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Research Report

Feasibility Study Plastic Roads Technology Transfer to Nepal

July 2023

Executive Summary

Background and Context

This research report serves as a cornerstone of the ReValue project. Orchestrated by German non-profit NIDISI gGmbH, ReValue embarks on a mission to reimagine the handling of low-value plastic waste from a liability to a sustainable resource. The project specifically targets the use of this plastic waste as a valuable additive in road construction in Nepal, leveraging a proprietary technology known as the *ReValue Method*, a collaborative development involving the Fraunhofer Institute, the University of Kassel, and EcoPals.

This report delves into road construction in Nepal, aiming to introduce the *ReValue Method* to improve waste management and road quality. It analyzes Nepal's road infrastructure, geographical, and weather conditions to customize the method for local use. The report also reviews current road construction technologies in Nepal, exploring how the technology can be integrated to enhance sustainability and efficiency.

Additionally, it investigates the local supply chains and key stakeholders in the road construction sector to identify challenges and opportunities in adopting this new technology. The socio-cultural factors influencing technology adoption are also considered, ensuring the *ReValue Method* aligns with Nepal's social and cultural norms.

In summary, the report provides a strategic framework for the successful introduction of the *ReValue Method* in Nepal, offering insights into the road construction industry's landscape to facilitate sustainable and efficient practices.

Key Findings

Road Construction in Nepal: As of mid-March 2021, Nepal had 97,105 kilometers of roads, with 33,528 kilometers constructed by the Federal Government, including 15,974 kilometers of blacktop roads. The provincial and local levels contributed to a total of 63,577 kilometers, with only 6.7% being blacktopped at the provincial level, and 47.6% federally. Regular maintenance is more frequent than new constructions or upgrades. Only 20.8% of the road network is paved, and unpaved roads, especially in hilly and mountainous regions, face safety risks due to erosion and flooding during the rainy season. Nepal's climate and topography present significant challenges to road construction, with monsoon rains affecting the construction process and road longevity. The government follows a tender process for road contracting, with a focus on cost, which often leads to a compromise in quality. Roads are expected to last only about 2 years before needing repairs, compared to 20 years in countries like Germany. The defect liability period for roads is just one year, after which the municipality bears the cost for repairs. Environmental factors, such as heavy rainfall, further degrade road quality. Contractors face financial challenges, needing to provide bid security and performance security, and often take loans to cover costs. Current road standards do not incentivize the use of additional binders or technologies to enhance road quality, leaving much room for innovation in the sector.

Technological Assessment: Cost-effective pre-mix methods using mobile mixers are prevalent for local roads, while asphalt plants are reserved for larger projects. The recent shift to asphalt for urban roads suggests a trend toward higher-quality pavement practices. Nepal houses over 100 traditional asphalt plants, but only a few counterflow drum and batch mixing plants that facilitate the addition of new materials like EcoFlakes used in the *ReValue Method*. These plants could enable higher-quality, plastic-enhanced roads without the need for new plants, only requiring machine modifications for upscaling. Worker training and managing environmental and safety risks are also critical for the adoption of such technologies. To conclude, while existing technologies can accommodate the technology, enhancements are necessary for broader implementation and quality control.

Supply Chain Analysis: Critical stages include sourcing consistent quality plastic waste, processing it into *EcoFlakes* with specialized machinery, and ensuring efficient distribution to construction sites, considering Nepal's challenging transportation infrastructure. An extra step during construction is the integration of *EcoFlakes* into

the mix, which does not significantly alter the standard process. A primary challenge is the currently limited supply of processed low-value plastic waste and the lack of facilities for large-scale production. Although there is an abundance of plastic waste, the costs of collecting, cleaning, shredding, and transporting are not offset by the sales of *EcoFlakes*, necessitating competitive pricing and significant initial investment to establish the necessary infrastructure.

Stakeholder Analysis: Private sector entities could initiate pilot projects through CSR activities, serving as key proponents for small-scale applications. Policy changes, essential for larger roads, depend on stakeholders like the Department of Roads and the Federation of Contractors Association of Nepal. Municipalities could expedite implementation by adjusting local guidelines. Construction companies prioritize low-cost methods and are open to innovations that offer cost benefits and comply with government mandates. Asphalt plants, potentially significant advocates for *Plastic Roads*, will invest in technology if mandated or cost-beneficial. Collaboration with local activists and organizations, like Green Road Waste Management, which is already promoting *Plastic Roads* and conducting relevant research, could be crucial. Together, these stakeholders can influence policy and contribute to the successful introduction and scaling of *Plastic Roads* technology in Nepal.

Socio-Cultural Considerations: The local community near the pilot *Plastic Road* in Gaindakot, Nepal, has shown a positive shift in attitude from initial skepticism to advocacy, due to the road's durability compared to conventional roads. It is emphasized that cultural barriers are minimal and acceptance is growing, as the technology demonstrates superior road quality and addresses the issue of bad roads—a significant concern in Nepal. It underscores the necessity of raising awareness for greater acceptance. However, it also highlights the need for social safeguards such as temperature monitoring and protective gear for workers to mitigate health risks, considering that Nepalese construction sites do not always adhere to the same safety standards as in countries like Germany.

Market Entry: Learning from other countries like India and Bhutan, which have successfully integrated waste plastic into road construction, Nepal's strategy includes starting with private roads and CSR projects to demonstrate the technology's viability. The roadmap involves public sector involvement for large-scale implementation, adjusting existing asphalt plants to incorporate *EcoFlakes*, and establishing a production infrastructure for Eco-*Flakes*. Training for local engineers and workers is also vital. Financially, while the macroeconomic benefits of using *EcoFlakes* are clear, their production cost is higher than the market price. Plastic Credits are suggested as a financial mechanism to cover the deficit and upscale the technology by accounting for the environmental costs of plastic waste management.

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Introduction

Background

This research report is a constituent of the ReValue initiative, generously supported by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection. The funding for this project spans from the start of 2022 until the end of 2023, through the "Export Initiative Environmental Protection" (EXI).

The ReValue project, helmed by NIDISI gGmbH, embarks on a visionary path of redefining the perception of unavoidable plastic waste from a disposal issue to a viable resource. NIDISI's ReValue aims to actively address the global plastic crisis by reimagining low-value plastic waste, which is currently deemed worthless, and reintegrating it into the value-added cycle.

In more concrete terms, the ReValue project aspires to harness previously non-recyclable (low-value) plastic waste as a valuable additive in road construction in Nepal. The proprietary *ReValue Method*, a collaborative development involving the Fraunhofer Institute, the University of Kassel, and EcoPals, has the potential to transform millions of tons of non-recyclable plastic waste while enhancing road durability. This innovative *ReValue Method* employs *EcoFlakes*, a product which has already been efficaciously implemented by the subsidiary EcoPals GmbH in Europe, on test routes in Potsdam, Vorarlberg, Kiel, and Aschaffenburg. In the spring of 2021, the first prototype road was constructed in Nepal. In recognition of these accomplishments, NIDISI ReValue was bestowed with the FAIRWandler Prize 2020, the Plastic Revolution Award, and the ifok Innovation Prize 2021.

To extend the successful implementation of the *ReValue Method* to Nepal, post the initial pilot run, multiple facets necessitate further exploration. These encompass the local recycling market; the technical deployment of the *ReValue Method* within the Nepalese context; and the prospective financing mechanism through Plastic Credits. Complementing these research priorities, the establishment of local recycling centers, adhering to the Verra Plastic Waste Reduction Standard (PWRS) certified Plastic Credits concept, will be experimented within the scope of the project.

