leading cause was the withdrawal of Ron 88 from the market, and the tightened subsidy requirement of Ron 90.

Table 5. Data on gasoline imports in Indonesia

Tabela 5. Dane dotyczące importu benzyny w Indonezji

Year	Gasoline products [million kL]			
	Ron 88, 90	Ron 95, 98	Ron 92	total
2010	12.283	0.048	0.381	12.712
2011	15.248	0.036	0.319	15.603
2012	17.621	0.036	0.213	17.870
2013	18.340	0.060	0.268	18.668
2014	18.829	0.064	0.619	19.512
2015	17.211	0.057	1.303	18.571
2016	12.879	0.140	3.783	16.802
2017	10.423	0.180	7.012	17.615
2018	9.229	0.277	9.295	18.801
2019	11.084	0.150	7.954	19.188
2020	9.732	0.106	6.157	15.995
2021	8.145	0.101	9.840	18.086
2022	15.106	0.115	6.391	21.612
2023	16.122	0.267	4.666	21.055

Source: MEMR 2023.

2.3. Model validation

The first step of the validation process is verifying the mental model with the real system. It is verified that the constructed model represents the demand for gasoline supply and bioethanol production in Indonesia from the upstream to the downstream sectors. And the next step is to validate the model by comparing the same year's historical data and simulation results. The validation process of the model is conducted by finding the error in the gasoline demand variable. The average deviation between the data and the simulation result calculates the percentage error. The error calculation for the gasoline demand variable is shown in Table 6.

The error result on the model is 6,762%. This is acceptable since < 10% of errors are categorized as a good result. Thus, the model has been validated and verified and can be simulated with the given scenarios according to its purposes.

Table 6. Model validation

Tabela 6. Walidacja modelu

Year	Gasoline demand [million kL]		Deviation [%]
	data	simulation	
2011	25.69	25.11	2.246
2012	28.43	26.09	8.221
2013	29.63	27.11	8.508
2014	30.04	28.17	6.222
2015	30.69	29.27	4.627
2016	31.99	30.41	4.924
2017	33.18	31.59	4.778
2018	34.17	32.82	3.945
2019	35.33	34.10	3.476
2020	30.94	35.43	14.530
2021	32.85	36.82	9.836
2022	41.91	38.25	8.729
2023	36.02	39.74	10.321
Error [%]			6.762

2.4. Model scenario

- Business as Usual

Business as Usual (BaU) is a standard scenario where all the variables remain, and no further intervention is needed on the variables and model. As in historical data, some variables have growth rates or declining rates. Those rates are maintained at the given number, and the simulation will show the scenario until 2030.

- Mandatory Scenario

The Mandatory Scenario has utilized bioethanol as another source of gasoline supply besides gasoline production and import. Bioethanol production is assumed to be smooth, and there is no significant problem regarding its production. Production quantity is also based on the bioethanol mandate by the government.

- Zero Gasoline Import

The last scenario is the Zero Gasoline Import Scenario. This scenario will reduce gasoline imports to 0, starting in 2024 (simulation period). The gasoline supply from imports will be entirely replaced by bioethanol production. Thus, this scenario will show how much bioethanol should be produced to get zero imports and what percentage of bioethanol should be blended into gasoline (Exx).

3. Result and analysis

3.1. Business as Usual

The simulation of this scenario gave a projection of the gasoline supply demand in Indonesia as if the government had yet to intervene to increase gasoline production nationally or bioethanol production. Therefore, all the trends continue every year of the simulation period. Table 7 gives a projection of crude oil parameters in Indonesia, and Table 9 projects gasoline parameters if the BaU Scenario runs until 2030.

