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Life Cycle Cost Analysis in System Dynamic Modeling on Indonesia's Green Toll Road

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Abstract. The increasing number of toll road construction projects certainly has a direct impact on environmental damage because it causes emissions, pollution, and congestion. The green road rating is a tool to measure the performance of green practices and the level of reforestation in toll road construction projects. However, the implementation of tools to identify the extent to which green concepts are applied in road construction projects is still lacking in Indonesia. Therefore, this study aims to examine the extent to which the implementation of green road tools contributes to the achievement of sustainability goals. This study aims to determine the green level of the toll road and identify the performance of each main category and subcategory related to areas of success and areas that need to be improved based on the points obtained. From these categories, it is then modeled with System Dynamics to determine the dependencies and the resulting life cycle costs. The tentative hypothesis is that improving road quality by implementing green roads on toll roads and modeling system dynamics can reduce life cycle costs. Therefore, the implementation of greener roads is needed in Indonesia for environmental sustainability and life cycle cost savings. Finally, policy recommendations are needed for improvement.

INTRODUCTION

Infrastructure development is one indicator of a country's progress. The infrastructure development program is part of supporting programs in other sectors. With development, it can spur economic growth and create jobs. The government's focus on paying attention to infrastructure was seen when it increased the infrastructure budget by 4.9 percent from IDR 399.7 trillion to IDR 419.2 trillion in the 2020 State Budget Plan (RAPBN). Infrastructure development in 2020 includes road construction, construction of bridges, construction of railway lines, and construction of airports. According to the Global Competitiveness Index Report 2010-2019 AS Figure 1, Indonesia's competitiveness in the Southeast Asia Region when compared to Malaysia and Thailand is still far behind. Infrastructure development, especially toll roads in Indonesia, which is still very lagging behind, is one of the causes of Indonesia's low competitiveness. The lack of toll roads and the low quality of infrastructure have resulted in very high logistics costs in Indonesia.

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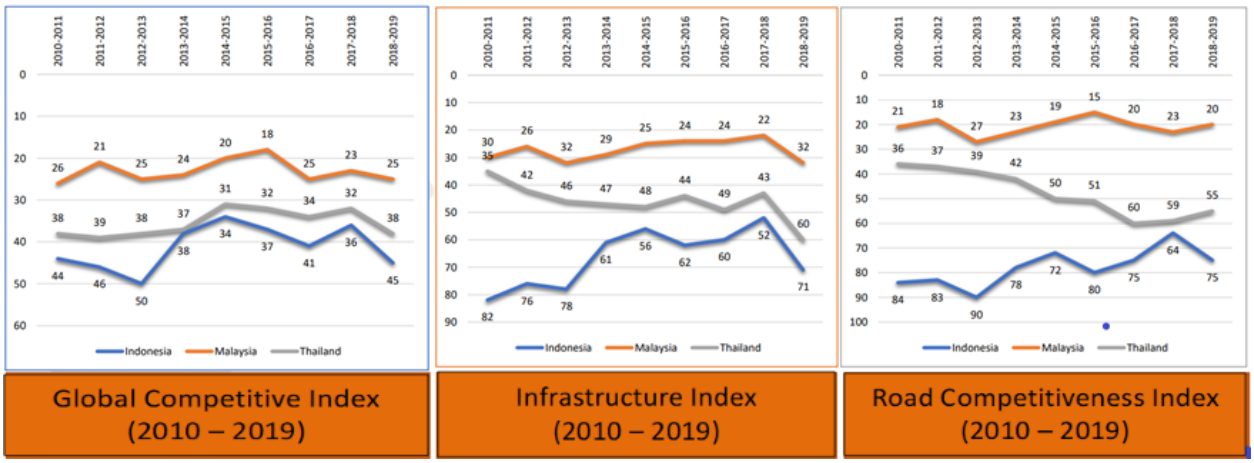

