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A Framework for green roads implementation in roads construction projects: A case study in Purworejo Regency

Larashati B’tari Setyaninge[1*], Melinda Dires[1], Agung Nusantoro[1]

[1] Civil Engineering Department, Universitas Muhammadiyah Purworejo, Purworejo, Indonesia
[*] Corresponding author’s email: laras.btari@umpwr.ac.id

Abstract

Framework is a simplified set of theoretical principles and practical guidance for carrying out implementation. Green roads are road construction projects that are planned and developed to a level of sustainability that is much higher than existing standard practices and use green and low-pollutant materials during the construction process. An organization needs to implement a framework because a framework not only provides a general overview but also detailed information about the content of each framework element and its relationship with other elements. This research aims to model a framework for implementing green roads on road construction projects in Purworejo Regency. The data used in this research is primary data obtained by filling out questionnaires by respondents. The analysis method used in this research is TOPSIS which is part of Multi Criteria Decision Making (MCDM). The framework created in this research includes ranking of green roads sub-categories with ease of implementation and waste reduction criteria. Based on data analysis, it was found that the ease of implementation criteria received a higher weight when compared to the waste reduction criteria. The framework for implementing green roads in Purworejo Regency consists of six categories, namely 1) environment, water, air and nature conservation; 2) transportation and society; 3) construction activities; 4) material and natural resources; 5) pavement technology for vehicles; 6) pavement technology for pedestrians. This framework can be used by contractors, planning consultants and project owners to create green roads construction.

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Keywords

Framework, Green roads, TOPSIS

Introduction

Roads are the main infrastructure in both urban and rural areas. Currently, road infrastructure development is being intensively implemented, especially in developing countries. The development of a country's infrastructure has a positive effect on economic growth in that country. Activities such as trade, electricity, communications and health also increased with the increasing development of road infrastructure [1].

When a country invests in building road infrastructure, the environmental impacts resulting from road construction also need to be considered, especially in long-term investment.

The construction industry is the largest contributor to pollution, depletion of natural resources, waste, global warming and climate change [2]. Road construction activities consume significant amounts of material and energy and produce large amounts of waste [3]. Construction of one mile of one-lane road requires energy equivalent to energy that consumed by 100 American households in one year. The carbon emissions produced in the construction were 1,200 tons of CO2, which is equivalent to the emissions of 210 passenger cars in one year [4].

In the past, most road projects were only aimed at increasing economic growth and creating jobs. Therefore, throughout planning, design, construction, maintenance and repair, the impact on the environment from aspects such as route selection, road type, construction methods and material selection are ignored [5]. The construction process not only produces large amounts of waste and pollution, but also consumes large amounts of natural resources. Therefore, a sustainable approach is needed to be applied in construction projects, especially road construction, starting from the design, construction and renovation stages [2].

The building construction sector has previously developed green rating systems, for example LEED, Green Globes and BREEAM to help stakeholders in the construction sector identify and implement green practices [6]. Even though green rating systems in building construction have been popular for the last ± 20 years, sustainability issues have not been seriously adopted in infrastructure projects, especially road infrastructure. The concept of sustainability is very important for road construction, because environmentally friendly practices can improve economic prosperity and quality of life and at the same time can protect the environment [6].

Green roads are road construction projects that are planned and developed to a level of sustainability that is much higher than existing standard practices [7] and use green and low-pollutant materials during the construction process [8]. A road can be said to be green if it applies sustainable practices compared to modern construction techniques to maximize the life of the road [9], whereas according to [10] a road can be categorized as a green roads if the road is designed with a new concept that includes landscape, ecological sub-elements, waste reduction, energy efficiency, and water and material conservation.

Based on research in the Netherlands, the green roads program can reduce carbon emissions by 28% for rigid road pavement and 37% for flexible road pavement [11]. The green roads program in this country emphasizes technological innovation consisting of treatments to increase the life of binder materials in flexible pavement, low-temperature asphalt mixing processes, the use of recycled materials and the use of LED lights for road lighting. The benefits of implementing the green roads concept include benefits for the environment (ecocentric) and benefits for humans (anthropocentric). Benefits for the environment include reducing the use of materials, fossil fuels, water, air pollution, greenhouse gas emissions, water pollution, solid waste and being able to restore habitat. Benefits for humans include improving access, mobility, health and safety, local economy, aesthetics and reducing life cycle costs [12].