Table 7. Projection of crude oil parameters in Indonesia with BaU Scenario

Tabela 7. Prognoza parametrów dotyczących ropy naftowej w Indonezji przy założeniu scenariusza BaU

Year	Crude oil parameter [million kL]		
	production	export	import
2024	34.28	9.64	23.54
2025	33.15	9.32	24.60
2026	32.06	9.01	25.70
2027	31.00	8.72	26.86
2028	29.98	8.43	28.07
2029	28.99	8.15	29.33
2030	28.03	7.88	30.65

It can be seen in both Tables 7 and 8 that the import parameter for crude oil and gasoline increases as the demand keeps growing. Table 8 also indicates Indonesia's declining crude oil production by as much as 3.3% annually. Meanwhile, crude oil imports have increased by up to 4.5% yearly, and 2029 will exceed 100% of crude oil production.

Table 8 shows that refinery production is increasing since crude oil, as the refinery input, will supply the demand for national output and imports. The table also implies that the gasoline import will reach more than 70% of the total gasoline supply in Indonesia in 2025. This indicates that the government should act and implement more supportive policies regarding the development of bioethanol production to reduce imports and meet the mandate.

Table 8. Data on gasoline imports in Indonesia

Tabela 8. Dane dotyczące importu benzyny w Indonezji

Year	Refinery production [million kL]	Gasoline production [million kL]	Gasoline demand [million kL]	Gasoline import [million kL]
2024	48.18	12.70	41.29	28.59
2025	48.43	12.78	42.91	30.13
2026	48.75	12.86	44.58	31.72
2027	49.14	12.96	46.32	33.36
2028	49.62	13.08	48.12	35.04
2029	50.17	13.23	50.00	36.77
2030	50.80	13.40	51.95	38.55

Source: MEMR 2023.

3.2. Mandatory Scenario

The Mandatory Scenario assumes that bioethanol is produced without any problem and that production is adjusted to meet the mandatory (E10 in 2024 and E20 in 2025 to 2030).

Bioethanol production could be increased by selecting the best feedstock and using proper conversion technology. Also, some policies and interventions support the producer, both feedstock and bioethanol producers.

Therefore, the demand for bioethanol should be set to the actual mandate and based on the national gasoline mandate. Fig 3 illustrates the model in the Mandatory Scenario. The scenario results in not only imports but also the bioethanol mandate being met. Hence, gasoline imports will be the most influential variable, resulting in declining numbers. The projection of gasoline imports in the Mandatory Scenario is given in Table 10; it also compares and deviates from the BaU Scenario.

The deviation between the Mandatory and BaU Scenarios is the amount of bioethanol produced based on the mandate. In 2024, bioethanol production will be 4.13 million kL, as E10 has been applied since 2020. When E20 is accelerated in 2025, bioethanol production will increase to more than 8 million kL. Therefore, gasoline imports also decline at the same rate as bioethanol production. In other words, to meet the mandate (E10 in 2024 and E20 in 2025), Indonesia should produce bioethanol, as mentioned in Table 9. It also implies that the more bioethanol is made, the less gasoline is imported.

