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Abstract	Malaysia is currently a net exporter of fossil energy in the form of crude oil and refined petroleum contributing to the country's economic development but not placing sufficient emphasis on its long-term environmental sustainability. The shortage of energy scenario can be a potent threat towards the economy as it will force prudent energy usage in different sectors. This will slow down economic growth and affect consumer market. This paper aims to investigate the impact of energy shortage on the dimensional indicators of Malaysia's energy security (ES) that has been analyzed in three dimensions: *energy availability, socio-economic and environmental sustainability*. The shortage of energy by 30% is a hypothetical scenario designed to replicate how this will impact Malaysia's overall energy security by discussing the dimensions of ES and its effects. A system dynamics approach is utilized to quantify this impact for a span of 5 years from 2015 to 2020 to analyze its effects on Malaysia's ES. Findings showed that an increase in energy shortage by 30% will greatly increase energy costs, thus impairing its affordability. As a result, the energy consumption hits the lowest limit set by the simulation suggesting an energy insufficiency to fulfill the demands of all sectors. Energy shortage will lead to an economic growth deficit but will instill an awareness to be energy-prudent, hence increasing energy efficiency amongst user groups, which can be a positive impact.

Keywords (separated by '-')	Energy security - System dynamics - Environmental sustainability - Socio-economy - Energy shortage

Quantifying the Impact of Energy Shortage on Malaysia's Energy Security Using a System Dynamics Approach

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Abstract Malaysia is currently a net exporter of fossil energy in the form of crude oil and refined petroleum contributing to the country's economic development but not placing sufficient emphasis on its long-term environmental sustainability. The shortage of energy scenario can be a potent threat towards the economy as it will force prudent energy usage in different sectors. This will slow down economic growth and affect consumer market. This paper aims to investigate the impact of energy shortage on the dimensional indicators of Malaysia's energy security (ES) that has been analyzed in three dimensions: *energy availability, socio-economic and environmental sustainability*. The shortage of energy by 30% is a hypothetical scenario designed to replicate how this will impact Malaysia's overall energy security by discussing the dimensions of ES and its effects. A system dynamics approach is utilized to quantify this impact for a span of 5 years from 2015 to 2020 to analyze its effects on Malaysia's ES. Findings showed that an increase in energy shortage by 30% will greatly increase energy costs, thus impairing its affordability. As a result, the energy consumption hits the lowest limit set by the simulation suggesting an energy insufficiency to fulfill the demands of all sectors. Energy shortage will lead to an economic growth deficit but will instill an awareness to be energy-prudent, hence increasing energy efficiency amongst user groups, which can be a positive impact.

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1 Introduction

Energy crisis can take several forms amidst which energy shortage is one of the severe forms of energy crisis. Energy shortage can arise in countries where there is a heavy dependence on non-renewable sources of energy and less contribution of alternative sources of energy in the fuel mix. This is a drawback for countries without high reserve margin or sources of fossil fuels. Malaysia is currently an exporter of fossil energy which contributes to the economic development, however less priority is given to its environmental sustainability in the long term. Energy crisis in Malaysia can lower the energy consumption and usage in industrial, transport and commercial sectors which are heavily dependent on energy consumption for its functioning. This in turn can reduce the industrial growth of the nation and hence hamper the economy and consumer confidence on the national energy policies.

The question arises where hypothetically if there is a shortage of energy in the near future, is there a contingency plan to anticipate this challenge? How will Malaysia address this crisis? Thus, this paper aims to address the possible effects that energy shortage can impair upon Malaysia's energy security (ES) by predicting result of the ES variables that have causal link to energy shortage indicator either directly or indirectly using system dynamics (SD) model. The model will simulate from year 2015 to 2020 (present time) in predicting the future scenario. Similarly, the same variables from energy reports and reviews can be compared from 2020 onwards to understand how it will perform over the span of the next 5 years. This paper firstly, discusses Malaysia's energy data, energy security dimensions, and the indicators. Then, the data collection method consists of a questionnaire survey followed by SD modelling of the dimensions and indicators is described. A simulated energy shortage scenario of 30% have been selected and justified and the simulated results have been represented graphically and discussed in this paper. Lastly, followed by the discussion of the results and conclusion which includes the main findings of this paper.