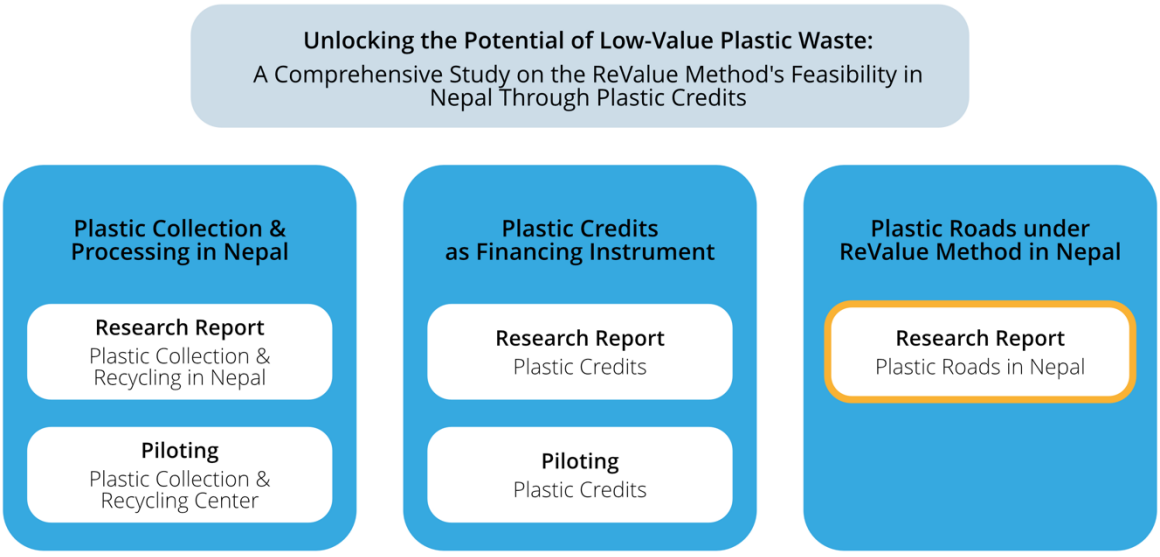

Figure 1: Visualization of ReValue Feasibility Research 2022-2023

In light of this, the present report aims to explore various facets of road construction in Nepal as a foundation for the prospective technology transfer of the *ReValue Method* into the Nepalese market. It will analyze the potential concerning the road network and examine the geographic and meteorological conditions in Nepal's local context. Furthermore, it will investigate the current methodologies employed in road construction in Nepal to determine the most effective way to transfer and apply the technology. Additionally, understanding the supply chains, their stakeholders, and the socio-cultural environment is crucial to developing a strategy for market introduction.

About NIDISI

NIDISI is a non-profit, steward-owned organization building social enterprises in Nepal and Germany. NIDISI aims to reduce social inequalities by developing integrated and financially autonomous structures. Innovation is at the heart of the designs created to propose ecological solutions to resolve burning social issues that can be reproduced on a large scale. NIDISI is active in the field of drinking water treatment, youth education, plastic recycling infrastructure, development of biodegradable menstrual pads and menstrual hygiene education.

In 2018, together with the community of Devgau Village (Nepal), NIDISI successfully established a social business providing drinkable water to the population living in the area. Since then, this enterprise has filtered and sold 1.8 million liters of water, making it a sustainable and independent entity led by the villagers.

In 2021, NIDISI built the first pilot Plastic Road in Gaindakot (Nepal), substituting bitumen, a crude oil-based substance, with upcycled low-value plastics. Since 2021, NIDISI has invested in Nepali plastic waste infrastructure and has already recycled 60t in its pre-implementation phase to specifically reintroduce low-value plastic waste into the value chain.

Since 2015, through the educational project, more than 30 children of unprivileged backgrounds received long-term support in the form of sponsorship for school-related expenses, mentorship, and personal development assistance.

In the field of Women Empowerment, NIDISI is setting up a social business named Sparśa. This Nepali non-profit organization will manufacture and sell compostable menstrual pads made from locally obtained banana fibers. By offering compostable alternative, Sparśa can decrease the negative environmental impact caused by the consumption of plastic-made conventional menstrual products. The profits generated by Sparśa will finance menstrual awareness campaigns in Nepal and women's rights advocacy. Since 2019, NIDISI has reached over 6,000 participants with its menstrual awareness workshops.

NIDISI has been active in Nepal for more than seven years and has built a vast network among domestic NGOs, INGOs, public institutions, and activists. Among others, NIDISI was awarded the 'ifok - Innovation Award 2021', Plastic Revolution Award (2020), FAIRWandler Award, Filippas Engel Award (2022), and Start Social '22 scholarship.

Goals of ReValue Method

The use of plastic waste as a bitumen modifier in roads, referred to in the following as *Plastic Roads*, has emerged as an innovation which uses plastic waste as an input material for road construction. *Plastic Roads* are addressing two main issues of the Nepali society A) sustainable development of connectivity with roads and B) increasing plastic pollution.

Road Development

A major concern for people in Nepal is the insufficient road network and the bad condition of existing roads. The Nepali road network is permanently under construction: The sub-tropical weather conditions, monsoon's heavy rainfalls and high traffic load, including large traffic volume as well as the presence of heavy trucks, lead to irreversible damage of the pavement within a short period of time. These potholes are not only a sign that bitumen

is losing its binding property by leaching into the groundwater but also provide a big safety risk, augment road accidents and slow down traffic.

Roads and particularly rural roads are essential for economic development, and poverty reduction as good connectivity and a reliable road network reduces travel times, improves travel safety and general accessibility to mobility. Reduced travel times have an impact on merchandise reaching faster, farmers would be able to sell their produce from the villages in the cities on the same day and economic activity could be boosted. The dust coming from traffic on gravel roads can be reduced thus tackling another urgent problem of air pollution.

Plastic Waste Management

Plastic pollution is a widespread and pressing environmental crisis. The safe disposal of plastic waste presents a significant environmental challenge. Due to its non-biodegradable nature, plastic waste does not decompose naturally, and even if placed in landfills, it can be reintroduced to the environment through erosion by air and water. This can obstruct drainage channels, cause harm to grazing animals that accidentally consume it, and contaminate construction fill, among other issues. To combat this problem, the most effective method of disposal is through recycling. For many valuable plastics like PET a recycling infrastructure already exists in Nepal. These are sold as a resource. Other less valuable plastics (e.g., multi-layered plastics), are not yet recycled and end up in landfill or get burned which is not a suitable end of life destination from either an environmental or economic point of view.

Our research has shown that incorporating low-value waste plastics in bituminous construction under the *ReValue Method* can significantly enhance the performance of the resulting pavement. By adding waste plastic to bitumen in proportions of approximately 6-10% by weight, the resulting mix exhibits improved Marshall stability, strength, fatigue life, and other desirable properties. This ultimately leads to greater longevity and enhanced performance of the pavement, thereby supporting the construction roads with greater benefit for the environment. Plastic waste can therefore find a suitable end-of-life destination in road pavement.

Research Objectives

This report is dedicated to a comprehensive exploration of the multifaceted dimensions of road construction in Nepal, serving as a foundational piece for the anticipated introduction and technology transfer of the innovative *ReValue Method* of *Plastic Roads* to the Nepalese market, to provide a solution both for waste management of low-value plastics as well as road quality in Nepal. The objective is to meticulously analyze the existing potential within the road network infrastructure, while also taking into account the unique geographical and meteorological conditions prevalent in Nepal. This analysis is essential to tailor the *ReValue Method* effectively to the local context.

In addition to the infrastructural and environmental assessment, this report delves into the technological practices currently in use within Nepal's road construction sector. By understanding these practices, it can be evaluated how *Plastic Roads* under the *ReValue Method* can be seamlessly integrated and adapted to enhance efficiency and sustainability in road construction projects in Nepal.

Furthermore, the report aims to provide an in-depth understanding of the local supply chains involved in the road construction industry, identifying key stakeholders and examining their roles and influences. This examination is crucial for recognizing potential challenges and opportunities in the technology transfer process.

Equally important is the consideration of Nepal's socio-cultural environment. The report seeks to gain insights into the social, cultural, and economic factors that could impact the adoption of new technologies in road construction. This understanding will enable the formulation of a well-informed strategy for the market introduction of the *ReValue Method*, ensuring it is sensitive to local needs and conditions.

Overall, this report endeavors to offer a holistic view of the road construction landscape in Nepal, providing a strategic framework for the successful technology transfer.

Methodology

The scope of this feasibility study encompasses field research in Nepal by conducting semi-structured interviews with road constructors, asphalt plant management, policy makers, municipalities, local communities and engineers.