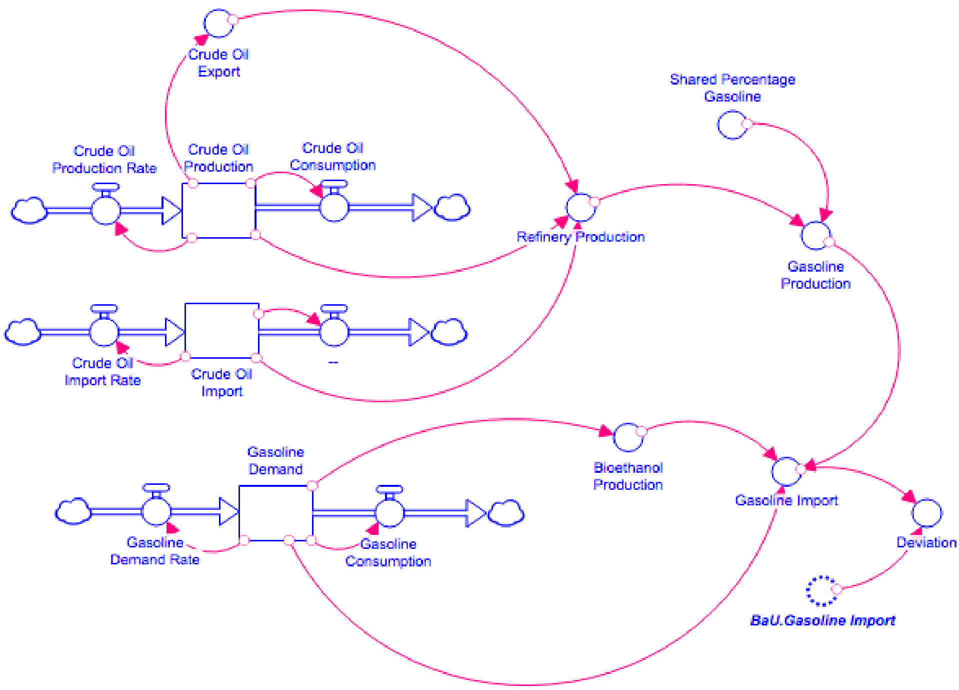

Fig. 3. Stock flow diagram of model in Mandatory Scenario

Rys. 3. Schemat przepływów zapasów w modelu w scenariuszu obowiązkowym

Table 9. Model validation

Table 9. Walidacja modelu

Year	Gasoline import [million kL]		Deviation [million kL]
	Mandatory Scenario	BaU Scenario	
2024	24.46	28.59	4.13
2025	21.55	30.13	8.58
2026	22.81	31.72	8.92
2027	24.09	33.36	9.26
2028	25.41	35.04	9.62
2029	26.77	36.77	10.00
2030	28.16	38.55	10.39

3.3. Zero Gasoline Import Scenario

In this scenario, gasoline import is entirely replaced by bioethanol production. Thus, the gasoline supply is supported by national gasoline production and blended bioethanol. Significant bioethanol will be produced to meet this scenario (zero import), as much as the gasoline import in scenario BaU, or around 31.54–43.91 million kL bioethanol.

Figure 4 shows both gasoline and bioethanol production to the gasoline supply contribution in Indonesia with this scenario during 2024–2030.

Figure 4 indicates that more bioethanol is produced than gasoline when this scenario is run. There will be a significant demand for bioethanol in Indonesia to replace gasoline imports. The government should select the most suitable policies to achieve the maximum bioethanol production.

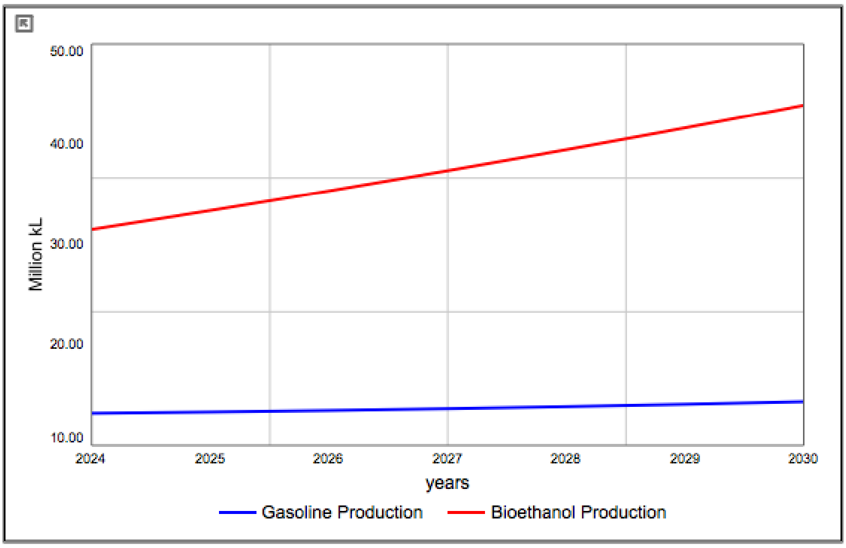

Fig. 4. Projection of gasoline and bioethanol production with Zero Import Scenario

Rys. 4. Prognoza produkcji benzyny i bioetanolu przy zerowym imporcie

The Zero Gasoline Import Scenario also gives the blending rate of bioethanol to gasoline if the import is diminished from the supply. The scenario assumes no problem with the engines' high bioethanol blending rate.

