Research in Transportation Business & Management 37 (2020) 100562

Contents lists available at ScienceDirect

Research in Transportation Business & Management

journal homepage: www.elsevier.com/locate/rtbm

The sectoral lens and beyond: Exploring the multidimensional perspectives of sustainable road infrastructure development

Gede B. Suprayoga[a,b,*], Patrick Witte[b], Tejo Spit[b]

[a] Institute of Road Engineering, Ministry of Public Works and Housing, Bandung, A.H. Nasution 264, Bandung, Jawa Barat ID 40294, Indonesia
[b] Department of Human Geography and Spatial Planning, Utrecht University, Utrecht, Princetonlaan 8a, Utrecht, NL 3584 CB, The Netherlands

ARTICLE INFO

Keywords:
Sustainability
Sectoral policies
Spatial perspective
Mixed-scanning methodology
Micro-level analysis
Indonesia

ABSTRACT

The incorporation of sustainability into road infrastructure development by public agencies in developing countries is limited by what they understand by the notion and how it can be adopted into their tasks. A limited sectoral perspective often dominates this understanding, leading a limited focus on specific sectoral elements included into a policy. This paper offers a framework and a methodology that will equip the agencies to incorporate the concept in an integrative way. A literature review was first conducted to develop the framework, followed by its exploration in the case study of Indonesia's Trans-Java road network corridors. This framework expands the sectoral perspective into a more comprehensive one, conceptualizing sustainability as contributions of various sectoral elements, which are still less integrated. The framework accounts for infrastructure and spatial and temporal dimensions, in which environmental, social, and economic effects of road development are discussed and shown to be interrelated. Institutional and political aspects were also added to the framework that demonstrate capacities for and constraints on integration. This study suggests a mixed scanning methodology to incorporate sustainability into road infrastructure development by paying attention to public agencies' tasks and the application's contexts.

1. Introduction

Since the late 1980s, sustainable development has attracted much interest from government agencies, businesses, and civic groups, resulting in various sectoral policy initiatives. The Brundtland Commission defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). This definition has since been widely adopted in many development fields. Bueno et al. (2015, p. 624) define transportation development projects as “sustainable” when they “contribute to favor economic development and fulfill the transportation needs of the society in a manner consistent with natural laws and human values.” In the policy sphere, many sectoral policies contribute to sustainable development. Gudmundsson, Hall, Marsden, and Zietsman (2016) present these policies in several government activity areas that provide essential public good and services: health and the environment, housing and urban development, manufacturing, transportation, agriculture, and energy. Öberg, Nilsson, and Johansson (2017) also substantiate that various sectoral policies, such as economic and natural resource efficiency, regional cohesion, and transportation safety, constitute the full account of the sustainability of the Trans-European Transport Network (TEN-T).

Thus, the sustainability of transportation infrastructure networks is supported by many sectoral elements from different public agencies. The sector-specific approach provides focused elements that guide the development policies, programs, and plans under the control of a specific agency (Gudmundsson et al., 2016). The application of this approach in highway planning is profoundly dedicated to mitigating and compensating for adverse environmental impacts (Heeres, Tillema, & Arts, 2016). On the other hand, a comprehensive perspective links multiple sectoral policies from various agencies (e.g., biodiversity protection, efficient energy use) beyond what a single agency can cope (Gudmundsson et al., 2016; Ramani, Zietsman, Gudmundsson, Hall, & Marsden, 2011).

However, a comprehensive account of sustainability is difficult to attain because of limited resources (e.g., knowledge, funds, and skilled personnel) and sectoral fragmentation (e.g., Gudmundsson et al., 2016). A few scholars have documented a systematic framework to identify numerous sectoral contributions and connect them on both a temporal and a spatial scale. For example, Cornet and Gudmundsson (2015)

* Corresponding author at: Institute of Road Engineering, Ministry of Public Works and Housing, Bandung, A.H. Nasution 264, Bandung, Jawa Barat ID 40294, Indonesia.
E-mail addresses: gede.budi@pusjatan.pu.go.id, g.b.suprayoga@uu.nl (G.B. Suprayoga), P.A.Witte@uu.nl (P. Witte), T.J.M.Spit@uu.nl (T. Spit).

https://doi.org/10.1016/j.rtbm.2020.100562
Received 15 October 2019; Received in revised form 30 July 2020; Accepted 10 September 2020
Available online 17 September 2020
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presented a meta-framework to construct a comprehensive and balanced set of indicators to assess sustainable transportation development. However, the empirical support for this framework in a specific institutional setting is lacking. Moreover, intergenerational equity (or the time dimension) is implicitly considered (Suprayoga, Bakker, Witte, & Spit, 2020). This paper explores various sectoral elements in a specific empirical setting and presents a framework and methodology for incorporating multiple sectoral elements into a comprehensive policy on sustainable road infrastructure development. Public agencies often have different objectives and resources, affecting how the sectoral elements are framed and measured on specific times and spaces. A new framework should cover a comprehensive set of these elements from the perspectives of these agencies (Gudmundsson et al., 2016).

The Trans-Java road networks (TJRNs) development project launched by the government in the 1990s was used as a case. First, road investment now constitutes more than one-third of Indonesia's public works (Prabowo, 2019). Most of this investment is allocated in Java to enhance economic competitiveness (CMEA, 2011) and support economic growth while reducing income inequality and poverty (Dharma, 2016). Second, road expansion is still mainly seen as a way to ease congestion in urban regions, as is the case in many Asian countries (Pojani & Stead, 2015). In Java, such an expansion was found to displace some people and bring about land conversion that threatened food security and ecosystem integrity (Davidson, 2015). Lastly, The World Bank (2014) reported that the road sector in Indonesia produced more than 30% of the country's total emissions, in which most cities producing the emissions are located in Java.