2 Literature Reviews

Malaysia's higher quality fossil fuels e.g. crude oil and natural gas are mainly exported to countries like Australia, India and Thailand [1] whilst lower grade coals are imported from countries like Australia, Indonesia and South Africa [2]. This has resulted in a net gain for Malaysian economy because refined petroleum products export has seen a growth (+RM 1.6 billion equivalent to 370 million USD) in the year 2019, while decreases were projected from liquefied natural gas (LNG) (−RM 961.6 million equivalent to 220.6 million USD) and crude petroleum (−RM 799.3 million equivalent to 183.3 million USD) [3]. Malaysia's ES depends heavily on the export of its premium tapis sweet crude oil and imported low grade oil which are refined in Malaysia. In order to be a net exporter, Malaysia has been increasing its refining capacity [4]. For example Pengerang Integrated Petroleum Complex (PIPC) in Johor, and Sipitang Oil & Gas Industrial Park (SOGIP) in Sabah has been established to meet this growing need of refinery, almost doubling the refining capacity nationwide from 588,000 bbl/d to 1,158,000 bbl/day [4]. Malaysia's LNG reserves stands at 1.183 trillion cubic meters which makes Malaysia having the 24th largest LNG reserve in the world [4]. As such, Malaysian oil and gas industry has contributed to 20% of the GDP in the recent years [5]. These statistics indicated the fact that Malaysia still have sufficient reserves of LNG and crude oil therefore there will be less concern in the short-term.

The demand for energy increases with economic growth and development, thus energy usage is also expected to increase. It is forecasted that the overall energy usage for Malaysia will increase by 4.8% by the year 2030 according to World Energy Market Observatory (WEMO) report [6]. While in the 19th edition of the WEMO report suggested that the overall final energy requirements for Malaysia will triple by the end of 2030 [6]. However, the question arises as to whether this is sustainable in the long run for Malaysia's ES to remain as a net exporter of fossil energy. The answer lies in the definition of ES as defined by International Energy Agency (IEA) as "the uninterrupted availability of energy sources at an affordable price." [7]. ES of a country depends on several dimensions, mostly the traditional 4 A's where *availability* and *affordability* is at the heart of almost all the ES definitions and the other two factors; *accessibility* and *acceptability* [8]. ES can also be defined as the "feature (measure, situation, or a status) in which a related system functions optimally and sustainably in all its dimensions, freely from any threats" [9]. The energy supply at all time must be stable and affordable for the community at large.

These dimensions and indicators mentioned for ES vary between countries in weightage. For Malaysia, the priority at this point is leaning towards socio-economy and the availability of energy in order to ensure that energy is supplied, distributed and reached to community at an affordable price whilst, keeping in mind the trade-off between natural resources with other countries that provide a net gain for the economy. The development of these two dimensions are given higher priority whilst environmental sustainability can be ranked the lowest amongst these three dimensions in term of concern and importance. These concerns are addressed by the Energy Commission of Malaysia in the Energy Malaysia report "Shaping the future of Malaysia's energy sector" [5]. In this report, strategies on how to address the challenges of renewable energy (RE) implementation and maximizing the energy efficiency of the country was presented, outlining a roadmap for the environmental sustainability dimension of Malaysia as this dimension decides the future of ES of any country. The key focus of the government is to protect the best interest of the consumers in terms of electricity and gas by regulating the market prices using new policies. Additionally, to increasing the RE penetration rate simultaneously curbing the carbon footprint. These have been discussed in the white paper published by the ministry and other government agencies like Economic Planning Unit (EPU) titled 'Malaysia's future energy landscape' and also 'Renewable energy transition roadmap (RETR 2035)' by Sustainable Energy Development Authority (SEDA). These are the current focus of the government, the ministries and the respective agencies like EPU,

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SEDA and energy commission [5]. The following methodology section discusses the methods used to collect data on the three ES dimensions and their indicators and the use of system dynamics to model these data.