The result shows that as much as 71–76% of bioethanol blending (E75–E80) is needed during 2024–2030 to achieve this scenario (Fig 5). Therefore, the Government should have regulated ethanol blending and its properties.

Figure 6 shows a bioethanol production comparison for the simulated scenario: Mandatory and Zero Gasoline Import. The zero-import scenario has an increasing trend with a demand of

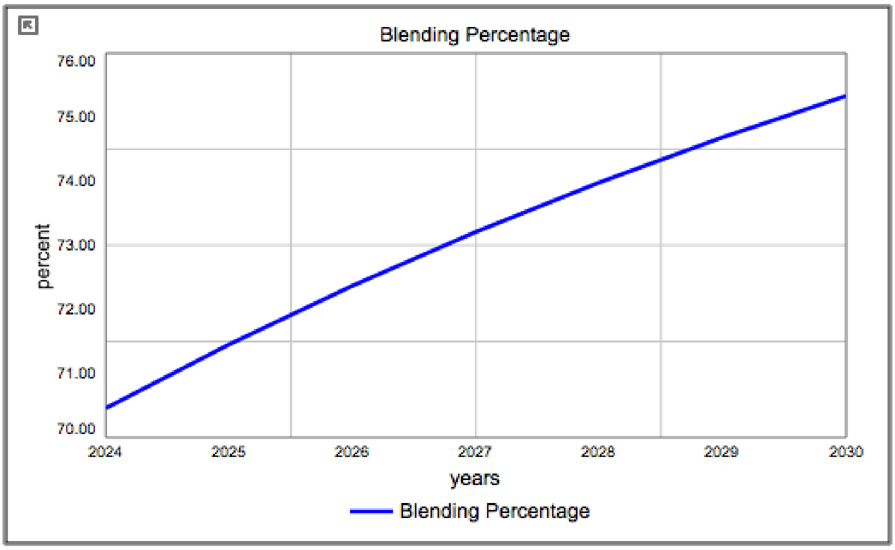

Fig. 5. Projection of bioethanol blending rate with Zero Import Scenario

Rys. 5. Prognoza udziału bioetanolu w mieszankach paliwowych przy zerowym imporcie

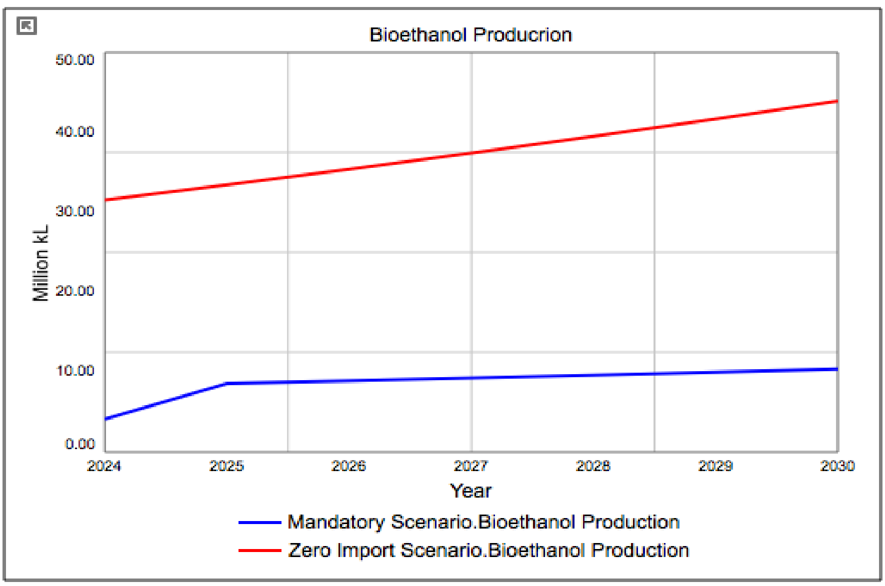

Fig. 6. Projection of bioethanol production of simulated scenarios

Rys. Prognoza produkcji bioetanolu w symulowanych scenariuszach

31.54–43.91 million kL bioethanol, while the Mandatory Scenario has a lower demand than the zero-import scenario. The mandatory scenario in 2025 implies that there will be a significant increase in bioethanol production due to the E20 mandate.