In pursuing sustainable development, public agencies have to incorporate all aspects (i.e., economic, social, and environmental) into policies and measurable indicators. However, this attempt is hindered by strong sectoral fragmentation. From an infrastructural sector perspective, Indonesia's Ministry of Public Works and Housing (MPWH) published a policy guideline on sustainable infrastructure construction, stressing reducing the adverse environmental impacts of road construction (MPWH, 2015). The Ministry of Development Planning, although only indirectly involved in road development, emphasizes road network expansion to link urban regions and isolated regions (MDP, 2014). Both policies focus on different sectoral elements, namely environmental impact mitigation on the one hand, and spillover effects on economic growth on the other. The Ministry of Transportation is responsible for policies on road safety (e.g., GoI, 2011). All of these policies are isolated from each other because of sectoral fragmentation, making it difficult to obtain an integrated view.

The following section presents a literature review. It first elaborates on the sectoral infrastructure perspective, and then adds other sectoral views to present a more comprehensive perspective. The developed analytical framework is then explored in the TJRNs. The third section explains the methodology applied to the case study. The fourth section presents the results, a discussion, and the conclusion.

2. Unraveling sustainable road infrastructure development as an integrative matter: The analytical framework

A framework is “a way to organize information according to a particular purpose or practice” (Gudmundsson et al., 2016, p. 214). It is needed to identify elements and the general relationships among them that one needs to consider to achieve particular objectives (Ostrom, 2011). Pei, Amekudzi, Meyer, Barrella, and Ross (2010) compare frameworks for sustainable transportation and identify six criteria that a framework must meet to be robust, namely, it should (i) be comprehensive, (ii) connected to goals, (iii) have internal integration, both horizontal (i.e., between departments) and vertical (i.e., between government levels, that is, national, provincial, and municipal levels), (iv) capture the interactions of development effects, (v) use agencies' perspectives, and (vi) identify agencies' capacities and constraints. A systematic literature search was conducted to find sources in Scopus and Web of Sciences to develop such a framework.[1] The review generated a conceptualization of four unique perspectives informing how sustainability is organized as indicators derived from various sectoral elements. The first is the infrastructure perspective, representing one group of these elements that Indonesia's policy strongly focuses. Three perspectives were then added to develop a comprehensive view by including other sectoral elements. As a starting point, an analytical framework was adapted from Witte, Wiegmans, Van Oort, and Spit (2012) to categorize the elements into perspectives. Each perspective comprises elements that can be divided into dimensions for a detailed discussion.

Witte et al. (2012) developed the framework to assess and recommend solutions to transportation bottlenecks along the TEN-T Corridor 24. For this study, the framework is used to evaluate multiple elements connected to a single goal (i.e., sustainable road infrastructure). We use the operational dimension instead of the organizational dimension as in the initial framework to present sectoral elements regarding road traffic activities and their impacts. The framework includes a temporal perspective that captures sectoral aspects from a short-term (provisional) and a long-term (permanent) perspective of road development, something that public agencies in some developing countries have failed to do (Othman, 2013). The governance dimensions are included as institutions, and various forms of political support by public agencies are still less coherent to support an integrated policy in developing countries (Pojani & Stead, 2015). Finally, a “lens” analogy is used for these dimensions as “a way of seeing” the elements (e.g., Cornet and Gudmundsson (2015)) by the agencies and as a way to locate the levels (e.g., a micro-and macro-level) at which the elements are found.

2.1. Infrastructure perspective (I)

This perspective coincides with sectoral infrastructure elements that focus on the physical aspects of road development. It acknowledges the mitigation of adverse impacts of this construction on the environment. For example, the Indonesia government policy refers to sustainable infrastructure as “… a concept that guides subsequent development activities in constructing a physical infrastructure that complies with economic, social, and environmental considerations” (MPWH, 2015, Article 1). Based on our review, this perspective also pays attention to minimizing the negative impacts of vehicular traffic.

Our literature review revealed that the physical dimension (A) comprises three sectoral aspects: First, the importance of the efficiency of resources (both materials and energy) used in road construction (e.g., Hameed & Hancock, 2014). Second, the importance of road pavement lifetime and durability is to the consumption of the resources (e.g., Dhakal & Oh, 2011). Third, sustainability is related to road resiliency, in which roads can cope with climate and other natural disasters (Csete & Buzasi, 2016). In this dimension, various physical road features (e.g., pavement structures, drainage systems, and soils) are necessary to obtain the resiliency. Regmi (2014, p. 11), for example, suggests that sustainability can be achieved by incorporating “higher design standards for [road] structural elements [by] considering lifecycle cost, using innovating construction technology and sustainable materials.”

In the operational dimension (B), the literature discusses sustainability regarding how the road operation can be made more

[1] The search process was conducted on June 25, 2019, and resulted in 490 research articles covering the period 2006–19. Only relevant articles were scanned and used for analysis. The contributions stem from the disciplines of engineering, ecology, environmental sciences, geography, and social sciences. In this review, we only highlighted the relevant works (N = 31), where the sectoral elements to construct the framework were found. The search terms and the list of examined articles are provided as supplementary material (Appendix B).

environmentally and socially friendly. First, traffic pollutants—such as GHGs, NO_x, SO_x, traffic noise, and vibration—should be sufficiently mitigated (e.g., Kokoli, Chassiakos, & Theodorakopoulos, 2007; Tatari, Egilmez, & Kurmapu, 2016; Tatari & Kurmapu, 2011). Second, sustainability is advanced as ensuring safe and secure mobility for all by, for example, minimizing accident risks and reducing the social costs of these risks (e.g., Litman, 2007). Third, access to roads (and their facilities) should be secured for all groups of people, especially vulnerable ones, including the disabled, the elderly, and children (e.g., Muench, Anderson, & Söderlund, 2010). This perspective frames sectoral elements into physical and operational dimensions. However, the dimensions disregard interactions with the broader social and natural environments in time and space that will be explored below.