3 Methodology

This study employs a mixed method approach; a pre-fronted data collection followed by a simulation using SD to create models in Vensim based upon the data collected. Qualitative data on Malaysia's ES and its three dimensions with respective indicators were collected from 117 participants in the field of engineering and energy in Malaysia. A survey using questionnaire with true/false statement was designed to collect data to generate the SD models; causal loop and stock and flow diagrams using Vensim. The questionnaire was designed based upon the literature review of Malaysia's ES with the aim to obtain input feedback from participants to understand the correct causal relation between the dimensional indicators of ES. While quantitative data was collected from energy statistics handbook published by the regulatory bodies of energy in Malaysia [10], energy reports by energy commission and IEA [11, 12]. The SD model defines the causal relation between the three dimensions defining the link between energy shortage and the dimensional indicators of ES of energy efficiency, energy wastage, RE in energy mix, growth in economic health etc.

Causal loop diagrams (CLDs) are created based on the qualitative data collected in Vensim keeping in mind the causal relations between the dimensional indicators. The CLD is then converted into a stock and flow diagram (SFD) where the quantitative data are given input in the respective chosen variables: energy shortage, vulnerability of energy supply and short term energy security in order to extract data in graphical form for the required variables. To quantitatively model any process there needs to be quantitative values and equations which defines each of the variables and flows. There are two assumptions according to Morecroft and Sterman (1994): (1) flows within processes are continuous, and (2) flow do not have a random component [13]. With these two assumptions in mind, one can consider any stock and flow system hence, the following SFD was created from its respective CLD. The CLD's and SFD generated in this research are illustrated in the next section.

4 Causal Loop Diagram and Stock Flow Diagram

This section illustrates the CLDs created based upon the questionnaire survey conducted with 117 participants. The CLD was categorized into three segments to better understand the causal relation between each of the dimensional indicators of ES in this research.

4.1 *Causal Loop Diagram (CLD)*

The CLD in Fig. 1 comprises of 3 balancing feedback loops with energy reserve to production ratio and imported energy as common indicators in 2 different loops. In each of these CLD's there will be an added external variable or an auxiliary variable that will be added for simulation purpose. The CLD shows the link between energy wastage and the direct causal link with 3 other variables in one of the balancing loops. The causal link shows that energy wastage will affect energy cost and energy efficiency directly which will be discussed in Sect. 5.

Figure 2 shows how energy cost is related to the energy consumption, energy intensity, growth in economic health and country's unemployment. These variables are simulated using SFD in Fig. 5. This figure shows a single balancing loop with

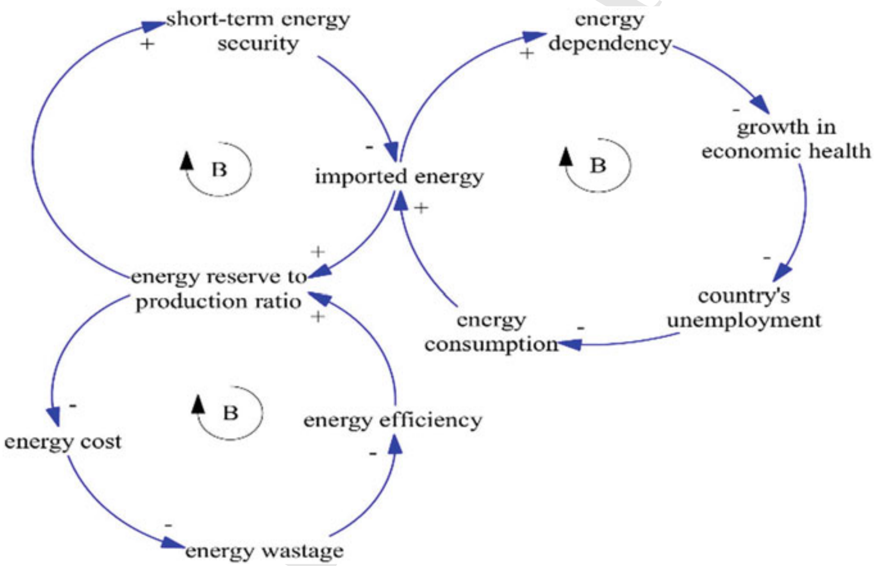
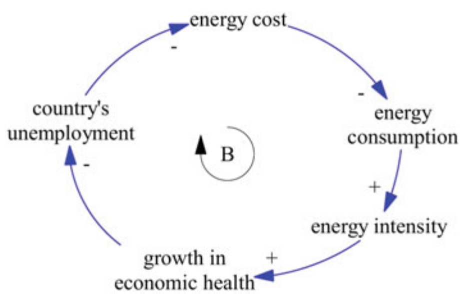