The field research was conducted from April to July 2023, allowing for a thorough examination of the local context and conditions in Nepal. By conducting interviews, and site visits, valuable data was collected to evaluate the suitability of *Plastic Roads* technology in the Nepali context and consider cultural factors in Nepal. This study aims to provide a robust assessment of the feasibility and potential benefits of implementing *Plastic Roads* technology to provide low value plastics a suitable end of life destination and increase the durability of roads in Nepal. The starting hypothesis was to develop a roadmap to support the adaptation of this innovative technology by municipalities and road constructors.

Road Construction in Nepal

Nepal's Road Network

The road system in Nepal is divided into two networks: the Strategic Road Network (SRN), which is managed centrally, and the Local Road Network (LRN), which is managed locally. The SRN includes national highways and feeder roads. The LRN includes all other roads. Urban roads are found within cities, while the other roads are categorized as district roads or village roads.

The total road length by mid-March 2021 was 97.105km. The overall road length in Nepal constructed by the Federal Government had expanded to 33,528 kilometers. This includes 15,974 kilometers of blacktop roads, encompassing both the strategic and local road networks, as well as 8,582 kilometers of gravel roads and 9,972 kilometers of fair-weather roads (FNCCI, n.d). Additionally, the combined length of roads built at the provincial and local levels, comprising various types such as blacktop (bituminous pavement), gravel, and fair-weather roads, amounted to 63,577 kilometers. Only 6,7% of roads at the provincial level have been blacktopped. 47,6% of the federal road network is blacktopped. The number of roads that receive regular maintenance is significantly higher than new road construction or upgrading of roads which is only 18,6% of the roads under maintenance.

Details	2015/16	2016/17	2017/18	2018/19	2019/20	202021*	Total
Black Topped	12173	12803	13707	14695	15424	550	15974
Graveled	6460	6822	7231	8594	8622	504	8582
Earthen	9675	9492	9150	9590	9198	284	8972
Total	28308	29117	30088	32879	33244	1338	33528

Source: Ministry of Physical Infrastructure and Transport, 202 * Till mid-March

Figure 2: Road Expansion by Federal Government (in Kilometers) (Government of Nepal. Ministry of Finance, 2021)

Details	Unit	2015/16	2016/17	2017/18	2018/19	2019/20	202021*
New road construction	KM	639	809	971	440	365	284
Upraded to Gravelled	KM	345	992	1313	1363	757	504
Upgraded to black topped	KM	264	630	904	988	729	550
Road Maintenance (Regular)	KM	9200	9500	9500	14719	7200	7187
Periodic Maintenance	KM	443	214	332	332	360	187
Bridge construction	Number	63	72	82	230	210	129

Source: Ministry of Physical Infrastructure and Transport, 2021 * Till mid-March

Figure 3: Status of Road Expansion in Last Five Years (Government of Nepal. Ministry of Finance, 2021)

Province	Earthen	Graveled	Black Topped	Total Roads	Province-wise Share (in Percent)	Road Density
1	9492	2522	768	12782	20.11	0.49
2	2733	2854	378	5965	9.38	0.62
Bagmati	11734	2690	1268	15692	24.68	0.77
Gandaki	9596	1252	646	11494	18.08	0.53
Lumbini	5428	2712	911	9051	14.24	0.41
Karnali	2969	209	89	3266	5.14	0.12
Sudurpashchim	3954	1158	214	5326	8.38	0.27
Grand Total	45,906	13,397	4,274	63,577	100	0.43

Source: Ministry of Federal Affairs and General Administration, 2021

Figure 4: Province-wise Details of local Roads (in kilometers) (Government of Nepal. Ministry of Finance, 2021)

The following graphic illustrates the condition of roads in Nepal. Only 20.8% of the road network, a total of 20,248 km, is paved. For the provincial road network, which serves as the main transportation routes for local businesses, the proportion of unpaved roads is as high as 93,2%.

	Earthen	**Gravel**	**Blacktop**	Total
Governmental	8972	8582	15974	33528
Provincial	45906	13397	4274	63577
Total	54878	21979	20248	**97105**

Figure 5: Road conditions in Nepal (in kilometers)

Especially in hilly and mountainous regions, unpaved roads pose a significant safety risk. Lack of proper drainage systems leads to erosion and flooding of the roads during the rainy season, rendering them impassable and requiring frequent reconstruction.

The Nepali government is committed to further expanding Nepal's road infrastructure, extending roads and improving the drainage systems.

Climate and geographical challenges of Nepal

Geographical Challenges

Nepal is a landlocked country bordered by India to the south, east, and west, and by China (Tibet) to the north. Its unique geographical position presents both challenges and opportunities for transportation and connectivity. With diverse landscapes encompassing the Himalayas, lush valleys, and rugged terrain, Nepal's geography poses significant obstacles to transportation. The country's primary means of transport include roadways and airways. Road networks serve as the backbone of Nepal’s transportation system, connecting major cities, towns, and rural areas. However, due to the challenging topography, many regions, particularly those in remote mountainous areas, still lack proper road infrastructure. Highways move in curves around the hills and mountains, slowing down driving speed and enhancing the need for safe and stable roads.

Railroads are only used to connect India and Nepal and do not play an important role in Nepali infrastructure. Air travel plays a crucial role in connecting various parts of the country, especially to inaccessible or remote regions. Instead of a seven to ten hours bus ride from Kathmandu to Pokhara it can be done within half an hour by plane. However, air travel is costly, inaccessible for most Nepali, and induces heavy emissions at scale. Rivers are used for leisure but there is no extensive river network for cargo transport. As we assess the feasibility of technology transfer for *Plastic Roads* in Nepal, understanding the existing transportation infrastructure and its limitations becomes paramount in evaluating the potential impact and suitability of this innovative solution within the country's unique geographical context.

Climate Challenges

One particularity of the region of Nepal compared to road construction in Europe or Africa are the heavy rainfalls in rainy season, known as *monsoon*, that are affecting construction processes as well as the expected lifetime of roads. The road quality is severely affected by heavy rain falls (Rana & Singh, 2018). In Nepal the distribution of rainfall varies across different regions of the country. Certain central and northern areas receive over 3,000 mm of precipitation, while the central and southern plains usually receive between 1,500 and 2,000 mm. In contrast, some high-altitude regions in the north receive less than 1,000 mm of rainfall (*World Bank Climate Change Knowledge Portal*, n.d.).[1] When pre-existing potholes are present on roads, whether caused by heavy traffic or other factors, rainfall exacerbates the issue. Water collects in the potholes, further weakening the pavement. This leads to the expansion of the potholes, creating resistance for vehicles traveling on the road. A similar effect occurs with cracks in the pavement. Water seeping through the cracks widens them and accelerates the disintegration of the pavement. This is primarily due to the hydrophobic nature of bitumen, which causes water to break the bond between the bitumen and aggregates. Additionally, the slow speed of vehicles during rainy conditions contributes to road failure, as the impact on the road surface is greater at lower speeds. Rainfall speeds up the occurrence of several other types of defects, including raveling, rutting, patch deterioration (Rana & Singh, 2018).

Rain and especially the persistent rain during monsoon season has a strong impact on ongoing construction. Due to heavy rainfall between Jun and end of August, most constructions get interrupted or postponed (Pant, 2022). The rain also provokes landslides and floodings, that can disrupt infrastructure and lead to required renovations (Shrestha, 2021). Generally, travel is slowed down, and accidents increase during the rain which makes traffic more time consuming and risky.

Observed Seasonal Precipitation

The identified sub-national units with the highest and lowest precipitation sums reflect the latest climatology, 1991-2020.