2.2. Spatial perspective (II)

The spatial perspective concerns the interrelatedness of road infrastructure and other spatial functions (e.g., housing, offices, manufacturing). These functions can be both conflicting—producing externalities—and complementary, creating spillover effects (Heeres et al., 2016). Heeres et al. (2016) consider that road infrastructure can be perceived as functional—connecting locations—and relational, as a part of areas. To focus on our case, the Indonesia Spatial Planning Act (GoI, 2008) refers to spatial management as the "expression of objects in spaces with their pattern (functional) and structural relationships [of these objects] in spaces." The functional dimension refers to the allocation of various land uses and their distribution in space. The structural dimension highlights that road network development can stimulate spatial quality and socio-economic improvement in specific regions, which are discussed in the literature about Land-use Transport Interaction (e.g., Arts, Hanekamp, & Dijkstra, 2014).

In the functional dimension (C), roads are perceived as potentially fragmenting neighborhoods and species' habitats and disrupting the landscape integrity (Thorne et al., 2014). Scholars discuss spatial elements of the development as externalities: noise, air, water, and soil pollution. Second, the reviewed literature discusses externalities resulting from land-use conversion to road surfacing (e.g., asphalt) (Csete & Buzasi, 2016). The conversion can occur at the expense of agricultural land and biodiversity (Joumard & Nicolas, 2010). Moreover, new road development can generate vehicular traffic volume and accelerate urban agglomeration (Pojani & Stead, 2015), which displaces green spaces (Neri, Menconi, Vizzari, & Mennella, 2010).

In the structural dimension (D), sectoral elements are discussed concerning the impact of accessibility, connectivity, and regional spillover on economic development because of road development. For example, road expansion may improve access to workplaces, schools, recreation sites, and other activity centers (e.g., Keshkamat, Looijen, & Zuidgeest, 2009). The construction of a new highway also affects goods delivery and passenger mobility, further improving economic growth and competitiveness (Joumard & Nicolas, 2010; Salling & Pryn, 2015). Road infrastructure development also serves as elements of a spatial sector strategy to distribute urban activities in space and connect vast isolated regions.

2.3. Temporal perspective (III)

The temporal perspective pinpoints the core concept of sustainability as a process that enhances both the current and the future potential to meet human needs and aspirations (Brundtland, 1987). From the definition, this perspective categorizes sectoral elements into two temporal aspects of road development: the short-term and the long-term effects. Both effects should be seen as integrated (Dernbach, 2003). The first aspect covers the provisional elements of the development that affect intragenerational equity, and the latter refers to the permanent elements that can determine intergenerational equity.

In the provisional dimension (E), scholars identify sectoral elements influencing sustainability regarding the immediate and temporary effects of development (Joumard & Nicolas, 2010). These effects include landscape change and the temporary displacement of people caused by road construction. The creation of jobs resulting from the construction is also mentioned (Joumard & Nicolas, 2010; Salling & Pryn, 2015). Some other consequences are identified, such as pollutants produced during the construction stage that affect water, soil, and air quality (Larrea-Gallegos, Vázquez-Rowe, & Gallice, 2017).

The literature review explores sectoral elements regarding the permanent effects of a (new) road development, such as the creation of a new structure of logistics costs (Tatari & Kurmapu, 2011) and the status of protected ecosystems and species' habitats (Thorne et al., 2014). Scholars also discuss the direct and indirect effects of road development, such as impacts on ecosystems' carrying capacity and future land-use changes (e.g., Joumard & Nicolas, 2010; Keshkamat et al., 2009). Ripple effects, such as climate change and ozone layer depletion at a larger scale, are also identified (Marzouk, El-zayat, & Aboushady, 2017). The irreversible and uncertain effects are also underlined. In this dimension, scholars also point out sustainability as the ability of road infrastructure to withstand natural disasters and catastrophic events (Joumard & Nicolas, 2010; Salling & Pryn, 2015).

2.4. Governance perspective (IV)

Governance is the management of the common affairs of political communities working in networks, involving all sectors and actors in the processes of regulation, coordination, and control (Alexander, 2005; Healey, 2006). Treib, Bähr, and Falkner (2007) categorize the elements of governance into three dimensions: (i) polity (i.e., actors' interactions can be either hierarchically or non-hierarchically structured), (ii) policy (i.e., regulations, directives, and decisions that are legally binding on different actors), and (iii) politics (i.e., the interaction of state and private actors in decisionmaking). Based on the papers reviewed, dimensions (i) and (ii) are grouped into the institutional (G) dimension, and dimension (iii) is included into the political (H) dimension.

The institutional dimension consists of both informal rules (e.g., sanctions and customs) and formal rules (e.g., constitutions and laws) that act as constraints on social interaction (North, 1991; Salet, 2002). Institutional fragmentation, including a lack of coordination, is mentioned as a constraint on sustainable transportation planning for public agencies (Hull, 2008; Stead, 2008) and is a common implementation problem in road infrastructure development or redevelopment (Heeres et al., 2016). Some scholars (e.g., Dhakal & Oh, 2011; Muench et al., 2010; Thorne et al., 2014) assert that agencies have to overcome fragmentation to agree on a set of objectives and mobilize resources. Flores, Montoliu, and Bustamante (2016) highlight individual sectoral arrangements (e.g., laws, standards, and guidelines) that guide public agencies' actions toward sustainability.

