Review

Rural Transportation Infrastructure in Low- and Middle-Income Countries: A Review of Impacts, Implications, and Interventions

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Abstract: The rural transport infrastructure sector is a critical force for sustainable development that is interwoven with many other sectors. Rural transportation is an underlying driver of many of the Sustainable Development Goals (SDGs) and a crucial contributor to many socioeconomic benefits for rural people around the world. This review paper expands upon, enhances, and cross-references the perspectives outlined in previous rural infrastructure-focused review papers. Firstly, this work gives a thorough look into the progress of the rural transportation sector in recent years by focusing on the thematic relationships between infrastructure and other components of sustainable development, namely, economics and agriculture, policy and governance, health, gender, education, and climate change and the environment. Secondly, several strategies, approaches, and tools employed by governments and practitioners within the rural transport sector are analyzed and discussed for their contributions to the wellbeing of rural dwellers in low- and middle-income countries (LMICs). These include rural roads, bridges, maintenance, and non-infrastructure approaches that include concepts such as advanced technological innovations, intermediate modes of transport (IMTs), and transport services. This paper concludes that enhancement, improvement, and extension of rural transportation infrastructure brings significant benefits to rural dwellers. However, this paper also calls for additional integration of the sector and increased usage of systems approaches that view rural transport as an active part of many other sectors and a key leverage point within rural development as a whole. Further, this paper notes areas for future research and investigation, including increased investigation of the relationship between rural transportation infrastructure and education, improved data collection and management in support of improved policymaking, improved prioritization of interventions and institutionalization of maintenance, and expansion of pro-poor transportation strategies and interventions.

Keywords: rural access; rural mobility; infrastructure; transportation; low- and middle-income countries; rural roads; bridges; maintenance

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1. Introduction

One-third of the global rural population—approximately one billion people—live farther than 2 km from an all-season road [1], creating isolated communities with little access to essential services. Without safe access, devastating consequences are faced by communities, including higher under-five infant mortality and lower gross-domestic product (GDP) per capita [2]. Investment in infrastructure has been shown to play an important role in global development, whereby networked infrastructure supports 72% of the Sustainable Development Goals (SDGs) [3]. More specifically, rural transport infrastructure, such as feeder roads and trail bridges, has links to 10 of the 17 SDGs, with SDG indicator 9.1.1 being measured as the proportion of the rural population with access [4]. While the importance of rural transport infrastructure has been studied significantly over the

past several decades, spending on infrastructure is still prioritized for urban development where economic growth and policy is focused [5]. Therefore, this paper focuses specifically on a review of rural transportation infrastructure and its many relationships to socioeconomic benefits including economic and agricultural, policy and governance, health, gender, education, and climate change and the environment, with an additional review of the implementation activities in the sector including rural roads, rural bridges, maintenance, and non-infrastructure approaches. The review provides an updated evidence base for rural access stakeholders including key policy makers in national and local governments; international finance institutions such as bi-, multi, and regional development banks; non-governmental organizations serving communities across the rural access sector; private sector organizations who are designing and constructing rural infrastructure; capacity building institutions who train the next generation of rural access implementers; and others, in order to assist in the prioritization of rural access networks.

2. Materials and Methods

An in-depth literature review of the rural transportation sector provided the informational basis for this paper. Varying contextual situations and perspectives were intentionally gathered to broaden the lens and perspective of the review. Searches were performed using Web of Science and Google Scholar to identify credible and relevant literature. Key search terms included phrases such as “rural transportation infrastructure”, “rural transportation development”, “rural transportation infrastructure developing communities”, and incorporated terms such as “access”, “mobility”, “connectivity”, “roads”, “bridges”, “trails”, and “paths”. Sources that did not directly reference transportation or the rural transportation sector were not included. Relevant libraries in the rural transportation sector were utilized, namely publications from leading non-governmental organizations (NGOs), such as Helvetas, and the rural access library provided by the Research for Community Access Partnership (ReCAP). As appropriate sources were collected and organized, themes were generated to classify papers based upon their central topics. These functioned to display the multifaceted impacts of rural transportation infrastructure globally, and the interwoven nature of transportation within these components of rural development. Further search terms were used to execute deeper analysis within thematic sections, for example, “rural transport infrastructure access health developing communities” and “rural transport infrastructure access education LMICs”. Synthesis of the thematically organized information found in these sources formulated the sector-wide conclusions drawn by this paper, and also exposed informational gaps that warrant further investigation. In this way, the methodology presented herein contains components of both a literature review and scoping review [6].

Results of the preliminary literature review showed that fairly comprehensive sectoral reviews of the rural transportation space were created in 2014 [7], 2016 [8], and 2019 [9]. The reviews from 2014 [7] and 2016 [8], while broad and systematic in nature, focused largely upon rural roads and their relationship to poverty reduction. While this lens covers a wide perspective in the rural transportation sector, new evidence and research have added nuance and depth to the discussion. An additional review was published in 2019 [9], yet, classifying itself as a “rapid review” with a limited number of sources and coming from the same author as the 2016 systematic review [8], it largely echoed the claims of the 2016 paper [8] and incorporated few new perspectives. In this way, the first objective of this paper concerns an update of the available literature within the sector since 2014. Only sources published in 2014 or later are included. The first sections of this paper will describe updated findings and conclusions made available by the literature concerning rural transportation relationships to economics and agriculture, policy and governance, health, gender, education, and climate change and the environment. These sections will expand upon the conclusions drawn from the three aforementioned previous reviews, and provide additional perspective and context to these ever-evolving discussions. The second focus within this paper is on particular strategies, interventions, and approaches

for realizing the multidimensional rural transportation-based benefits addressed in the first sections of the paper. The latter sections of the paper will serve to address these tools and concepts that cultivate benefits for rural dwellers and outline several related areas for further inquiry.

3. Review of Recent Rural Transportation Literature

3.1. Economic and Agricultural Impact

Economic growth has long been considered a major determinant of peoples' quality of life with regard to global development. Accordingly, economic indicators such as GDP (or GDP per capita) have been considered a "yardstick" for measuring the progress of development for decades [10]. It is widely accepted that rural transport infrastructure is a critical driver of economic growth and development, as it contributes to market access, agricultural production, creation of firms, and poverty reduction, and generally facilitates the movement of goods and people [4,10–20]. Further, the literature describes the agriculture sector as the dominant activity [21] and the "backbone" of many local economies in LMICs [22], recognizing that a large portion of the world's rural poor depend upon agriculture for both income and subsistence [7]. In Sub-Saharan Africa, agricultural work has an employment share of 60% [11,21,23], and in India, about 43% of the country's land area is used for agriculture that employs over 50% of the country's workforce [24]. Additionally, a large majority of households in LMICs live in areas where markets are unevenly distributed across space [25], and where transportation of people and goods is intrinsically related to the geographic organization of economic activity [18,26]. Therefore, the importance of transport infrastructure grows proportionally to remoteness, as rural economics are frequently characterized by under-used resources and marginal economic activities [27]. Generally, a lack of accessibility in developing contexts has been classified as one of the main drivers of continued poverty, which is displayed by limited agricultural output and economic activity [4,28]. Investment in and implementation of transportation infrastructure is often justified and financed by claims that it will contribute to the economic growth of rural and poor communities [29]. In this way, rural road expenditure has been suggested to be one of the most effective methods of poverty reduction, per dollar spent [5]. Yet, there are underlying mechanisms that pull these sectors together [30], and because rural transportation infrastructure is not randomly allocated, the direction of causality between transport infrastructure and economic growth is debated [11]. There are overwhelmingly positive trends within the links among rural roads, agriculture, and poverty [31], yet recent review papers and additional literature concur to suggest that impacts can be both complex and diverse [7,32,33].

A widely discussed burden experienced by rural farmers is limited market access, which can reduce the inputs available to rural farmers, limiting agricultural output [16]. Poor road conditions and limited rural transportation infrastructure separate farmers from tools, techniques, and strategies, leaving farmers locked in a cycle of poverty with their core income-generating agricultural processes characterized by restricted technologies and limited yields [23,30]. Rural farmers are faced recurrently with decisions about upgrading technology and other inputs, which is often expensive, and may not be feasible given a common need to balance market participation with household-level subsistence [30]. However, improved rural access has aided in supporting rural farmers' access to technologies, techniques, and useful inputs such as fertilizers, pesticides, irrigation, and mechanized tools, resulting in greater outputs [9,24,31,34,35]. For example, after installation of a new trail bridge in rural Nicaragua, farmers spent nearly 60% more on intermediate inputs aimed at boosting their outputs [25]. Further, improved transportation networks can reduce the costs of holding inventories [24], make farmers' income more resilient to changes in transport costs [30], and may encourage the hiring of additional farm labor [34]. Increased access may also affect rural farmers' crop choices [9], and in some cases, lead to crop diversification [34]. In sum, evidence suggests that market access and technology adoption

amongst rural farmers are intertwined and should be examined jointly as positive outcomes from increased rural connectivity [30].

Another important focal point of the literature discusses the periphery of urban areas, examining the connections between the urban and rural economic systems instead of addressing them independently [21,36,37]. As modern economic growth in rural areas of LMICs largely involves structural urbanization and movement away from agricultural income and production [21], transport is a crucial variable in these equations [10]. In this way, improved transportation infrastructure that creates peri-urban connections has been shown to support increased, or newfound, access to labor markets, and studies confirm that this subsequently drives increased household income [33,38]. By allowing movement out of agricultural work and into what is generally described as “non-farm work” or “wage labor” [33], rural transport infrastructure allows for an increase in income for rural dwellers through self-employment and industrial or manufacturing roles [9,14,24,29,33]. Here, previous review papers concur with additional new evidence to show that rural transportation infrastructure brings connections to new labor markets, which contribute directly to increased income by opening new channels of employment [7–9]. Described as a primary impact of increased rural accessibility [36], non-agricultural income is often used as an outcome metric for identifying impacts of increased rural access [11,22,26,33]. To this end, studies show that participation in non-farm income-generating activities has allowed rural families to increase their incomes and consumption [39] and quality of life [40]. A review of the Pradhan Mantri Gram Sadak Yojana (PMGSY) project in India found that a new road in a village contributed to a 9% decrease in the share of workers in agriculture, and a corresponding increase in wage labor [41]. These results are common within the literature, as demonstrated by a 5% increase in household consumption and a nearly 20% increase in total labor earnings in Indonesia after a one-standard-deviation improvement in road quality [29], as well as further studies that reported 28% [38] and 38% [33] increases in household income, from Nepal and Cameroon, respectively, due to increases in wage labor after newfound road access. Additionally, rural trail bridges in Nicaragua erased an 18% decrease in labor market earnings reported during flood incidents, helping to eliminate market access uncertainty related to extreme weather events [25].

However, many people live without the means to abandon agriculture as their main source of both income and subsistence, and thus, remain engaged in low-income or subsistence agriculture [7]. For these rural dwellers, peri-urban accessibility and synergistic connections between markets of different sizes can contribute to poverty reduction and create channels for pro-poor income generation [14,37], increase agricultural income, and reduce inequalities between agricultural and manufacturing-based incomes [29]. Urban and rural market access metrics are difficult to disentangle [36], as centralized markets rely on the production and transportation of food, which is inherently a spatially diffuse activity occurring in rural areas and influenced by rural markets [21]. Additionally, small-holder farmers contribute significantly to existing markets, as demonstrated by the 95% of horticultural produce being grown by farmers in Kenya [44]. Market access is often a large hindrance to growth, as food is difficult and expensive to transport and may spoil along the journey [17,44,45]. Existing transportation barriers fragment food production and distribution operations into “marketsheds”, which increase costs and reduce the welfare of both producers and customers [11]. This is exemplified by the fact that nearly 50% of African farmers live five hours or more away from markets [46]. Yet, rural transportation interventions have displayed positive impacts on market access, and the achievement of efficient access to markets is often visualized as an important method to improve the wellbeing of the world’s rural poor [8,12,20,24,47,48]. The economic benefits of rural transportation infrastructure are largely related to market access, which has been shown to increase household consumption and income, human capital and local GDP, and also boost agricultural production [20,25,31,35,40,48]. In alignment with this, the aforementioned Nicaraguan study found that newly implemented trail bridges significantly reduced un-

certainty in market access for rural farmers who continued agricultural work after the intervention, and their farm-based income increased by up to 75% [25].

Transportation is a core component of food security in rural areas in LMICs [21,49]. Food is an essential good that requires spatially diffuse production, is bulky and perishable, and is difficult to move [27,50,51]. Beyond access to markets and technologies, farmers in rural areas are heavily dependent on their yields for subsistence and personal consumption. In Uganda, 58% of households across the country are defined as existing in subsistence, and up to 80% of households live in subsistence in particular districts [21]. In rural areas, costs are high and income levels are low, resulting in a large fraction of total expenditures accredited to food supplies [21]. Additionally, rural houses tend to consume substantially less, and are generally less food secure than houses which are nearer markets, which is directly influenced by transportation [20]. The most rural households also have the least diverse and healthy diets [20]. However, as the benefits related to increased rural transportation infrastructure involve access to markets and non-farm work, these benefits also include improved food security [49] and per capita food consumption [39]. Despite little discussion about transportation and food security in previous reviews, the significance of the relationship has been highlighted by ReCAP and the Partnership on Sustainable, Low Carbon Transport (SLoCaT), by directly linking rural transport to SDG 4, which endeavors to achieve food security and zero hunger [4]. This is illustrated further by a report estimating that the 70% increase required in food production to feed the global population in 2050 could be halved if post-harvest losses were eliminated, which largely occur due to transport inefficiencies [44].

Another dimension of the literature focuses more directly upon transportation costs, and describes them as both a major impediment to development in Africa and other developing contexts [21] and a central component of economic theory [11]. Transport costs generally decrease with the integration of additional transportation infrastructure in rural areas [8,16,30,31,44,46,52]. However, evidence has pointed to ambiguous pathways by which transport costs are related to market access and economic activity [20], and further, has shown that transport costs can both newly arise and begin to increase as new services emerge or grow in tandem with new infrastructure [33]. Other evidence references additional underlying mechanisms of transport costs such as road quality [44], fuel costs [12], and overall asset management [53]. Further, researchers have suggested expanding economic analyses beyond transport costs to examine trade costs, and methods by which a reduction in trade costs may increase income in rural areas [11,14,54].