	1991-2020				1961-1990				1931-1960				1901-1930			
Units: mm	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Country: Nepal	50.99	193.92	763.43	242.68	48.66	178.78	821.91	263.21	51.10	156.86	870.61	263.84	51.74	163.01	885.80	265.39
Highest: Central	37.75	245.28	1054.29	339.74	36.40	215.42	1111.13	355.71	39.93	187.73	1211.44	363.18	38.72	186.67	1248.81	363.56
Lowest: Mid Western	56.41	133.53	490.09	148.45	54.19	132.44	543.15	170.92	55.80	116.66	561.85	165.59	57.38	125.99	559.11	171.81

Figure 6: Observed Seasonal Precipitation in Nepal, 1991-2020. (World Bank Climate Change Knowledge Portal)

One of the primary challenges impacting the durability of road pavement and bridge structures is the issue of vehicle overloading. This problem is primarily caused by freight vehicles such as trucks, tipper-trucks, and dump trucks. Overloading of vehicles significantly contributes to the premature deterioration of road pavements, leading to substantial costs associated with pavement maintenance and vehicle operation. Moreover, this issue has significant economic implications for the transportation infrastructure and commodity prices (FNCCI, n.d.).

Policy Framework and Road Construction Guidelines

For public roads in Nepal, the contracting process is done through a tender for which the eligible construction companies can bid. This happens on the governmental level for highways, on the provincial level for the strategic road network and on the municipal level for local roads.

The procedure runs as follows: The Department of Roads or the respective municipality publishes the Bid with the respective **Bill of Quantities (BoQ)** visible for potential contractors. The municipality publishes a notice where all the information of road construction tender is mentioned including the BoQ. Within the BoQ, the quantity of

1 In comparison, in Germany, annual mean precipitation is lowest in the North German Plain, where it fluctuates from 500 to 750 mm; in the Central German Uplands, it ranges from nearly 750 to 1,500 mm and in the Alpine regions up to and exceeding 2,000 mm. (https://www.britannica.com/place/Germany/People)

each ingredient for the respective type of road is specified as every road has different requirements regarding frequency of traffic and other factors. Eligible and interested construction companies can apply for bidding through an online platform where the prices of materials and other information are inserted. After the deadline the municipality selects the best bid based on cost and awards the contract. The contractor receives the money for construction in three installments, starting phase, the mid phase, and the end phase. The contractor should provide all the invoices to the municipality to claim the expenses for the construction.

Decision making process

During the road construction process, the work will be supervised by the engineers of the municipalities, and it happens in the presence of the beneficiaries, as to say, the local communities living next to the road and profiting from it. They help ensure the quality of the final road.

Additionally, for local roads, a user committee can decide on upgrading a road which they partly finance themselves. This is only possible for roads with a max of 10 Mio. NRP budget and made of concrete. The monitoring and evaluation of the construction would still be done by the municipality engineers.

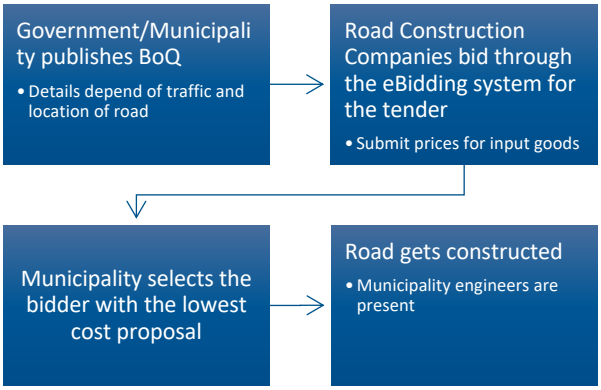

Figure 7: Contracting process of public road construction in Nepal

After construction, local roads get certified by the engineers of the municipality by making a strength test on site. For highways, the Quality Research and Development Centre of the Department of Roads is responsible for the quality check. The contractor is supposed to follow the BOQ provided by the Municipality and ensure the quality by including the correct amount of the materials mentioned in the BOQ.

Current Road Standards

Nepal Road Standards, first established in 1971 and revised in 2014, apply to all rural strategic roads being built in Nepal. Different standards are used for non-strategic (local) roads and urban roads. (Federation of Nepalese Chambers of Commerce & Industry (FNCCI), n.d.) The roads are divided into the "Local Road Network" (LRN) and the "Strategic Road Network" (SRN). While the SRN is directly managed by the national authority, the Department of Roads, the responsibility for the LRN lies with regional and local authorities.

The relevant institution that regulates road construction in Nepal is the Department of Roads, as part of the Ministry of Physical Infrastructure and Transport of the Government of Nepal. Under the Department of Roads, the Quality Research and Development Center (QRDC) is responsible for researching new technologies. The QRDC is also the entry point to start policy changes to include new technologies such as *Plastic Roads*. NIDISI together with Green Road Waste Management already started a process to showcase pilot roads, test results and related literature to advocate for a policy change that will make Plastic Roads an approved technology in Nepali road construction.

For the roads constructed on municipal level, the respective municipality sets the necessary quantities of ingredients based on traffic needs and environment individually per road. They have a certain liberty in doing this assessment, but based on limited resources for research and testing, they follow the guidelines made by the Department of Roads.

The (current) Nepal Road Standard (from 2070 lunar calendar, 2014 AD) reads as follows:

> 15: PAVEMENT
>
> *a. The selection of pavement type is determined based on the traffic volume and composition, soil characteristics, weather, performance of pavements in the area, availability of materials, energy conservation, initial cost, and the overall annual maintenance and service-life cost.*
>
> *b. Pavement surface type provided should be consistent with the selected design speed for the highway.*
>
> *c. For selection and design of road pavements guidelines published by the Department of Roads shall be followed.*

Private Market
No policy change is required for private roads and roads financed outside the public tender process. Companies are free to choose their construction methods and road constructor within their industrial premises.

Challenges of Road Construction in Nepal

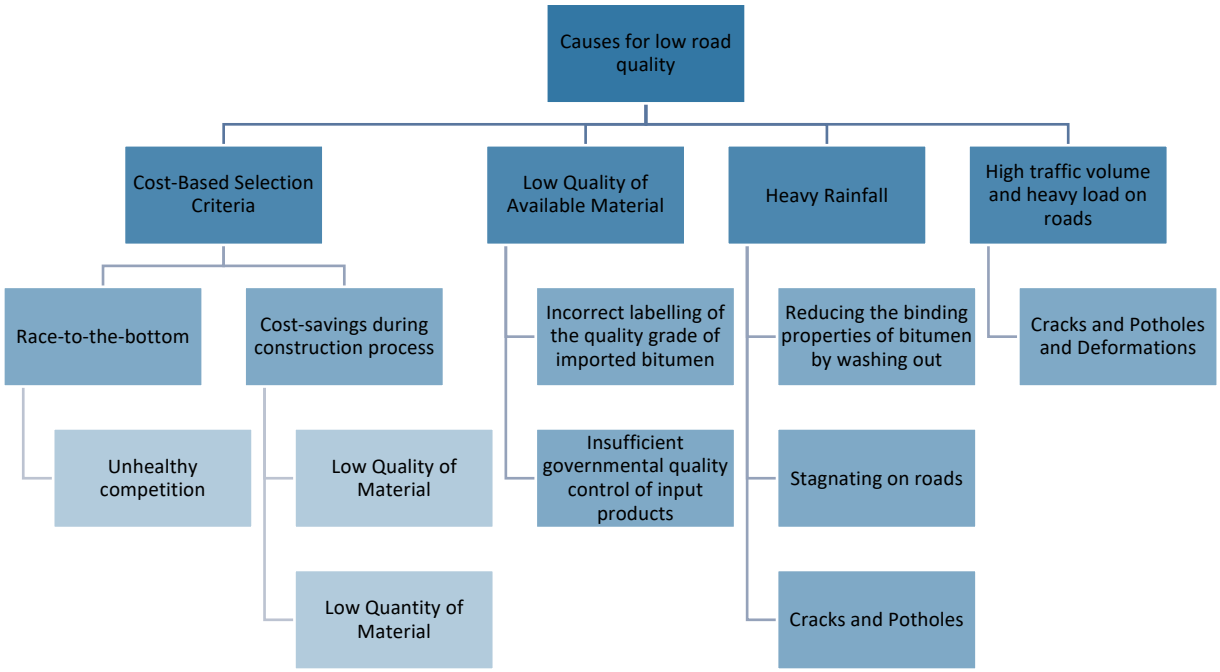

Figure 8: Factors for low road quality

Cost-based selection criteria for awarding a contract for a public road.
The criteria for the selection of the contractor are purely based on minimal cost principle: The award criteria from an example bidding document reads as follows:

> *"The Employer shall award the Contract to the Bidder whose offer has been determined to be the lowest evaluated bid and is substantially responsive to the Bidding Document, provided further that the Bidder is determined to be qualified to perform the Contract satisfactorily"*
> (Gaindakot Municipality, 2023).