Based on the Green Roads Rating Guidelines, there are five categories of green roads criteria. The five categories consist of water, air and natural environmental conservation; transportation and society; construction activities; materials and natural resources and pavement technology. These five categories are divided into 35 sub-categories. Previous research on green roads and sustainable roads focused on the principles of sustainable roads, stakeholder understanding regarding the green roads concept as well as readiness and obstacles in its implementation. Research on creating a framework as a guide in implementing green roads is still rarely carried out. This framework will later contain green roads categories and subcategories based on a ranking from the easiest to most difficult subcategories based on stakeholder perceptions in road construction projects.

Throughout 2022, there will be one road construction project, one periodic maintenance project, one road capacity increase project, four road rehabilitation projects and ten road improvement projects in Purworejo Regency. Construction projects and road improvements are directly affect to development in the areas through which the roads pass, such as opening up new areas, creating job opportunities during the project, reducing the impact of disasters, and increasing the accessibility of social services such as health and education. Therefore, it is important for the Purworejo Regency government through the DPUPR Purworejo Regency to start implementing green roads construction, so that the road construction that will be carried out does not only focus on economic growth but also pays attention to environmental sustainability. This research aims to create a framework for implementing green roads in Purworejo Regency based on the criteria of ease of implementation and waste reduction.

Method

This research uses a quantitative approach which uses primary data as the main data. Primary data was obtained through filling out questionnaires by respondents. The questionnaire consists of two parts, the first part is the weighting of criteria consisting of ease of implementation criteria and waste reduction criteria. The second part of the questionnaire is an alternative weighting consisting of five categories and 35 green roads sub-categories which can be seen in Table 1. Filling out the questionnaire uses a 1-5 Likert scale, an explanation of the weights and linguistic variables on the Likert scale can be seen in Table 2.

Table 1. Research Variable

Category		Subcategory
Environment, Water, Air and Nature Conservation (EC)	EC-1	Environmental awareness training
	EC-2	Risk mitigation
	EC-3	Reduction of air/dust pollution during construction/post-construction
	EC-4	Environmental management system certificate and construction innovation
	EC-5	Reforestation
	EC-6	Protection and avoidance of habitat loss
	EC-7	Provision of road drainage systems
	EC-8	Restrictions on street lighting
	EC-9	Noise reduction
Transportation and Society (TS)	TS-1	Arrangement of street ornaments and landscape
	TS-2	Provision of stopping facilities to enjoy interesting view
	TS-3	Providing access and facilities for public transport users
	TS-4	Geometric design and road equipment facilities to reduce energy use
	TS-5	Implementation of road safety audits by independent parties
	TS-6	Providing pedestrian access and facilities
	TS-7	Community involvement in planning
	TS-8	Providing access and facilities for cyclists
Construction Activities (CA)	CA-1	Planning construction waste recycling activities and contractor office/base camp waste
	CA-2	Method of using construction equipment/fleet with certain technology so that emissions can be reduced
	CA-3	Monitoring/recording water use during construction
	CA-4	Use of construction equipment that meets emission limits
	CA-5	Reducing the use of fossil fuels in construction
	CA-6	Coordination between designer and constractor to effective construction implementation time
	CA-7	The contractor has a quality management system (QMS) certificate
	CA-8	Quality of construction implementation assurance by contractor that the construction product meets the quality in the tender process
	CA-9	Use of renewable energy and implementation of innovation
	CA-10	Prepare documents for investments or "carbon purchasing" activities related to efforts to reduce greenhouse gases or carbon emissions
Material and Natural Resources (MN)	MN-1	The use of dismantled material which is used as recycled material in the road project, on different roads through mixing in the field, or in the road material factory
	MN-2	Reuse of demolition materials other than soil at local locations
	MN-3	The use of local materials such as aggregate, asphalt, cement, reinforcement, and trees
	MN-4	Use a minimum of 90% of excavated soil material for local embankment
	MN-5	Utilization of dismantled materials outside the project site
	MN-6	Street lighting that uses renewable energy resources
Pavement Technology for Vehicles (PTV)	PTV-1	Design of Road Pavement Life Plan
	PTV-2	Use of cold mix for flexible pavement
	PTV-3	Use of porous pavement equipped with water outlets
	PTV-4	Designing pavement surfaces that can reduce noise
	PTV-5	Designing warm asphalt mixes
Pavement Technology for Pedestrian (PTP)	PTP-1	Pedestrian pavement design that maintains the function of the sidewalk
	PTP-2	Use of materials made without heating
	PTP-3	Porous pavement surface design
	PTP-4	Design of a pavement surface whose roughness meets the requirements for pedestrian paths.
	PTP-5	The use of materials made by heating lower than standard temperatures