Alongside the previously described benefits, review papers have acknowledged that within rural transportation, agricultural and economic impacts can vary across contexts [7–9]. Firstly, a lack of data, information, and standardized reporting processes related to road conditions, transportation costs, usage, and perceived benefits makes the overarching impacts difficult to measure [11,43,48,55], especially without incorporating biases [52]. Similarly, there does not exist a perfect, nor universally utilized, indicator for economic wellbeing, and thus, multiple metrics must be considered in unison to develop a realistic understanding of the impacts of rural transportation and associated interventions [11,33]. Accordingly, recent reviews document several economic indicators that serve as measurements of impacts, many of which may be represented per capita or on a community-wide basis [7–9]. Another difficulty within rural transportation and agro-economics is endogeneity [11,35,48], which refers to the non-random placement of transportation infrastructure that causes researchers to debate whether rural roads support and stimulate rural economic growth, or whether rural economic growth emerges via other, “natural” means and then attracts allocation of new infrastructure [11,20,43,54]. This is partially caused by the construction of new infrastructure, or maintenance of existing works occurring in strategic and profitable locations, as determined by implementing and governing organizations [31,34]. Accordingly, scholars have reported difficulty in understanding the underlying mechanisms of rural transportation economics [20], despite observing positive trends in many contexts [7].

Recent reviews report that the greatest benefits of new rural transport infrastructure could be realized in areas with low road density [9]; however, impacts are seemingly most significant in close proximity to newly implemented infrastructure, with diminishing returns for the most remote rural dwellers [8,9]. The complexity of externalities related to growth in certain areas may lead to only marginal benefits for the poorest households [7,8]. Several sources mention that larger impacts from rural transportation interventions are likely to be seen in less-remote rural areas that are in closer proximity to urban centers [9,12]. Those who are considered “non-poor” are more likely to reap benefits, as they have the resources to take advantage of new infrastructure, unless implementations are specifically designed to address and consider poor and vulnerable groups [7,8]. Accordingly, a Cameroonian study showed that increased road connectivity led to a 33% increase in income for households classified as “above median income” but had no effect on households classified as “below median income”, which exemplifies the suggestion that rural transportation infrastructure may not lead to structural changes [33], and further, may exacerbate social inequities in certain situations [15]. In this way, the debate continues about the capacity for rural transportation infrastructure to be a catalyst of systemic economic change and to alleviate poverty in rural areas [7,9].

There are vast benefits for rural communities in economic and agricultural sectors accredited to rural transportation infrastructure [7–9,11], including improvement in labor market and agricultural market access, increased access to agricultural inputs, reduction in transportation costs, and improved food security. However, the improvement of rural transportation infrastructure is a necessary but not sufficient condition for poverty alleviation [7–9], and the literature still deliberates upon the underlying mechanisms of rural economic networks [11,43]. These results do not discourage progress, but encourage closer examination of the systems that create these dynamics at a local level [43]. Future research in this arena should investigate the overlapping peri-urban space, as migration becomes increasingly common and the lines between rural and urban areas are further blurred. Additionally, approaching rural agro-economics with a food security lens will become increasingly important as populations grow, the climate changes, and food production becomes a greater priority. Lastly, promoting pro-poor interventions and integrations in rural economic systems will become an important branch of future work. Overall, economic benefits will remain a powerful means of attracting further research and investment into the rural transportation sector, and transportation contains great potential to contribute to scalable poverty alleviation in rural areas of LMICs. Table 1 provides a summary of key points related to the impacts of economics and agriculture while Table 2 summarizes future research recommendations.

3.2. Policy and Governance Impact and Implications

Rural transportation infrastructure and services require planning, funding, maintenance, and regulation, coordinated through transport-specific policy and governance on a local, national, regional, or international level [2,7,56–61]. Generally, there is agreement within the literature that transport policies often display limited effectiveness and sustainability [58], due to a host of challenges experienced by governments in LMICs, including varying levels of political commitment, accountability, benevolence, capacity, and fiscal efficiency [62]. In response, leaders within the sector, such as ReCAP and SLo-CaT, have produced literature and key messages directly addressing the governance of rural transportation, calling for increased and improved funding and commitment to rural access, as well as localization of policies, strategies, and action plans specifically in rural and disadvantaged communities [49]. Additionally, many studies propose new tools, guidelines, and methodologies of collecting data, projecting theoretical outcomes, and advising evidence-based policy and decision making [1,57,60,63–65]. Further, many sources concur that governments have overlooked the importance of transport services, unrealistically expecting the private sector to fill this gap [7,47,66]. Lastly, despite trends toward decentralization of governance and support of localized government within recent

years [56], the poorest of the poor continue to miss out on the benefits of infrastructure and transport-based investments [7,58]. In recognition of these challenges, authors advocate for a “rights-based” method of governance that ties transport and policy together by addressing transportation as a precondition that is distilled from, and directly impacting peoples’ access to, basic human rights [67]. However, effective transportation policies are often lacking in developing countries, and often fail to address the specific challenges and opportunities presented by the rural context due to an urban focus [47,56,65].

Previous review papers have generally acknowledged investment in rural transportation infrastructure as a primary output and display of policy and governance [7,8]. Investment in rural roads has positive benefits in many respects [7,8], yet newer studies have shown that there are nuances and difficulties attached to large-scale rural transportation financing, and emphasize examining the social benefits of investment returns, beyond just economics [7,41,62,63,67–69]. Financing is one of the most prominent and thoroughly studied components of transportation policy and governance in LMICs [9,62]. Generally, it is thought to be the responsibility of the central governments of LMICs to subsidize infrastructure interventions [62], with potential financial help from development organizations or multilaterals [2]. However, vast gaps exist between projected needs and actual funding. For example, in 2019, global spending on road transport from the world’s top 10 official development finance (ODF) donors amounted to approximately USD 10.4 billion, and yet, the Africa Infrastructure Country Diagnostic claimed that funding needs for road infrastructure in Africa alone can reach up to USD 18 billion annually [11]. Therefore, it is frequently suggested that governments of LMICs create a consistent revenue stream to fund rural infrastructure investments, such as tolls or fuel taxes [2], yet this is rarely seen in practice, especially in rural and poor areas [56,62,69]. The impetus placed upon governments is motivated by evidence included in previous review papers suggesting that investment in rural roads has delivered broad benefits, including high levels of economic return and poverty reduction when compared to other forms of public spending, especially in countries with low road network densities [7–9]. Additional research has echoed the value and potentially transformative nature of rural transportation investment on sustainable development in LMICs. However, authors are wary about the difficulties of fully understanding and addressing the complex factors that determine the cost-benefits, cost-effectiveness, and ability to reach rural people [9,56,62,69]. While construction costs and engineering inputs can be calculated with relative ease, evaluating the benefits of infrastructure projects is a considerably more difficult and nebulous endeavor [11]. Investments into different interventions have different levels of effectiveness in different contexts [7], in part due to varying levels of institutional weakness, including commitment-, finance-, and benevolence-related issues across contexts [62]. Previous reviews have focused on investment specifically in rural roads, and only briefly discussed investment in other interventions such as trails and trail bridges [7–9]. Recent literature has continued this trend and expanded to include results that support funding of maintenance of bridges and culverts, and general “spot-improvements” in rural road networks [63–65,70–72]. Overarchingly, the financial component of rural transportation governance is quite complicated, and relies heavily upon the management and mitigation of institutional weaknesses, which tend to compound and result in ineffective financing or project choice [62].

Table 1. Summary of economics and agriculture impact of rural access.

Key Point	Evidence	Location	Data
Improved rural transportation infrastructure supports improved access to agricultural technologies for rural people who depend on agriculture for both income and subsistence	Aggarwal, 2018; Berg et al., 2018; Brooks and Donovan, 2020; Damania et al., 2016; Hine et al., 2019; M.N., 2017; Olagunju and Akinbile, 2020; Shamdasani, 2018; Workman et al., 2020	India, Kenya, Nicaragua, Nigeria, Sub-Saharan Africa, Tanzania	<ul style="list-style-type: none"> - In Nicaragua, an increase of nearly 60% in farmers' spending on intermediate inputs [pesticides and fertilizers] was observed after the construction of a new bridge [25]. - A study using data from Nigeria found that a 10% increase in transport costs reduced the potential of a farmer using mechanized techniques by 2.4% [30].
Improved rural transportation infrastructure supports improved access to non-farm work for rural people, which, in turn, increases their income	Akkoyunlu, 2015; Alder et al., 2018; Ali et al., 2015; Asher et al., 2019; Brooks and Donovan, 2020; Bucheli et al., 2018; Charlery et al., 2015; Gertler et al., 2019; Gollin and Rogerson, 2014; Hine et al., 2016, 2019; Hine, 2017; M.N., 2017; Maparu and Mazumder, 2017; Seng, 2015; Spey et al., 2019; Starkey and Hine, 2014; Yamauchi, 2016; Yeboah, 2015	Nepal, Nicaragua, India, Cameroon, Indonesia, Ghana, Cambodia	<ul style="list-style-type: none"> - Asher et al. found that a new road decreased the share of workers in agriculture by 9% and created an equivalent increase in wage labor [41]. - In Indonesia, improved roads led to an 8.5% decrease in the likelihood of working in the agriculture sector for each log point increase in road quality [29]. - In Cameroon, road access led to a 38% increase in total household income due to a 63% increase in self-employment and wage labor [33].
Improved rural transportation infrastructure supports increased income for rural people who do not move out of agricultural work, or who depend on agriculture for subsistence	Aggarwal, 2018; Akkoyunlu, 2015; Alder et al., 2018; Ali et al., 2015; Asomani-Boateng et al., 2015; Berg et al., 2018; Brooks and Donovan, 2020; Bucheli et al., 2018; Gertler et al., 2019; Gollin and Rogerson, 2014; Hine, 2017; Hine et al., 2016, 2019; Kanu et al., 2014; M.N., 2017; Njenga, 2014; Porter, 2014; Starkey and Hine, 2014; Stifel et al., 2016; Stifel and Minten, 2017; Workman et al., 2020	Indonesia, India, Kenya, Sub-Saharan Africa, Ethiopia, Nepal, Nicaragua, Ghana, Tanzania	<ul style="list-style-type: none"> - Bringing collection points 0.5 km closer to rural farms in Tanzania led to a rise in net farm income of 4.25% [42]. - In Nicaragua, newfound access supported by the presence of a newly constructed bridge increased farm-based profits by 75% [25].
Rural transportation infrastructure supports food security for rural people	Afolabi et al., 2016; Ahmed et al., 2017; Cook et al., 2017; Gollin and Rogerson, 2014; Njenga, 2014; Seng, 2015; Stifel and Minten, 2017; Workman, 2018; Workman et al., 2020	Ethiopia, Kenya, Cambodia, Bangladesh, Tanzania	<ul style="list-style-type: none"> - Stifel and Minten found that remote houses in Ethiopia had less diverse diets, were more food insecure, and overall consumed 55% less than houses nearer to markets [20]. - Gollin and Rogerson showed that in a model economy, a 10% increase in agricultural total factor productivity and a 10% decrease in transport costs would lead to a 20% decrease in the amount of people engaged in subsistence agriculture, improving both welfare and food security [21].
Improved rural transportation infrastructure generally lowers transportation costs, but the relationship is complex	Aggarwal, 2018; Ali et al., 2015; Asomani-Boateng et al., 2015; Damania et al., 2016; Donaldson, 2018; Geddes, 2019; Gollin and Rogerson, 2014; Hine, 2017; Hine et al., 2016; Kanu et al., 2014; Njenga, 2014; Olagunju and Akinbile, 2020; Russ et al., 2017; Spey et al., 2019; Stifel and Minten, 2017	Cameroon, Kenya, Nigeria, Ghana, Ethiopia, India	<ul style="list-style-type: none"> - A 10% increase in the quality of rural roads in Nigeria led to a 12% increase in crop production output and a 2.2% increase in overall household income [16]. - In Cameroon, 69% of survey respondents claimed that construction of a new road raised transportation costs [33].
Rural economic dynamics related to rural transportation are difficult to understand due to varying contexts and measurements, and concepts such as endogeneity	Aggarwal, 2018; Ali et al., 2015; Banerjee et al., 2020; Berg et al., 2018; Donaldson, 2018; Hine et al., 2016, 2019; Russ et al., 2017; Shamdasani, 2018; Spey et al., 2019; Starkey and Hine, 2014; Stifel et al., 2016; Stifel and Minten, 2017; Storeygard, 2016	Nigeria, Ethiopia, India, Sub-Saharan Africa, China	<ul style="list-style-type: none"> - After gaining new road access, 55% of Cameroonian survey respondents stated that their crop sales stayed the same, yet 31% of survey respondents reported that their crop sales increased [33]. - A study examining the impact of transportation infrastructure on economic development in China found that regions closer to transportation networks had higher levels of GDP per capita but also had higher income inequality [43].
The poorest of the poor often have the most difficulty in realizing the economic and agricultural benefits of rural transportation infrastructure	Asomani-Boateng et al., 2015; Hine et al., 2016, 2019; Meijer, 2018; Spey et al., 2019; Starkey and Hine, 2014	Cameroon, Ghana	<ul style="list-style-type: none"> - New road connectivity in Cameroon led to a 33% increase in total income of households that earned "above median income", but had no impact on houses that earned "below median income" [33]. - Starkey and Hine (2014) cite a study from Nepal that found new roads increased income of "disadvantaged" groups by 15% but "non-disadvantaged" groups' income increased by as much as 37% [7].

Table 2. Future research recommendations for economics and agriculture.

Recommendation	Evidence
Examine peri-urban areas and the trends of urbanization and migration to augment understanding of rural economics and transportation	Akkoyunlu, 2015; Alder et al., 2018; Gollin and Rogerson, 2014; Maparu and Mazumder, 2017
Improve data collection and analysis to lead to deeper understanding of complex rural economic dynamics interlaced with rural transportation infrastructure	Ali et al., 2015; Banerjee et al., 2020; Hine et al., 2016, 2019; Russ et al., 2017; Starkey and Hine, 2014; Storeygard, 2016
Integrate a food security lens into study of rural economics and agriculture related to transportation infrastructure	Ahmed et al., 2017; Cook et al., 2017; Gollin and Rogerson, 2014; Njenga, 2014; Seng, 2015; Stifel and Minten, 2017
Focus on pro-poor methods and interventions that make benefits accessible for the poorest rural dwellers	Asomani-Boateng et al., 2015; Hine et al., 2016, 2019; Meijer, 2018; Spey et al., 2019; Starkey and Hine, 2014

There is substantial evidence pointing to data and informational gaps that are limiting the extent to which investments can impact rural communities [56]. Previous review papers initially suggested that data gaps existed with regard to supporting policymakers' decisions [7,8], and newer research concurs but also addresses the vast dependence of prioritization and planning of transportation interventions upon relevant data [11,60]. Information supporting the initiation of interventions as well as examining their impacts can be both exceedingly difficult and expensive to acquire [11,60]. Recent literature also acknowledges that governments often have different bodies that collect and manage data, and may have additional bodies based upon the classification of particular infrastructure [73]. In some situations, however, funding and resources may be limited enough that relying on estimation or secondary data is more effective. Overall, it is suggested that regardless of the data collection methods, rural transportation investments should be grounded by comparative and empirical analyses that help to ensure the maximum benefit is reached by use of the available resources [11,56]. Increased access to data by policymakers will help to relieve the financial information asymmetry that contributes to institutional weakness [62].