There is a screening of qualified companies for the road construction to fulfil the second part of the above-mentioned criteria. However, within this pool of qualified companies, the lowest price is the only criterion, leading to unhealthy competition that drives the price down.

This "race-to-the-bottom" leads to very small profit margins for the construction companies, low quality of the input materials and therefore low quality of the final road. An interviewed constructor estimates the lifespan of a black top road that is built under good conditions to be 3-4 years in Nepal, but because of the price downward spiral, the lifespan of a road is about 2 years before potholes call for reparations. In contrast, in Germany, a road is anticipated to have a lifespan of approximately 20 years (Landesbetrieb Straßenbau, 2023).

No long-term liability from the construction companies

The defect liability period of the road is 1 year in which the contractor must repair the damage which happens on rare occasions based on poor construction or design mistakes. After this period, the municipality is covering the charges for repair and renovation. Therefore, a road construction company has a great interest in constructing the public road as foreseen by the ministry and no incentive to deviate from the plan by experimenting with new technology or adding binders that enhance the quality.

Availability of good quality input goods

Another challenge for road constructors is the low or undefined quality of the material available. Even though only grade 6 to 10 bitumen is officially allowed in Nepal, low-quality materials still get imported and sold under incorrect superior labelling, according to interviewed construction company owners. This generates poor outcomes as the binding property of lower grade bitumen is reduced.

Environmental factors

The deterioration of the black top roads can be attributed to heavy rainfall. The water washes out the bitumen and its binding quality and potholes occur as described in the Chapter Climate Challenges.

Necessary funds to join the bidding process.

To enter the bidding process, a deposit or bank statement as bid security is necessary. It can vary, in one example of a local road it amounts up to 140.000 NPR. The bid security is an unconditional bank guarantee or a cash deposit in the employer's account. Additionally, the costs are not fully covered from the start of the construction. Consequently, the construction firm needs to make advance payments. At the start of the construction process of public roads, the contractors receive10% of the total amount which not even cover the material costs of the construction. Contractors must take advance payments or take costly loans that have similar interest rates than the overall profit margin of the project. Additionally, there will be a performance security the contractor has to provide that is at least 5% of the bid price, higher if the bid is more than 15% below the average cost of the other bids.

Alternative Road Construction Technologies in Nepal

In most countries of the global north, additional binders or bitumen modifiers are mixed into the asphalt that enhance its capacity to withstand rain, heat and cold. These include, for example, virgin plastic, rubber recycled polypropylene (PP). Currently, no binder or other additives to enhance the road quality is used in Nepal. The current road guidelines specify very narrowly the input goods for a new road and do not include any additional binders. There is therefore no incentive for construction companies to add anything as they will be paid according to specified quantities and their quality will be measured according to the fulfillment of the standard.

The road construction sector in Nepal offers a great potential for innovation as no additional technology is used. Conventional binders do not find their use. The asphalt currently contains only chips (gravel) and bitumen and uses cement as a filler material. Technologies such as Reclaimed Asphalt Pavement (RAP) have great potential for cost-saving due to reuse. The introduction of binders or bitumen modifiers such as *EcoFlakes* under the *Re-Value Method* have great potential for improving quality as there is no competing technology available on the Nepali market.

Use of Plastic Waste in Road Construction

The NIDISI spin-off, EcoPals, is working on a process for reusing low-value plastic as an asphalt modification which was extensively researched with the Frauenhofer Institut. *EcoFlakes* were developed based on a damage-free pilot surface laid in 2021 and current laboratory tests. *EcoFlakes* are a plastic blend of recycled thermoplastics and additives for improving asphalt properties. In the development of their additive, EcoPals focused on the use of low-value plastic for *EcoFlakes*, plastics for which no adequate end-of-life destination is currently available. Other thermoplastics can also be used in road construction, however, higher value plastics can be recycled into new products and using those in road construction would divert them from their existing recycling infrastructures. *EcoFlakes* can be added to common asphalt mixes (especially stone mastic asphalt) by adding them to the asphalt production at 6-10% of the binder content. The mixing temperature should be between 140° C and 175° C. The admixture of *EcoFlakes* increases in particular the deformation resistance of the asphalt without any restrictions in cold flexibility. Properties comparable to those of thermoplastic modified bitumen can be achieved. The composition of the additive does not give rise to any additional pollutant emissions, so that occupational health and safety are not impaired. The aging behavior of bitumen is also not negatively affected.

Description of the ReValue Method

To prepare the aggregate mix for road construction, it is first heated to a temperature range of 140-175°C within a central mixing plant or a drum-mixer. Next, the *EcoFlakes* are introduced into the drum. This injection occurs either at 2/3 length of the drum or through an opening above the pugmill in a batch mix plant. The waste plastic initially coats the heated aggregates, after which the bitumen is added at a temperature that corresponds to the binder grade and mix type. Utilizing a central mixing plant enables better temperature control and mixing, resulting in a more consistent mixture, while the application of heated bitumen spray further enhances the overall process. The following road construction process is identical to conventional road construction processes in Nepal.

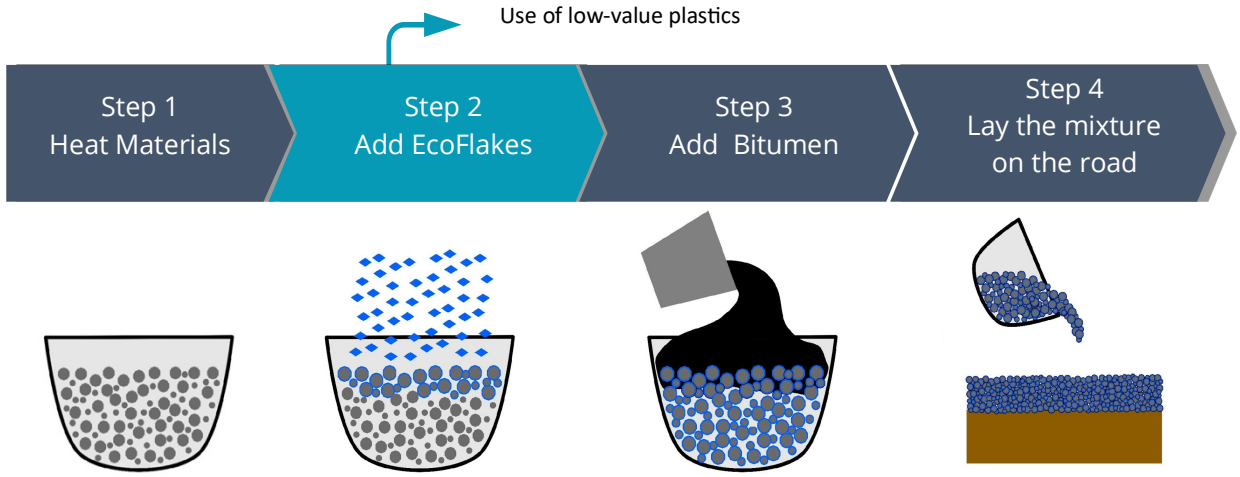

Figure 9: ReValue Method Step-by-Step

Benefits of the use of plastic waste in roads

The *ReValue Method* using *EcoFlakes* offers several notable benefits, particularly in terms of its effects on asphalt. One significant advantage is the increased resistance to rutting, which refers to the formation of permanent deformations on the road surface caused by heavy traffic loads. By incorporating the *ReValue Method*, the asphalt exhibits improved resistance, ensuring enhanced durability and longevity of the road.

