Addressing the Global Energy Crisis: Development of a Renewable Energy Model for Sustainable Cities—A Case Study in Yogyakarta Province

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Abstract. Energy is one prominent issue today. The current global energy crisis will affect domestic energy security. Yogyakarta Province is one of Indonesia's provinces with no reserves or potential for non-renewable primary energy resources. Meanwhile, although Yogyakarta Province has renewable energy sources, such as biogas, micro-hydro, solar energy, wind, and waste to energy, these have not utilized optimally on a large scale. The purpose of this research is to find, design, and analyze the key variables in the sustainability model of renewable energy in Yogyakarta Province. The method analysis uses the Cross Impact Matrix Multiplication Applied to Classification (MICMAC). The result showed that variables are influence variables, including economic indicators comprising scare energy supply, affordable energy prices, and rising global energy prices. Then, regulatory indicators encompassed laws and regulations supporting renewable energy from central and regional governments. The urgency of this research is that EBT-based power plant projects in Yogyakarta and several regions in Indonesia, in general, face intermittency and variability that is still not optimal. Intermittency here is a situation where electricity generated from renewable energy cannot always be generated. At the same time, the variability in question is the instability of the energy produced. So the sustainability aspect in the development of renewable energy-based power plants is essential. In addition, the constraints on NRE-based power plants are the high investment and operational costs, as well as institutional governance at the central and regional levels. Therefore, developing renewable energy-based power plants requires the collaboration of all parties, especially the community, central and regional governments, and the private sector.

Keywords: Energy Security · Key Variable · Sustainability Model · Renewable Energy

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1 Introduction

Energy is the source of life, and if energy runs out, it means life will be destroyed; along with the increase in a country's population, the need for energy will also increase [1]. In the context of global energy, several parts of the world (Europe, in particular the UK, and China) are experiencing an energy crisis marked by soaring gas and coal prices, followed by an increase in oil prices.

This global energy crisis will eventually affect all countries, including Indonesia, due to their import dependence. In the case of Indonesia, it will impact fuel and Liquid Petroleum Gas/LPG prices, the costs of which will increase sharply. Indonesia is a net exporter for coal and Liquid Natural Gas/LNG, so it principally benefits from the trade balance side. In addition, compared to other countries, primary energy consumption in Indonesia shows that Indonesia is the 3rd largest country in the world that consumes fossil energy after China and India.

Consequently, soaring energy prices will influence the rising prices of other commodities and services, thereby threatening an increase in inflation that exceeds the target. Therefore, Indonesia's condition is vulnerable to increases in primary energy prices, especially petroleum (including fuel oil and Liquid Petroleum Gas/LPG), due to its high dependence on imports, significantly since the government partly subsidizes it for the fuel price and LPG products (Fig. 1).

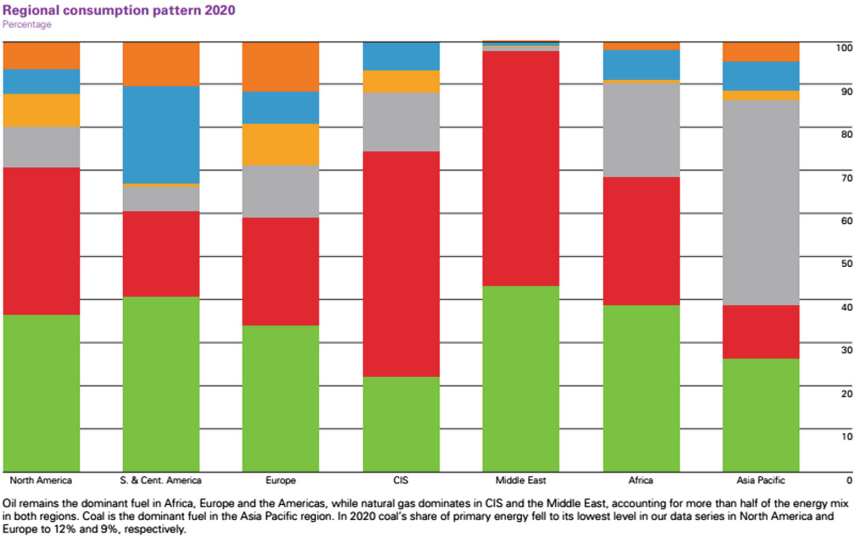


Fig. 1. Comparison of Regional Consumption Pattern 2020 in North America, South and Central America, Europe, CIS, Middle East, Africa and Asia Pacific. Source: [2].