A consequence of a lack of evidence-based transport policy for rural communities is the tendency for the poorest people in a given community to miss out on the benefits of rural transportation infrastructure and services altogether [7,8,58]. Despite the larger populations of poor community members in rural areas [67], review papers have acknowledged that those who benefit from new roads, and any services that develop as a consequence, will typically only be those who can afford to do so [7]. Evidence has noted that local elites are often better situated to experience benefits such as saved costs, increased productivity, added land value, and increased access to social services than the rural poor [67]. Additionally, government "non-benevolence" often favors these wealthier community members over their comparatively poor and rural counterparts [7,62]. A related phenomenon is called "cream-skimming," which suggests that only the most profitable interventions are financed, systematically leaving out the poor [62]. Often, this occurs because the data regarding the impacts of rural transportation investments upon the poorest of the poor is lacking [7], and in this way, transport governance without specific "pro-poor" approaches and methodologies may actually exacerbate inequality in rural areas [7,67]. In response, authors have suggested decentralized management of rural transportation infrastructure, which can more accurately and effectively respond to the needs of rural populations [56,65]. Aside from this, very few strategies and examples of pro-poor policymaking and rural transportation interventions exist. One of the few is Vietnam's significant public spending on transportation in the late 1990s and early 2000s. An impact evaluation from 2002 positions the intervention as directly pro-poor, evidenced by explicitly pro-poor strategization found in all stages of the project, which resulted in the poorest 40% of households experiencing some of the strongest impacts of the intervention [67]. An additional example is found in the Beni-Jomsom-Sadak road constructed by the Nepali Army, as it helped increase

the income of the poorest households in the area by 28% and had a neutral impact upon wealthier households [38].

Conclusively, policy and governance play enormous roles in the direction of rural transportation infrastructure and services, and are intertwined with many basic human rights, such as access to water, sanitation, healthcare, and education. Carefully planned and comparatively analyzed investments should continue to produce cross-sectoral and multidimensional benefits, if based on thoughtfully collected and managed data and evidence. Future research should expand upon the non-monetized benefits realized through interventions, and expand political frameworks to consider services and universal coverage as priorities. Authorities should focus on continuing the general trend of decentralization of governance seen in the past three decades [56], in an effort to incorporate local and context-specific solutions, especially related to a changing climate [2,63,74]. Pro-poor policies and financing mechanisms should be prioritized [67], and rural–urban linkages should be examined for their contributions to growth [37]. Rural transportation’s emergence as a sector in its own right should be acknowledged and supported at a policy level to continue utilizing infrastructure and services as vectors for sustainable and inclusive development in LMICs. Additionally, combatting governmental non-benevolence will be an important step in ensuring that the rural poor are adequately served by transportation infrastructure. Table 3 provides a summary of key points related to policy and governance while Table 4 summaries future research recommendations.

3.3. Health Impact

Access to healthcare is a multidimensional metric [75]; however, physical (or geographic) access is consistently described as one of the most critical components of access to healthcare globally [76,77]. The literature shows that lack of physical access remains a dominating factor in decreased utilization of healthcare services which, in turn, propagates negative health outcomes [77–85]. Previous transportation sector review papers have noted the substantial evidence that depicts time, distance, travel mode, and infrastructure as combining transport-related factors that result in the decreased usage of healthcare services and negative health outcomes [7–9]. Access to healthcare is widely considered to be a basic human right [85,86] and a pillar of sustainable development [84]. However, physical access remains an issue, especially in rural and high poverty areas within LMICs [77,81]. These communities are systematically left out of the majority of health services [87] by the geographic bias of healthcare centers and corresponding transportation networks toward wealthier and more populous urban centers [83,88,89]. Subsequently, in large part due to transportation-based issues, many people in rural and impoverished communities simply go without healthcare services [90], and therefore, face immense health challenges [76,86,91]. However, previous reviews of existing evidence have found positive correlations when investigating the impacts of rural road improvement upon healthcare access in rural communities [8,9].

While previous reviews suggest that the medical literature downplays the impacts of transportation on rural health [7], there now exists a host of evidence about communities facing geographic barriers to healthcare around the world. Many publications from both medical- and transportation-based sources point to transportation obstacles as significant barriers to care [92–99]. Often, publications use distance to describe a lack of access [78,80–85,90,100–104]. The concept of “distance decay” [76,105] suggests that utilization of healthcare services decreases as the distance required to reach them increases. However, in LMICs, the Euclidean [geometric straight line] distance between a person’s place of dwelling and place of healthcare is typically an inaccurate indicator of their ability to access healthcare [84,91,102]. In many circumstances, time is a more accurate metric for measuring access, as it considers the details of travel more closely [77,78,84,89,91,103,106]. The mode of travel and the status of transportation infrastructure are critically important factors that influence the amount of time required for access [82,86,102,107–109]. Many poor rural families do not own vehicles, cannot afford to hire vehicles [110] and are not within

reach of public transportation systems that typically only follow patterns of commerce [90]. Thus, the available modes of transportation are often less advanced, and people are left to rely upon low-technology and high-effort options, compounding the burdensome and time-consuming nature of their journeys [84,86,101,110–112]. Additionally, an ill or injured person, or an adult traveling with children, will have decreased ability to travel via these means, and doing so can be slow, dangerous, or life-threatening [81,82,84]. Furthermore, limited road networks, poor quality of roads, and precarious terrain may also restrict travel mode options, and decrease the prevalence of public transportation services [81,82,113]. In accordance, the World Health Organization (WHO) recommends using time over distance as the primary metric for measuring physical access specifically because of varying modes of travel, unpredictable routes, challenging infrastructural situations, and seasonal changes related to accessibility [78,84,107,108]. Despite the WHO's recommendation, which dates back to 2001 [114], there is no universally agreed-upon standard for acceptable travel time to medical care. Within the literature, standards for timely access can range from 30 min to 60 min [84], and even up to 2 h, as used by a WHO report examining travel time to reach emergency obstetric care in Burkina Faso [115].

Additional research expands upon previous reviews by showing examples of circumstances where health outcomes were affected by a lack of access, namely limited tuberculosis testing in Ghana [79], decreased immunization rates in Nepal [103], and increased mortality coupled with decreased life expectancy in rural Brazil [100]. The evidence in medical- and transportation-based sources describing geographic barriers to care is plentiful and continues to grow, yet the evidence of infrastructure interventions directly improving healthcare usage and resulting in positive healthcare outcomes is less substantial, and largely anecdotal [7]. Additional sources have added to the anecdotal pool of evidence, such as a report that notes improvements in access to healthcare via the creation of a community-run bus service in Sri Lanka [116]. Sectoral reviews have begun to expand upon existing evidence by including various studies, which show that improved transportation infrastructure increases vaccination rates, attendance at hospitals, use of birth attendants, use of latrines, access to preventative care, access to clean water, use of contraceptives, and reductions in morbidity [8,9]. Beyond these reviews, a small number of studies exist confirming the positive impacts of road improvement projects, such as a 10% increase in post-intervention hospital access in Ghana [12], and a 30% increase in post-intervention access to medical facilities in India [117]. Additionally, a study in Cambodia showed an increase in the availability and usage of public transport to reach healthcare after a road improvement project [86].

Previous review papers have shown that women and children are disproportionately affected by transportation-based barriers to healthcare, as confirmed by significant evidence from the medical and transportation fields [7–9,118–131]. A 2017 meta-analysis examining Sub-Saharan Africa found that women traveled, on average, 15 km and 108 minutes walking to reach skilled child birthing services, far beyond a 5 km maximum walking distance for heavily pregnant women, and a reported 60 minute WHO maximum travel recommendation for pregnant women [132]. Geographic access to care has been described as the single greatest contributor to maternal mortality [113], and accordingly, access to maternal care has previously been described as the greatest perceived benefit of improved roads for women [8]. It is known that distance is a disincentive for women in seeking care [102,110,133,134] and usage of health facilities for skilled care at childbirth was found to be inversely correlated with the distance and time women were required to travel [132]. Limited use of skilled care for childbirth poses a tremendous issue for both maternal and child survival and is, thus, a critically important aspect of sustainable development [105]. In addition, previous reviews have noted that access to an all-season road can have significant positive impacts for women with regard to their awareness of contraceptives [9].

Table 3. Summary of policy and governance impact and implications of rural access.

Key Point	Evidence	Location	Data
Investment into rural transportation infrastructure is a primary function of governance with significant benefits for rural dwellers, yet nuanced complexities	Afukaar et al., 2019; Ali et al., 2015; Asher et al., 2019; Banwatt, 2014; Barrett et al., 2017; Berg and et al., 2017; Bukhari, 2020; Espinet et al., 2018; Estache et al., 2015; Hine, Sasidharan, et al., 2019; Hine, Starkey, et al., 2019; Hine et al., 2016; Modinpuroju et al., 2016; Starkey and Hine, 2014; Sustainable Mobility for All, 2019; Viet Nguyen et al., 2017	Vietnam, Mozambique, India, Pakistan, Ghana, Morocco, Sub-Saharan Africa	<ul style="list-style-type: none"> - In Morocco, a total investment of USD 3.3 billion over 17 years lifted the country's rural access index (RAI) from 43% to 79%. Considering Morocco's population at the time, this amounted to a cost of more than USD 100 per person [2]. - In 2019, a total of USD 10.4 billion was spent globally on road transport by the world's top 10 official development finance (ODF) donors, yet the Africa Infrastructure Country Diagnostic states that that funding needs for road infrastructure in Africa alone are up to USD 18 billion annually [16].
Improvements in data collection, processing, and management can improve policymaking and investment related to rural transportation infrastructure	Ali et al., 2015; Espinet et al., 2017; Es-tache et al., 2015; Hine, 2014; Hine et al., 2016; Starkey and Hine, 2014; Transport and ICT, 2016	Mozambique, Tanzania	<ul style="list-style-type: none"> - Household surveys documenting rural access in Tanzania covered only 3917 households in 409 villages across the country, developing a very limited representation of rural access across the country's 950,000 square kilometers of land area [1]. - Costs of road roughness and GPS data collection instrumentation on vehicles can cost between USD 8000 and 12,000, limiting these tools' accessibility and ability to support policy [56].
The poorest members of communities are the most frequently overlooked by most rural transportation governance and policy	Afukaar et al., 2019; Banwatt, 2014; Charlery et al., 2015; Estache et al., 2015; Golmohammadi, 2018; Hine et al., 2016; Starkey and Hine, 2014	Vietnam, Ghana, Nepal	<ul style="list-style-type: none"> - A "pro-poor" example of rural transportation policy, the Vietnamese Rural Transportation Strategy, was observed to most significantly impact the poorest 40% of rural dwellers across the country [67]. - Another pro-poor example is from Nepal, where the Beni-Jomsom-Sadak road helped increase the income of the poorest households in the area by 28% and had a neutral impact upon wealthier households [38].

Table 4. Future research recommendations for policy and governance.

Recommendation	Evidence
Examine means of data collection and analysis that can support improved policymaking within rural transport to further extend the benefits of rural transportation infrastructure, to include services, and to benefit the poorest members of communities	Afukaar et al., 2019; Ali et al., 2015; Espinet et al., 2017, 2018; Es-tache et al., 2015; Golmohammadi, 2018; Hine, 2014; Hine et al., 2015, 2016; Iimi and Rao, 2018; Modinpuroju et al., 2016; Starkey and Hine, 2014; Talpur et al., 2014; Transport and ICT, 2016
Investigate decentralization of governance to support needs and priorities of local communities, including adaptation to climate change	Espinet et al., 2018; Hine, 2014; Schweikert, Chinowsky, Kwiat-kowski, et al., 2014; Sustainable Mobility for All, 2019

The relationship between rural transportation and access to healthcare has been intensively studied, yet new research has shown increased nuance and illuminated particular areas that require additional analysis. Another future inquiry lies within the suggestion that increased connectivity may result in increased transmission of communicable diseases, contributing to negative health outcomes [8,9]. Future research will need to tackle the deeper social and cultural inequities and inequalities [136]. Additionally, improved ambulances and systems of emergency health present a promising subject for further research in this sector, as they are important for child birthing and other emergency reproductive health needs [137–139]. Lastly, disadvantaged groups within communities, such as those living with disabilities, should be prioritized, as evidence shows that people living with disabilities experience geographic barriers to healthcare acutely [103,104,140–143]. Research from Thailand found that physical disabilities severely limited people’s movement, unless they could afford to hire transportation, which was rarely possible [109]. However, future research should include expanding upon the examination of mobility, health, and disabilities, to support inclusive transportation infrastructure interventions and address the needs of disabled community members directly. Table 5 provides a summary of key points related to health while Table 6 summaries future research recommendations.

3.4. Gender Impact

Rural transportation infrastructure, and corresponding services, may appear to impact entire populations equally, yet there exists wide agreement within the literature that the effects are heavily gendered [136,144–146]. Men and women do not reap the benefits of transportation infrastructure equally, as specific gendered challenges may limit women’s ability to utilize infrastructure and services. Further, ongoing gender inequity and inequality delay development progress in low-income countries [136,146,147]. Infrastructure interventions, especially those that are “gender-blind” [144,146,148], often lean toward men’s needs and result in the continuation of the status quo, propagating inequalities along gender lines [136]. The opposite perspective, “gender-aware” approaches, which tackle typically unspoken issues of gender upfront, recognize underlying social trends, and acknowledge distinct mobility needs have been transformational in certain cases [144]. Correspondingly, mobility has been recognized as a key dimension of gender equality [149], and interventions that support women’s mobility have been shown to influence more egalitarian attitudes about gender in rural communities [150]. Previous review papers have briefly acknowledged that there are benefits specific to women, which are evidenced by positive correlations between improved transport infrastructure and an increase in educational, health-based, and economic opportunities available to women [8,9]. Further, previous review papers have pointed out that rural men and women travel differently, in terms of frequency, distance, and purpose [7], and recent research has shown that these differences produce different perspectives about needs and benefits from transportation infrastructure [144,145,149]. In accordance, projects such as the Gender Mainstreaming research initiative from ReCAP have emerged to place explicit attention on gendered transportation issues and build upon the limited evidence base of gender-disaggregated transportation information and perspectives [144,151].

Table 5. Summary of health impact of rural access.