Fig. 1 CLD of energy availability and energy efficiency

Fig. 2 CLD of energy cost and the indicators that are directly affected by the energy cost



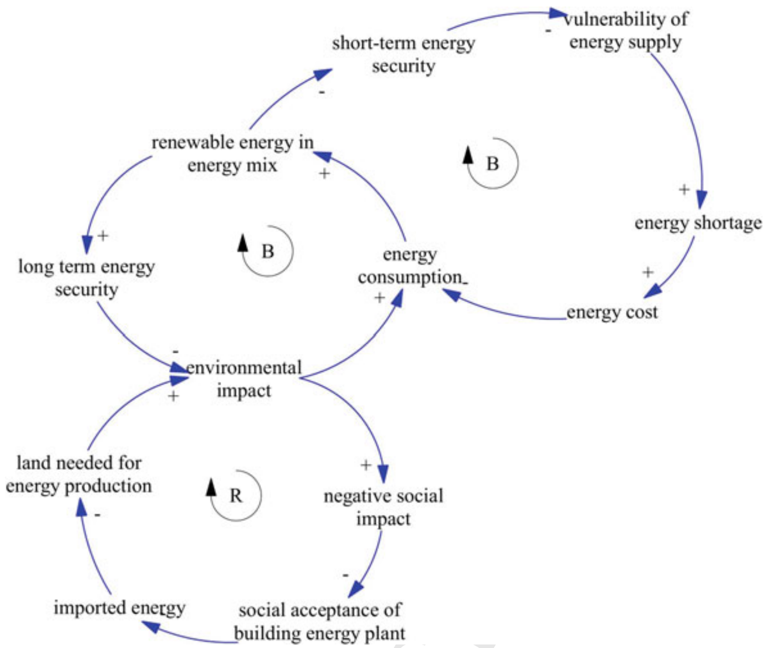


Fig. 3 CLD of environmental and social impact that the increase of RE has on other indicators

5 variables in it, where '+' shows the positive influence in the relation between the variables and vice versa for '−'sign.

Figure 3 shows the CLD of environmental and social impact which comprises of 2 balancing loops and 1 reinforcing loop in it with environmental impact, energy consumption and RE in energy mix as the common indicators in the 3 loops.

Figure 4 shows the combination of three CLD's breakdown that is derived based upon the causal relation developed between indicators in the questionnaire survey.

4.2 Stock and Flow Diagram (SFD)

Quantitative values and equations are required for quantitative modelling using SD. These equations and input values defines each of the variables and flows in the SFD. Stocks in SFD are also known as 'levels' which represent accumulation in a system that determines the current state of the system [14]. SFD in Fig. 5 was converted from the CLD in Fig. 4 by assigning these stocks, flows and by equating the variables. In the SFD created, there are 2 assigned stocks, energy production to reserve ratio, and environmental impact. Imported energy, short-term ES, land needed for energy production and negative social impact are the flows. The additional variables added are unemployment rate, energy intensity, percentage of vulnerability, percentage of