For this reason, the urgencies of this research are as follows: First, the Special Region of Yogyakarta (DIY) Province is one of the provinces in Indonesia that does not have reserves or potential for non-renewable primary energy resources. So far, non-renewable energy needs, such as oil and natural gas, have been met from outside DIY. DIY is also

in the Java-Madura-Bali (JAMALI) interconnection system and still needs a large-scale generating system. Meanwhile, DIY has renewable energy sources like biogas, water, sun, wind, waves, and biomass. This renewable energy source is alternative energy, although until now, it has yet to be used optimally. Hence, the absence of reserves of energy resources, which results in dependence on energy supply in DIY from other regions, must receive special attention from the DIY government. In meeting energy needs, it is indispensable to develop energy resources. Considering that the development of energy sources takes a long time and costs a lot, in planning for the future national energy transition, it is necessary to carry out good planning supported by policies in the region's energy sector.

Second, the energy transition policy that only looks at short-term needs (shortsighted) can fundamentally encourage under-investment in the face of growing demand for clean energy and fossil energy (which is still growing). Improper application of transitional energy can also make Indonesia vulnerable when supply disruptions occur domestically and in a global/regional context.

Third, energy needs not accompanied by increased energy production will cause the country to experience an energy crisis [3]. Modern technologies can produce energy from renewable and non-renewable sources, including nuclear, hydrogen, coal, methane gas, liquid coal, and carbon dioxide. Renewable energy is a source produced from sustainable energy resources if appropriately managed.

Therefore, it is necessary to study NRE planning, especially in assessing how sustainable NRE is in each region, so that each area can optimize the potential of NRE in its respective regions. Thus, in the future, an energy transition can be encouraged that sees the needs and opportunities not only in the short term but also in the long term.

The urgency of this research is that renewable energy-based power plant projects in Yogyakarta and several regions in Indonesia in general face intermittency and variability that is still not optimal [4]. Intermittency disini yaitu keadaan dimana listrik yang dihasilkan dari renewable energy tidak bisa dihasilkan sepanjang waktu. Sedangkan variability yang dimaksud yaitu ketidakstabilan energi yang dihasilkn. Sehingga aspek keberlanjutan (sustainability) pada pengembangan pembangkit listrik berbasis renewable energy sangat penting. Disamping itu kendala pada pembangkit listrik berbasis EBT adalah mahalnya biaya investasi maupun operasional, dan tata kelola kelembagaan di pusat maupun daerah. Oleh sebab itu pada pengembangan pembangkit listrik berbasis renewable energy diperlukan kolaborasi semua pihak, terutama masyarakat, pemerintah pusat dan daerah, serta swasta. Based on the research background and urgencies, the research objectives is to designing the key variable indicators (internal and external environment) in the sustainability of renewable energy development in the DIY Province.

1.1 Energy Resources

Energy is a source of life; if energy runs out, it means that life will increase the population of a country, then the need for energy will also increase [5]. Energy needs not accompanied by an increase in energy production will cause the country to experience an energy crisis. Energy sources that can be produced by new technologies, both from renewable energy sources and non-renewable energy sources, include nuclear, hydrogen, coal methane gas, liquefied coal, and carbon dioxide Fields [6]. Renewable energy is an

energy source that is produced from sustainable energy resources if appropriately managed, including geothermal energy, wind, bioenergy, sunlight, currents, and waterfalls, as well as the movement and temperature differences of the sea layers [7].

Energy planning is essential to do to find out the potential use of energy needed by the community [8]. Indonesia's energy sources have fossil energy reserves such as oil, gas, and coal, as well as non-fossil energy reserves such as geothermal, water, wind, and solar power Fields [9]. The use of fossil fuels damages the environment, and its reserves continue to run out, so dependence on fossil energy must be reduced by replacing it with renewable energy with abundant reserves, including geothermal energi Fields [3].

1.2 Renewable Energy Sustainability

To overcome the energy supply crisis and avoid environmental damage due to global warming, new, renewable and more environmentally friendly alternative energy sources are needed [10]. The use and development of renewable energy is becoming increasingly important given the increasingly limited sources of fossil or renewable energy [11]. Energy sources available in an area, this must be done by studying the physical and chemical characteristics of the geothermal reserves [12].

Sources with large energy reserves can be developed into power plants, while resources with relatively small energy reserves can be used for other purposes, such as direct use for fisheries, agriculture and geotourism [13]. The potential that can be exploited is mainly in the fisheries, agriculture and geotourism sectors, for example in the Parangwedang area, Parangtritis Village, Bantul Regency [12].

1.3 Biogas Development

Technological developments show that almost all household appliances, offices, hotels and other equipment use electricity, all of which rely on fuel oil [14]. At the same time, energy conversion technologies have been discovered for power plants of various scales and capabilities, such as hydropower energy (PLTA), nuclear energy (PLTN), geothermal energy (geothermal), biodiesel energy, and others. Dependence on the use of petroleum cannot be tolerated, because energy needs continue to increase along with population growth, industrialization, and current technological developments [15].