Key Point	Evidence	Location	Data
There are significant transportation-based barriers to rural peoples' access to healthcare, namely, the distance and time involved in travel, the mode of travel, and the infrastructure used during the journey	Abihiro et al., 2014; Agbenyo et al., 2017; Akullian et al., 2016; Ashiagbor et al., 2020; Benevenuto et al., 2019; Carrasco-Escobar et al., 2020; Chen et al., 2017; Devkota and Panda, 2016; Dos Anjos Luis and Cabral, 2016; Ebener and Stenberg, 2016; Faier-man et al., 2015; Forrester et al., 2016; Garchitorena et al., 2020; Idei and Kato, 2020; Juran et al., 2018; Kapwata and Manda, 2018; Kassaw Tegegne et al., 2018; King et al., 2018; Kironji et al., 2018; Lankowski et al., 2014; Makanga et al., 2017; Neely and Ponshunmugam, 2019; Ouko et al., 2019; Ouma et al., 2018; Re-shadat et al., 2018; Schwitters et al., 2015; Shamaki et al., 2017; Starkey and Hine, 2014; Strasser et al., 2016; Sulemana and Dinye, 2014; Tanou and Kamiya, 2019; Tansley et al., 2017; Titus et al., 2015; Ussiph and Kofi, 2017; Varela et al., 2019; Verma and Dash, 2020; WHO, 2001; Yasuoka et al., 2018	Burkina Faso, Sub-Saharan Africa, Malawi, Mozambique, Nigeria, Ghana, Brazil, South Africa, Iran, Nepal, Uganda, Madagascar, Peru, Cambodia, India, Rwanda, Sierra Leone, Kenya, Tanzania	<ul style="list-style-type: none"> - In Peru, the median travel time to primary, secondary, and tertiary health facilities was 1.9–2.3 times longer in rural areas than urban areas [77]. - A study covering Sub-Saharan Africa found that only 7 of the 48 countries in the region had less than 50% of the population within a two hour travel range of public emergency healthcare facilities [106].
The availability of rural transportation infrastructure is directly related to peoples' access to healthcare and, thus, impacts their health outcomes	Asomani-Boateng et al., 2015; Benevenuto et al., 2019; Costa et al., 2017; Devkota and Panda, 2016; Hine et al., 2016; Hine, Sas-idharan, et al., 2019; Idei and Kato, 2020; Kanuganti et al., 2015; Kuupiel et al., 2019; Starkey and Hine, 2014	Ghana, India, Cambodia, Nepal, Brazil, Sri Lanka	<ul style="list-style-type: none"> - In eastern Ghana, it was found that 62% of the population had to travel over 10 km to access diagnostic testing for diseases such as tuberculosis [79]. - In Brazil, the under 5 mortality (per 1000 births) was up to 44% higher in rural areas compared to the number in urban areas within the same state [100].
Women and children are disproportionately affected by limited access to healthcare caused by compounding transportation-based barriers	M. Ahmed et al., 2018; Alam et al., 2016; Aoun et al., 2015; Fis-seha, 2017; Fogliati et al., 2015; Hanson et al., 2017; Hine et al., 2016; Hine, Sasidharan, et al., 2019; Karra et al., 2017; Kenny et al., 2015; Kumar et al., 2014; Mahiti et al., 2015; Mugo et al., 2018; Munguambe et al., 2016; Ouko et al., 2019; Panciera et al., 2016; Parajuli and Doney, 2017; Ruktanonchai et al., 2016; Shah et al., 2015; Shamaki et al., 2017; Starkey and Hine, 2014; Tanou and Kamiya, 2019; Treacy et al., 2018; Vadrevu and Kan-jilal, 2016; Wong et al., 2017; Yasuoka et al., 2018	Burkina Faso, India, Nepal, Liberia, East Africa, Tanzania, Nigeria, Sierra Leone, Rwanda, Ethiopia, South Sudan, Bangladesh, Sub-Saharan Africa, Kenya	<ul style="list-style-type: none"> - In 2015 alone, over 300,000 women died from childbirth complications globally, with 99% of the deaths occurring in low- and middle-income countries. According to Ouko et al., poor geographic access to healthcare services is the single biggest contributor to maternal mortality rates [112]. - In Northeast Ethiopia, only 18.4% of mothers reported delivering their youngest child in a health facility, with distance from the nearest facility being the most common reason for home births [135].

Table 6. Future research recommendations for health.

Recommendation	Evidence
Investigate the occurrence of increased transmission of communicable diseases due to increased accessibility from rural transportation infrastructure	Hine et al., 2016; Hine, Sasidharan, et al., 2019
Examine social and cultural inequities and inequalities limiting women’s ability to gain benefits from rural transportation infrastructure	Bradbury and Porter, 2020
Address emergency health and medicine components of rural transportation such as ambulances	Dennis and Pullen, 2015; Jackson et al., 2017; Ramadany, 2017
Develop inclusive relationships between rural health and rural transportation infrastructure that serve community members with disabilities	Akullian et al., 2016; Badu et al., 2018; Devkota and Panda, 2016; Eide et al., 2018; King et al., 2018; Munthali et al., 2017; Vergunst et al., 2015

Employment is directly related to men and women’s daily travel patterns and usage of transportation infrastructure, and is in itself gendered. Limited transport and transportation infrastructure exacerbates gender roles that make entrepreneurship difficult [152], and limit women’s work to domestic and agricultural duties [148]. A disproportionate level of household duties fall on women, who embark upon shorter, but more frequent trips, as they are typically burdened with activities such as the collection of water and firewood [28,144–146,149,153–155]. Women frequently travel with dependents [148], and because they have less access to vehicular travel than men, often walk further and rely upon more basic infrastructure such as footpaths and trail bridges to complete household chores [144]. Women are more likely to be responsible for unpaid care [or household] work [136,148], which results in exclusion from other economic opportunities [144], and keeps them physically distanced from formalized work opportunities [151]. This type of travel caused by gendered work and social standing also negatively affects women’s food security as compared to men [156]. Because of this overburden, women’s economic gains and status in society are restricted [155]. However, a theory of change derived from a systematic review suggests that improved mobility can enhance women and girls’ economic advancement via access to formalized opportunities [149]. Further, studies based in India have examined the impacts of rural transportation infrastructure on women’s employment and economic gains, finding positive correlations, and generally showing that women are more likely to find paid work outside of their homes or farms when transportation infrastructure is improved on a local level [150,155]. Evidence from Bangladesh shows that improving rural access can improve women’s economic status by providing women with the opportunity to develop micro-, small-, and medium-sized enterprises [28]. Additionally, research from Nicaragua showed that rural trail bridges allowing new and safe access resulted in a 60% increase in women entering the labor market [25]. Further, there is substantial evidence pointing to the benefits of the inclusion and employment of women in rural road maintenance, construction, rehabilitation, management, and planning, affirmed by previous review papers [7,149,153,157]. Via this inclusion, women can realize short-term economic benefits [7,146], but also long-term entrepreneurial opportunities, and see progress towards higher social status and development of their agency through expression of specific needs in infrastructural planning and implementation processes [7,149,153,157,158].

Women often find themselves reliant upon public transportation in contexts where female vehicle ownership is not socially accepted [136], or when they are culturally restricted from using particular intermediate modes of transportation (IMTs) such as bicycles [7,144,148,154]. Yet, public transportation is typically less accessible for women and girls due to the cost and the types of trips that they need to make [144,145,149], and difficulties are compounded by safety and security concerns [146,148,153,159]. In accordance, a lack of access to safe transportation has been suggested to be a main barrier for women’s access to the labor market [160]. Further, gender-based violence is common in public trans-

portation services and urban periphery areas [7,149], and provides a significant roadblock to women's mobility overall [148]. Security concerns have been described as a main factor impacting women's travel decisions [149]. Increased transportation infrastructure also adds to the amount of traffic and cash that flows through particular areas, to which violence and harassment have been attributed as unforeseen byproducts [148]. Clearly, underlying sociocultural norms play a role, and emphasize the importance of rural transportation interventions and systems that take gender-aware approaches to specifically and distinctly address women's safety and security concerns [144,147,148,157,161–163].

Despite the significant amount of evidence and encouraging progress contributed to the rural transportation sector concerning gender from groups such as ReCAP, future research should expand to directly incorporate gender into policies and practices, and acquire gender-disaggregated data to support and enforce policy decisions [28,147,157,161–164]. Gender mainstreaming has been termed an obligation and responsibility of the transport sector, warranting radical change [136]. In this way, women's perspectives should be included more closely and genuinely [137], in order to break down the "invisibility" that women routinely experience in conversations of policy, planning, and management [146,147,151,163]. Gender-specific monitoring and evaluation of projects and policies will be a crucial step in developing both equity and accountability [152,163]. Further, gender impacts should be considered alongside other vulnerabilities that can exacerbate transportation issues, such as disabilities and marginalization of particular ethnic groups [153,163]. Additionally, and while incorporating gender-aware approaches, interventions will need to specifically address men's perspectives and overarching power with regard to women's mobility, as men play a critical leading role in the success, failure, and change of future interventions in the transportation sector [149,164]. Lastly, there is a dearth of information describing gender-based transportation issues outside of the gender-binary classification. Expanding perspectives to incorporate gender fluidity and non-binary experiences of gender will be a valuable step in making rural transportation interventions and services inclusive and sustainable for all in the future. Table 7 provides a summary of key points related to gender while Table 8 summarizes future research recommendations.

3.5. Education Impact

Education is considered a basic human right, a key to long-term poverty reduction, and its importance for all aspects of developmental progress is reinforced by the inclusion of SDG 4 [165]. Despite these benefits that are vastly accepted by governments, NGOs, and economists [166], a variety of barriers to education persist, demonstrated by the 17% of adolescents and youth globally that are not in school [167]. Transportation infrastructure plays a critical role in ensuring that both students and teachers can access and utilize schools [168,169]. However, previous review papers describing rural transportation infrastructure and its impact upon education have only begun to elucidate evidence and useful conclusions. A positive correlation between transportation infrastructure and various educational metrics is mentioned, and nuanced concepts such as employment tradeoffs and teacher absenteeism are briefly discussed [7,9]. Beyond this, however, the evidence base for educational impacts with regard to increased transportation infrastructure connectivity is weak and warrants additional research [8].

Table 7. Summary of gender impacts of rural access.

Key Point	Evidence	Location	Data
Improved rural transportation infrastructure can support the expansion of women's employment opportunities and, thus, their economic status overall	Abhishek et al., 2020; Adeel et al., 2017; Bradbury and Porter, 2020; Brooks and Donovan, 2020; Casabonne, 2015; Grover, 2019; Gupta et al., 2018; Lei et al., 2017, 2019; Mason et al., 2017; Naybor et al., 2016; Plymouth University, 2014; Saleh and Nahiduzzaman, 2016; Sherpa et al., 2020; Starkey and Hine, 2014; Tanzarn, 2019, 2020; Tumbahangphe, 2016	Nepal, Peru, Nicaragua, India, Bangladesh, Tanzania, Uganda, Pakistan, Argentina, Côte d'Ivoire, Ethiopia	<ul style="list-style-type: none"> - A Nicaraguan study showed a 60% increase in the number of women entering the job market after the installation of a new bridge [25]. - In India, it was found that in communities with egalitarian gender norms, women's chance of non-farm employment increased by 78% when the community was connected with rural roads, while men's non-farm employment was not significantly affected [150].
Sociocultural norms impact women's ability to reap benefits of rural transportation infrastructure through biases and issues of safety	Abhishek et al., 2020; Adeel et al., 2017; Casabonne, 2015; Costa et al., 2017; Gupta et al., 2018; ILO, 2017; Jenkins, 2020; Mulongo et al., 2020; Naybor et al., 2016; Njenga and Tanzarn, 2020; Nyangueso et al., 2020; Starkey and Hine, 2014; Tanzarn, 2019, 2020; Tumbahangphe, 2016	Pakistan, Uganda, Nepal, Peru, Argentina, Nicaragua, Ethiopia, Kenya, Tanzania, Liberia, Sierra Leone	<ul style="list-style-type: none"> - Five times more women (60%) than men (12%) were responsible for the gathering of water in Ghana, vastly elongating their travel times and restricting their modes of travel [144]. - An analysis in Pakistan found that of 120,000 trips, women were 4 times less mobile than men, accounting for 20% and 80% of the trips, and 21% and 79% of the trip duration, respectively [145].

Table 8. Future research recommendations for gender.

Recommendation	Evidence
Incorporate concepts of gender, including genuine considerations of both men’s and women’s voices and perspectives, directly into policy and practice related to rural transportation infrastructure	Abhishek et al., 2020; Bradbury and Porter, 2020; Grover, 2019; Gupta et al., 2018; Hada, 2020; Jackson et al., 2017; Jenkins, 2020; Mulongo et al., 2020; Njenga and Tanzarn, 2020; Nyangueso et al., 2020; Saleh and Nahiduzzaman, 2016; Tanzarn, 2020; Tumba-hangphe, 2016
Examine gender-disaggregated data, monitoring, and evaluation of projects and policies to support improved equity and accountability	Mulongo et al., 2020; Plymouth University, 2014
Investigate gender and transportation issues alongside other social vulnerabilities	Casabonne, 2015; Mulongo et al., 2020
Expand the concept of gender within transportation to include non-binary and gender fluid experiences	

Multiple aspects of rural transportation become important when examining its relationship to education. Factors that make school access difficult can combine and interact in a way that is described as the “distance cost” of attending school [170]. In many cases, the physical distance alone is enough to negatively impact educational enrollment and attainment [169,171]. Evidence from rural China describes an average commute of up to 5 km for a primary school [171] and a study from Brazil mentions commutes of up to 12 km [172]. Further evidence from Brazil shows that a longer journey to school, even in urban areas, directly correlates with decreases in educational performance [173]. Beyond distance, travel mode also represents a critical aspect of distance cost, and rural community members are often relegated to low-tech options such as walking [172,174,175]. Walking to school is indicative of both geographic isolation and socioeconomic status, as evidenced in data from South Africa that showed 81% of students in rural areas and 85% of commuters from the lowest socioeconomic quintile walked the entirety of their commutes to school. Walking these distances can negatively impact school attendance, as shown in Nepal, where students who walked their commutes to school demonstrated higher dropout rates in more rural areas [174]. A third factor in defining the cost of attending school is safety, which directly affects the ability and willingness of students to make the journey. Dynamics of safety that rural people are forced to consider as they commute to schools daily include pavement quality, lighting of roadways [86], overall length of the journey [165,166], weather events, and animal attacks [172]. Additionally, the infrastructure itself affects the distance cost of attending school [86]. A study in India found that much higher poverty rates and lower rates of educational attainment existed in the nearly half of the country’s rural villages that [in 2001] were not connected by all-season roads [176]. Beyond connectivity, or quantity of roads and infrastructure, the inferior quality of aging and decaying roads and infrastructure contributed to an increased distance cost in rural Brazil [172].

Despite the multidimensional transportation barriers between students and schools, a small number of recent studies show that improved infrastructure can help to decrease distance costs and improve educational outcomes. An Indian study that focused on the construction of new feeder roads displayed a 7% increase in post-construction enrollment [176]. Similarly, a small but positive correlation between road density and primary school enrollment was shown in Namibia [177], and improved roads in Cambodia led to increased numbers of teachers in schools [86]. Additional evidence shows that improvements in road infrastructure can support encouragement of community usage of the infrastructure as well as creation of transport services, such as an increase in familial interest in purchasing two-wheeled vehicles to help children travel to school more easily and consistently in Cambodia [86]. Generally, these results are in line with recent reviews that also show positive correlations [8,9].