The political dimension concerns the human agency and interactions of the sectoral actors to manage development processes (Redclift, 1991). The first aspect reviewed includes actors' knowledge, awareness, and other capacities (e.g., Muench et al., 2010; Thorne et al., 2014). Second is the relatively narrow focus and defensive positions of actors to agree on a common goal (Ramani et al., 2011). The dimensions in this perspective categorize elements that act as capacities for and constraints on the integration of sustainability into transportation development (Gudmundsson et al., 2016).

2.5. Toward an integrative approach to sustainable road infrastructure development

Sectoral approaches are not explicitly considered the interrelations between sectoral elements. Such approaches consider infrastructure elements and other sectoral elements as isolated problems. Infrastructure agencies and other government bodies have explored an integrative approach to dealing with the interaction between sectors

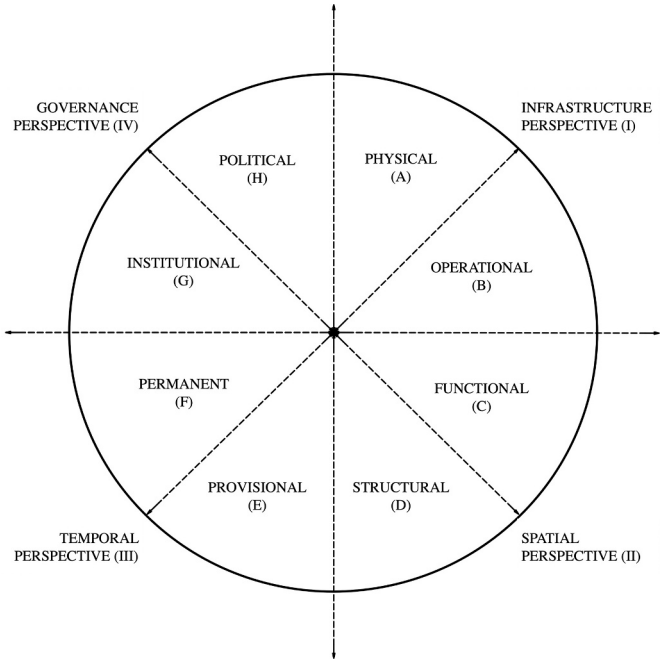

Fig. 1. The analytical framework (adapted from Witte et al., 2012).

within a fragmented institutional context (Heeres et al., 2016). Integration, therefore, is about coordinated planning and decision making among several sectoral agencies. These agencies have various frames of thinking in time and space that add a comprehensive perspective on sustainable development (e.g., Gudmundsson et al., 2016).

Related policies on sustainable road infrastructure often show a firm infrastructural sectoral approach (e.g., MPWH (2015) in the Indonesian case). This paper intends to broaden the infrastructure perspective into a more comprehensive one by incorporating the spatial, temporal, and governance perspectives. Fig. 1 shows that the sectoral elements within the dimensions and perspectives interact with each other. Following Witte et al. (2012), each dimension/perspective in Fig. 1 is associated with the others and is represented as interrelated. For operationalization purposes, Fig. 1 is used as a lens consisting of four sides/quadrants (I–IV), each of which has two dimensions (A–H). Different sides of the lens reflect different sectoral elements. The analytical framework is used to identify (i) which elements do stakeholders perceive to contribute to sustainability, (ii) at which levels the elements are found, and (iii) how they may be interrelated.

3. Case study and methods

3.1. Case study

The TJRNs project is an ambitious large-scale road development project, with 1167 km of toll expressways connected by arterial and local roads on the corridor networks (Tempo.co, 2017). The expressways are parts of the Trans-Asian Highways (AH-2) (UNESCAP, 2016) and are the main backbone for surface logistics transportation and passenger mobility in the populous island of Java (see Fig. 2). The networks connect major urban regions, such as Jakarta, Bandung, Semarang, and Surabaya, where industrial and service activities and transportation hubs (e.g., airports and seaports) are located. Better connectivity between these regions is expected to enhance economic competitiveness at both the international and national levels through efficient logistics movement (i.e., time travel saving) (CMEA, 2011). The strategic role of TJRNs makes it essential for the central government to take responsibility for the implementation. Provincial and municipal jurisdictions are concerned that the road investment will induce local economic development and accessibility improvement only at the micro-level, that is, in urban regions.

As mentioned in Section 2.5, the policy regarding road sustainability refers to the mitigation of physical construction's adverse impacts on the environment (i.e., MPWH, 2015). Such definitions regard road development as isolated from other concerns, such as land-use planning, traffic pollution reduction, employment, local economic development, ecosystem conservation, social displacement, and other socio-environmental concerns. In integrating environmental policies into the road infrastructure development, planners and decision-makers rely on two environmental assessment procedures, namely the project-level environmental impact assessment (EIA/AMDAL) (MPW, 2011) and the corridor-level strategic environmental assessment (SEA/KLHS). Both procedures capture environmental impacts; economic and social impacts are only briefly considered (e.g., Fischer (1999)). It is inevitably difficult to achieve integration for some reason. First, no mandatory SEA of the corridors was performed to guide the road development plan. Second, EIA has weaknesses in terms of a lack of macro (strategic) analysis of impacts and a fragmented focus on small projects. Third, both tools are performed too late in the planning process to provide useful recommendations. Finally, the political interests of building roads to boost economic development have threatened the value of implementing the procedures and recommendations, particularly for the local government, where there is limited financial capacity and innovation to manage roads within their administration (Darmoyono, 2019).