FIGURE 1. Indonesian Performance Index

To overcome this lag in the RPJMN (Perpres 18/2020) the Government of Indonesia is targeting 2500 km of new toll roads from 2020-2024. With the growth of road length that continues to increase, it will certainly result in a reduced availability of natural resources as a form of road structure, increasing the amount of waste generated by the construction process, increasing emissions generated at the construction and operational stages, decreasing productive land due to land transfer due to road construction, and various other impacts related to the environment either directly or indirectly. Based on the above, it is necessary to develop a construction process that can reduce the use of natural resources and minimize the occurrence of waste generated through the green road concept. The benefits of green roads at least include the following: (a). Benefits for the environment (ecosystem) are reducing the use of materials, fossil fuels, water, air pollution, greenhouse gas emissions, water pollution, solid waste, and being able to restore/shape habitats; (b). Benefits for humans (anthropocentric) are increasing access, mobility, human health and safety, local economy, awareness, aesthetics, and reducing life cycle costs[1]. The road construction and transportation sectors contribute greatly to environmental degradation as they consume large amounts of materials and energy and generate large amounts of waste [2] and create threats such as emissions, pollution, congestion, and financial scarcity [3]. Construction activities, including road construction, certainly have an impact on the environment, resources, raw materials, and people [4].

Several countries in the world have established a green road scoring system such as the inclusion of Green LESES in New York and Green Roads in Washington in the United States, in the UK; there is funding from the Sustainability National Roads Administration (SUNRA) [5]. The Australian Infrastructure Sustainability Council developed a technical infrastructure sustainability assessment system to assess the level of sustainability of existing and new infrastructure by including roads and highways. South Korea is also another country that has embraced sustainable technology and strategies in road construction. The South Korean government has implemented the Korea Carbon Green Growth Policy to help tackle environmental problems such as climate change and global warming [6]. The green rating tool can be used to measure the performance of indicators in determining the level of greenery, measure sustainable practices, and promote decision-making in the road construction industry. However, other research states that implementing green construction on highway projects faces many challenges related to materials, equipment, codes and standards, financial, regulatory, and cultural issues [7]. Presidential Regulation of the Republic of Indonesia Number 61 of 2011 concerning the National Action Plan for Reducing Greenhouse Gas Emissions was released to meet the GHG emission reduction target by 2020 [8]. Furthermore, the Ministry of Public Works in Indonesia has integrated green practices into the road construction industry by enacting relevant laws and regulations under Law Number 13/PRT/M/2015.

From the perspective of project preparation, the increase in investment costs in green infrastructure projects correlates with the need for project investment costs. This is because the process of planning and preparing green infrastructure is more complex in several aspects are: (1). Green infrastructure needs preparation that

considers the natural, environmental, and social aspects of an integrated project; (2). Green project planning requires more permits and administrative processes; (3). Green projects need to be designed inclusively because they are closely related to the quality of life and the balance of nature while in this case there are often conflicting interests among stakeholders; (4). Many aspects of green projects contain rigid qualitative assessments such as land availability and quality, water quality, emission levels, energy efficiency, and others.

Generally, a fairly high increase in costs appears in the post of green infrastructure project design costs which can reach 5% higher than conventional project designs [9]. In addition to design costs, costs related to setup including management costs, human resources, ratings, and even commissioning requirements such as green ratings also have the potential to arise. These costs are at least influenced by several things, sector regulations, lender requirements (including the fulfillment of environmental & social management framework/ESMF aspects), and the availability of experts [10]

The method of System dynamics (SD) is a science that studies system feedback structure and behavior. It is generally used to deal with complex, dynamics, nonlinear systems, especially in the field of society and economy. In addition, it has a tight connection to sustainable development research: Meadows, Meadows Randers, and Behrens (1972) used the SD model to establish the WORLDIII Model and wrote The Limits to Growth, which triggered a worldwide discussion in sustainable development. Randers (2000) took a further step to illustrate the breakthrough in sustainable development by imitating realistic conditions using WORLDIII Model. In China, several researchers using the modelling dynamic model to assess sustainable development on the national level of energy, society and environment, and regional level. SD method has been a mature scenario analysis tool in macro sustainable development analysis. Environmental impacts vary due to different types of infrastructure. Some types of infrastructure are very energy-consuming, such as public transportation. Some can result in severe environmental pollution, such as energy supply projects. According to existing research results, pollution from infrastructure is more severe than in other industries. However, some infrastructure was built to reduce environmental pollution, such as sewage and waste treatment plants. There is a positive or negative side to it, the implications for resources and the environment will be enormous because infrastructure is generally large-scale and has strong productivity [11].