Biogas is a fuel produced by the decomposition of organic matter under anaerobic conditions. The development of biogas technology in Indonesia has been widely recognized since the 1970s. The technology of using biogas equipment to process livestock manure has developed in rural areas, but now biogas technology has begun to be used in urban areas. In 1981, the development of waste processing technology in Indonesia through biogas installations was funded by the Food and Agriculture Organization (FAO), such as biogas installations in several provinces [16]. In the 2000s a household biogas reactor was developed with a simple structure, the material is made of plastic and can be installed at a relatively affordable price. The use of biogas to generate electricity is not a new technology. However, the application of household scale electricity generation from biogas fuel is still limited.

Biogas is a fuel produced from the decomposition of organic matter that occurs under anaerobic conditions. Animal waste processing techniques using biogas installations

have developed in rural areas, but now biogas technology has begun to be used in urban areas. In 1981, the development of waste treatment technology with biogas installations in Indonesia was developed through financial support from the Food and Agriculture Organization (FAO) such as biogas installations in several provinces. In the 2000s a household-scale biogas reactor was developed with a simple construction, with materials made of plastic which were ready to be installed at relatively affordable prices. Utilization of biogas for electricity is not a new technology. However, the application of household-scale power plants using biogas fuel is still limited [1].

1.4 New and Renewable Energy in Rural Areas

Biogas is a renewable energy source because it is produced from biomass. Substrates for the biogas process can be grown locally at low cost, such as cow dung, agricultural waste or energy crops. Biogas will increase the energy supply of an area and also make an important contribution to natural resource conservation and environmental protection [12]. The development and implementation of a biogas power generation system based on local resource potential will increase regional energy supply and energy security, thereby reducing dependence on fuel [17].

The government's efforts to develop alternative energy sources have encouraged efforts to develop renewable energy from livestock, cattle farming is one of the industries that has great potential for alternative energy development. The use of alternative energy sources from livestock waste provides many advantages, namely high quality and odorless fuels and products, therefore the use of alternative energy sources that are renewable and environmentally friendly, such as livestock manure is an option [18]. Indonesia has the potential to develop three alternative energy sources (renewable resources), namely nyamplung biofuel, geothermal, solar and biogas. One thing that can be done is to process livestock manure into an alternative energy source to replace fuel oil (BBM), namely biogas [19].

The prospects for developing biogas technology are very large, especially in rural areas where the majority of the population is engaged in animal husbandry and agriculture [20]. Converting cow manure into an alternative energy source for biogas is a very profitable way because you can take advantage of nature without destroying it, thus maintaining the ecological cycle [21]. Biomass with a high moisture content, such as animal manure and food processing waste, is very suitable as a raw material for biogas production. Biogas development faces enormous opportunities. Biogas energy can be obtained from household wastewater, livestock wastewater, market organic waste, and the food industry [22].

1.5 New and Renewable Energy in Cities

Development of new and renewable energy (EBT) as energy that can be renewed quickly through natural processes, such as geothermal energy, biomass, water, solar and wind [23]. The development of new and renewable energy (EBT) in global discourse continues to increase as a form of future energy integration and as part of sustainable development. Many countries in the world, especially developed countries, have used this energy, while in third world countries, including Indonesia, there are still many obstacles in

developing EBT [24]. One of the reasons is energy policies that do not favor alternative energy. Developing countries still believe that fossil fuels are still used as a cheap source of energy and this fuel must continue to be obtained in large part by providing subsidies from the state budget, which in turn hinders the development of EBT [25].

In order to increase energy production while reducing the use of fossil fuels, the government has identified the greatest potential for new and renewable energy, which is one of the most effective ways to reduce greenhouse gas emissions, including hydroelectric power [26]. PLTA/PLTH itself is actually divided into two, namely mini hydro power plants and micro hydro power plants, this shows that there are many large rivers and several waterfalls with flowing water which are very suitable for hydroelectric power plants. This method is part of Indonesia's efforts to reduce greenhouse gas emissions [27].

1.6 Sustainable Cities

Sustainable cities utilize renewable resources lower than their generation rate, and use nonrenewable resources lower than the rate of developing renewable alternatives while reducing their impact on the environment [28] In the future, one of the main challenges for society is the transformation of cities into sustainable settlements [29] Diaman The city itself is a center of energy consumption, but has great potential for renewable energy integration due to the infrastructure and resources that exist in the city [30] The feasibility of a particular renewable source varies from place to place. However, prioritizing certain renewable energy resources is itself an important topic that must be considered in sustainable urban development [31].