Table 2. Likert Scale Weights and Linguistic Variables

Weight	Linguistic Variable
1	Very not important
2	Not important
3	Quite important
4	Important
5	Very important

The questionnaire was filled in by respondents consisting of owners, consultants and contractors involved in road construction projects in Purworejo Regency. According to [13], a decision-making group should have a minimum of five and a maximum of 50 members. In this research, there were five respondents from each stakeholder, so there was total 15 respondents. Respondents were selected using purposive and snowball sampling methods. After all respondents have filled out the questionnaire, the results of the questionnaire will be tabulated for further analysis using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). TOPSIS method as a Multi Criteria Decision Making (MCDM) is widely used to solve practical decision problems. This is because the concept is simple and easy to understand, computationally efficient, and has the ability to measure the relative performance of decision alternatives in simple mathematical form [14]. According to [15] general the steps in the TOPSIS method are:

1 Create a decision matrix for alternatives (m) and criteria (n).
2 Calculating the normalized decision matrix (rij)
3 Calculating the weighted normalized decision matrix (yij)
4 Determine the positive ideal solution (V+) and the negative ideal solution (V-)
5 Determine the distance to the positive ideal solution (Di+) and the distance to the negative ideal solution (Di-)
6 Determine the preference value for each alternative (Vi), the greater the Vi value indicates that the alternative is better to choose.

Results and Discussion

The results of data analysis are divided into two parts, namely criteria weighting and alternative weighting which will be explained in a separate sub-chapter.

Criteria Weighting

The weighting of the criteria namely ease of implementation (C1) and waste reduction (C2) criteria can be seen in Table 3. Based on Table 3, it appears that the ease of implementation criteria (C1) has a higher weight compared to waste reduction criteria (C2). Both criteria are included in the important category according to stakeholder perceptions.

Table 3. Criteria Weighting

	Criteria	Weight
C1	Ease of implementation	4,267
C2	Waste reduction	4

Alternative Weighting

Alternative weighting uses the TOPSIS method which starts by creating a decision matrix to determining the preference value for each alternative. A decision matrix is created for each green roads category by calculating the average answers from respondents. The decision matrix for the environment, water, air and nature conservation (EC) categories can be seen in Table 4.

Table 4. Decision Matrix of Environment, Water, Air and Nature Conservation (EC) Category

Subcategory	Decision Matrix	
	C1	C2
EC-1	3,933	4,000
EC-2	3,867	3,800
EC-3	4,067	4,000
EC-4	4,000	4,067
EC-5	4,000	3,867
EC-6	4,000	4,000
EC-7	3,867	4,000
EC-8	3,200	3,267
EC-9	3,733	3,533

After creating a decision matrix for each green roads category, the next step is to create a normalized decision matrix. Below is an example of calculating a normalized matrix for subcategory EC-1 with criteria C1. The results of the normalized decision matrix calculation for the environmental, water, air and nature conservation (EC) categories can be seen in Table 5.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (1)$$

$$r_{EC-C1} = \frac{3{,}933}{\sqrt{3{,}933^2 + 3{,}867^2 + 4{,}067^2 + 4{,}000^2 + 4{,}000^2 + 4{,}000^2 + 3{,}867^2 + 3{,}200^2 + 3{,}733^2}}$$

$$r_{EC-C1=0{,}340}$$

Table 5. Normalized Decision Matrix of Environment, Water, Air and Nature Conservation (EC) Category