Green Rating Tool

The Green Road Assessment System is several systems used to rank green roads, assessing a road that meets the green or not green criteria, where the system used refers to certain criteria of the green road itself. In other words, to assess a road that meets the green or not green criteria can be based on various assessment tool systems that have been published in various countries. There are several Systems of Green Road Ratings issued or developed by several countries in the world, including America with Green roads version 1.5 and I-LAST, Australia with INVEST and Indonesia with Green Road Guidelines. Green Road construction has so far attracted the attention of construction industry players in Indonesia, since 2015 the Green road Rating has been carried out by the Research and Development Agency of the Department of Public Works [12]. Green Road Ranking is carried out to realize sustainable construction in accordance with the Minister of Public Works and Public Housing Regulation No. 05/PRT/M/2015 concerning General Guidelines for the Implementation of Sustainable Construction in the Implementation of Infrastructure in the Field of Public Works and Settlements. Green Road Ranking in Indonesia is a system that is prepared to encourage sustainable practices in voluntary road construction activities. This activity must meet the requirements in the form of a Life Cycle Cost document or be represented by a Feasibility Study Report and environmental documents such as Amdal / UKL-UPL / Environmental Permit. Road construction activities are rated according to the level of application of the criteria for the Green Road [13].

Many research and innovations in construction technology to reduce the negative impact of the development process and construction activities on the environment have been carried out, one of which is the green highway concept. Initial research and technology development of the green highway concept was first introduced in 2002 in the United States. Green highway rating system can be interpreted as a tool that is used as a reference in a sustainable concept that includes all the processes of road development be it planning, design, construction, operation and maintenance.

The application of the green highway concept has several obstacles including financial barriers, namely lack of funds for sustainable maintenance, high cost, insufficient information about costs & benefits, lack of funds for the design and implementation process. The drive to apply the green highway concept continues to require the developer to apply the green highway concept to the toll road to be built. The developer needs a basis to decide whether the development of a toll road with a green highway concept is the right decision [14]. System of Green Road Rating is a number of systems used in determining the green road rating, assessing a road meet the criteria of green or not green, where the system used refers to certain criteria of the green roads themselves. The following is an overview of dynamic system modeling and the factors in a project.