Furthermore, the method leads to an increase in resistance at high temperatures. This characteristic is crucial, as roads are subjected to elevated temperatures during hot weather conditions such as the extreme heat in Southern Nepal. The strengthened asphalt can withstand higher temperatures without compromising its structural integrity, reducing the risk of deformation and pavement failure. Another key benefit is the good adhesion properties between bitumen (a binding agent) and aggregate (the granular material in asphalt). The *ReValue Method* ensures a strong bond between these components, resulting in a more stable and durable road surface. This enhanced adhesion contributes to improved overall performance and longevity of the asphalt pavement. Moreover, roads constructed with the *ReValue Method* can be recycled. Recycling plays a vital role in sustainable road construction, reducing the demand for virgin materials and minimizing waste. By utilizing the *ReValue Method*, the asphalt can be recycled and reprocessed for future use, promoting a circular economy approach in road infrastructure development.

The technology has a minor impairment on cold flexibility, referring to the ability of the asphalt to remain flexible in low-temperature conditions. It does not significantly impact the overall performance and functionality of the road. For Nepal, cold resistance only plays a major role in high altitudes as greater parts of the country experiences subtropical climate. With the *ReValue Method*, the asphalt maintains the necessary flexibility required to withstand temperature fluctuations and prevent cracking or damage.

Lastly, the *ReValue Method* contributes to reduced CO2 emissions due to the reuse of existing materials. By incorporating waste plastic, the demand for new bitumen is reduced, alongside finding an alternative to landfill of the materials. This aligns with sustainability goals and helps mitigate the environmental impact of road construction. Overall, the *ReValue Method* offers numerous benefits, including increased resistance to rutting, improved resistance at high temperatures, good adhesion properties, confirmed recyclability, and reduced CO2 emissions. These advantages contribute to the development of more durable, sustainable, and environmentally conscious road infrastructure.

Limitations of the technology

Overall, the scientific literature suggests that the use of plastic waste in road construction is beneficial, yet most studies regarding the Life-Cycle Assessment and environmental impact of plastic waste in roads in general have been conducted in the context of high-income countries and there is a significant gap for low-income countries, especially South Asia, despite India pioneering comparable technologies (World Bank, 2023, p. 38). The *EcoFlakes* mixture has been improved to create the best result and it has been tested in lab conditions and in pilot projects in Europe, however further research on its properties under extreme heat (like the sub-tropical Terai region of Nepal) and extreme rainfall (such as the monsoon season in Nepal) are yet to be tested.

Technological Assessment of the Road Construction Sector

In Nepal, roads constructed using a flexible pavement containing bitumen are commonly referred to as blacktop roads. These roads are typically built using either a premix or an asphalt blacktop method. In the premix process, gravel aggregates with similar sizes are mixed on-site using a spot-mix or a mobile mixing machine. This technology offers advantages such as cost-effectiveness and the ability to easily mobilize equipment. On the other hand, asphalt, also known as blacktop, is produced using aggregates with varying sizes and is mixed at an asphalt plant, which can be either fixed or transportable within a short period. The hot asphalt mix is then transported to the construction site, with the capacity to remain hot over distances of up to 50 km. Asphalt's benefits include the formation of fewer voids within the blacktop due to the different gravel sizes, but it comes with the disadvantage of high initial capital expenditures, making investment in an asphalt plant financially viable only for projects with substantial volumes.

In Nepal, the majority of roads are constructed using pre-mix, which is mixed on-site using rented or owned machines. The pre-mix method is a prevalent choice due to its cost-effectiveness and suitability for smaller projects. The biggest share of Nepal's road network are local roads. Smaller roads are done with a spot-mix. Asphalt, being more suitable for large projects, is less used in Nepal. Notably, the utilization of asphalt for urban roads within Pokhara is a relatively recent development, as pre-mix was the standard method used until a year ago. The transition to asphalt for urban roads signals a potential shift in construction practices, particularly for larger projects, although the capital costs remain a significant consideration in the decision-making process.

Machine Requirements for the technology transfer

The mixing process can happen within a mobile mixer (so-called 'spot-mix'), as currently used for pre-mix road, or within an asphalt mixing plant. No new equipment is needed to implement the technology on site for the first pilot roads. For large scale implementation, additional feeders have to be installed on existing asphalt plants which requires an investment for asphalt companies. Highways and airports get asphalt from a batch mixing plant. In the future, it is expected that more roads will be done with asphalt, however, the share is currently still low.

Figure 10: Spot-mix on a construction site, June 2023

Pre-Mix

Mobile mixing machines bear the risk that the *EcoFlakes* come in direct contact with the fire source and overheat, releasing toxic fumes. This can be avoided by measuring the temperature and training the personnel for adequate dosing of the *EcoFlakes*. Storing the *EcoFlakes* unsafely next to the heat source on the construction site could also lead to its inflammation. The heat is not evenly distributed within a drum mix which could pose a challenge. This risk can be mitigated by regularly measuring temperature on site.

Asphalt Plants

There are over 100 asphalt plants in Nepal. The traditional asphalt plants are suitable for adding plastic through the conveyer belt that also carries the gravel. However, this bears the risk that the heat is not evenly distributed and the plastic either not melts enough or burns if it comes in contact with the power source.

Figure 11: Ammann batch mixing plant, Kathmandu Valley, July 2023

Within a counterflow drum mixing plant, this risk would be eliminated as the heat source is directed opposite the plastic input and heat could be better regulated. As of July 2023, five counterflow drum mixing plants exist in Nepal. For highways and airport roads batch mixing plants are required by the Road Construction standards. In batch mixing plants, the heat circulates evenly and has no direct contact with the aggregate, making it also a safe option for adding the *EcoFlakes*. Four batch mixing plants with patented Ammann technology currently exist around Kathmandu, Nepal. As these mixing plants are engineered in Germany and fabricated in India, they are also suitable for conventional German road construction technology and provide a similar construction environment.

Both the counter-flow drum mixing plant and the batch mixing plant possess the technological predisposition of a safe environment that can measure and control input and output as required. Additionally, they are equipped with wet-dust collectors to contain pollution by the asphalt production. Currently, they do not have the necessary feeder to insert the plastic into the mixing process, but their design is already thought to add additional steps both for adding a plastic additive as well as Recycled Asphalt Pavement. Construction companies will be able to adjust their machines within 2-3 months with the additional feeder in the drum-mix or batch-mix plant.

Important aspects of the Technology Transfer

During the production phase, it is crucial to address the following aspects:

(i) Ensuring a **consistent and uniform distribution** throughout the aggregate is essential to maintain control over the performance of asphalt mixes and ensure good quality. This is possible within the asphalt plants in Nepal but poses challenges in mobile mixing machines.

(ii) Regular **Verification** of the effectiveness of using plastic waste to coat the aggregate is necessary to confirm the claimed benefits and **determine the appropriate replacement of bitumen**. If the coating process is not effective, it could potentially compromise the durability of the asphalt mix.

(iii) It is necessary **to regulate the properties of the input plastic**, including the source of plastic material, acceptable dimensions, maximum impurity levels, and melt-flow value to calculate the optimal mixture ratio.

(iv) It is recommended to implement **better controls to ensure accurate dosage of plastic**. The use of calibrated containers is advised for this purpose. In pre-mix or older asphalt plants this is not possible as the *EcoFlakes* get added with the gravel. With the newer asphalt plants, the design and software foresee a specific feeder just for the additive, therefore, quantities can be controlled perfectly.

(v) It is important to monitor the temperature during the mixing process. In the asphalt plant, the temperature is controlled and between 160° C and 180° C. The output asphalt is about 110-120° C, depending on the needed transport distance. Processing the plastics into *EcoFlakes* ensures a predictable and uniform melting point of the additive. For mobile mixing machines additional equipment for temperature control is required.

An introduction to this innovative technology is needed to prepare the unskilled and semi-skilled construction workers for the new step in the process. Therefore, a skilled engineer should showcase the required steps at the beginning of construction. In the pilot road, the interviewed workers reported that the new technology is easy to adopt, and they enjoy producing *Plastic Roads* as they can feel the enhanced quality already in the production process. They got instructed by their supervisor who received the calculations from an engineer and applied the process on their own.