The research has been conducted to construct a system dynamics model of the gasoline supply and demand in Indonesia. After being a concept, developed, and verified, the model simulates several scenarios to project gasoline supply, demand, and bioethanol production in Indonesia. Bioethanol production will supply the gasoline demand and will be blended with gasoline by a certain percentage. The research has given the number of bioethanol production needed to meet the government mandate and to eliminate gasoline imports.

The government should first choose the proper feedstock for bioethanol, which has a higher sugar content, is suitable for Indonesia's land and climate, and has much potential as the production tends to grow yearly. Cassava is a potential bioethanol feedstock in Indonesia, but it competes with food. The government should regulate the policy regarding this issue.

There are also several policies to be proposed by the government of Indonesia to increase bioethanol production, since mandatory and zero gasoline import scenarios require a significant amount of bioethanol. Those policies include incentives for feedstock producers, mainly if they produce feedstock dedicated to bioethanol; incentives for bioethanol producers in terms of tax deduction or loans with lower interest; price regulation for gasoline and bioethanol, thus bioethanol could compete with fossil fuel price; incentives for the customer who buys bioethanol-blended-gasoline; incentives for automotive manufacturers if they can adjust the engine for high blended bioethanol; and many more.

Conclusion

A system dynamic model of gasoline supply and demand to assess bioethanol production in Indonesia has been constructed with related variables. The model has helped us understand the gasoline supply-demand trend in Indonesia and simulated several scenarios to achieve the bioethanol mandate and reduce gasoline imports.

The result shows that if there is no intervention in the gasoline supply-demand system in Indonesia, the import trend tends to grow each year and will reach more than 70% share of the total supply. If the Mandatory Scenario is used, the bioethanol mandate will be achieved (E10 in 2024 and E20 in 2025), and the scenario will also reduce gasoline imports to 4.13–10.39 million kL during the simulation period. Meanwhile, the Zero Gasoline Import Scenario will need 31.54–43.91 million kL of bioethanol, and the blending rate will be around 71–76%. Therefore, the government should set an E75–E80 mandate if gasoline imports are to be abolished.

Several policies can support the scenario and can be proposed to the government, such as incentives for feedstock producers, mainly if they produce feedstock dedicated to bioethanol;

incentives for bioethanol producers in terms of tax deduction or loans with lower interest; price regulation for gasoline and bioethanol; incentives for the customer who buys bioethanol-blended-gasoline; incentives for automotive manufacturers if they can adjust the engine for high blended bioethanol.

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References

Abbas et al. 2014 – Abbas, S.K., Ibrahim, W.K. and Hameed, Z.A. 2014. Improvement of Gasoline Production. *Technical Report*, Pahang: Muthana University.

Akhmad and Amir 2018. Study of Fuel Oil Supply and Consumption in Indonesia. *International Journal of Energy Economics and Policy* 8(4), pp. 13–20.

Azadeh, A. and Ariani, H.V. 2016. Biodiesel Supply Chain Optimization via a Hybrid System Dynamic-Mathematical Programming Approach. *Renewable Energy* 93, pp. 383–403, https://doi.org/10.1016/j.renene.2016.02.070.

Bautista et al. 2019 – Bautista, S., Espinoza, A., Narvaez, P., Camargo, M. and Morel, L. 2019. A System Dynamics Approach for Sustainability Assessment of Biodiesel Production in Colombia. Baseline Simulation. *Journal of Cleaner Production* 213, pp. 1–20, https://doi.org/10.1016/j.jclepro.2018.12.111.