According [32] a sustainable city is a knowledge-based city, hence every aspect of the city must demonstrate efficiency; energy efficiency is an important sustainability principle that must be enshrined in sustainable cities to prevent unnecessary energy wastage. Energy efficiency is defined as using less energy by increasing the system's efficiency to produce the same product output. For example, from light bulbs to HVAC units, the energy expended should be less than inefficient alternatives but with the same or much better output. This concept allows us to improve existing systems to achieve technical and economic performance while addressing environmental issues.

Sustainable urban development is increasingly recognized as essential to achieving collectively agreed sustainability goals at local, regional, and global scales and, more broadly, to ensure the well-being of people around the world [33]. Issues of management and sustainable use of urban landscapes require some theoretical framework to set goals and evaluate results. Resilience theory is arguably one of the most suitable in urban environments because it allows the integration of ecosystem function with the social dynamics [34].

2 Methods

This research was designed with mixed methods based on theoretical concepts and secondary and primary data. Explorative qualitative research in this study encompassed an in-depth understanding of the research subject and object, mapping the problems,

directly observing the field, conducting in-depth interviews with core and supporting sources, and collecting primary and secondary data.

The secondary data used came from literature studies, and quantitative data came from the Ministry of Energy and Mineral Resources of the Republic of Indonesia and the DIY Provincial Public Works Office of Housing and Mineral Resources Energy. While the primary data used a research questionnaire covering economic, social, environmental, regulatory, and institutional governance dimensions, with a total of 20 variables (appendix 1. Long Theme Variable Used).

Based on the research background and urgencies, this research aims to determine what variables are the critical (internal and external environment) in the sustainable development model of renewable energy in Yogyakarta Province, using *the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC)* (Fig. 2).

The stages of the cross-impact matrix multiplication applied to the classification (MICMAC) analysis method are as follows:

1. MICMAC analysis uses data with a non-parametric scale, i.e., ordinal, with 0 for no relationship, 1 for a weak relationship, 2 for a moderate relationship, and 3 for a strong relationship.
2. MICMAC uses expert assistance in obtaining data. The experts in this study comprised academics and NGOs engaged in empowerment activities in the new renewable energy sector in Yogyakarta Province, as well as local governments and industry.
3. Data were collected using a questionnaire with structured questions. Each expert filled out the questionnaire through a Focus Group Discussion (FGD), where they were asked to discuss and agree on each variable item by filling in questions for each indicator by dividing the group and asking them to answer the questionnaire; one group was for one answer.
4. The FGD or questionnaire to the experts was conducted twice. At the first meeting, the question focused on identifying all the system or program variables to be evaluated and their operational definitions. The operational definition agreement helps the experts have a collective understanding and perception. After collecting the variables, the experts were asked to fill in the relationship between each variable with a non-parametric value according to point 1.
5. The FGD results were then entered into the MICMAC module and discussed in the second FGD. The participants of the first and second FGDs were the same people. This second FGD aimed to confirm the results of the system under study, enrich information, determine the understanding of the system, and identify key drivers in the system.

Based on the identification results, 20 main variables were obtained with the potential for sustainability of waste to energy, influencing (influential), and influenced (dependent), as seen in Appendix 1.

Figure 3 presents the results of filling out the Matrix of Direct Influences (MDI). MDI revealed the relationship between variables and each other. The filling of the MDI was based on the Forum Group Discussion carried out with stakeholders, both from the government and the private sector.

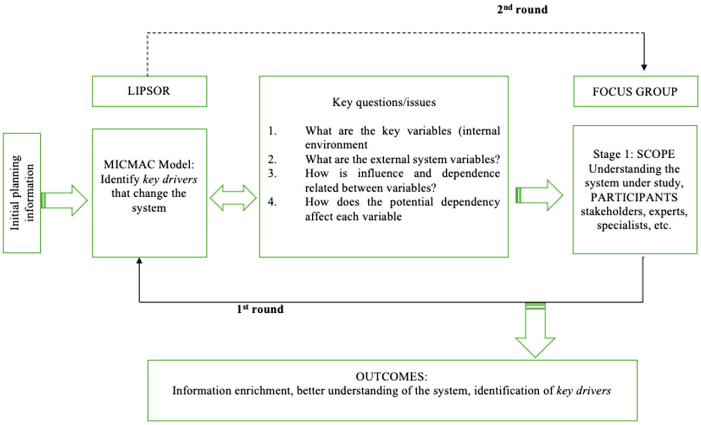


Fig. 2. Kerangka Kerja MICMAC (Modified from Stratigea, 2013 by Fauzi, 2019)