Several recent studies have illuminated an important component of the relationship between rural transportation infrastructure and education: the tradeoff between human cap-

ital and short-term profit opportunity costs. In previous review papers, the critical nuance presented in this tradeoff has only very briefly been discussed [7–9]. When new roads are constructed in villages, community members become connected to educational institutions, but they are also directly connected to labor markets. In many circumstances [31,176,179], newfound exposure to labor markets can decrease both enrollment and attainment as boys and girls as young as 12 years old find low-skill employment to supplement their families' incomes. Often, children leave school early to pursue work in businesses run by their parents or other household members [86]. While these circumstances are heavily dependent on localized market structures and opportunities, they are also impacted by both cultural norms and policy in rural areas that may advocate for education over immediate profit [176].

There are gendered aspects to be considered with regard to education and transportation. Generally, women have lower access to transportation methods and services [178], and education is traditionally less valued for girls, meaning they will reap less benefits of improved transport infrastructure for schools [170,179]. However, gender-specific interventions can be effective, as displayed by the results of an Indian study that showed a 32% increase in age-appropriate enrollment for girls, as well as a 12% increase in girls passing the secondary school certificate exam when the girls were given bicycles to help access schools [170]. Additionally, a study in Brazil found that school attendance for girls increased after rural roads were improved [180]. Beyond these studies, however, increased evidence is required to improve substandard educational opportunities for girls globally.

Generally, there exists a positive correlation between improved transport infrastructure and education as described in new evidence as well as in recent review papers [7–9]. However, the overall pool of evidence is still relatively shallow, and calls for additional investigation. A component of future study should focus on increasing directness and decreasing the cost of transportation to school, by identifying transportation programs and policies that function in parallel with other interventions [172]. Additionally, while many authors still support the construction of new schools over the construction of roads as the most effective intervention [166,168,169,174,181], future research should further investigate this approach and associated costs and benefits. Table 9 provides a summary of key points related to education while Table 10 summarizes future research recommendations.

3.6. Environmental and Climate Change Impact and Implications

Climate change presents one of the greatest challenges to achieving the SDGs by 2030 [182,183]. As a major catalyst for over half of the SDGs, and a specific target of SDG 11, rural transportation infrastructure will function as a “lifeline” for poor rural communities as the “deep uncertainty” of climate change manifests [4,59,63,183,184]. The impacts of climate change upon rural transportation infrastructure are only briefly referenced by previous review papers [9], yet the immensity and inevitability of changes are widely agreed upon in subsequent literature [185–190]. Similarly, the widely acknowledged social and economic benefits of rural transportation infrastructure, as described throughout previous sections of this paper, are a point of agreement within the literature. However, researchers concur that these benefits have the potential to be decreased or eliminated as extreme weather events and changes in sea levels, temperatures, and precipitation become increasingly intense and commonplace in the near future [4,59,74,182,183,188–194]. In this way, tradeoffs between rural socioeconomic benefits, transportation finances and investment, and environmental effects will complicate the means by which climate impacts are mitigated. Methods that protect benefits for rural dwellers will require adaptations to the changing climate that incorporate context-specific considerations of the various tradeoffs [59,74,183,190,195,196].

Table 9. Summary of education impacts of rural access.

Key Point	Evidence	Location	Data
Significant transportation-based barriers impact rural children's ability to access education	Adukia et al., 2020; Carvalho, 2016; Damon et al., 2016; Glewwe and Muralidharan, 2016; Haepp and Lyu, 2018; Idei et al., 2020; Mbiti, 2016; Mokiti and Vanderschuren, 2017; Muralidharan and Prakash, 2017; Sharma and Levinson, 2018; Tigre et al., 2017	India, Brazil, Cambodia, China, South Africa	<ul style="list-style-type: none"> - In Nepal, students who walked to school showed higher dropout rates in more rural areas [174]. - In South Africa, a study showed that 81% of students in rural areas and 85% of commuters from the lowest socioeconomic quintile walked the entirety of their commutes to school [175].
Improved rural transportation infrastructure supports rural communities' access to education	Adukia et al., 2020; Hine et al., 2016; Hine, Sasidharan, et al., 2019; Idei et al., 2020; Lu-cas, 2019	India, Namibia, Cambodia	<ul style="list-style-type: none"> - A study from India estimates that connecting a village with a new paved road can increase middle school enrollment by 7% over the following three years [176]. - In Cambodia, the rates for both primary and secondary education were lowest, 41.2% and 5.9%, respectively, amongst households that owned no two-wheeled vehicles, showing a relationship between educational attainment and transportation [168].
Improved rural transportation infrastructure can decrease incentive to access education by providing direct access to labor markets and increased income	Abu-Qarn and Lichtman-Sadot, 2019; Adukia et al., 2020; Aggarwal, 2018; Hine et al., 2016; Hine, Sasidharan, et al., 2019; Idei et al., 2020; Starkey and Hine, 2014	India, Israel, Cambodia	<ul style="list-style-type: none"> - Aggarwal found that newfound road access had a negative effect on school enrollment for 14–20 year olds, reducing enrollment by 11% as teenagers joined the local workforce instead of attending school [31]. - Starkey and Hine (2014) cite an earlier work by Aggarwal, also suggesting that improved rural transport infrastructure decreased enrollment for kids aged 14–20 who instead found work opportunities [7].
Gender-specific approaches to the relationship between rural transportation and education can be critical in ensuring access to education for rural women and girls	Abu-Qarn and Lichtman-Sadot, 2019; Bhattarai et al., 2020; Iimi et al., 2015; Muralidharan and Prakash, 2017	India, Israel, Brazil, Nepal	<ul style="list-style-type: none"> - A study from India showed a 32% increase in age-appropriate enrollment for girls, as well as a 12% increase in girls passing the secondary school certificate exam, when the girls were given bicycles to help access schools [170]. - In Nepal, it was found that boys had a higher school attendance rate than girls, and urban girls attended school at a rate 6 percentage points higher than rural girls [178].

Table 10. Future research recommendations for education.

Recommendation	Evidence
Expand the relatively limited amount of evidence relating rural transportation infrastructure and education	Hine et al., 2016; Hine, Sasidharan, et al., 2019; Starkey and Hine, 2014
Investigate further the debate between the construction of schools and the construction of roads in support of rural education	Glewwe and Muralidharan, 2016; Idei et al., 2020; Masino and Niño-Zarazúa, 2016; Mbiti, 2016; Sharma and Levinson, 2018

Climate change will disproportionately affect poor communities, and especially those in LMICs that already have minimal infrastructure and services [59,74]. For example, countries such as Ethiopia, where 84% of districts are classified as vulnerable to climate change due to a combination of frequent exposure to disasters and already limited rural accessibility [197], will be especially in need of cross-cutting adaptation from pervasive sectors such as transportation. As such, much of the available literature regarding climate change and rural transportation infrastructure discusses proactive and wide-reaching techniques for climate change mitigation. Strategies such as increasing and institutionalizing maintenance of road networks and building redundancy into transportation networks [63,186] embrace mitigation as an opportunity to protect and bolster access, rather than just a challenge [59,183,190]. Similarly, the Africa Community Access Partnership (AfCAP), a component of the ReCAP initiative, was developed to build upon the capacity of transportation authorities across Africa with a heavy focus on climate adaptation. The AfCAP initiative has worked to develop both engineering and non-engineering methods for mitigation, to expand the relatively scarce planning data that exist across Africa, and to develop specific links between climate change and rural transport infrastructure [187]. Further, authors have suggested particular tools that involve satellite imaging, geographic information systems [GIS], and spatial data, to aid in the mapping of climate change impacts, as well as both infrastructure and community vulnerability [197]. Generally, other suggestions include adjustment of planning criteria, specific construction materials, methods, and standards, and addressing transport services themselves. Overall, strategies should be backed by resilient and specific designs that are allocated in situations with individualized and contextualized economic and feasibility analyses [59,63,74,182–184,186,194,197].

Researchers hypothesize that approximately 25 million km of new roads will be constructed by 2050 [196], with a large amount, potentially as high as 90%, being constructed in LMICs [15,191,198]. In many of these locations, roads will be constructed in some of the world's last remaining pristine wilderness areas, despite evidence that roads attract new forms of activity which directly impact land usage, forest cover, and particular species, and may contribute to larger-scale environmental degradation [9,15,191,192,195,196,198,201]. Accordingly, new evidence suggests moving away from reactive approaches to environmental damage limitation [201] and supporting conservative and proactive enforcement strategies that minimize irreversible effects without prohibitively expensive post-construction modifications [191,195,196]. Environmental Impact Assessments [EIAs] can be useful tools in certain cases [201] and the construction of roads in particular areas where substantial socioeconomic benefits are realized with only minimal environmental damages may be an applicable solution for authorities in LMICs with limited funds and organization [191,194–196,202]. Areas with biodiversity and carbon-sequestering significance can be largely protected from the cascading effects of transportation infrastructure through bolstered legislation and enforcement [196], though some authors argue that these are imperfect solutions [195,201]. Encouraging governments to tackle even small environmental protection actions in a timely fashion, by promoting specific goals and objectives and including positive reinforcement, has been successful in particular circumstances [203]. The complexity of the associated balancing act will warrant cooperation and collaboration between political frameworks, ecological experts, and rural infrastructure planners [9] to

effectively manage the trade-offs between social and economic benefits in the short term and environmental impacts in the long term [198].

Transportation is culpable for 23% of global energy-related carbon dioxide emissions annually, and trends predict that the global number of light-duty vehicles will double by 2050, with the largest increases in India and southeast Asia [199]. Accordingly, non-motorized and pedestrian infrastructure and services are becoming popularized as a potential means of continuing socioeconomic transportation benefits in urban areas and reducing carbon emissions with limited costs [199,200,204]. Non-motorized traffic represents a majority in many cities of Africa and Asia [200], where upwards of 60% of the population [on both continents] is expected to live in cities by midcentury [45]. However, future work in the sector should consider exploring the applicability of IMTs and non-motorized or pedestrian transportation in rural settings, as urbanization expands and reduces the boundaries between urban and rural areas. Presently, these strategies have yet to expand beyond the confines of the urban context and remain focused in the megacities of the global south such as Bangalore, India. However, placing an emphasis on pedestrian infrastructure in low-income urban areas has proven beneficial for low-income communities in those areas [204] and, thus, the translation to low-income rural settings presents a logical topic for future inquiry.

Especially in poor rural areas, which are dependent on minimal transportation infrastructure, finding context-specific means to adapt to climate change and mitigate negative effects will be a priority in coming years [198]. A balance between short- and long-term costs and benefits will be required [194], as well as collaboration between multisectoral bodies that can ultimately combine to drive thoughtful policy-making activities [59,71,74]. Adaptive concepts that integrate climate modeling, mitigation techniques, and methods of maintenance into infrastructure design, planning, and policy will need to continue to gain traction in global discussions [74,185,186,197]. Additionally, consistent and thorough management of transportation resources with regard to climate change will give governments potential leverage points to influence development and poverty at large [74,187]. In this way, future planning should utilize the strengths of local people, who can provide a valuable perspective in ongoing discussions, including their capacities and the impacts on their livelihoods, and should be involved in all stages of this process [9,183,205]. Expanded data will be useful in informing policy change [187,197], and may be supported by innovations such as satellite imagery [15,51]. Closing the gap between mitigation and adaptation research and associated actions and policies should be a priority within engineering, policy, and infrastructural planning [59,74,183,190,206] and will require unified strategies across international, national, and sub-national levels [187]. Table 11 provides a summary of key points related to climate change and environment while Table 12 summarizes future research recommendations.

Table 11. Summary of climate change and environment.

Key Point	Evidence	Location	Data
Mitigating the impacts of a changing climate on rural transportation infrastructure will preserve and extend the benefits for rural people	Arnold et al., 2018; Chinowsky et al., 2015; Espinet et al., 2018; Maritz et al., 2019; Schweikert, Chinowsky, Espinet, et al., 2014; Schweikert, Chinowsky, Kwiatkowski, et al., 2014; Srinivasan et al., 2018; Verhaeghe et al., 2019; Wiggins and Gongera, 2017	Mozambique, Zimbabwe, Africa, Ethiopia, South Africa, Bangladesh, Malawi, Zambia	<ul style="list-style-type: none"> - Maritz et al. states that the African continent is facing a direct liability of USD 150 billion to repair and maintain existing roads damaged by temperature and precipitation changes directly linked to climate change [189]. - Arnold et al. states that approximately 90% of Ethiopia's road network is composed of dry-weather roads that are not usable during the rainy season due to inadequate crossings [197].
Extension of rural transportation infrastructure requires evaluation of environmental impacts and tradeoffs to minimize negative environmental impacts and contributions to climate change	Asher et al., 2020; Chinowsky et al., 2015; Damania et al., 2018; Healey et al., 2020; Hine, Sasi-dharan, et al., 2019; Laurance et al., 2014; Meijer, 2018; Montgomery et al., 2014; Perz, 2014; Pfaff et al., 2018; ReCAP, 2018	Mozambique, Malawi, Zambia, Brazil, Indonesia	<ul style="list-style-type: none"> - It is predicted that 90% of all new road construction will occur in developing nations, often in regions with critically important biodiversity and ecosystems [191]. - Following the construction of a new highway in India, Asher et al. found a 20% decline in forest cover in a 100 km band around the highway [198].
Improvement of infrastructure compatible with intermediate or non-motorized traffic may become a critical leverage point for reducing carbon emissions and environmental impacts related to transport globally	Creutzig et al., 2015; Pojani and Stead, 2015; Rahul and Verma, 2018; ReCAP, 2020	India	<ul style="list-style-type: none"> - One study claims that the infrastructural investment savings for low-carbon transport could be as high as 20 trillion USD globally by the year 2050, with non-motorized transport playing a significant role [199]. - Pojani and Stead report average non-motorized trip distances of 1 km in Latin America and 2.1 km in Southeast Asia, showing a useful contribution to carbon emission reduction [200].

Table 12. Future research recommendations for climate change and environment.