3.2. Methods

Following Witte et al. (2012), this study applied a mixed-scanning methodology to explore sectoral elements derived from public agencies' perspectives on the sustainability of road infrastructure development. The methodology reduces the discrepancies between the rationalist and the incrementalist approach (Etzioni, 1967, 1986). In the first approach, policy actors become aware of a problem, establish a goal, carefully weigh alternative means, and choose among them. The incrementalist approach seeks to adapt strategies to handle the actors' limited cognitive capacities and reduce the scope and cost of information collection through serial evaluations. Etzioni (1967) suggests the analogy of two cameras to illustrate the application of the methodology: “a broad-angle camera that would cover all parts of the sky but not in great detail, and a second one which would zero in on those areas revealed by the first camera to require a more in-depth examination” (Etzioni, 1967, p. 389). In this study, a macro-level analysis scanned sectoral elements that concern all the network corridors. In contrast, the micro-level analysis stressed the elements found at a specific level, namely urban regions. Several levels with varying degrees of detail and coverage can be included (e.g., national, regional, local); thus, “the [elements] selected can be explored as fully as is feasible” (Etzioni, 1967, p. 389).

For data collection, we initially conducted semi-structured interviews with 24 key interviewees from public agencies operating at national, provincial, and municipal levels. The selection was based on their knowledge and their involvement in road infrastructure development during one or more phases of the TJRNs project, such as planning/design, construction, and operation. The interviewees were decision-makers, middle managers, and planners in agencies' units for road management/public works (5 persons), regional development (4), spatial/infrastructure planning (8), environment (2), and transportation management (5). In the interviews, they positioned themselves as the representatives of the agencies with legal mandates. An interview protocol was developed to guide the interviews. We structured our interview questions as follows: (i) What missions and tasks do the organizations own to support the sustainability of the road infrastructure development?; and (ii) What attempts have been made and at which levels do the organizations accomplish the goal? To gather in-depth

Fig. 2. The Trans-Java road network.

qualitative data about elements at the micro-level, we interviewed spatial/transportation planners in four urban regions, namely Purwakarta (2 persons), Cirebon (1), Semarang (3), and Surabaya (3). Davidson (2015, p. 46) argues that these fast-growing urban regions represent Jakarta's suburban expansion, spanning "across Java's dense north coast, [and] … expressway project designed to connect Jakarta [the capital] with Surabaya (and beyond)." Therefore, specific stakeholders' perspective regarding road development in these regions also need to be considered.

All interviews were audio-taped and then transcribed verbatim. Before the analysis, the transcripts were sent to the interviewees for comments and confirmation. Texts from the transcripts were extracted and categorized for content analysis (Silverman, 2014) to confirm and expand sectoral elements in each dimension/perspective (Fig. 1 and Sections 2.1–2.4). We added responses from researchers and experts from universities and research institutes to confirm and refine the levels where the element should be considered (Appendix). In total, 37 stakeholders were interviewed.

4. Multidimensional perspectives on sustainable road infrastructure development

4.1. Macro-level analysis

Concerning the physical dimension (A), interviewees mentioned sectoral elements that support the sustainability of road infrastructure development (Table 1). First, one interviewee said that the efficient use of resources (materials and energy) in road construction is essential in this, as already found in the infrastructural sector policy (i.e., MPWH, 2015). Second, they said that the use of local materials minimizes the amount of energy consumed by transportation. Other sectoral elements complement the dimension, including road resiliency, reliable pavement designs, and well-functioning drainage systems. Road resilience was said to be the ability of road infrastructure to withstand disaster events and protect the road pavement structure from damage that shortens the lifetime. The interviewees mentioned that reliable pavement designs and pavement durability helped anticipate future traffic growth and obviated early reconstruction, which would consume excessive material and energy.

The interviewees named several sectoral elements related to the operational dimension (B). First, three of them said that present road development had increased road traffic volume, inducing a massive release of GHGs into the atmosphere. These interviewees from the highway unit told the policy of "predict and provide" (e.g., Tennøy (2010)), in which road capacity expansion is required to increase levels of service (LoS) and reduce the amount of GHGs released as a result of congested roads. The policy stipulates that the mitigation of GHG emissions includes increasing average speeds, which had been recorded far below the maximum speed limit (50 km/h on urban roads and 80 km/h on interurban roads) (i.e., MPW, 2011, 2012). When there is congestion, vehicles spend more time on the road, and numerous acceleration and deceleration events lead to an increase in emissions (e.g., Smit, Brown, & Chan, 2008). Sustainability was also related to reducing polluting emissions, such as air, noise, and vibration, from vehicular traffic. However, the gas emission sources other than GHGs were not specified in the interviews. Driving comfort was mentioned as facilitating swift logistics and passenger movements (economic benefits from time travel saving). The results show that sustainability is also associated with reducing accident risks, aimed at saving people's lives and improving societal welfare (i.e., GoI, 2011).

From a spatial perspective, the study identified several sectoral elements connecting to sustainability. In the functional dimension (C), interviewees mentioned a concern about preventing the loss of agricultural and forest lands, threatening food security. They admitted that the development has encouraged the rapid conversion of agricultural lands to urban functions (e.g., housing, offices, and factories) and endangered the landscape integrity by fragmenting species' habitats and eliminating biodiversity. In the structural dimension (D), some sectoral concerns were stated, including the connectivity of isolated regions, accessibility and people's mobility, and regional development. Moreover, the interviewees pointed out a spatial development policy to remove isolated regions, facilitate goods and people movement, and attract foreign investment throughout the road network corridors (i.e., MDP (2014)).

Table 1
Sectoral elements contributing to sustainable road infrastructure development.