	1 : HBT	2 : KHE	3 : KPE	4 : SEMM	5 : KS	6 : MMME	7 : PM	8 : MK	9 : MPLLB	10 : IKLH	11 : TLL	12 : LING	13 : UUPP	14 : UUPD	15 : IZN	16 : TEBT	17 : SPP	18 : SPT	19 : KPT	20 : TKE
1 : HBT	0	1	3	2	3	3	3	3	2	2	2	2	0	0	0	0	2	2	2	2
2 : KHE	3	0	3	3	3	3	3	0	2	2	2	2	2	2	0	3	0	0	0	0
3 : KPE	3	3	0	3	3	3	3	3	2	2	2	2	2	2	0	3	0	0	P	3
4 : SEMM	0	0	3	0	3	3	3	0	2	2	2	0	0	0	0	0	0	0	2	3
5 : KS	0	0	0	1	0	3	3	1	0	0	0	0	2	2	2	0	0	0	2	3
6 : MMME	0	1	0	1	2	0	3	2	0	0	0	2	1	1	2	2	0	1	3	2
7 : PM	0	0	0	1	3	3	0	2	2	2	2	3	1	1	2	2	1	2	3	1
8 : MK	0	0	0	1	3	P	2	0	0	0	0	2	0	0	0	1	0	0	0	2
9 : MPLLB	1	0	0	0	0	2	2	0	0	3	3	3	1	1	0	0	0	1	0	0
10 : IKLH	0	0	0	0	0	0	0	0	0	3	0	3	3	2	2	1	0	0	1	0
11 : TLL	0	0	0	0	0	0	0	0	3	3	0	3	0	0	0	0	0	2	1	1
12 : LING	0	0	0	0	0	2	2	0	3	1	2	0	0	0	2	0	0	2	1	0
13 : UUPP	1	0	2	3	3	2	3	2	2	2	2	2	0	3	3	3	3	3	3	3
14 : UUPD	1	0	2	2	3	2	3	2	2	2	2	2	3	0	3	3	3	3	3	3
15 : IZN	0	0	0	0	3	3	3	1	0	0	0	P	0	0	0	3	2	2	3	3
16 : TEBT	0	0	0	0	2	2	3	0	P	P	1	P	0	0	2	0	0	1	2	2
17 : SPP	2	0	0	0	0	2	2	0	3	3	2	2	1	1	0	2	0	2	2	3
18 : SPT	3	0	0	0	0	2	2	0	3	3	2	3	1	1	1	3	3	0	3	3
19 : KPT	3	1	1	3	2	3	3	2	2	1	1	3	0	0	1	0	2	3	0	3
20 : TKE	2	0	0	2	3	2	2	2	2	1	1	3	0	0	2	1	1	2	2	0

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Influences ranged from 0 to 3, with the possibility to identify potential influences:
0: No influence
1: Weak
2: Moderate influence
3: Strong influence
P: Potential influences

Fig. 3. Matrix of Direct Influences of Key Variable Indicators in Sustainability Development Model of Renewable Energy in Yogyakarta Province

3 Result and Discussion

3.1 Direct and Indirect Key Variable's Indicator

The results of the MDI table analysis with MICMAC software produced a mapping as depicted in Fig. 4 Variables that fell into first quadrant, or called influences variables, include three economic indicator variables, consisting of scarcity of energy supply (PEL), cheap and affordable energy prices (HBT), and rising global energy prices (KHE). Also, two regulatory indicator variables emerged, i.e., laws and regulations supporting EBT, both from the Central and Regional Governments (UUPP & UUPD).

In this case, the influence or determining variable has the strongest influence compared to variables in other quadrants, with little dependence on other variables. Therefore, this variable can serve as a key factor in urban development of sustainability.