Recommendation	Evidence
Continue investigation into dynamic, evidence-based, policy-driven, locally specific, and multistakeholder mitigation and adaptation techniques that preserve the benefits delivered by rural transportation infrastructure	Arnold et al., 2018; Asher et al., 2020; M. Burrow, 2014; Cervigni et al., 2016; Chakwizira, 2019; Chinowsky et al., 2015; Hine, Sasidharan, et al., 2019; Maritz et al., 2019; Meijer, 2018; Paige-Green and Verhaeghe, 2018; Robert-son et al., 2015; Schweikert, Chinowsky, Espinet, et al., 2014; Schweikert, Chinowsky, Kwiatkowski, et al., 2014; Verhaeghe et al., 2019; Workman, 2018

4. Review of Rural Transport Interventions, Strategies, and Approaches

Throughout the available literature in the rural transportation sector, a variety of interventions, strategies, and approaches are mentioned. Many of these activities are commonplace in their implementation around the globe, and provide insight into activities, regarding physical infrastructure and beyond, that have substantial associated benefits for rural dwellers as described thematically in previous sections. Existing review papers have suggested that analysis of different types of interventions is a useful mode of investigation in order to provide planners with context [7] and to attract investment and further research. Yet, the limited existing literature outlines the informational and research-based gaps between and within interventions that, when investigated further, may lead to expanded benefits for poor rural communities. The following sections serve to compile and categorize relevant evidence regarding rural transportation interventions, strategies, and approaches and their effectiveness across different circumstances. Each section contains tables similar to previous sections that outline both key points and recommendations for future research.

4.1. Rural Roads

In an attempt to extend the benefits that rural transportation infrastructure can bring to communities [7–9,207], particular experts have honed their focus onto pieces of the rural transportation system that serve different functions [208]. Rural roads are a widely discussed strategy that may also be referred to as feeder roads, tertiary roads, low-volume rural roads (LVRs), community-level roads, village-roads, and lower class roads [34,38,209–213]. Despite varied interpretations of rural roads across different contexts [214], characteristics such as a limited traffic volume [214,215], low travel speeds [216], limited levels of engineering [such as sealing and drainage] [2,216], and a focus on first [or last] mile mobility challenges appear routinely [217]. According to the literature, rural roads provide impacts in the “first mile” of a community, which refers to the area farthest from the market when considering the flow of agricultural goods from rural areas toward populous market areas. Similarly, rural roads are powerful interventions in the “last mile”, which refers to the area closest to the rural habitation when considering the flow of goods and services outward from urban centers toward rural communities [218]. Because of the focus on these areas, many authors have supported investment into rural roads as a more cost-effective and impactful implementation for the poorest members of rural communities than investment into the main components of the road network [48,217,219]. Recent review papers have also articulated this point and reinforced the ability of rural roads to specifically target the poorest and most isolated communities in LMICs, especially in countries with low road densities [7,8]. To this end, authors have recommended that researchers, governments, and donors place a more concerted effort on rural roads in an attempt to support social equality and address multidimensional poverty [220–222]. Agencies such as ReCAP have developed manuals regarding the implementation, maintenance, and management of LVRs in countries such as Afghanistan and Myanmar [223,224]. Governments in countries such as India, Ethiopia, Liberia, Rwanda, and Ghana have rolled out massive feeder road campaigns aimed at providing and sustaining socioeconomic benefits for rural dwellers [41,208,209,219,221,225]. Despite substantial evidence in support

of these interventions, the complete impacts of expanded rural roads still warrant further research [213,215].

In Sri Lanka, India, and Ghana, low-volume roads represent 70%, 58%, and 50% of the total road network, respectively, and serve large portions of the populations despite seeing low vehicular traffic [215,222,226]. As contributors to improved mobility for large populations within rural and isolated areas, rural roads directly support the poorest members of communities, who are at a “transport disadvantage” and frequently miss out on the benefits of larger and more major transportation infrastructure due to proximity or financial constraints [7,207,209,222]. Therefore, some authors have suggested that rural roads yield greater contributions to social welfare than higher-level and more engineered roads, and can be described as a “pro-poor” intervention [8,51,207,227]. Recent review papers acknowledge that rural roads can be more effective in reducing poverty than roads of higher standards, and may reduce poverty up to three times more per unit of investment than tarmac roads [7,8]. Specifically, rural roads support an increase in living standards by providing stimulus to poor areas that are reliant upon agriculture-based economics [216,227]. Focusing on the first and last mile of communities, rural roads help to decrease costs of transportation between rural villages and markets, supporting both agricultural production and market activity [8,218,227]. In continuation and expansion of these beneficial trends, evidence suggests the concept of poverty-centered allocation of funds for rural road creation and prioritization. Generally, this strategy employs the use of a socioeconomic lens when considering the benefits and priorities of rural transportation [209], intending to aid policymakers and rural road authorities to further capitalize on the characteristics of rural roads that drive poverty alleviation by employing a clear focus on social dynamics and impacts [221].

Strategically implementing rural roads in LMICs is a challenging endeavor. Typically relying on limited engineering, basic materials, and being constructed without prior technical appraisal, rural roads often require substantial maintenance that can be difficult to effectively deliver in environments with limited resources and institutional organization [211,215,222,226,228]. Further, road construction in many LMICs is often driven by political connotation and lacks formalized strategy, which limits the positive impacts that may be cultivated for rural dwellers [221]. Yet, despite challenges, several national governments of LMICs have embarked upon large feeder road construction campaigns, including the aforementioned PMGSY project that was initiated in 2000 with the objective of providing new access to an all-weather road for unconnected villages across India [41]. The project focused on all villages with a population of at least 500 people and excluded all roads not defined as village roads or other district roads [31]. The program linked unconnected villages either to other villages with improved, all-weather roads, or directly to market centers [34]. Similarly, in Ethiopia, the Universal Rural Road Access Programme (URRAP), funded and organized by the central government and technically supported by regional governments, has constructed thousands of rural roads connected to isolated woredas and kebeles [Ethiopia’s smallest administrative units] since 2010 [2,209,227]. The mobility potential of the communities has increased significantly as areas previously only accessible on foot are now accessible by motorized vehicles [209]. Studies about the URRAP project have shown that the project has contributed to increased household-level welfare by connecting remote communities to main networks and markets [227]. Recent review papers add that building upon the limited road density that pre-existed in Ethiopia has been a factor in the success of the URRAP project, which planned originally to build over 70,000 km of new roads and increase the country’s level of rural access to about 80% [2,8].

Overall, the literature focusing on rural roads and associated impacts for rural communities in LMICs has found significant benefits, including that rural roads have increased cost-effectiveness in comparison to expansion of the main transportation network [8,207,227]. Future research considering the impacts of LVRRs in developing contexts should address the limited household-level data available regarding these impacts [38], and continue to use research to inform policy, especially regarding the prioritization of rural transportation

works [213]. Beyond this, additional inquiries may involve feeder services, which could help to increase the benefits experienced by rural dwellers who experience newfound access [7], and should address the connections between feeder roads and larger trunk network components [208]. Table 13 provides a summary of key points related to rural roads while Table 14 summaries future research recommendations.

Table 13. Summary of rural roads.

Key Point	Evidence	Location	Data
Rural roads are pro-poor interventions that can be more beneficial to rural communities than larger infrastructure in certain circumstances	Agarwal et al., 2017; Ampadu and Addison, 2017; Gamage et al., 2016; Hine et al., 2016; Kwarteng et al., 2018; Naimanye and Whiteing, 2016; Nakamura et al., 2020; Rosman, 2015; Sieber and Allen, 2016; Starkey and Hine, 2014; Workman et al., 2018	Sri Lanka, India, Ghana, Sub-Saharan Africa, Ethiopia	<ul style="list-style-type: none"> - One study claims that rural feeder roads may have internal rates of return between 12 and 35% depending on the local context [227]. - In Ghana, the feeder road network makes up 42,190 km out of 62,200 km, or 68%, of the total national road network [216].
Despite the challenges within the implementation of rural roads, there are several examples of successful programs around the world	Agarwal et al., 2017; Aggarwal, 2018; Asher et al., 2019; Gamage et al., 2016; Hine et al., 2016; Kwarteng et al., 2018; Naimanye and Whiteing, 2016; Nakamura et al., 2020; Ra-jović and Bulatović, 2016; Rolt et al., 2020; Rosman, 2015; Shamdasani, 2018; Sustainable Mobility for All, 2019	Sri Lanka, India, Ghana, Sub-Saharan Africa, Ethiopia	<ul style="list-style-type: none"> - Ethiopia's Universal Rural Road Access [URRAP] originally planned to construct and upgrade more than 70,000 km of rural roads across the country, and was observed to increase the country's RAI by 6% from 2010 to 2016 [227]. - In 2013, India had a road network of over 4,689,842 km, with 58% of those roads considered to be rural [226].

Table 14. Future research recommendations for rural roads.

Recommendation	Evidence
Address a lack of household-level data regarding the benefits of rural transportation infrastructure interventions such feeder roads	Charlery et al., 2015
Investigate services related to feeder roads and their corresponding connections to larger trunk roads	Iimi et al., 2018; Starkey and Hine, 2014

4.2. Rural Bridges

Considered to be an “invisible” component of rural transport, bridges are frequently overlooked in the rural transportation sector and receive only minimal discussion throughout the literature as locally important pieces of infrastructure [7,8,146,229]. For example, despite the estimated 330,000 bridges in existence across the region, there is no active inventory of bridges in Sub-Saharan Africa [186]. As many rural and isolated communities around the world experience limited and slow-paced investment in rural infrastructure and remain dependent on minor or trail-based infrastructure for years to come, rural bridges will continue to play a critical role in the facilitation of many socioeconomic benefits [230,231]. Defined differently based upon context and application, footbridges, trail bridges, and pedestrian bridges are critical leverage points within rural infrastructure, especially in countries with large numbers of water crossings, multiple monsoon seasons, or hilly and treacherous terrain, such as Bangladesh, Rwanda, and Nepal [8,231,232]. Within the sector, leading non-governmental organizations have developed bridge-building implementation strategies that leverage and reinforce bridges' vast utility in increasing rural access and maintaining benefits delivered by rural transportation [7,8,233,234]. Yet, despite the growing evidence backing the strength of bridges as a valuable rural transportation intervention and cost-effective investment, cultivating institutional support for

continued implementation and investment will require further research and deepened understanding [25,230,233,235].

Rural bridges are often thought of as an extension of the transportation infrastructure network, despite the active role that they play in determining the passability and functionality of important road segments [8]. In the absence of bridges, communities that rely principally on non-motorized means of mobility are frequently separated from food sources, markets, schools, and forms of income [158]. However, governments in LMICs often focus on measurements and metrics such as the RAI, which measures rural access based directly on peoples' proximity to an all-season road, and thus overlook terrain features and waterways where bridges are necessary components of the system for continuous mobility [50]. Further, many governments have limited capacity and technical knowledge for the construction of bridges, vastly limiting their ability to execute implementation and upkeep, and limiting bridges' utility [230,235]. Yet, bridges are an integral part of many countries' transportation systems, such as in Nepal, where over 7500 rural bridges exist and 450 more bridges are expected to be built every year. Similarly, bridges are critical infrastructure in Liberia, where there is an average of one bridge and three culverts per five kilometers of road [66,158]. In response to this gap left by governments and institutions, the rural bridge niche of the rural transportation sector is led largely by small NGOs. Actors such as Engineers in Action (EIA), Puentes de la Esperanza, Bridging the Gap (BtG), and Tony Ruttiman have supported the construction of rural bridges in a host of countries around the world, focusing on low-cost, community-centered approaches to increased and sustained mobility [236,237]. Further, the Belgian Development Agency (ENABEL) has partnered with local governments in Uganda and Tanzania to develop strategies and materials related to the construction of stone arch bridges that take advantage of low labor costs and material durability [238]. Moreover, particular NGOs have become global leaders in rural bridge implementation, such as Helvetas and Bridges to Prosperity (B2P), who are working to meet communities' needs through extensive application and study of bridges, and continued partnership with governing bodies, within various programs across the globe [234,239].

As leaders in the sector, Helvetas and B2P have largely vocalized and mainstreamed both communities' needs and the immense benefits related to rural bridges across the globe. Helvetas' work has advocated for bridges as essential components of rural transportation in Nepal, due to its extraordinary terrain, strong monsoon season, and multitude of water crossings that deepen the rural access challenge. Helvetas has been constructing rural bridges in Nepal for over 40 years by supporting bridge technology and implementation, as well as community capacity building and formation of partnerships with local and national governments [158,234]. Similarly, B2P has placed a focus on bridge-building in Rwanda, where hilly terrain and multiple monsoon seasons augment limited rural access and create a substantial need for improved rural transport infrastructure. Since 2012, B2P has constructed over 80 bridges in Rwanda, serving over 400,000 rural dwellers through comprehensive support in site identification, design, construction, and maintenance, and partnership with governments and institutions at multiple levels [239]. Work from both Helvetas and B2P has employed community-based labor and implementation of bridges, and has displayed success in creating immediate impacts upon local communities, including in the forms of both localized economic opportunities and a strong sense of community ownership surrounding new bridges [158,239,240]. Specifically, bridges constructed by B2P in Rwanda have helped to increase labor market income by 25% over a baseline mean [232]. In Nicaragua, B2P's bridges have increased women entering the labor market by 60%, increased welfare by 11%, and eliminated an 18% decrease in labor market earnings during flood events [25]. Further, the federal government of Nepal has credited Helvetas' rural bridge construction and improvement work with an increase in school attendance of 20% observed across the country [241].

Future evidence should emphasize the impacts of rural bridges upon isolated communities around the globe in the pursuit of further scale and substantial institutional

support [230]. To this end, B2P works actively within a research agenda related to rural transportation including usage impacts and evaluations of rural bridges, and plans to continue this work with construction of an additional 150 bridges in Rwanda and an associated randomized controlled trial study by 2023 [232,233,239]. Researchers should also consider further investigation of seasonal bridge trends, expanding on the conclusion that no apparent change in bridge usage patterns during rain events in Rwanda may suggest that bridges minimize seasonal and extreme weather-related transportation interruptions [239,242]. Additional future efforts should look toward the formalized and institutionalized maintenance of bridges [243] and toward the adaptation of bridges to climate-resilient standards [241]. In general, expansion and formalization of the place of rural bridges within the rural transportation sector, and further engagement of governing bodies, would serve well to further advocate for the improved access of rural dwellers around the globe. Table 15 provides a summary of key points related to rural bridges while Table 16 summarizes future research recommendations.

4.3. Maintenance of Existing Infrastructure

Road authorities and development agencies working in LMICs frequently attempt to cultivate the beneficial outcomes of rural transportation and alleviate the problems ascribed to minimal mobility by implementing new infrastructure [12,244–247]. As previously mentioned, up to approximately 25 million kilometers of new roads across the globe are expected to be constructed by 2050 [196]. However, substantial evidence exists suggesting that the provision of better, as opposed to new, transport infrastructure can be a critical factor supporting and sustaining socioeconomic benefits in rural and poor areas [207,217,244,248]. Repair instead of replacement of paths and minor roads may have a greater impact on poverty than improvement of the main network [207], while continued construction of new infrastructure at the expense of intermediate repairs can negatively impact long-term growth [12]. Both recent reviews and further evidence suggest that maintenance [and similarly described activities such as rehabilitation] can be a highly cost effective intervention with reported rates of return on investment of up to 40%, compared to a rate of 10% more commonly achieved through the creation of new infrastructure [7–9,207]. However, rural infrastructure authorities in LMICs often lack the necessary resources, organization, and strategy to properly maintain roads, leading to rapid degradation that both increases costs over time and counteracts benefits for rural people [4,22,211,247,249]. Accordingly, the literature has presented strategies to organize, institutionalize, and incentivize rural transportation maintenance works by advocating for increased data collection and management [58,60,249,250], improved funding arrangements [215,246], and increased participatory and community engagement [7,228,251]. In general, the intermediate improvement of existing infrastructure has the potential to provide a powerful leverage point in the rural transportation sector, by navigating around the political and economic constraints typically faced during construction of new infrastructure, and emphasizing social benefits for rural dwellers [12,246].