Subcategory	Decision Matrix	
	C1	C2
EC-1	0,340	0,347
EC-2	0,334	0,329
EC-3	0,351	0,347
EC-4	0,345	0,353
EC-5	0,345	0,335
EC-6	0,345	0,347
EC-7	0,334	0,347
EC-8	0,276	0,283
EC-9	0,322	0,306

After creating a normalized decision matrix for each green roads category, the next step is to create a weighted normalized decision matrix. Below is an example of calculating a weighted normalized matrix for subcategory EC-1 with criteria C1 and C2. The results of calculating the weighted normalized decision matrix for the environmental, water, air and nature conservation (EC) categories can be seen in Table 6.

$$EC11_{C1} = normalized\ decision\ matrix\ EC1\ x\ weight\ C1 \quad (2)$$

$$EC11_{C1} = 0{,}340\ x\ 4{,}267$$

$$EC11_{C1} = 1{,}449$$

$$EC11_{C2} = normalized\ decision\ matrix\ EC1\ x\ weight\ C2 \quad (3)$$

$$EC11_{C2} = 0{,}340\ x\ 4$$

$$EC11_{C2} = 1{,}387$$

Table 6. Weighted Normalized Decision Matrix of Environment, Water, Air and Nature Conservation (EC) Category

Subcategory	Decision Matrix	
	C1	C2
EC-1	1,449	1,387
EC-2	1,425	1,318
EC-3	1,498	1,387
EC-4	1,474	1,410
EC-5	1,474	1,341
EC-6	1,474	1,387
EC-7	1,425	1,387
EC-8	1,179	1,133
EC-9	1,376	1,225
V^+	1,498	1,410
V^-	1,179	1,133

After the weighted normalized decision matrix is formed, the next step is to determine the V+ and V- values for each criterion. V+ is the highest value and V- is the lowest value in the matrix for each criteria. Based on table 6 above, it can be seen that the V+ value for C1 = 1,498 and the V+ value for C2 = 1,410, while the V- value for C1 = 1,179 and the V- value for C2 = 1,133. These V+ and V- values will later be used to calculate D+ and D-.

The calculation of D+, D- and V for EC-1 subcategory is described as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(Vj^+ - yij)^2} \quad (4)$$

$$D_{EC1}^+ = \sqrt{(1{,}498 - 1{,}449)^2 + (1{,}410 - 1{,}387)^2}$$

$$D_{EC1}^+ = 0{,}054$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(Vj^- - yij)^2} \quad (5)$$

$$D_{EC1}^- = \sqrt{(1{,}179 - 1{,}449)^2 + (1{,}133 - 1{,}387)^2}$$

$$D_{EC1}^- = 0{,}371$$

$$V_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (6)$$

$$V_{EC1} = \frac{0{,}371}{0{,}371 + 0{,}054}$$

$$V_{EC1} = 0{,}872$$

Table 7. D+, D- and V Value for Environment, Water, Air and Nature Conservation (EC) Category

Subcategory	D+	D-	V	Rank
EC-1	0,054	0,371	0,872	4
EC-2	0,118	0,307	0,722	7
EC-3	0,023	0,408	0,946	1
EC-4	0,025	0,405	0,943	2
EC-5	0,074	0,361	0,831	5
EC-6	0,034	0,389	0,920	3
EC-7	0,077	0,354	0,821	6
EC-8	0,423	0,000	0,000	9
EC-9	0,222	0,217	0,495	8