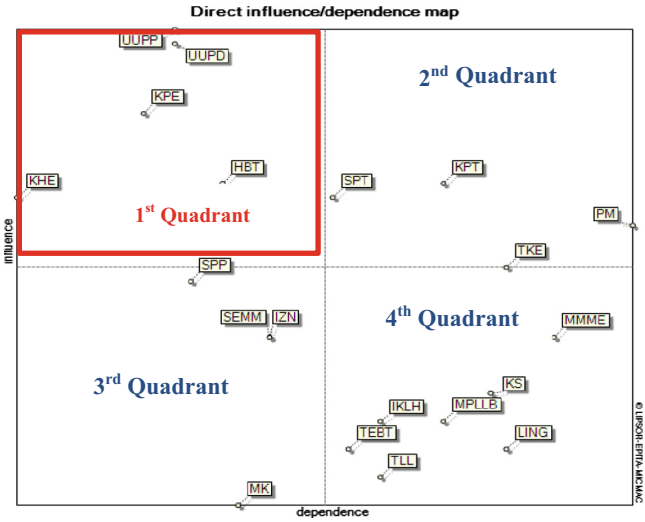


Fig. 4. Map of Sustainability Variables by Effect and Dependence

In this case, Yogyakarta Province is one of the provinces in Indonesia that does not have a network of power generation systems, so the energy supply is completely dependent on the JAMALI (Java-Madura-Bali) power system. Therefore, if there is a shortage of energy supply from the JAMALI power generation system, it will impact the sustainability of energy needs in the DIY Province and other areas with a network of power generation systems. Likewise, if there is an increase in the price of electrical energy, it will also impact sustainability and energy dependence in DIY. Hence, it is predicted that social unrest will occur if it happens. Then, the DIY government will face a critical situation because Yogyakarta does not have a network of power generation systems. Thus, the DIY government really must be able to condition that the variables influenced, consisting of cheap and affordable electrical energy prices, energy supply, as well as central and local government laws and regulations, support the development of sustainable cities, one of which is developing EBT in DIY. In this regard, DIY Regional Regulation No.15 of 2018 concerning New Renewable Energy and DIY Regional Regulation No.6 of 2020 concerning DIY Regional Energy General Plan 2020–2050 have been issued.

In addition, three of the four variables in the governance indicators are included in the relay variables (2nd quadrant). Relay variables illustrate that the variables in this quadrant are unstable in achieving sustainable EBT development since all interventions on this variable will impact the system. Among them are a controlled EBT management system (SPT), inter-stakeholder cooperation (KPT), transparent and equitable management of fossil energy (TKE), and community participation (PM), which fell under social

indicators. For this reason, it is particularly important for the DIY Provincial Energy and Mineral Resources Office to cooperate with multi-stakeholders to accelerate the development of EBT, for example, by opening opportunities for collaboration with private investors who will develop NRE in Yogyakarta Province, universities in Yogyakarta, and its surroundings. Especially in the context of developing NRE in each university, the example is developing solar panel energy at each university for the domestic needs of the university. This is an effort to achieve sustainable urban development by utilizing energy resources.

In addition, one of the efforts made by local governments in carrying out sustainable urban development is inviting industry and households to develop EBT in their respective sectors jointly. For example, industries and households are equipped with RE technology, which is simple and can be implemented quickly. Thus, they can harvest electrical energy from their places to meet their energy needs. As in Africa, people are invited to use solar panel energy at home with simple solar panel technology, and then the technology is sold to residents using a community installment system. The Indonesian government has used solar panel energy as regulated in ESDM Minister Regulation No. 26 of 2021. It governs the use of solar panels and the electricity sale and purchase agreement between PLN and the community. However, in practice, the regulation is still widespread or has yet to be achieved by all levels of society.

Furthermore, environmental indicators are included in the dependent variable quadrant (3rd quadrant). Dependent variables cannot stand alone (highly dependent on other variables), so they have an insignificant effect. These variables include two variables in social indicators, including the realization of an energy-independent society (MMME) and the occurrence of social conflicts due to rising energy prices and the scarcity of energy supply (KS), and one regulatory indicator, i.e., a consistently applied NRE energy transition policy (TEBT).

MMME variables can be realized if other supporting variables exist, such as central and regional government policies to develop energy-independent communities through NRE development programs in the regions. Likewise, the KS variable needs to stand alone because this variable depends on other variables, such as the security of the NRE energy supply and the low and affordable price of NRE that needs to be pursued. The TEBT variable is also a dependent variable because it is very dependent on other variables, such as regulatory encouragement in the form of laws in the Central and Regional Governments so that DIY renewable energy transition policies can be sustainable for urban development.

Next, in quadrant 4, autonomous or excluded variables have little influence and dependence on other variables, so they will not stop the operation of a system. This quadrant consists of standardization of NRE supporting facilities (SPP), which is an indicator of governance; NRE energy subsidies for low-income communities (SEMM), which is an economic indicator; easy EBT investment licensing (IZN), which includes regulatory indicators and reducing poverty (MK) which is included in the social indicators. In this case, EBT energy subsidies have an insignificant effect as the demand for NRE in DIY is still low compared to the market for fossil energy circulating in the community. The investment level in DIY Province still needs to be higher, causing investment licensing to be in quadrant four or have little influence and dependence.

Likewise, the development of EBT in DIY has been insignificant, so it has not impacted poverty reduction.

The results of the MDI table analysis with MICMAC software produced a mapping, as depicted in Fig. 5. Variables that fell into quadrant one, or called influences variables, include three economic indicator variables, consisting of scarcity of energy supply (PEL), cheap and affordable energy prices (HBT), and rising global energy prices (KHE). Also, two regulatory indicator variables emerged, i.e., laws and regulations supporting EBT, both from the Central and Regional Governments (UUPP & UUPD).