Table 15. Summary of rural bridges.

Key Point	Evidence	Location	Data
Rural bridges are a critical part of the rural transport infrastructure network that support and enhance rural access, especially in countries with difficult to travel terrain	Acharya et al., 2016; Alatalo, 2020; Arehart et al., 2020; ENABEL, 2013; Hine et al., 2016; Iimi and Rao, 2018; Noriega et al., 2021; Sherpa et al., 2020; Smith et al., 2017; Workman and McPherson, 2020	Nepal, Liberia, Rwanda	<ul style="list-style-type: none"> - Bridges are critical infrastructure in difficult to pass terrain, such as in Liberia, where there is an average of one bridge and three culverts for every five kilometers of road [66]. - In Nepal, over 7500 rural bridges exist and 450 more are expected to be built annually [158].
Leaders in the rural bridge sector are generally NGOs, such as Helvetas and Bridges to Prosperity [B2P], amongst others	Acharya, 2019; Brooks and Do-novan, 2020; Chhetry, 2015; Mon-tangero, 2019; Noriega et al., 2021; Sherpa et al., 2020; Thomas et al., 2021	Nepal, Nicaragua, Rwanda	<ul style="list-style-type: none"> - Bridges to Prosperity has constructed over 80 bridges in Rwanda alone serving 400,000 people since 2021. By 2023, the organization plans to build nearly 150 additional bridges across the country [239]. - Helvetas has been constructing rural bridges in Nepal for over 40 years by supporting bridge technology and implementation, as well as community capacity building and formation of partnerships with local and national governments [234].

Table 16. Future research recommendations for rural bridges.

Recommendation	Evidence
Examine further formalization and institutionalization of construction and maintenance of rural bridges by governments and other public sector bodies	Acharya et al., 2016; Ede et al., 2019; Montangero, 2019

Rural transportation maintenance is made difficult by the spatially diffuse nature of rural networks and their distance from central governance [12,244]. Additionally, rural transportation networks are difficult to evaluate in terms of condition and socioeconomic worth, which often make them low priorities for governments that are focused on high traffic volume infrastructure [252,253]. Prioritization strategies give implementing or governing agencies the capacity, insight, and opportunity to focus attention on areas where road conditions are worst and communities are poorest, which many authors have claimed brings the strongest impacts upon local welfare [12,207,217,248]. However, a standardized guide or hierarchical methodology for road maintenance is lacking in the rural transportation sector, and available approaches frequently stem out of support for a particular economic goal or political stance, which routinely results in leaving the poor behind [207,215,226,247,252]. Because of this, a widely mentioned strategy is asset management, which helps to incentivize governance by describing rural transportation infrastructure as valorized assets. Asset management both institutionalizes the acts of maintenance and facilitates hierarchical categorization by tying specific economic metrics to maintenance activities and corresponding infrastructural components. Further, this ideology works to create a holistic view of the transportation network that involves the long-term planning and preparation for maintenance that is usually overlooked by governments in LMICs and lost within fragmented approaches [53,66,246]. Effective consideration of the rural road network as a high-value national asset, by changing the perspective of the infrastructural life cycle and associated provision of resources, has worked to reduce poverty levels in LMICs via improved maintenance of rural low-traffic volume roads [4,246].

Further, the literature points to large gaps in data collection and processing as root challenges preventing effective road maintenance in LMICs [60,215,246,249,250]. Often, useful data are prohibitively expensive or difficult to acquire, and their absence results in both ad hoc and politically biased works [60,215]. As an example, only 4% of municipal road condition data is available in South Africa, causing confusion related to maintenance roles and responsibilities at that level [249]. Data classification and reporting play important roles, as recent review papers note that the description of roads as being in “poor condition” fails to incorporate potential aspects of seasonal passability, missing structures, maintenance history, or details of surface conditions [8]. Suggestions for improved data collection and processing tools and methods are abound, and include examination of road roughness, geospatial analyses, cost-effectiveness analyses, examination of distance and linkages to key facilities, and combinations of the metrics of infrastructural age, length, traffic volume, and relative importance in efforts to inform and persuade policy makers [60,64,215,226,254,255]. In this way, national databases used for prioritizing maintenance can be both initiated and bolstered using improved methods to support decision making. Improved data acquisition techniques can help to reduce maintenance costs by reducing or eliminating expenses tied to collecting and processing relevant data [249]. Further, a recently published UNESCO Engineering Report suggests that new technologies and advanced engineering applications may aid in the pursuit of the SDGs by supporting data collection for predictive maintenance of transportation infrastructure [256].

An integral part of ensuring the efficient and effective maintenance of rural transportation infrastructure is the organized and adequate allocation of funding [244,257]. Funding for maintenance, in comparison to the investments made for new infrastructure, is nearly always insufficient in LMICs [53,215,249,257–259]. Generally, this comes from an unclear division between maintenance and construction investment and occurs frequently when road investments from outside donors dry up after only a few years [8,207,217]. Limited

financial resources may also be related to non-existent or ineffective policy directing maintenance initiatives, which causes poor allocation of funds and leaves the bulk of investment directed to new construction of roads. Often, this is exacerbated by poor alignment between local and central governments even when funds are available [53,244,246]. However, authors suggest that routine maintenance should be identified as a specific component of spending priorities [228] that can be supplemented by forms of user fees such as tolls and taxes [244]. Yet, user-based income can be minimal or non-existent, or can be collected and directed toward maximized profit gain, which fails to produce an effective nexus between usage and maintenance costs as seen in many African countries [12,244,251]. To meet this need, several sources point to performance-based contracting as a particularly useful mode of creating and sustaining a culture of maintenance and effectively utilizing funds [228,246,249,257]. Generally, associating performance metrics with funding and contracts helps to cultivate particular outputs [228] and pushes toward the optimization of returns [257]. However, due to the relatively small size of maintenance contracts in LMICs, big players are often discouraged to partake [246]. Yet, positive examples of country-based management of maintenance funds do exist, particularly in Ethiopia, where the creation of a road fund in 1997 has led to the reformation of maintenance culture and improved road management across the country [251].

Authors suggest that successful and sustainable maintenance plans in rural areas of developing countries often involve engaging community members in partnership with public works groups [9,228,244,260]. In this way, local communities provide critical insight into addressing localized maintenance issues [12,261]. In the maintenance process, rural communities provide perspective and information unavailable to centralized road authorities [244,262], as they are closely in tune with particular needs and circumstances [12]. Community ownership also impacts the long-term sustainability of maintenance works, as community buy-in helps to establish day-to-day access and sustain good road conditions [251]. Further, community involvement in maintenance works can bring means of gainful employment and examples show that maintenance labor brings economic gain for women and disadvantaged groups in particular [7,12,153]. Positive examples of community-based road maintenance exist, including the application of Japanese “do-nou” technology in Kenya, which assisted the local community to maintain rural roads using local materials and expertise and initiate its own development [263]. Further, performance-contracted microenterprises often run and organized by women, provide a community-based method of maintaining roads that result in a positive feedback loop of road improvement and local income generation as seen in Nepal, Vietnam, Peru, Chile, and Nicaragua [244,261]. However, local groups can rarely afford the expenses and manage the logistics required for maintenance without additional support and reliance on community labor [251]. Despite successful cases and examples of community capacity, thoughtful management of maintenance responsibilities should still be a priority of local government, to prevent decay of infrastructure that forces repair from local people who are often unable to contribute much in terms of resources or technical knowledge [4,243,244]. Expansion and scale of community-based road maintenance schemes will require future research, advancing the techniques to encompass further communities and increasingly comprehensive maintenance procedures [260].

In sum, maintenance presents a valuable, but frequently overlooked, intervention within the rural transportation sector. By focusing efforts and available resources on the preservation of existing works, instead of creating new ones, governments, development agencies, and rural communities may be more likely to cultivate and maintain the myriad of associated benefits of rural access [217]. However, future research should look to examine the institutional issues that display insufficient maintenance as a symptom [247] and examine improved funding mechanisms and continued and scaled community engagement [244,260]. Table 17 provides a summary of key points related to maintenance while Table 18 summarizes future research recommendations.

Table 17. Summary of Maintenance.

Key Point	Evidence	Location	Data
Strategies such as Asset Management can assist road authorities in the institutionalization and prioritization of maintenance efforts, which can extend socioeconomic benefits for rural dwellers	Agarwal et al., 2017; Asomani-Boateng et al., 2015; Chamorro and Tighe, 2019; Chongvilaivan et al., 2016; Cook et al., 2017; Ellis and Menendez, 2014; Gamage et al., 2016; Geddes, 2019; Gongera and Petts, 2015; Iimi and Rao, 2018; Leta, 2019; Ludwig et al., 2016; Sieber and Allen, 2016; Streatfeild, 2017; Yamauchi, 2016	Ghana, Indonesia, Timor-Leste, Liberia, Paraguay	<ul style="list-style-type: none"> - In Paraguay, a contextualized road management strategy targeting an access rate of 80% was successful in improving road quality from a mean Unpaved Road Condition Index (UPCI) score of 3.8 to a mean UPCI score of 6.3 [252]. - Streatfeild states that each dollar saved by a government that allows road quality to deteriorate instead of performing maintenance increases user costs by USD 2–3, emphasizing the need for improved maintenance strategies [247].
Improved data collection techniques can help to reduce costs and aid in prioritization of maintenance efforts	Agarwal et al., 2017; Chamorro, 2015; Espinet et al., 2017; Gamage et al., 2016; Hassan, 2018; Hine et al., 2016; Leta, 2019; Modinpuroju et al., 2016; Saharuddin, 2019; Shrikant et al., 2016; UNESCO, 2021	Mozambique, South Africa	<ul style="list-style-type: none"> - Only 4% of the road condition data for municipal roads in South Africa are available, and the lack of data confuses maintenance coordination and responsibilities [249]. - A study in Mozambique found that using improved techniques, including technology such as smartphone apps for low-budget survey and road condition assessment, could survey and post-process data for 1560 km of roads in a total of 13 work days [60].
Performance-based contracting can be effective means for mitigating financial issues with regard to maintenance of rural transport infrastructure	Asomani-Boateng et al., 2015; Ellis and Menendez, 2014; Gamage et al., 2016; Geddes, 2019; Hassan, 2018; Hine et al., 2016; J. T. Jenkins and Peters, 2016; Leta, 2019; Ludwig et al., 2016; Mbabazi, 2019; Odoki and Odongo, 2016; Rajović and Bulatović, 2016; Sieber and Allen, 2016; Suthanaya et al., 2017	Ghana, Indonesia, Liberia, Egypt	<ul style="list-style-type: none"> - SANRAL, the South African body responsible for maintenance of 92% of the country's road network, utilizes performance-based maintenance contracting, which has resulted in only 38% of the road network being in fair to poor condition, a relatively low number compared to other African nations [249].
Partnerships with local communities can provide mutually beneficial outcomes for communities that increase their income and also support maintenance efforts of local and national road authorities	Asomani-Boateng et al., 2015; Casabonne, 2015; Cook et al., 2017; Ede et al., 2019; Ellis and Menendez, 2014; Fukubayashi and Kimura, 2014; Hine, Sasidharan, et al., 2019; Idei, 2018; J. T. Jenkins and Peters, 2016; Rajović and Bulatović, 2016; Starkey and Hine, 2014; Sustainable Mobility for All, 2017; Workman, 2018	Ghana, Liberia, Peru, Nicaragua, Argentina, Nepal, Vietnam, Nigeria	<ul style="list-style-type: none"> - The national entity responsible for road maintenance in Peru has gradually transferred responsibility to local groups, and now nearly 200 local maintenance organizations are responsible for the upkeep of over 17,000 km of rural roads [244]. - Integration of a community based maintenance program allowed communities in Kenya to improve road conditions independently for a cost of USD 5–10 per meter, as compared to traditional rehabilitation projects which cost USD 20–40 per meter [263].

Table 18. Future research recommendations for maintenance.

Recommendation	Evidence
Investigate of increased formalization and institutionalization of maintenance efforts to include improved prioritization and funding	Ellis and Menendez, 2014; Ludwig et al., 2016; Streatfeild, 2017; Sustainable Mobility for All, 2017

4.4. Non-Infrastructural Approaches

Non-infrastructural interventions augment the socioeconomic benefits that rural dwellers experience from improved rural transport infrastructure by operating as unique leverage points that address issues of isolation through different lenses. These strategies are mentioned throughout the literature as tools, concepts, and methods that may range from the employment of satellite imaging or remote sensing for data collection to the formulation and enforcement of motorcycle taxi regulations. In examination of the relationship between rural transport infrastructure and non-infrastructural approaches, and associated impacts upon rural peoples' access and mobility, this section will serve to identify and synthesize the available information regarding intermediate modes of transportation (IMTs), innovations, and transportation services

4.4.1. Intermediate Modes of Transportation

Modes of transportation (also referred to as means) are often overlooked throughout a transportation sector that focuses heavily on physical infrastructure. However, in many circumstances, intermediate modes of transportation (IMTs) provide a critically useful means of travel for rural dwellers with limited access to larger vehicles or more improved infrastructure [264]. Generally, IMTs refer to two- or three-wheeled small vehicles, such as motorcycles or tricycles, but may also include bicycles, hand or animal-drawn carts, rickshaws, or mopeds [65,149]. Despite appearing unconventional and informal as regular modes of transportation, these modes of transportation are becoming increasingly common in LMICs, and in many countries in Asia, Africa, and Latin America, most vehicles on low-volume rural roads are now motorcycles [65,251,265]. Rural dwellers often find IMTs to support their mobility and increase access as they can be easy to use, cheaper to own, and are generally less dependent on formalized or improved infrastructure [222,251,266,267]. Due to their increased maneuverability, suitability to poor roads, and widespread availability in poor communities, sources suggest that IMTs may be particularly useful for women, who may not have access to other forms of transport [7,149,268]. IMTs have been instrumental in aiding women's access to healthcare centers displayed by evidence from Burkina Faso, Tanzania, Cambodia, and Kenya [86,105,112,113]. Another aforementioned example showed that bicycle programs directed at girls in India led to increases in school enrollment [170]. However, additional sources report that cultural circumstances may prevent women from using or owning IMTs, and observation of women drivers of IMT-based services are extremely rare in patriarchal societies [7,56,161,268]. Beyond this, additional challenges related to IMTs relate to their inherent danger, such as motorcycle crashes and limited use of helmets, and often limited ability to carry cargo or travel in inclement weather which limit effectiveness in harvest seasons [56,264,267,269]. Noticing these dangers and challenges, particular governments have outlawed the usage of IMTs for transportation services, for example, in Ghana, where motorcycle taxis were banned in 2012, but they persist readily and remain commonly used by rural dwellers across the country [65]. Generally, governments, other state actors, and international donors are reluctant to allocate funds towards IMT-related projects, and the few initiatives that have been attempted have not succeeded, driving the focus of larger portions of resources on more expensive and conventional major infrastructure [56,251]. Despite this, evidence from Liberia shows that support for IMT usage and infrastructural improvements geared towards IMTs can be more cost-effective in sustaining socioeconomic benefits than traditional road improvements [270]. Moving forward, increased regulation of IMT-based services will be crucial in maintaining the benefits that IMTs bring to rural communities with limited

access to vehicular transport or improved infrastructure [271]. Further future research will focus on making IMTs useful modes of transport year-round, including harvest seasons, and improving gender integration relation to IMTs and associated infrastructure worldwide [56,268].