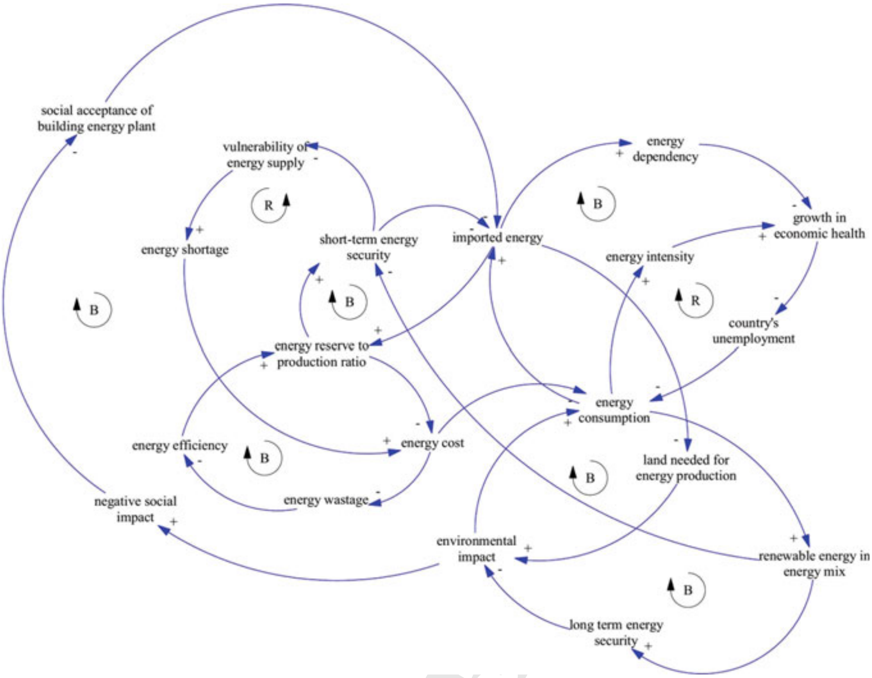


Fig. 4 Combination of CLD's 1, 2 and 3 to create the overall CLD

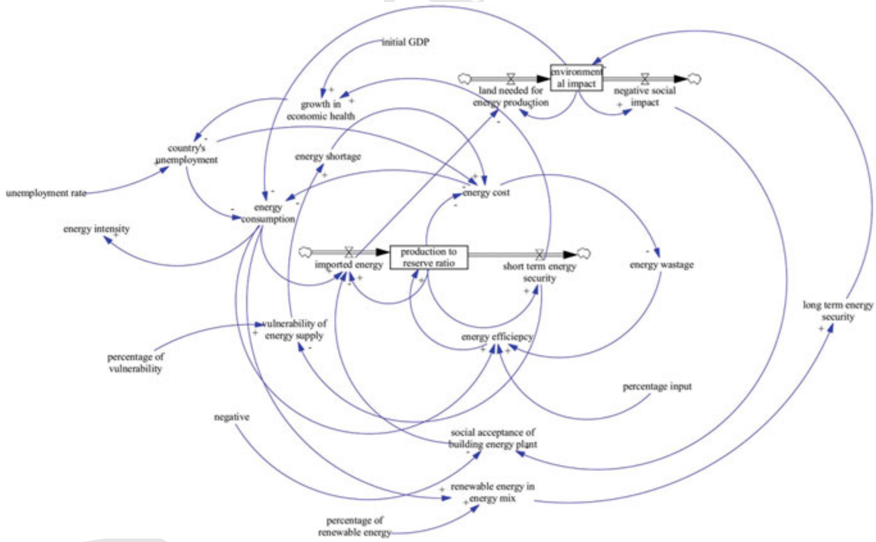


Fig. 5 SFD that was converted from CLD simulating different scenarios

renewable energy, initial GDP, and percentage input. The model is verified through stakeholder engagement sessions. Malaysian stakeholders from the field of energy security, energy modelling and sustainability were involved actively to verify and improve the model. The model is editable based on the stakeholder feedback if necessary.