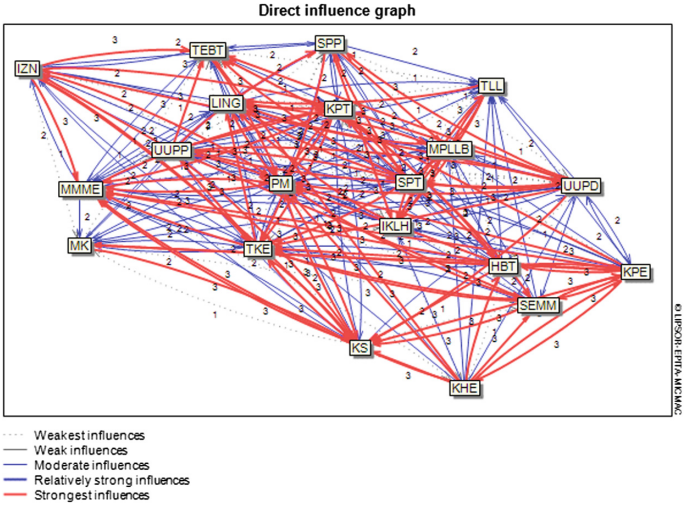


Fig. 5. Direct Influence Relationship Between Sustainability Variables (Color figure online)

Figure 5 is a graph of the direct influence of variables. The image describes the line where the dotted line indicates the strength is fragile, while the straight black line implies weak strength.

Likewise, a thin blue line signifies medium strength, and a thick blue line denotes muscular strength. Finally, a thick red line represents powerful strength. Also, Fig. 6 depicts that each variable was dominated by a powerful relationship, indicated by the dominance of the thick red graph [35].

Figure 6 is a graphic visualization of the indirect effect. The graph displays the relationship between each variable, showing that all NRE indicators have a relatively moderate and robust influence on each other. In addition, the most substantial impact in the indirect influence graph is indicated by the variables UUPD (local government law), UUPP (central government law), PM (community participation), TKE (transparent and equitable management of fossil energy), and MPLLB (reducing environmental pollution and hazardous waste). It indicates that the five variables have the most substantial influence on the development of EBT in Yogyakarta.

Figure 7 shows the shift in the order of several variables. For example, the cheap and affordable energy prices (HBT) variable in the MDI matrix is ranked 4th as an

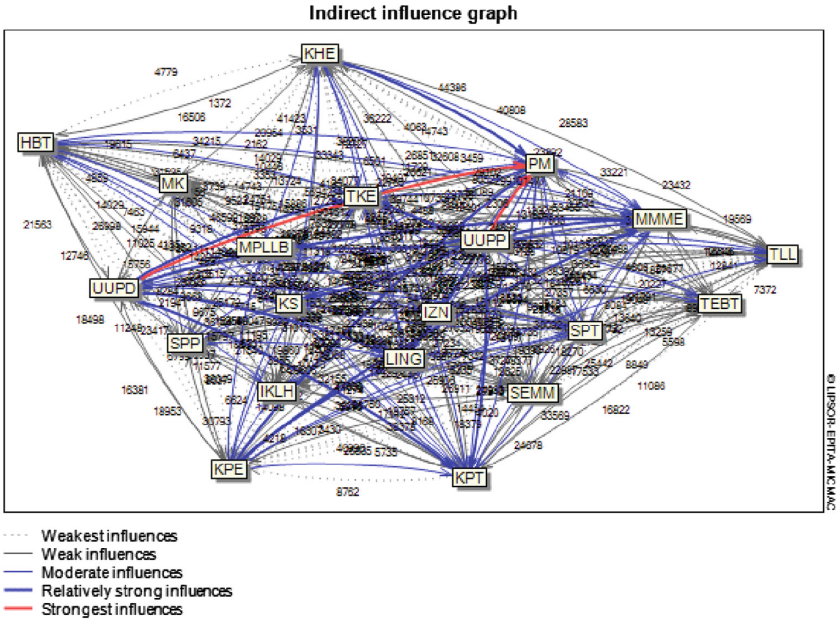


Fig. 6. Indirect Influence Relationship Between Sustainability Variables

influential variable. Still, after iterations were carried out by considering the indirect influence factor, this variable is ranked 6th. Likewise, the energy governance variable, originally in the 9th place, becomes the 10th order. On the other hand, some variables have an increasing order, such as the increase in local energy prices, from 6th to 4th place.

Viewed from the dependence aspect, the three main variables (community participation, creating an energy-independent society, and creating a sustainable environment for future generations) are consistently in three significant orders as dependence variables. On the other hand, several variables have decreased by one level after the MDII iteration, i.e., energy governance, social conflicts due to rising energy prices and scarcity of energy supply, and environmental pollution and hazardous waste. Meanwhile, the variable of cooperation between related parties rose in rank from 7th to 4th after considering indirect effects. The shift in these variables due to the indirect impacts can be seen in Fig. 7.