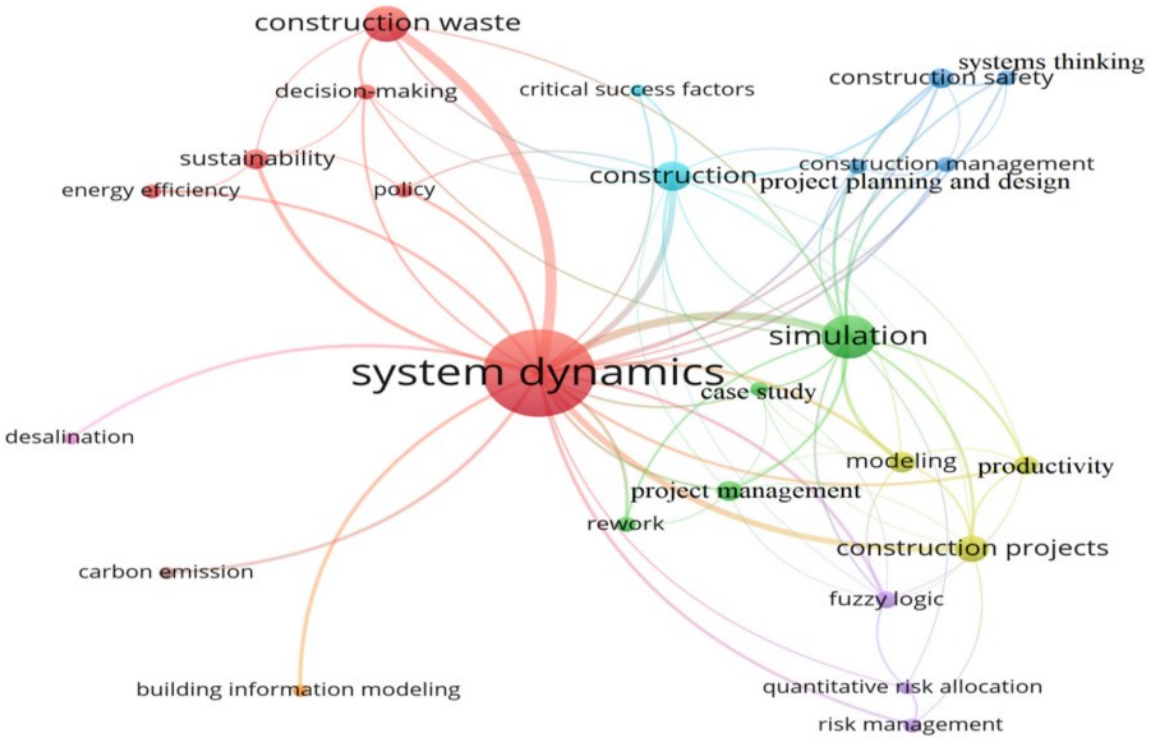

FIGURE 2. System Dynamics Modeling

In other words, to assess a road that meets the criteria of green or not green can be based on various rating tools systems that have been published in various countries. There are several System of Green Road Ratings issued or developed by several countries in the world, including America with Green roads version 1.5 and I-LAST, Australia with INVEST and Indonesia with Green Road Guidelines. For more details, the rating system is grouped with several aspects and factors as illustrated in the following table 1.

Based on the data above it is known that in ranking a road included in a green road can be based on various rating systems in the form of Guidelines (manuals) that have been published in various countries. Each rating system has a tendency that is different from each other in determining indicators as an instrument of assessment.

TABLE 1. List of Rating Systems

Description	*Green Road USA*	*INVEST*	*Green Lite*	*I-Last*	*Green Road* **Indonesia**
Year development/ Country of origin/ Developer	2011/ USA/ *Washington University*	2012/ USA/ Federal Highway Administration	2008 / USA / New York State of Transportation	2010 / USA / Illinois Department of Transport	2013 / Indonesia / Road & Bridge Development Center (Pusjatan)
Applies to the project phase	Project development	Planning Project development Operation Maintenance	Planning Design Construction Operation Maintenance	Project Development	Project Development
Attributes to consider	Water, Amount of water lost, Aquatic habitat, Air, Light, Noise, Materials, Local materials, Recycling, Waste, Energy, Ecology, Other modes, Life Cycle Cost		Water, Amount of water lost, Light, Noise, Carbon, Materials, Local materials, Recycling, Waste, Energy, Electricity, Fuel, Ecology, Society	Water, Amount of runoff, Light, Noise, Carbon, Materials, Energy, Electricity, Ecological Community, Other modes, Life Cycle Cost	Water, Quantity, Water quality, Aquatic habitat, Air, Light, Noise, Carbon, Materials, Local materials, Recycling, Waste, Energy, Fuel, Ecology, Community, Life Cycle Cost, other modes
Number of Points & Minimum Points	118 16	160 System Planning 85 Project Development 117	278 75	233 30	100 20
Point scale	1-5	1-3	1-3		0-6
Reward Level	Certified Award < 32 Bronze Award 32-42 Silver Award 45-53 Gold Award 54-63 Evergreen>64	None < 30% Bronze Award 30% Silver Award 40% Gold Award 50% Platinum Award 60%	Certificates 15 – 29 Silver 30 – 44 Gold 45 – 59 Evergreens (60 & up)	N/A	Certified Award < 20 Bronze Award 20-30 Silver Award 30-45 Gold Awards >45
Percentage from category	Pavement Materials & Technology (40%) Environment & Water (19%) Design & Construction (13%) Access & Equity (28%)	Pavement Materials & Technology (10%) Environment & Water (2%) Design & Construction (8%) Access & Equity (73%) Energy Efficiency (7%)	Pavement Materials & Technology (25%) Environment & Water (8%) Design & Construction (30%) Access & Equity (2%) Energy Efficiency (35%)	Pavement Materials & Technology (18%) Environment & Water (37%) Design & Construction (20%) Access & Equity (18%) Energy Efficiency (7%)	Pavement Materials & Technology (20%) Environment & Water (27%) Design & Construction (19%) Access & Equity (14%) Energy Efficiency (20%)

Indonesia Green Road

Green Road in Indonesia is a voluntary evaluation of road construction that seeks to apply green criteria at the design and construction phase to achieve road sustainability. The development of green road criteria was adopted from international sustainable rating tools, such as Green Road, INVEST and ILAST that are focused on the project development on design and construction. The category is divided into 5 areas and the main requirements that must be fulfilled are road construction plan, life cycle cost analysis and environmental documents shown in Table 2.