Identified social risks using pre-mix on a construction site were missing protective gear such as masks and gloves for the workers, and open fire to heat the bitumen, as well as the fumes of the hot bitumen in its heating spot and from the mixing drum. The smell seemed to be unhealthy but no equipment for its monitoring was available. No data about the toxicity of the fumes or their composition has been gathered yet. Further research in this regard in recommended. Theoretically and ideally, it stems only from bitumen as the burning point of plastic has not been reached, but this cannot be assured.

Figure 12: Plastic Road construction with manual method, June 2023

Identified environmental risks on a pre-mix site were the spilled bitumen around the construction area during the carrying and handling of liquid bitumen, and the flying pieces of shredded plastic that the wind carried away from the pile.

Nepali road construction practices do not follow the same safeguards as European road construction and are not comparable in quality and precision**. The added plastic in the *Plastic Road* process however only adds two possible risks**: environmental contamination by shredded plastic pieces around the area, and the fumes of the mixing drum of which no data is available. Supervising some construction sites during the implementation of the *Plastic Roads* can mitigate these risks. Within the counter-flow and batch mixing asphalt plants, these risks are mitigated as the mixing happens in a controlled environment.

To conclude, the use of *EcoFlakes* as an additive is possible within the current technological framework of Nepal. The *Plastic Roads* technology would be suitable for both techniques as plastics can be mixed with the aggregate. Investment in machine adaptations would support upscaling the use of the technology to larger projects and allow an improved quality management, however, no new asphalt plants are required.

Supply Chain Assessment

In addition to assessing the technical implementation and market potential of the technology, implementing *Plastic Roads* in Nepal requires to evaluate the whole supply chain process that the technology adds to the construction. The use of plastic waste in road construction adds at least three additional steps in the upstream supply chain for the implementation of *EcoFlakes* in *Plastic Roads*:

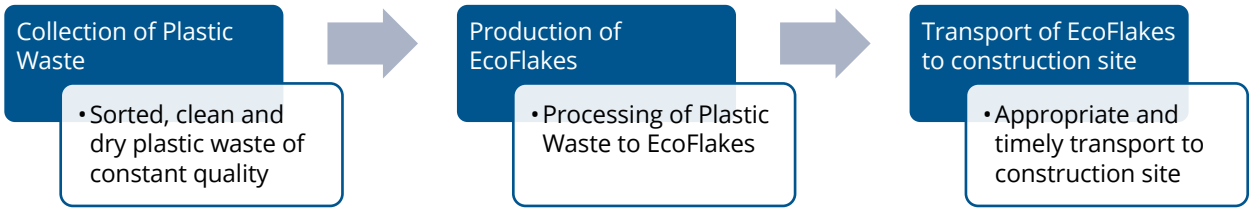

Figure 13: Supply Chain Additions for Plastic Roads

(1) Appropriate and consistent quantities and quality of clean and dry low-value plastic waste must be reliably sourced from the existing waste management infrastructure.
(2) The sourced low-value plastic waste must be processed into *EcoFlakes* by specialized machinery and further additives. Currently, there are no service providers in Nepal with the appropriate technical equipment for large-scale production, which makes it necessary to set up new production facilities.
(3) After production the *EcoFlakes* need to be distributed from the processing plant to the construction sites. Due to the poorly developed transportation infrastructure long transport times must be considered during the planning. Higher prices and inaccessibility due to transport, especially in hilly and remote areas, are to be expected. Production in multiple sites will improve the timely nation-wide supply.

During the construction, the only additional step is inserting the *EcoFlakes* into the drum mix on the asphalt plant or spot-mix on site before adding the bitumen. For this step, one worker should be in charge and monitor the ratio of added plastic.

The remaining construction process does not deviate from the conventional road construction.

Main challenge: Limited Supply in Nepal

During construction of the pilot road, one challenge was obtaining shredded low-value plastic and transporting it to the construction site. The current offering on the market is limited. The processing of low-value plastic is not financially viable and there is currently no low-value plastic processing center in Nepal that can cater to the needs of large-scale *Plastic Roads* production. To implement *Plastic Roads*, this infrastructure must be developed.

Even though low-value plastic waste is available in huge quantities, the collecting, cleaning, shredding and transporting of the plastic generates a cost that cannot be covered by the sales of the *EcoFlakes*. Private and public buyers have shown interest in using this innovative technology only if it also generates a short-term cost advantage for the construction project, therefore, *EcoFlakes* have to be sold at a competitive price. Setting up the low-value plastic collection and processing infrastructure in Nepal requires a high investment and production will create a financial deficit, even though it creates an economic gain by providing a solution for low-value plastic waste.

Socio-Cultural Considerations

Cultural Barriers

Interviewees living close to the pilot road built in 2021 in Kalika Chowk, Gaindakot demonstrated a positive attitude towards the pilot road. Neighbors of the new road narrated initial skepticism for the new technology. Two years after the construction of the *Plastic Road* in their neighborhood the road is still in a better state than a conventional road built shortly after, which is why they would advocate for the *Plastic Road* technology. Beneficiaries said that the *Plastic Road* gets very soft in the heat of the summer, and in this condition heavy traffic can leave marks on the pavement. Nonetheless, after cooling down, the road returns to its original shape. No damage has been reported and therefore, beneficiaries favor the construction of additional pilot roads.

Raising Awareness for greater acceptance

From the learnings of the pilot road, no major cultural barriers to the implementation of the *Plastic Roads* to Nepal were identified. General risk aversion creates hesitance to experiment with new technologies. Trust can be built by evidence: showcasing pilot roads that prove much better quality than traditional roads. In informal conversations within Nepal, the explanation of the *Plastic Roads* project created positive reactions. Bad roads and potholes are a major concern for the Nepali population and therefore, a technology that promises and proves better quality is highly welcomed.

Social Safeguards

Construction sites in Nepal do not follow the same safety standards than in Germany. While the controlled environment of an asphalt plant can contain the risk of dangerous fumes and provide accurate data, the construction of *Plastic Roads* with pre-mix technology bears unknown risks. Due to the lack of data, no clear assumptions about the toxicity of the fumes can be made. On construction sites, workers worked without protective masks. To mitigate the risk of toxic fumes, devices for temperature monitoring of the mixing drum have to be available on site and construction workers have to be trained to use protective gear and recognize risks during construction.

The road construction is not as rigorously monitored and to the same standards as German constructions. Therefore, imperfections in the final product can be assumed and special caution has to be given when introducing new technology to the market.

Stakeholder Analysis

Stakeholder analysis plays a crucial role in understanding the dynamics and relationships among different actors involved in the implementation of *Plastic Road* technology in Nepal. This chapter examines key stakeholders, their roles, and their potential impact on the adoption and upscaling of *Plastic Roads* to determine the roadmap for the technology transfer to Nepal.

Private Sector and local industry

For smaller roads, pre-mixing methods are commonly used. In the context of *Plastic Roads*, it is crucial to consider private actors who are interested in undertaking Corporate Social Responsibility (CSR) projects. These actors can serve as important stakeholders as they have the potential to initiate pilot projects for *Plastic Roads*. These pilot projects not only provide opportunities for testing the technology on a smaller scale but also help in creating awareness and showcasing the feasibility and benefits of *Plastic Roads* to a wider audience.

Policy Makers: The Department of Roads, specifically the Quality Research and Development Center

The adoption of *Plastic Road* technology on a larger scale, particularly for bigger roads, necessitates policy change. Key stakeholders in this regard include policy makers, the Department of Roads, and the Federation of Contractors Association of Nepal. Policy makers play a crucial role in approving and implementing new regulations and guidelines that facilitate the adoption and integration of *Plastic Roads* into the existing infrastructure framework. The Department of Roads, under the Ministry of Transport and Physical Infrastructure, as a government agency responsible for road construction and maintenance, can act as a key facilitator and driver of change in implementing *Plastic Roads*. Collaboration with the Federation of Contractors Association of Nepal and convincing contractors of the benefits of the technology can provide essential support in advocating for policy change. Their bargaining power can have a great impact on the policy making processes in Nepal.