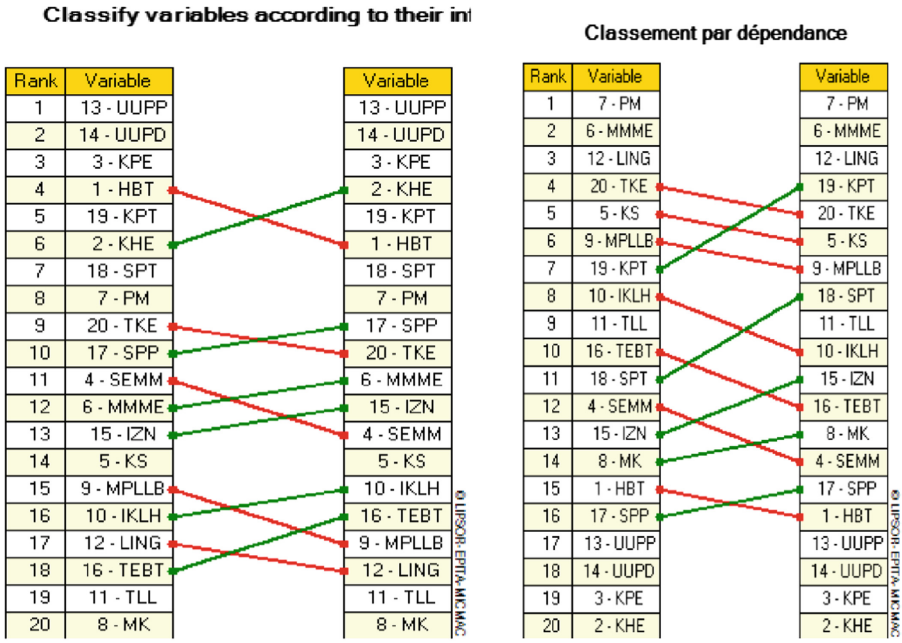


Fig. 7. Variable Ranking by Effect and Dependence.

4 Conclusion

This article highlights the importance of renewable energy planning and development in Yogyakarta Special Region (DIY) Province in the context of the global energy crisis and Indonesia's dependence on energy imports. This study identifies key variables that influence the sustainability of renewable energy development in DIY using the MICMAC method. The results showed that variables such as scarcity of energy supply, cheap and affordable energy prices, and rising global energy prices have a major influence on the sustainability of renewable energy in DIY. In addition, policies and regulations from central and local governments also play an important role in supporting the development of renewable energy.

This research is original because it focuses on identifying key variables in renewable energy development in provinces that do not have non-renewable energy reserves, and offers solutions based on multi-stakeholder collaboration to address these challenges. This research also provides insight into the importance of the role of communities and cooperation among stakeholders in accelerating the development of renewable energy.

The implications of this research for the future include the importance of long-term planning and policy development that supports the renewable energy transition. DIY local governments need to increase cooperation with various parties, including the private sector and academia, to optimize the potential of renewable energy in the region. In addition, this study emphasizes the need for simple and affordable renewable energy technologies for the community to increase energy independence and reduce dependence

on fossil energy. Thus, this research makes an important contribution to efforts to achieve sustainable urban development through renewable energy resources.

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Lampiran 1. Variable Used for Each Indicators

No	Long label	Short label	Theme
1	Cheap and affordable energy prices	HBT	Economy
2	Rise in global energy prices	KHE	Economy
3	Scarcity of energy supply	KPE	Economy
4	Energy subsidies for low-income people	SEMM	Economy
5	The occurrence of social conflicts as a result of rising energy prices and the scarcity of energy supply	KS	Social
6	Creating an energy independent society	MMME	Social
7	Increase community participation	PM	Social
8	Reduce poverty	MK	Social
9	Reduce environmental pollution and hazardous waste	MPLLB	Environment
10	Increasing the value of the Environmental Quality Index	IKLH	Environment
11	Creating a sustainable environment	TLL	Environment
12	Creating a sustainable environment for future generations	LING	Environment
13	Laws/Perpres/Presidential Decrees that support EBT from the Central Government	UUPP	Regulation
14	Laws/regulations of governors/regulations of regents/mayors that support EBT from local governments	UUPD	Regulation
15	Easy EBT investment licensing	IZN	Regulation
16	Consistently implemented NRE energy transition policy	TEBT	Regulation
17	Standardization of NRE supporting facilities	SPP	Governance
18	Controlled NRE management system	SPT	Governance
19	Cooperation between related parties	KPT	Governance
20	Fossil Energy Governance that is transparent and has the principle of Justice	TKE	Governance

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