TABEL 2. Green Infrastructure in Indonesia

Main Categories	Sub - Category	Amount of Credit Category
Environment and water	1. Environmental and Management Systems and Innovation 2. Drainage arrangement 3. Flood Control 4. Dust Reduction 5. Noise reduction 6. Planting Trees and Plants 7. ISO Certified Quality Management and Environmental Management 8. Environmental and ecosystem protection 9. Light Settings	27
Transport and Society	1. Provision of access and pedestrians 2. Provision of access and cyclists 3. Provision of public transport access 4. Provision of geometric designs and facilities 5. Safety Audit 6. Society participation 7. Providing facilities for beautiful scenery 8. Provide Ornaments and Landscape	14
Construction Activities	1. Possession of ISO certificates in quality management and environmental management. 2. Reuse old materials at the project site 3. Reduction of fossil fuels from outside construction work. 4. Equipment emission reduction on project site 5. Reducing paving emissions 6. Regulation of water use at the project site 7. Contractor warranty 8. Use of renewable energy 9. Carbon requirement 10. Coordination between planning and construction.	19
Materials and Natural Resources	1. Reuse materials 2. Earthwork Balance 3. Recycled materials 4. Use of local ingredients 5. Light Efficiency 6. Use excess material outside the project site	20
Sidewalk Technology	1. Long pavement design 2. Permeable Pavement 3. Warm Mix Asphalt 4. Cold Sidewalk 5. Enough sidewalk	20
Total Points		**100**

METHODOLOGY

This research consists of 6 stages, stage 1 is to conduct a literature study from previous research related to green road and green rating systems to obtain the main aspects of the application of green road. Phase 2 is to conduct interviews with toll road construction experts and designers, environmental experts, toll road investors. This is to justify and validate the main aspects that have been obtained from the previous literature review. Phase 3 develops a questionnaire based on the main aspects that have been determined and these aspects are described with indicators of the application of the green highway concept in toll road development investments based on the literature and the green rating system. These indicators become research variables which are measured using a Likert scale as the measurement scale. Stage 4 conducted a survey by distributing questionnaires to obtain data on perceptions of toll road business entities regarding the application of the green toll road concept to investment in toll road development in Indonesia.

After that, stage 5 is the processing of the survey results. The results of the survey questionnaire are then interpreted using descriptive analysis and Cartesian diagrams to see the position of the variables in the priority quadrant. Stage 6 is the creation of a dynamic model. A causal loop diagram (CLD) is used to describe the relationship between the variables involved in a systematic pattern. a positive relationship that is directly proportional, where the addition of value to the variable will be caused by the addition of value to the variable it affects. The negative arrow indicates an inverse relationship, the increase in the value of this variable will be caused by a decrease in the value of the variable. Effect of variables from the CLD that has been made, it can be seen that each variable is interrelated.

TABLE 3. Green Infrastructure factors in Indonesia

Aspect	Variable	Indicator
Water Management & Drainage	X1	Reduction of pollutant levels in water resources.
	X2	Road slope and side cliff design with high water permeability.
	X3	The use of pavement material with high water permeability.
Green Materials	X4	The use of non-hazardous recycled materials.
	X5	The use of environmentally friendly materials.
Sustainable Sites	X6	Design and selection of environmental alignment of road alignments
	X7	Land use plan integrated with road development areas.
	X8	Protection, enhancement, and restoration of wildlife habitat in the area of road development.
	X9	Protection, replanting trees and mitigating the cutting trees in the area of road development.
	X10	Green road landscape management.
Energy, Emission and Waste Reduction	X11	Reducing fuel consumption by using environmentally friendly equipment.
	X12	Reducing the use of electricity by using renewable energy.
	X13	Improved road performance and services.
	X14	Noise reduction during construction and operation.
	X15	Waste material management.
Social and Economy	X16	Business development and employment around the road.
	X17	The location of local material sources around the road.
Life Cycle Cost Analysis	X18	Life cycle cost analysis of using alternative designs and environmentally friendly pavement materials.
	X19	Life cycle cost analysis of using alternative water management and environmentally friendly drainage designs.
	X20	Life cycle cost analysis of the use of alternative environmentally-friendly road-building structures.