Table 8. V Value and Green Roads Subcategory Ranking

Category	Subcategory	V	Rank
Transportation and Society (TS)	TS-1	0,361	5
	TS-2	0,000	8
	TS-3	0,692	2
	TS-4	0,591	3
	TS-5	0,258	6
	TS-6	1,000	1
	TS-7	0,062	7
	TS-8	0,401	4
Construction Activities (CA)	CA-1	0,487	8
	CA-2	0,610	5
	CA-3	0,393	9
	CA-4	0,781	4
	CA-5	0,583	6
	CA-6	0,811	2
	CA-7	0,795	3
	CA-8	0,929	1
	CA-9	0,527	7
	CA-10	0,000	10
Material and Natural Resources (MN)	MN-1	0,247	5
	MN-2	1,000	1
	MN-3	0,556	3
	MN-4	0,459	4
	MN-5	0,000	6
	MN-6	0,939	2
Pavement Technology for Vehicles (PTV)	PTV-1	0,274	4
	PTV-2	0,501	2
	PTV-3	0,262	5
	PTV-4	1,000	1
	PTV-5	0,367	3
Pavement Technology for Pedestrian (PTP)	PTP-1	1,000	1
	PTP-2	0,706	2
	PTP-3	0,589	3
	PTP-4	0,467	4
	PTP-5	0,000	5

D+, D- and V calculations are carried out for all subcategories in the environmental, water, air and nature conservation (EC) categories. The results of these calculations can be seen in Table 7. The highest V value indicates that this subcategory has the highest preference. The highest preference for EC category is the subcategory for reducing air/dust pollution during construction/post construction (EC-3). This indicates that by considering ease of implementation and waste reduction criteria, the implementation of reducing air/dust pollution during construction/post-construction has the highest preference.

For other green roads categories, calculations are carried out using the same steps, starting from creating a decision matrix to calculating the V value. The V value for each green roads category along with its ranking can be seen in Table 8.

Discussion

The criteria that received the highest weight was the ease of implementation. The implementation of green roads in Indonesia has experienced various obstacles. The main obstacle in implementing green roads is limited budget [16]. The implementation of sustainable construction generally requires higher costs, these costs are known as the green cost premium [17]. Based on [18] the most critical obstacle in implementing sustainable construction is the lack of human resources and the skill level of these resources. There is still a lack of experts and skilled workers who have been trained to support sustainable construction. The influence of political obstacles on the successful implementation of sustainable construction is also often found in several studies [19]. The implementation of sustainable construction will be successful if stakeholders, especially the government as legislators, make sustainability policies and also develop various policy documents to enforce sustainability in all aspects of development [20].

For Environmental, Water, Air and Nature Conservation (EC) category, the highest preference is reducing air/dust pollution during construction/post-construction. Dust is divided into two types, namely coarse dust and fine dust. If inhaled fine dust can cause respiratory problems (respiratory tract infections) and acute recurrence of bronchial asthma [21]. Reducing air/dust pollution can be done by providing trees. Various types of plants can binding dust to the surface of their leaves. Several types of plants that are resistant to absorbing cement dust include mahogany, tanjung, canary and red meranti [22]. The second-ranked preference is environmental management system certificates and the application of work implementing innovations. An example of an environmental management system certificate is SNI 19-14001-2005 or ISO 14001: 2004. The third ranked preference is protection and avoidance of habitat loss. Protection and avoidance of habitat loss can be done in various ways, for example by moving road routes because they pass through or are close to protected forests, providing crossing facilities for animals and installing caution signs for nearby animals. The road in Indonesia that already has crossing facilities for animals is the Riau-Dumai Toll Road. At the bottom of the toll road construction, five underpasses were built in tunnels form which were used as passageways for elephants and bears. This animal tunnel has a span of 25 – 45 meters with a height of 5.1 meters. Green plants are planted at the edge of the tunnel to resemble a natural habitat.

For Transportation and Society (TS) category, the highest preference is the provision of pedestrian access and facilities. The results of this research are in line with Law No. 22

Year 2009 that every road used for public traffic must be equipped with facilities for pedestrians and people with disabilities. Pedestrian access and facilities are also very important, especially for areas with the Transit Oriented Development (TOD) concept. TOD is a city development concept that maximizes mixed and integrated land use by promoting healthy lifestyles (walking and cycling) and the use of mass public transportation [23]. The second preference is the provision of access and facilities for public transport users. This is linear with first preference, where providing access and facilities for pedestrians is usually followed by providing access and facilities for public transport users. Access and facilities for both pedestrians and public transport users in Purworejo Regency are adequate. Bus stops are equipped with shade and zebra cross for road crossings are always available in busy locations such as schools, universities and markets.