4.4.2. Innovations and Advanced Technologies

The literature emphasizes that up-to-date, consistent, and harmonized geospatial data are a critical tool supporting improved research, implementation, and policymaking, and suggests that the absence of these data is a major barrier for rural transport governance and investment [15,50,60]. In this way, innovations and advanced technologies that are designed to provide faster, easier, less resource-intensive, more accurate, and more cost-effective data collection are playing an increasingly vital role throughout the sector [60,63,272]. Innovative technologies and strategies are becoming increasingly useful and widely implemented in the rural transportation sector worldwide, even despite a history of technological innovations being used mainly in higher income and urban settings in LMICs [15,242,272]. In accordance, several studies have proposed and investigated the impacts of new data collection methodologies, techniques, platforms, and tools, with the objectives of reducing cost, requiring less time, effort, and professional skill, and providing policymakers with critical information. Proposed ideas have included GIS applications, adaptations to climate change, network analyses, smartphone applications developed for cross-referencing field data, satellite imagery, traffic data, interviews, and asset management, which have been researched, analyzed, and piloted across a host of contexts [57,60,63–65,74,273]. Namely, a Mozambican case study developed a methodology to prioritize rural transportation investments amidst uncertainty from climate change related disasters by utilizing geospatial data coupled with multidimensional cost-benefit analyses, resulting in low-budget and resilient improvements to the network [63]. Data collection tools used to examine road or bridge conditions and usage levels, details of particular networks, and socioeconomic impacts include motion-activated digital cameras, accelerometers, smartphone applications, satellite imaging, and may further expand into the realms of drones or other unmanned aerial vehicles [UAVs] moving forward [60,63,242,272]. Technological innovations in the rural transportation sector have begun to expand beyond data collection, and into the storage, analysis, and presentation of data, through the usage of global road databases and open-source platforms [15,50]. Open Street Map (OSM) is an example of a crowdsourced tool providing extensive geographic information that supports increasingly comprehensive global road datasets such as the Global Roads Inventory Project (GRIP). However, even crowdsourced tools such as OSM are subject to biases toward urban and more populous areas, which reiterates a need for further innovation within the collection of data in rural areas [15]. Other steps within future research may involve expansion upon the data processing capacities of computer vision, machine learning, and artificial intelligence, which could be used to automate the collection, translation, and export of rural transportation related data more accurately and efficiently [242,256,272].

4.4.3. Transportation Services

Transportation infrastructure and services are intrinsically tied together, especially in poor rural contexts with limited access, limited private vehicle ownership, and high reliance on public transport [7,57,65]. Transportation services play a critical role in making infrastructural interventions useful [4], and several authors state that rural transportation interventions are incomplete without service components [19,229]. Rural transport services may be viewed generally as means of transport used to move people and goods in rural areas, as part of full- or part-time ventures by people intending to make a profit by providing on-demand and “point-to-point” transportation for both passengers and cargo [47,264]. Generally, this includes motorized transport between village areas and markets, but can also include smaller village to village movement [47]. However, transportation services are difficult to organize in rural areas and in locations where road conditions limit their

effectiveness [19,259]. Transportation authorities and development agencies in LMICs are frequently reluctant to become involved with interventions regarding transport services largely due to costs and regulations [47]. Authorities in LMICs rarely have one governing body concerned with both transport infrastructure and services, and the groups governing services usually have less funding and capacity in comparison [65]. The tendency to overlook and underfund services is exemplified by the 98% of the World Bank's investment in transportation being focused upon infrastructure, leaving only 2% to cover services, observed as recently as 2007 [9]. To this end, evidence also points to a need for additional and more accurate data supporting rural transportation services, such as information about traffic, coverage, frequency, costs of operation, and relationships to markets [7,47,56]. Transportation services are a "forgotten problem" in rural transportation policy [47] and in accordance, review papers have noted that access interventions should be designed more holistically as a measurement of both available infrastructure and adequacy of services [7].

While there are examples of success related to new roads creating new opportunities for services, such as in the PMGSY project in India, services appear to be caught within a gap in between the private and public sectors that does not always allow new infrastructure to facilitate new services [41,222]. Unregulated and unmanaged services create a negative effect on development overall, as the service gap is largely bridged by informal management groups who focus on profits, making the services unreliable, unsafe, and prohibitively expensive for rural dwellers [47,56,229]. Often vastly dependent on IMTs, such as the booming motorcycle taxi situation in many countries, rural services can inherit the issues navigated by these modes of transportation [61,229,274]. Suggestions in the literature for improving this situation involve building upon local governmental capacity [2] and decentralization of government authorities [56], improved regulation, up-front budget allocation, and incorporating services into donor schemes, subsidies, and rural transportation investments [47]. Additionally, some sources suggest public-private partnerships (PPPs) as a means for addressing these methods of improvement [275]. Generally, improved regulation and enforcement of rural transportation services moving forward will be a crucial step in ensuring that rural populations who depend largely on informal services can safely and reliably access the benefits of these methods of transportation [61,222]. Table 19 provides a summary of key points related to non-infrastructure approaches while Table 20 summarizes future research recommendatio.

Table 19. Summary of non-infrastructure approaches.

Key Point	Evidence	Location	Data
Intermediate modes of transportation [IMTs] can provide a critical means of mobility for rural dwellers who may lack access to larger and more formal means of transportation	Afukaar et al., 2019; Asafo-Adjei et al., 2017; Bishop et al., 2018; Chen et al., 2017; Gupta et al., 2018; Hine, 2014; Idei and Kato, 2020; J. Jenkins, 2020; J. T. Jenkins and Peters, 2016; Kwarteng et al., 2018; Muhia and Bishop, 2018; Muralidharan and Prakash, 2017; Mustapha et al., 2017; Ouko et al., 2019; Peters et al., 2018; Starkey, 2016; Starkey et al., 2020; Starkey and Hine, 2014; Tanou and Kamiya, 2019	Ghana, Liberia, Pakistan, Sierra Leone, Burkina Faso, Tanzania, Cambodia, Kenya, India, Kenya, Sub-Saharan Africa	<ul style="list-style-type: none"> - A study found that in Sierra Leone, between 60 and 95% of travel on roads open to conventional vehicles, for both passengers and freight, are motorcycle taxis [161]. - In Siaya County, Kenya, motorcycles were deemed a critical mode of transportation as more than 50% of the road network was composed of tertiary roads [112].
A wide variety of advanced technology and innovative interventions can improve data collection, processing, and storage procedures that support decision making and prioritization within rural transportation	Afukaar et al., 2019; Espinet et al., 2017, 2018; Meijer, 2018; Modinpuroju et al., 2016; Schweik-ert, Chinowsky, Kwiatkowski, et al., 2014; Shrestha et al., 2014; Talpur et al., 2014; Thomas et al., 2020; UNESCO, 2021; Workman, 2017; Workman and McPherson, 2020	Mozambique, Rwanda, Ghana, Nepal	<ul style="list-style-type: none"> - In Rwanda, computer vision was used to monitor pedestrian use of footbridges, collecting a total of 33,800 daily bridge crossings with an overall error bias of only 2.63% per hour of counting [232]. - The Global Roads Inventory Project (GRIP) found of the road lengths included in their innovative global analysis, only 35% were paved and only 50% were accessible year round [15].
Rural transportation services bolster and enhance the benefits experienced by rural dwellers due to improved rural transportation infrastructure	Afukaar et al., 2019; Cook et al., 2017; Hine, 2014; Hine et al., 2015; Hine, Starkey, et al., 2019; Mbabazi, 2019; Starkey, 2016; Starkey et al., 2017; Starkey and Hine, 2014; Talpur et al., 2014; Usman, 2014	Nigeria, Ghana	<ul style="list-style-type: none"> - Motorcycle taxis in Uganda, called boda bodas, make up about 85% of traffic in rural areas providing a critical service to rural dwellers [259]. - In northern Ghana, 90% of all registered vehicles are motorcycles and motor tricycles, which are frequently used as taxis across the area [65].
Rural transportation services are often caught in a gap between the public and private sectors, resulting in limited effectiveness and, thus, limited benefits for rural people	Afukaar et al., 2017; Asher et al., 2020; Ehebrecht et al., 2018; Hine, 2014; Hine et al., 2015; Kwart-eng et al., 2018; Starkey, 2016; Sustainable Mo-bility for All, 2019; Usman, 2014	India, Nigeria, Ghana	<ul style="list-style-type: none"> - A study from 2006 found that at that time, nearly 1 billion people, or a third of the global rural population, lacked access to transport services [2]. - As recently as 2007, it was seen that 98% of the World Bank's lending for rural transport was dedicated to road building and maintenance, overlooking transport services dramatically [47].

Table 20. Future research recommendations for non-infrastructure approaches.

Recommendation	Evidence
Investigate the formalization and regulation of IMTs, including their use in rural transportation services, and their wider applicability with regard to seasons, cargo, and gender concepts	Hine, 2014; Jenkins et al., 2018; Muhia and Bishop, 2018
Expand innovative technological interventions related to rural transportation infrastructure to include the capacities of computer vision, machine learning, and artificial intelligence	Thomas et al., 2020; UNESCO, 2021; Work-man, 2017
Examine methods for improving services through regulation, local government capacity, and various funding schemes	Afukaar et al., 2017; Hine, 2014; Hine et al., 2015; Kwarteng et al., 2018; Starkey and et al., 2016; Sustainable Mobility for All, 2019

5. Conclusions

Rural transportation infrastructure is a critical component of development in isolated communities in LMICs across the globe. More formally, it is considered a vector toward the accomplishment of at least half of the SDGs, including ending poverty (SDG 1), zero hunger (SDG 2), ensuring healthy lives (SDG 3), quality education (SDG 4), gender equality (SDG 5), access to water and sanitation (SDG 6), economic growth (SDG 8), combating climate change (SDG 13), and most importantly, building resilient and sustainable infrastructure (SDG 9), which specifically includes rural transport- and mobility-based metrics within the goal [4,276]. Through connections to other sectors, and by playing an integrated and active role within these sectors, the importance of using rural transportation as a leverage point for sustainable development is clear. In this way, rural transportation has emerged into a standalone sector that is central to addressing a multitude of public challenges in a global system [2,4,7,8,56,67,69,81]. Yet, despite the progress and evidence presented throughout the literature, the rural transportation sector is not integrated [61]. As a necessary, but not sufficient, condition for poverty alleviation, rural transportation should be viewed as a critical component embedded within the aforementioned thematic sectors [7–9]. Future work should pursue increased interdisciplinary study [17], and employ systems approaches that build upon and integrate rural transport with its connections to other sectors. To this end, the lens of the provision–preservation–services continuum described in several works published by ReCAP suggests that a combined scope of investment, maintenance, and focus on services can expand the benefits that rural dwellers experience through conceptualization of the system at large. This ideology works to ensure that rural transportation investments are well-planned, cost-effective, and deeply in-tune with the needs of communities [277]. Expansion upon this idea and upon holistic and systematic views of the sector will be crucial to combine and understand the dynamics between the aforementioned themes and strategies.

In support of the pursuit of the benefits experienced by rural dwellers, further research will be required to continuously improve upon investments and interventions within the rural transportation sector. While many facets of the sector as represented by sections in this review have been studied thoroughly, additional research is clearly warranted with regard to education and maintenance. Carefully crafted future research endeavors should build upon the reviews published to date, yet also approach critical overarching issues and concepts such as policy, data collection, urbanization, and pro-poor interventions.

The rural transportation sector would undoubtedly benefit from aggregated statistics, beyond the limited and anecdotal evidence that currently exists. Further, improved data, as mentioned in many of the above sections, will be instrumental in showing correlation between improved infrastructure and other benefits such as improved health outcomes in developing contexts around the globe [7]. Specifically, future research should use improved data to support policy development and prioritization of interventions. Determining a decision-making strategy for prioritization of maintenance will be a crucial step toward effectively utilizing the limited resources and capacities experienced by most rural

transportation authorities in LMICs [58,66,153,257]. An important manifestation of this improvement is within the increased institutionalization and formalization of maintenance of all types of transportation infrastructure, with a particular focus on bridges [243].

A variety of metrics have been proposed and applied to measure the impact of rural transportation. While other intervention sectors such as water, sanitation and household energy have developed some consensus on key measures (i.e., water or air quality measures), the transportation sector has not identified consensus impact metrics. While it is out of the scope of this paper and the authors' expertise to propose common metrics, we review the current state of the interventions, metrics, and measurement outcomes identified in the literature.

Common themes that emerge from this review include direct measures of economic consumption, agricultural production, agricultural market and labor market earnings. In an ongoing randomized controlled trial in Rwanda [232], investigators are measuring these outcomes while also seeking to identify if a simple measure of consumption is sufficiently correlated to other country- and intervention-specific outcomes in a way that could be applied in other transportation contexts.

Overarchingly, rural transportation investments and interventions are politicized [222] and, thus, policy must be visualized as a tool for the propagation of improvement for rural people. Additionally, future research, investment, and interventions should be re-focused to maintain a pro-poor lens, and reinforce ideas and strategies that support benefits for the poorest of the poor in communities around the globe [7]. Lastly, the continued overlap of urban and rural areas will be a focal point of future research, as the divide between rural and urban areas is shrinking and lenses of research will have to modify their approaches to understand this phenomenon. In an era of increased migration and urbanization, it is suggested that urban and rural areas cannot be studied in isolation, especially considering the intertwined dynamics of transportation, which propel economics and support agriculture by moving people and resources in both directions [14,45].

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