5 Simulated Scenario

5.1 Increase in Energy Shortage by 30%

This is a hypothetical scenario created where there is an increase in energy shortage by 30% compared to the current value in year 2015. The value of 30% assigned to energy shortage is indirectly related to the 20% RE penetration target of the government as documented by energy commission [5]. This input of 30% increase in energy shortage alongside the most relevant input variables are tabulated in Table 1 while Fig. 3 shows the causal relation between energy shortage and renewable energy in the energy mix. The causal relation indicates that an increase in RE in the energy mix leads to a decrease in short term ES indicated by '−' sign on the link. Additionally, a '−' sign from short term ES to vulnerability of energy supply shows that there is an increase in vulnerability of energy supply because a '−' sign in CLD indicates a change in the opposite direction from the initial [13]. An increase in vulnerability of energy supply in turn leads to an increase in energy shortage indicated by '+' sign in the link in Fig. 3. This relationship between RE in energy mix and energy shortage via the two other variables mentioned is the basis of the selection in this scenario. It is a clear indication of the possibility of an increase in energy shortage in the future when there is a need to increase the RE in energy mix in order to anticipate the increasing demand and shortage. The target is to increase RE in the energy mix to 20% by 2025 [5]. While this percentage may change in the Renewable Energy Transition Roadmap (RETR) 2035, which will have its outcome documented in the 12th Malaysia plan (2021–2025) [5]. The energy shortage has been assigned a value of 30% increase assuming a change in RE in energy mix, will lead to a proportional change in energy shortage based on the simulated CLD in Fig. 3. An additional 10% have been assigned to energy shortage compared to RE in energy mix because it is clear from the energy reports that Malaysian government is going forward for higher

Table 1 Value of input variables for SFD

Input (2015)	Value (%)
Energy shortage	30
Vulnerability of energy supply	5
Short term energy security	80

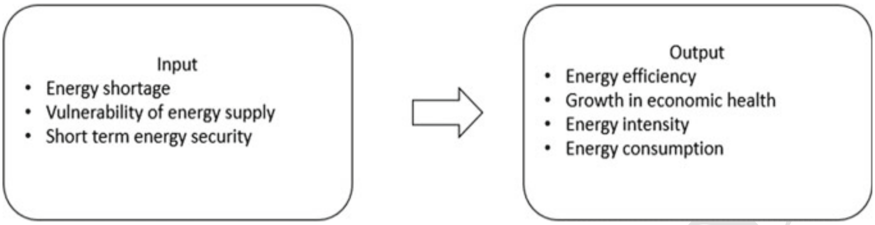


Fig. 6 The inputs and output variables measured using SD model

percentage of RE in energy mix in the new 12th Malaysia plan, hence leading to higher energy shortage based on the causal relation.

The input values are taken from the quantitative data provided in energy statistics of Malaysia [10]. These input variables gave the simulated results for the 4 output variables depicted in Fig. 6. The simulated results are discussed in the following section.

5.2 Energy Shortage Scenario Results

Figure 7 shows the results of the SFD simulation in Fig. 5. These graphical representations depict how the 4 output variables changes over a period of 5 years from 2015 to current year 2020. The input variables for the SFD and their values are extracted from Table 1.

6 Discussion

The results show the intricate relationships between the variables in Fig. 4. Hence proving the criticality of understanding the causal relation between each of the variables as it effectively shows an impact that energy shortage can have on Malaysia's ES. This futuristic scenario modelling allows the policy makers of the nation to take note of the variables that are critical towards achieving long-term ES. 4 such variables have been discussed on how they are affected by an 30% increase in energy shortage scenario and its impact on the ES of Malaysia.

Energy consumption variable shows a decrease by almost 50% which is expected with a decrease in energy supply that will be created due to the shortage of energy. While energy efficiency increases to a small extent for the next two years and then remains constant until the 5th year mark. There is a minimal change in the growth of economic health over the 5-year period while the most amount of fluctuation is shown in energy intensity as it decreases over the span of time. Each of these output variables affects each other directly or indirectly with respect to the increase in energy