Center for Technology of Energy Resources and Chemical (CTERC) 2016. Indonesia Energy 2016 – Energy Development in Supporting Green Industry. Jakarta: Agency for the Assessment and Application of Technology.

Devold, H. 2013. *Oil and gas production handbook. An introduction to oil and gas production, transport, refining and petrochemical industry.* Oslo: ABB Oil and Gas.

Forrester, J.W. 1961. Industrial Dynamics, Sistem Dynamics Series. Massachusetts: Pegasus.

Harsono et al. 2015 – Harsono, S.S., Salahuddin, Fauzi, M., Purwono, G.S., Soemarno, D. and Kissinger 2015. Second Generation Bioethanol from Arabica Coffee Waste Processing at Smallholder Plantation in Ijen Plateau Region of East Java. *Procedia Chemistry* 14, pp. 408–413, https://doi.org/10.1016/j.proche.2015.03.055.

Hasibuan, S. and Nazir, N. 2017. The Development Strategy of Sustainable Bioethanol Industry on Iconic Sumba Island, Eastern Indonesia. *International Journal on Advanced Science, Engineering and Information Technology* 7(1), pp. 276–283, https://doi.org/10.18517/ijaseit.7.1.1796.

ICCT – International Council on Clean Transportation 2011. *An Introduction to Petroleum Refining and The Production of Ultra Low Sulfur Gasoline and Diesel Fuel.* Maryland: Math Pro.

Jupesta, J. 2010. Impact of the Introduction of Biofuel in the Transportation Sector in Indonesia. *Sustainability* 2(6), pp. 1831–1848, https://doi.org/10.3390/su2061831.

Khatiwada et al. 2016 – Khatiwada, D., Venkata, B.K., Silveira, S. and Johnson, F.X. 2016. Energy and GHG Balances of Ethanol Production from Cane Molasses in Indonesia. *Applied Energy* 164, pp. 756–768, https://doi.org/10.1016/j.apenergy.2015.11.032.

Mayasari, F. and Dalimi, R. 2018. Assessing Bioethanol Production to Fulfill Energy Demand in Indonesia Using System Dynamics Modeling. *TENCON 2018 – 2018 IEEE Region 10 Conference*, https://doi.org/10.1109/TENCON.2018.8650307.

Mayasari et al. 2019 – Mayasari, F., Dalimi, R. and Purwanto, W.W. 2019. Projection of Biodiesel Production in Indonesia to Achieve National Mandatory Blending in 2025 using System Dynamics Modeling.