Nr.	Perspective/dimension/elements	Level		# of sources
		Macro	Micro	
I.	Infrastructure perspective			
A.	Physical dimension			
	Efficient energy use	X	X	1
	Use of local materials	X		1
	Resilience to disasters	X		6
	Sufficient drainage capacity against early damage	X		3
	Use of recycled pavement materials	X		3
	Reliable pavement design	X	X	5
	Pavement durability	X	X	8
B.	Operational dimension			
	Reduction of GHG release	X		3
	Enhancement of driving comfort	X	X	5
	Level of service (LOS) improvement (congestion relief)	X	X	8
	Multifunctional infrastructure design		X	3
	Multimodal infrastructure provision (walking, cycling)		X	5
	Mitigation of traffic noise and other polluting emissions	X	X	7
	Accident risk reduction	X	X	10
	Travel time saving		X	2
II.	Spatial perspective			
C.	Functional dimension			
	Designs based on topographical limitations		X	6
	Provision of green features		X	5
	Formation of land use patterns		X	11
	Improvement of access to urban centers and transportation hubs		X	8
	Aesthetic enhancement		X	6
	Locally sensitive street design		X	7
	Protection of agricultural lands	X	X	14
	Preservation of forests and species' habitats	X	X	14
D.	Structural dimension			
	Ending regional isolation	X	X	4
	Accessibility enhancement	X	X	10
	Connectivity improvement	X	X	14
	Distribution of spatial development	X	X	16
	Increased economic growth (and competitiveness)	X	X	13
III.	Temporal perspective			
E.	Provisional dimension			
	Reduction of pollutant emissions during construction		X	3
	Just and proper land acquisition and community resettlement		X	5
	Monitored health and safety of the project's surroundings		X	5
	Allocation of jobs to local people		X	4
	Management of traffic delays (during construction)		X	2
	Water use efficiency		X	4
F.	Permanent dimension			
	The maintained ecosystem's carrying capacity	X	X	10
	Mitigation of damage to the ecosystem	X	X	6
	Minimization of changes to the landscape		X	5
	Minimization of social displacement		X	9
	Restructured transportation costs	X	X	4
IV.	Governance perspective			
G.	Institutional dimension			
	Compliance with regulations and standards	X	X	14
	Continual monitoring of compliance	X		10
	Cooperation and coordination of agencies	X	X	11
	Implementation of best practices	X		4
	Public participation		X	10
	Public private partnerships	X	X	5
	Funding capacity		X	6
H.	Political dimension			
	Actors' awareness of integrated issues		X	6
	Shared vision	X	X	5
	Commitment to a long-term plan	X	X	8
	Actors' knowledge	X	X	5
	Actors' leadership	X	X	11
	Transparency and trust		X	3
	Presence of a long-term vision	X	X	9

Concerning the temporal perspective (III), at the macro-level, sustainability is mostly linked to anticipating the long-term effects of road development. First, the interviewees were concerned about the ecosystem's carrying capacity across the network corridors. They highlighted two central sectoral issues: water scarcity and soil quality degradation because road development is followed by an enormous demand for housing and public utilities. Second, sustainability is associated with overall economic development in the corridors through the restructuring of transportation costs due to reduced travel times and vehicle operating costs. This claim reflected the sectoral policy concerning economic competitiveness (i.e., CMEA, 2011).

The governance perspective (IV) explored the sectoral elements from the institutional (G) and the political dimension (H). In the first dimension, interviewees emphasized the role of regulations and standards in meeting higher environmental requirements. They also pointed out the responsibility of public agencies to monitor compliance with the requirements. Second, cooperation and coordination between sectoral agencies across different jurisdictional levels were necessary to resolve the competing interests and expand the limited capacities (e.g., a lack of skilled personnel and limited funds). Partnerships with the private sector were also mentioned as being of relevance to enhance funding capacities. The second dimension (H) included several policy elements as being crucial: co-shared visions, political commitments, knowledge of integrated issues, and leadership. These elements were considered to be lacking. The leadership and commitment were necessary to resolve competing interests between sectoral agencies and secure the resources needed to achieve a long-term goal, such as sustainable development.

The findings of the macro-level analysis show that multiple sectoral elements contribute to the sustainability goal, as discussed in the analytical framework. Therefore, sustainable road infrastructure development is not only the contribution of particular agencies responsible for road management. However, the contribution comes from various agencies, which are still less incorporated into the present policy (i.e., MPWH, 2015). The framework proves useful to expand perspectives of the contributing elements that can be further explored at the micro-level.

4.2. Micro-level analysis

The micro-level analysis revealed several additional sectoral elements. At the micro-level, sustainability is closely related to the mitigation of road development effects on the urban environment. The

interviewees also used a limited time perspective to identify issues related to the displacement of people during road construction. The result shows that limited funding is the primary constraint on maintaining road conditions and enhancing urban regions' connectivity (and accessibility). The findings at this level complement sectoral elements identified at the macro-level, mostly located in the operational (I—B), functional (II-B), provisional (III-E), perpetual (III-F), and institutional (IV-G) dimensions (Table 1).

In the operational dimension (I—B), the mitigation of traffic impacts on the urban environment was highlighted. First, sustainability is closely related to the improvement of non-motorized transportation modes, such as cycling and walking (i.e., in Semarang). The interviewees mentioned sustainability concerning equal access to roads and facilities for vulnerable users (e.g., the disabled, the elderly, and children). It was said that road expansion in an urban region would balance the area's size and that the traffic volume (i.e., in Semarang and Surabaya) would relieve congestion, decrease fuel consumption, and reduce traffic emissions. This response reflects a common situation in cities in the global South, where road capacity is too small to accommodate present traffic volumes (e.g., Cervero, 2013). The congestion has increased GHG emissions, as noted in the Indonesian government policy (i.e., MPW, 2012). The design of multifunctional roads, such as a combination of road rest areas and local markets, would unlock the economic potential because it facilitates a meeting place between local sellers and regional travelers (i.e., in Purwakarta and Semarang).