Based on the previous results, the application of the Green Highway Concept in Toll Road Development in Indonesia obtained 6 main aspects [14]. six aspects include water management and drainage, green materials, sustainable sites, energy emissions and waste reduction, social and economic, life-cycle analysis. The 6 aspects translated into 20 indicators obtained shown in table 3.

In the dynamic modeling for retrofit roads in previous studies[15][16], the key success factors in toll road planning are shown in Tables 4 and 5.

TABLE 4. Toll Road factors in Indonesia

Aspect	Variable	Indicator
Economic Analysis	X1	The needs and demands of economic activity
	X2	Government Concession
	X3	Traffic growth
Quality of Service	X4	Toll road quality
	X5	Vehicle volume
	X6	The existence and comfort of the rest area
Operation Management	X7	toll rates
	X7	Operation cost
	X8	Maintenance cost

TABLE 5. Dynamic Modelling success factor

Aspect	Variable	Indicator
Modeling	X1	Dynamic Modeling
	X2	Dynamic Model Explanation
	X3	Model Objectivity
The Role of Stakeholders in Management	X4	Use of Dynamic Modeling
	X5	Key Person in Dynamic Modeling
	X6	Modeling Disclaimer by Stakeholders
Mental Block	X7	The difficulty of Dynamic Modeling application
	X8	Project management has a problem
	X9	Dynamic Modeling is not practical

From these factors, the most influential variables to the weakest influencing the dynamics of modeling the implementation of green road development will be obtained. The questions asked in the questionnaire using a Likert scale format where this scale is used in a questionnaire survey and is an independent rating scale to measure the extent to which the respondent's opinion on a question. The form of the Likert scale that will be used in this questionnaire is 1 to 5 where 1 = “strongly disagree”; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree.

RESULTS AND DISCUSSION

The Most Influencing Factor

The Statistical Package for the Social Sciences (SPSS) processing stage is run with Expert Choice software, after each main factor/criteria, sub-factor/criteria are obtained, the next step is synthesis to get the overall weight of the existing criteria. The calculated data shows that the overall order of the most influencing factors in Toll Road Dynamic Modeling show in table 6. Based on the main factors and sub-factors in the Green Road, then modeled in the Dynamic System to see the influence of the interrelationship of these factors. With this System Dynamic modeling, it can be seen the dependence between factors and life cycle costs in the operation of Green Road which is shown in Figure 3 below.

TABLE 6. The Most Influencing Factor

Factor
Road slope and side cliff design with high water permeability.
The use of pavement material with high water permeability.
The use of environmentally friendly materials.
Protection, replanting trees, and mitigating the cutting trees in the area of road development.
Green road landscape management.
Reducing the use of electricity by using renewable energy.
Improved road performance and services.
Life cycle cost analysis of using alternative designs and environmentally friendly pavement materials.
Life cycle cost analysis of using alternative water management and drainage designs that are environmentally friendly.
Life cycle cost analysis of the use of alternative environmentally friendly road building structures.
Traffic growth
Toll road quality
Operation cost
Maintenance cost
Model Objectivity
Key Person in Dynamic Modeling

Modelling Scenario

The scenario model is made based on the most influential factors that aim to improve system performance in overcoming existing problems, the types of scenarios that will be carried out are retrofit green scenarios and lifecycle cost analysis (LCCA) by providing several improvement scenarios. From the scenarios made, it can provide an alternative to choosing retrofit cost savings when applied to similar projects.