International Journal of Energy Economics and Policy 9(6), pp. 421–429, https://doi.org/10.32479/ijeep.8319.
MEMR 2015 – Ministry of Energy and Mineral Resources (MEMR) Republic of Indonesia 2015. Ministry Regulation about the Third Change of Ministry Regulation No. 32/2008 about Supply, Utilization and Commercial of Biofuel as other fuels, Jakarta.
MEMR 2923 – Ministry of Energy and Mineral Resources of the Republic of Indonesia (MEMR) 2023. Handbook of Energy and Economic Statistics of Indonesia 2023. Ministry of Energy and Mineral Resources of the Republic of Indonesia, Jakarta.
Mgeni et al. 2015 – Mgeni, S.T., Mero, H.R., Mtashobya, L.A. and Emmanuel, J.K. 2025. Utilizing fruit wastes as a sustainable feedstock for bioethanol production: A review. *Cleaner Energy System* 10, https://doi.org/10.1016/j.cles.2025.100188.
Nakanishi, T. and Komiyama, R. 2006. *Supply and Demand Analysis on Petroleum Products and Crude Oils for Asia and the World*. The Institute of Energy Economy Japan.
Pabendon et al. 2017 – Pabendon, M.B., Efendi, R., Santoso, S.B. and Prastowo, B. 2017. Varieties of Sweet Sorghum Super-1 and Super-2 and Its Equipment for Bioethanol in Indonesia. *IOP Conference Series: Earth and Environmental Science* 65, https://doi.org/ 10.1088/1755-1315/65/1/012054.
PwC Indonesia 2016. *Oil and Gas in Indonesia – Investment and Taxation Guide*. PwC Indonesia, Jakarta.
Repele et al. 2017 – Repele, M., Udrene, L. and Bazbauers, G. 2017. Support Mechanisms for Biomethane Production and Supply. *Energy Procedia* 113, pp. 304–310, https://doi.org/10.1016/j.egypro.2017.04.070.
Rutz, D. and Janssen, R. 2007. *Biofuel Technology Handbook*. München: WIP Renewable Energies.
Samimi et al. 2020 – Samimi, A., Kavosi, K., Zarinabadi, S. and Bozorgian, A. 2020. Optimization of the Gasoline Production Plant in order to Increase Food. *Progress in Chemical and Biochemical Research* 3(1), pp. 7–19, https://doi.org/10.33945/SAMI/PCBR.2020.1.2.
Sterman, J.D. 2000. *Business Dynamics: System Thinking and Modelling for a Complex World*. Massachusetts: McGraw-Hill.
Wahyuono et al. 2015 – Wahyuono, R.A., Hakim, M.N. and Santoso, S.A. 2015. Feasibility Study on the Production of Bioethanol from Tapioca Solid Waste to Meet the National Demand of Biofuel. *Energy Procedia* 65, pp. 324–330, https://doi.org/10.1016/j.egypro.2015.01.060.
Zabed et al. 2025 – Zabed, H.M., Dar, M.A., Chowdhury, F.I., Xie, R. and Qi, X. 2025. *Bioethanol Production from biomass: Introduction and Technology*. Reference Module in Materials Science and Materials Engineering, Elsevier.

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Model dynamiki systemowej podaży benzyny i popytu na produkcję bioetanolu w Indonezji

Bioetanol jest alternatywnym rozwiązaniem, które zaspokaja zapotrzebowanie na benzynę i bezpośrednio zmniejsza import. Ma właściwości podobne do benzyny i jest bardziej zrównoważony, po-

ważeż pochodzi z biomasy i charakteryzuje się niższą emisją. Badania mają na celu ocenę produkcji bioetanolu w kontekście realizacji obowiązkowego wykorzystania bioetanolu w Indonezji i zmniejszenia importu do 2030 r., poprzez stworzenie dynamicznego modelu systemu podaży i popytu na benzynę w Indonezji. Dzięki wykorzystaniu oprogramowania do dynamiki systemowej STELLA model pomoże zrozumieć trendy podaży i popytu na benzynę w Indonezji wraz z powiązanymi zmiennymi, a przy pomocy kilku scenariuszy przeprowadzona zostanie symulacja w celu osiągnięcia określonych celów. Jeśli w modelowanym systemie nie ma żadnych interwencji, tendencja importu benzyny będzie rosła z roku na rok, osiągając ponad 70% całkowitej podaży. Wymóg dotyczący bioetanolu zostanie osiągnięty, gdy zastosowany zostanie scenariusz obowiązkowy, który przewiduje 20% domieszki do benzyny w 2025 r. Scenariusz ten spowoduje zmniejszenie importu benzyny do 4,13–10,39 mln kL w okresie symulacji. Tymczasem scenariusz zerowego importu benzyny będzie wymagał 31,54–43,91 mln kL bioetanolu, a stopień domieszki bioetanolu wyniesie 71–76%. Dlatego też rząd powinien ustanowić wymóg E75–E80, jeśli import benzyny ma zostać zniesiony. Przedstawiono również kilka polityk, które mogą wspierać ten scenariusz i które można zaproponować rządowi, takich jak zachęty dla producentów surowców i bioetanolu, regulacja cen benzyny i bioetanolu oraz zachęty dla klientów i producentów samochodów.

Słowa kluczowe: produkcja bioetanolu, proporcje mieszanki, import benzyny, podaż i popyt na benzynę, dynamika systemu