From the functional dimension (II-C), the interviewees underlined harmonization between urban landscapes and road/street layouts. They suggested planting “green” roadsides to create a less harmful and intrusive environment and improve visual aesthetics, including installing street furniture and designing streets for pedestrian safety (i.e., in Cirebon). This concern implies that urban roads/streets can be made attractive and pleasant and environmentally friendly, for example, to promote active travel (e.g., Vale, Saraiva, & Pereira, 2016). The interviewees also linked sustainability with the improvement of people's access to public facilities, such as schools, at a city scale (i.e., in the case of Semarang).

Both the provisional (III-E) and the permanent (III-F) dimension were discussed at this level. The interviewees said that road construction impacts the local environment and the community—in the form of, for instance, people displacement, health and safety problems, traffic congestion, and water use—require immediate attention. In the long run (III-F), interviewees said that they needed to pay attention to the consequences of landscape change and social displacement. One interviewee mentioned that the displacement had eroded trust among community members, as road construction created a physical barrier that divided them into smaller neighborhoods (i.e., in Cirebon). However, trust can be sustained and developed through network management strategies that are more than just physical contacts (e.g., Klijn, Edelenbos, & Steijn, 2010).

Finally, the institutional (IV-F) dimension elaborated some elements as constraints (i.e., funding limitation and low public participation). The interviewees acknowledged that there are limited public funds to support regular maintenance (e.g., Darmoyono, 2019), and poor road condition has threatened people's mobility and access to urban facilities. Public agencies perceived that low public participation as a constraint on gaining public support to related policies and programs, improving ownership, and encouraging self-management of local roads (e.g., urban streets). At this level, broad participation is stimulated as funding is limited to maintenance and rehabilitation. The following section will discuss an integrative approach that captures the interactions of sectoral elements.

5. Conclusion

The results show that the sustainability of road infrastructure development is contributed by various sectoral elements from the infrastructure, spatial, temporal, and governance perspectives. Therefore, sustainability is not merely a matter of mitigating road construction impacts, which the existing policy strongly focuses on (i.e., MPWH, 2015). By using the analytical framework, from a spatial perspective this study explores the contributions of other sectors, such as regional planning, economic development, environmental management, agriculture, and forest conservation. The temporal perspective revealed numerous sectoral contributions, such as job and employment in short-term and ecosystem degradation, and restructured transportation costs in the long-term. The governance perspective explored the mobilization of sectoral mechanisms, processes, and arrangements by different public agencies for integrating sustainability into road infrastructure development. A vast majority of these sectoral elements were confirmed in this study by focusing on the micro-level.

The identified sectoral elements are not isolated from each other; they intersect and jointly contribute to achieving the sustainability goal. Such interactions are found within and between dimensions/perspectives, as well as between the levels of analysis (i.e., macro- and micro-levels). For example, efficient energy use in road construction can be achieved by utilizing local materials. An improvement in the level of service (LoS) and in time travel saving can contribute to increased economic growth. However, the interaction is complex, and political factors also determine the outcomes (Banister & Berechman, 2001). The identified elements also interact between levels. For example, urban regions, whose primary function is to collect and distribute goods and services, influence sustainability at the macro-level through better connectivity of different land functions (e.g., housing, offices, factories) in urban regions. In other words, sectoral elements found at a higher level are constituted by those at a lower level. Otherwise, sectoral elements found at the lower level affect sustainability at a higher level; for example, traffic congestion that increases GHG emissions at a city scale affect the total production of the emissions globally.

This paper also explored the possible application of a mixed-scanning methodology to unravel the intricate nature of the sectoral elements at a macro and micro level. Most literature on this exploration is still fragmented into sectors and levels, focusing solely on either the micro-level (e.g., urban region) or the macro-level (e.g., network corridor) (Fabbro, Brunello, and Dean (2015)). The framework and the methodology presented in this study explicitly show sustainability as an integrative matter, involving various sectoral contributions at different levels. For managerial practice, the methodology helps to identify numerous sectoral elements that should be incorporated into a more comprehensive policy and indicator on sustainable road infrastructure development. The methodology is also valuable to show that public agencies have diverse tasks and mandates, but also a limited capacity (e.g., knowledgeable and skilled personnel, funds, coordination, and political commitment) to include all sectoral elements into a single policy. Thus, in the pursuit of sustainable development, public agencies must aware of the others' tasks and coordinate effectively.

6. Discussion

Most decision making by individual public agencies is often carried out in sectoral thinking (Ashford & Hall, 2011). From our study, it appears to be fragmented sectoral focuses, and the public agencies tend to use sectoral perspectives to incorporate sustainability into a road development policy. In fact, various sectoral elements are found to interact with others (e.g., Jeon, Amekudzi, & Guensler, 2013). The analytical framework (Section 2) helps the public agencies to recognize the multiplicity of perspectives on the elements and move away from merely a reactive approach (i.e., impact mitigation of road construction). For public agencies, the framework presented here expands their perspectives on these elements and prepare for the necessary coordination with relevant actors from other sectors for integration (Heeres et al., 2016). As Pojani and Stead (2015) argued, public

agencies in developing countries show less awareness of the interrelatedness of these elements and less recognizing the merits of coordination, making it challenging to arrive at a comprehensive policy.