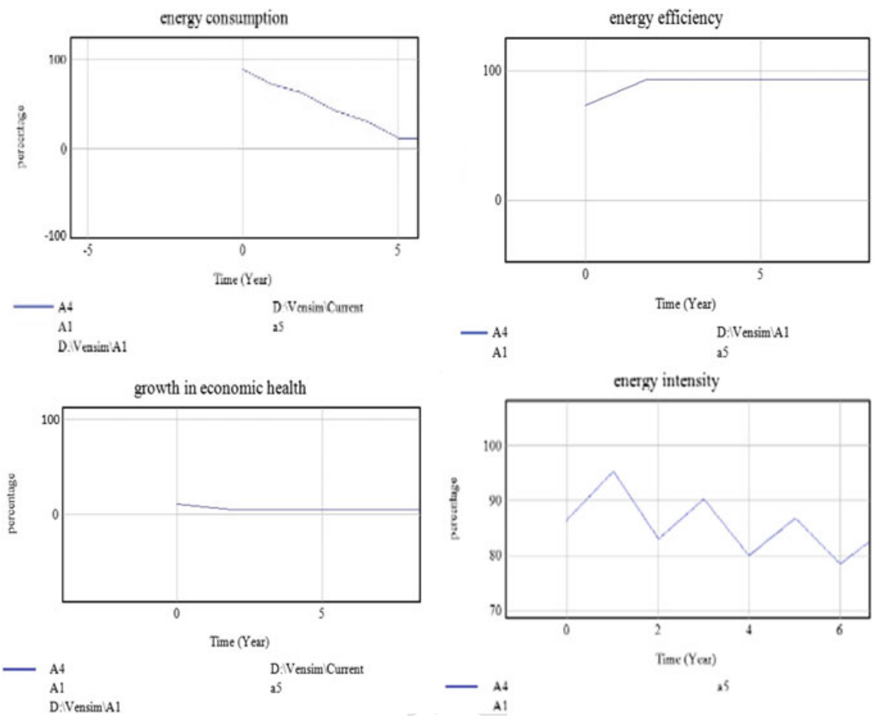


Fig. 7 Energy consumption, energy efficiency, growth in economic health and energy intensity prediction for 5 years using 2015 data's as the base

shortage to 30%. With an increase in energy shortage to 30%, it will significantly increase the energy cost, which will impair its affordability.

As a result, the energy consumption has hit the lowest limit set by the simulated model. Hence, this will result in rising electricity tariff to the dissatisfaction of consumers. In turn, consumer dissatisfaction will affect the socio-economic dimension of ES making it vulnerable for the nation. Socio-economic dimension of ES is given top priority in a developing country like Malaysia hence it is necessary to ensure that this dimension does not deteriorate much. The only positive effect that can be drawn from this scenario is that the increase in energy cost will indirectly cause a decrease in energy wastage, resulting in an increase in energy efficiency by a small margin shown in Fig. 7. While the decrease in energy consumption is expected to cause the growth in economic health to decrease, thus hitting its lowest point with an approximation of 3%. A reduction in energy intensity can be seen at 85% in the 5 years mark.

A key relation that can be established is energy shortage causes a decrease in energy consumption as well as a growth in economic health which leads to reduced energy wastage. In this context, less energy wastage is seen as the only positive outcome as it leads to an increase in energy efficiency. Subsequently, the increase in energy efficiency is an opportunity to improve Malaysia's ES though it still hampers the growth in economic health and leading to less consumption of energy for different sectors. There is a mixed response of this scenario towards the Malaysia's ES as a whole as it will be more harmful than beneficial for the country.

7 Conclusion

This paper provided an insight on how energy shortage in Malaysia can impact the three dimensions of Malaysia's ES. Currently there is no policy in place for Malaysia to specifically address ES, it is difficult to effectively manage and monitor the country's ES, as demonstrated through different scenarios proposed in this paper. Statutory body like the Energy Commission, regulatory body like SEDA, and the Ministry of Energy and Natural Resources provided mitigation plans to address different ES related crisis, but a nationwide approach is yet to be seen. The simulated scenario in this paper demonstrated an impact that a change in variables (e.g. energy shortage) can have on ES indicators such as energy consumption, energy efficiency, growth in economic health, and energy intensity. The results suggest that there will be an overall damage to the ES in terms of a sustained decrease in energy consumption and slight decreases in energy intensity and growth in economic health. There will be a marginal increase in energy efficiency due to an indirect effect of increasing energy costs, which can be drawn as the only positive outcome from the crisis scenario. The results suggest an urgent need to strategize against ES challenges in the near future and in addressing energy shortage in the context of ES via appropriate policies. This is a dynamic process hence the indicators and values need to be monitored based upon the quantitative data available to the public by energy agencies. Further research in the dimensional indicators and its causal relation will allow the model to be improved and validated further to understand different aspects of Malaysia's ES and its contribution to future energy policy-making for a better and sustainable development.

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