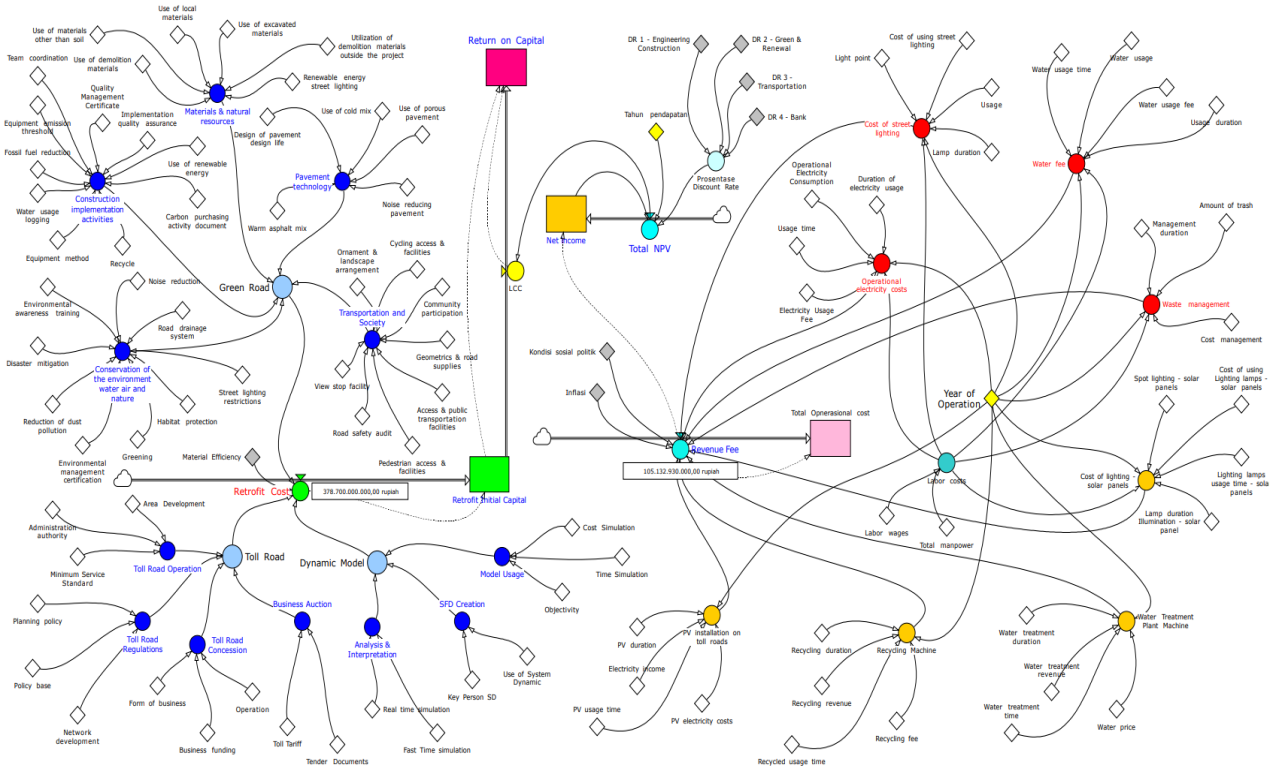

FIGURE 3. Result Green Road System Dynamics Modeling

The implementation of Green Road on toll roads requires additional costs in its construction costs. Although initially it requires higher costs, but with the use of alternative uses of environmentally friendly water management and drainage designs, reduction of pollutant levels in water sources, use of harmless recycled materials, protection, enhancement and restoration of wildlife habitats in road development areas, reducing electricity use by using renewable energy, reducing fuel consumption by using environmentally friendly equipment and using pavement materials with high water permeability can reduce toll road life cycle costs.

The most prioritized factor in implementing the green toll road concept in toll road development in Indonesia is improving road performance and service. These priority factors are then modeled in a Dynamic System so as to provide a reference for how a factor influences each other and how the life cycle costs are generated by these factors.

FIGURE 4. Life Cycle Cost Analysis

CONCLUSION

Indonesian toll road projects, which are currently growing rapidly, need to apply green roads to maintain a balance between the environment and sustainability. Adopting good green practices in Modeling Dynamics can make life cycle costs more efficient. Although currently the implementation of green roads is still voluntary, it is necessary to make several policies or strategies such as regulations related to material standards and planning related to toll road design to support sustainability.

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