The results show that the mitigation of road construction impacts on the environment is only a part of the overall elements that constitutes sustainability. As in the analytical framework, sustainability is also related to the promotion of economic and societal wellbeing—although the latter is still less explicitly mentioned. Therefore, the pursuit of the sustainability goal cannot be represented only by a particular agency (i.e., road management/highway agency). Other agencies are also responsible, and they are those assigned to economic development, regional planning, road safety, forest conservation, environmental protection, public administration, standardization, and others. In Indonesia or elsewhere, such a comprehensive view is still less well-formulated in policies because of limited funding and personnel capacities and lacks coordination between public agencies (Darmoyono, 2019; Delphine, 2019; Regmi, 2014).

To sum up, one can lose track of multi-sectoral and multilevel analysis when using a sectoral perspective but a comprehensive perspective is limited by agencies' capacities. The realistic choice is to apply both perspectives where appropriate. It can be performed by mapping and evaluating the sectoral elements at particular levels into specific tasks of the agencies and policy objectives. The mixed-scanning methodology helps to identify which policy elements need to consider at a macro-level (i.e., network corridors) or at a micro-level (i.e., urban regions), and which agencies are responsible for achieving specific policy objectives in a fragmented decision-making environment. Therefore, coordination between these agencies can also be enhanced. The results shown in the Appendix are not for generalization but they refine the sectoral elements into more detailed spatial levels and provide an overview of the distributions. We suggest that follow-up research transforms the elements into policies and indicators at appropriate levels and include other stakeholders, such as NGOs and communities, for further exploration.

Author statement

Gede B. Suprayoga acquired the study's funding, conceptualized and wrote the original paper draft, and performed the investigation and the formal analysis. Patrick Witte and Tejo Spit developed the methodology, supervised the study, and reviewed and edited the paper draft. All authors read and approved the final paper manuscript.

Funding

This work was supported by the Indonesia Endowment Fund for Education (LPDP) grant (Nr. 20160222015432). The Ministry of Finance, Republic of Indonesia, granted the funding. The findings, interpretations, and conclusions presented in this article are entirely those of authors and should not be attributed in any way to the ministry.

Declarations of Competing Interests

The authors declare that they have no competing interests.

Acknowledgements

The authors would like to thank Professor Leonie B. Janssen-Jansen for commenting on the conceptual design of the manuscript. Professor Janssen-Jansen died in 2018. The authors also wish to thank to Agus B. Sailendra (Indonesian Road Development Association), Doni J. Widiantono, pH.D. (Ministry of Land Affairs and Spatial Planning), Dr. Maulidya I. Junica (Ministry of Public Works and Housing), Ibnu F.P. Poerwo, pH.D. (Indonesian Association of Planners), and Dr. Sri Hendarto (Bandung Institute of Technology) for valuable insights on the Indonesian road infrastructure development, and to M. Idris (Ministry of Public Works and Housing) for the administrative supports of the data collection.

Appendix A. Refined spatial levels of elements and distributions.

Perspective	Dimension	Elements	Spatial level*			
			International	National	Regional	Local
Infrastructure (I)	Physical (A)	Efficient energy use		X		
		Use of local materials		X		
		Resilience to disasters		X	X	X
		Sufficient drainage capacity against early damage		X	X	
		Use of recycled pavement materials		X		X
		Reliable pavement design		X	X	X
		Pavement durability	X	X	X	X
	Operational (B)	Reduction of GHG release	X	X		X
		Enhancement of driving comfort		X		X
		Level of service (LOS) improvement (congestion relief)		X		X
		Multifunctional infrastructure design				X
		Multimodal infrastructure provision (walking, cycling)			X	X
		Mitigation of traffic noise and other polluting emissions	X	X	X	X
		Accident risk reduction		X	X	X
		Travel time saving				X
Spatial (II)	Functional (C)	Designs based on topographical limitations				X
		Provision of green features				X
		Formation of land-use patterns		X	X	X
		Improvement of access to urban centers and transportation hubs				X
		Aesthetic enhancement				X
		Locally sensitive street design				X
		Protection of agricultural lands		X	X	X
	Structural (D)	Preservation of forests and species' habitats	X	X	X	X
		Ending regional isolation		X	X	X
		Accessibility enhancement		X	X	X
		Connectivity improvement		X	X	X
		Distribution of spatial development		X	X	X
		Increased regional economic growth (and competitiveness)		X	X	X

Temporal (III)	Provisional (E)	Reduction of pollutant emissions during construction				X
		Just and proper land acquisition and community resettlement				X
		Monitored health and safety of the project's surroundings				X
		Allocation of jobs to local people				X
		Management of traffic delays (during construction)				X
		Water use efficiency				X
	Permanent (F)	Preservation of ecosystem's carrying capacity	X	X	X	X
		Mitigation of damage to the ecosystem	X	X	X	X
		Minimization of changes to the landscape		X		X
		Minimization of social displacement	X	X	X	X
		Restructured transportation costs		X	X	X
Governance (IV)	Institutional (G)	Compliance with regulations and standards	X	X	X	X
		Continual monitoring of compliance		X	X	X
		Cooperation and coordination		X	X	X
		Implementation of projects' best practices		X	X	
		Public participation				X
		Public-private partnerships		X		X
		Funding capacity		X	X	X
	Political (H)	Actors' awareness of integrative issues		X		X
		Shared vision		X	X	X
		Commitment to a long-term plan		X	X	X
		Actors' knowledge		X	X	X
		Actors' leadership		X	X	X
		Transparency and trust		X	X	X
		Presence of a long-term vision		X	X	X

Note: Distributions of the elements at various spatial levels (*stated by ≥4 referring sources [median = 4]).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rtbm.2020.100562.

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