For Construction Activities (CA) category, the highest preference is quality of construction implementation assurance by contractor that the construction product meets the quality in the tender process. One of the success factors in road construction projects is the implementation of an effective quality assurance program [24]. The second preference is coordination between designer and contractor to effective construction implementation time. Communication and coordination is one of the main obstacles in completing construction projects in Purworejo Regency. Communication and coordination between designers and contractor is very important in the construction process, because basically the construction process is a transformation from conceptual (architectural) designs done by designers into physical facilities done by contractor, so this is natural if team coordination and communication becomes second preference.

For Materials and Natural Resources (MN) category, the highest preference is the reuse of dismantled materials other than soil at local locations. An example of dismantled material other than soil that can be reused is dismantling road asphalt as a road foundation layer material. The research results of [25] show that the addition of 0.5% and 2.5% cement can improve the CBR value by 36% and 94% respectively so that it can be used as a lower foundation and upper foundation material for highways. Apart from dismantling asphalt, another dismantling material that can be used is dismantling concrete roads. Based on [26], the characteristics of the concrete road demolition material fragments meet the coarse aggregate specifications so they are suitable for use in AC-WC mixtures. The results of testing the characteristics of the AC-WC mixture using concrete road demolition material as a substitute for coarse aggregate, with an Optimum Asphalt Content (OAC) value of 5.90%, resulting in VIM, VMA, VFB, stability and flow values that meet specifications are 10% and 20% variation.

For Pavement Technology for Vehicle (PTV) category, the highest preference is designing pavement surfaces that can reduce noise. Pavement design that can reduce noise can be done in various ways, including mixing with high porosity, using fine aggregate on the order of 1.27 mm - 6.35 mm and using additional layers for concrete pavement. The noise value of double-layer porous asphalt pavement is generally lower than other conventional pavements. Placing a thinner top layer with finer aggregate results in lower noise values. This provides a sense of security for road users and provides a sense of comfort for residents who stay close to the road network [27]. The second preference is the use of cold mix for flexible pavement. Cold emulsion asphalt mixtures have a low viscosity level, so they do not need to be heated and do not cause pollution, saving costs and time [28]. For Pavement Technology for Pedestrian (PTP) category, the highest preference is pedestrian pavement design that maintains the function of the sidewalk. Designing pedestrian pavement that maintains the function of the sidewalk can be done in various ways, for example, preparing a drainage basin cover on the surface of the sidewalk and providing utility boxes.

Green roads practices that have been ranked using TOPSIS will be used as a basis for creating the framework. According to [29] a framework is a simplified set of theoretical principles and practical guidelines for carrying out the implementation and adoption of benchmarking. The framework in this research consists of six green roads categories starting from the Environmental, Water, Air and Nature Conservation (EC) to the Pavement Technology for Pedestrians. The green roads practices contained in the framework are arranged based on the highest preference value with the ease of implementation and waste reduction criteria.

Conclusion

This research aims to create a framework for implementing green roads in Purworejo Regency based on ease of implementation and waste reduction criteria. Based on data analysis, it was found that the ease of implementation criteria received a higher weight when compared to the waste reduction criteria. However, the difference in weight between the two criteria is not very significant and both are still included in the important category. The framework for implementing green roads in Purworejo Regency consists of six categories. The environmental, air and nature conservation category consists of nine subcategories with the highest preference is reduction of air/dust pollution during construction/post-construction. The transportation and society category consists of eight subcategories with the highest preference is the provision of pedestrian access and facilities. The construction activity category consists of ten subcategories with the highest preference is quality of construction implementation assurance by contractor that the construction product meets the quality in the tender process. The materials and natural resources category consists of six subcategories with the highest preference is the reuse of dismantled materials other than soil at local locations. The pavement technology category for vehicles consists of five subcategories with the highest preference is design pavement surfaces that can reduce noise. The pavement technology for pedestrian category consists of five subcategories with the highest preference is pedestrian pavement design that maintains the function of the sidewalk.

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