Municipalities

Collaboration with municipalities can serve as a strategic shortcut for the implementation of *Plastic Roads*. Engaging with municipalities to use their leeway in guidelines for local road projects can facilitate the adoption of *Plastic Road* technology. Successful pilot road projects can serve as compelling evidence to convince municipalities of the benefits and feasibility of *Plastic Roads*, leading 1) to increased acceptance and integration of pre-mix *Plastic Roads* in their infrastructure development plans and 2) to policy change to also use plastic in large scale projects made with asphalt.

To implement *Plastic Roads* in Nepal, policy change is necessary. The municipalities can be an entry point for local adjustments; however, it is of great importance that the Government of Nepal supports the project and adjusts its policies. In the implementation, NIDISI and EcoPals engineers will work closely with the road construction sector, transferring the necessary know-how. Asphalt plants will adjust their design based on what is needed on the market, therefore, the focus should be first on the policy change.

Construction Companies

In the construction sector, adherence to current guidelines is a standard practice. During interviews, construction companies expressed their primary priorities, which revolve around achieving low-cost construction for project works while meeting the specified quality requirements. The liability period, typically limited to one year, presents little incentive for them to experiment with new technologies, as their compensation is tied to the quality standards set in the road construction guidelines. Consequently, there are limited opportunities for reducing input quantities stipulated in the tender, such as substituting bitumen with alternative materials. However, construction companies demonstrate willingness to adopt new technologies if they offer a cost advantage and are mandated by their customers.

Asphalt Plants

Asphalt plants are commonly owned by construction companies that both produce asphalt for their own construction projects and sell asphalt to external clients. These plants are driven by a vested interest in advocating for practices that provide cost advantages while also aligning with the quality requirements set by the government for asphalt pavements. With the government's current focus on transitioning from premix technology to asphalt, the demand for asphalt is expected to grow. If the use of plastic waste in road construction becomes compulsory, asphalt plants will be compelled to upgrade their facilities to meet the new quality standards and accommodate the integration of plastic waste into the asphalt production process. The asphalt companies do have significant weight in Nepal's economy and can lobby for policies that improve their cost and quality. They have not yet taken a stand on *Plastic Roads* but informal sources stated, they are pushing for the implementation of Recycled Asphalt Pavement in Nepal's road construction. Asphalt companies might join in the process of advocacy for the policy change that requires the use of waste plastic in any form if it provides a cost advantage for them.

Local Activists

The issue of plastic waste management and bad road conditions are well known in Nepal. There is potential for collaboration with local activists in the field of environmental sustainability and waste management. There is currently one other organization, Green Road Waste Management, that is advocating for *Plastic Roads* in Nepal. In 2018, they constructed the first *Plastic Road* in Nepal using pre-mix technology and have been researching in the field for the last 5 years. NIDISI ReValue supported them with research findings and collaborated in further developing the recycling infrastructure. Green Road Waste Management does not have the technology of the patented *EcoFlakes* additive yet, which is necessary for a quality output of the asphalt plants. Green Road Waste Management started the policy change process this year by submitting the documentation to the Department of Roads, which will also allow the implementation of the ReValue Methodology using *EcoFlakes*. At the time of writing, another research and pilot project of an asphalt paved road is planned with UNDP and local governing bodies to test different mixing ratios of plastics and the use of asphalt. With municipal engineers and the Department of Roads involved in the testing process, the results have a great impact on the policy decisions. Joining forces, NIDISI ReValue and Green Road Waste Management can bring the innovative technology to Nepal.

Market Entry

During the research, steps in the roadmap for the technology transfer have been identified. Initiating market entry through the construction of private roads and engaging with big industrial players can showcase the viability of the technology. However, for large-scale implementation, policy change is essential, necessitating involvement from the public sector. The integration of *EcoFlakes* and collaboration with existing asphalt plants are additional critical components of the roadmap.

Inspiration from other countries

Comparable *Plastic Road* projects have been implemented in various countries (World Bank, 2023). Most prominent examples in Asia, that led to changes in the respective national road construction process are India and Bhutan.

Plastic Roads in India

The idea of *Plastic Roads* was pioneered by Indian Dr. Varsudevan, who led research on new uses of waste plastic in India and found out that melted waste plastic had great qualities as a binder in road construction. After proving the enhanced quality of the *Plastic Roads* through pilot roads, policy change was made to the Indian Road Guidelines in 2013. The specifications for the type of plastic used for road construction are broad and include LDPE, HDPE, PU and PET. Now, all new roads in India must be constructed with waste plastic. The Ministry made the use of waste plastic compulsory for all new roads in a 50km perimetry on national highways within 50km periphery of an urban area that has more than 500.000 habitants (Ians, 2021). Nonetheless, this is not yet the case today for all roads due to unavailability of adequate plastic supply or hesitations of the construction companies in some states (Chandran, 2017).

From India, a major learning is that policy change is the key driver for large scale implementation and public support, while NIDISI ReValue should also anticipate the challenges of pioneering a new technology in Nepal when the infrastructure for the plastic processing is not sufficient yet to cater to large projects. An incremental adaptation is more realistic.

Plastic Roads in Bhutan

The technology was introduced to Bhutan in 2015 by Rikesh Gurung, founder of Green Road in Bhutan. Giving the plastic from the local landfill a new purpose, his activity was able to enhance the lifespan of the landfill by a few years and highlighted the macroeconomic win for the country through the use of waste plastic in roads: enhanced road quality, cheaper construction cost, solution for plastic waste management, raised awareness for plastic waste and enhanced lifespan of the landfills which ultimately convinced policy makers to include plastic waste in the Bill of Quantities. In this scenario, no new road standards were established, but the tendering process was changed. This example provides an inspiration for advocacy for *Plastic Roads* from a macroeconomic perspective by using not only the quality of the pavement but also the positive externalities such as an end-of-life destination for plastic waste which also applies to the context of Nepal.

These two examples illustrate *Plastic Roads* in general, that uses waste plastic without a patented additive. *EcoFlakes*, has a specific combination of plastic types to enhance its quality and predicts its characteristics. This technology has not yet been implemented in Asia.

Plastic Roads in Senegal

The introduction of *EcoFlakes* to Senegal was prepared by a research project given to local renowned engineers, financed by a German organization affiliated with EcoPals.

The research was done by scientists with a broad network including the Road Division within Senegal. Tests were partly conducted with resources of the governmental owned laboratory. The Road Division was involved in the

research process and supported the policy change. *Plastic Roads* were first constructed in the private sector to show their durability and promote them. Construction companies can buy the *EcoFlakes* from a local organization which focuses only on the production of *EcoFlakes*.

In Senegal, the acceptance of the technology transfer has been driven by local scientists and policy makers so that the German initiator company could exclusively focus on the production and sales of the *EcoFlakes* while not interfering with other steps of the road construction process. For Nepal, NIDISI ReValue can use this inspiration to focus on filling the gap in the market that currently neither provides any asphalt additive nor processing of low-value plastics.

No competition: Pioneer in asphalt additives

While *EcoFlakes* as a bitumen modifier entered an already existing market of additives in Europe, there is no such competition in Nepal as conventional binders are currently not in use. The use of *EcoFlakes* therefore does not compete with the properties and prices of existing binders, but with the status quo that is using merely bitumen and gravel. The quality improvement of asphalt without additive compared to asphalt with *EcoFlakes* will be even greater than tests in Germany where samples were compared to German common standards.

EcoFlakes can therefore be the pioneer in the Nepali market for asphalt additives while also offering a product made from recycled plastic instead of chemically engineered virgin products. Introducing *EcoFlakes* on the market in Nepal will change road construction practices while solving an environmental issue of plastic pollution.

Starting the market exploration with Private Roads and Industrial Sites

The market entry starts with the construction of private roads and targeting big industrial players to adopt *Plastic Roads* on their industrial sites. To start the introduction to the Nepali market, private roads that can be build outside the policies for public roads can work as our entry point and show the viability of the *Plastic Roads* Technology.

As local roads get blacktopped with pre-mix that gets produced with small scale equipment on site, this can be the entry point for diffusing the *Plastic Roads* technology on a large scale. No new equipment or additional skills are needed for pilot projects. When the use of asphalt will be more common, *Plastic Roads* technology can also be constructed with the existing machines in Nepal, however, an additional feeder for the *EcoFlakes* would be necessary.

An appellation for CSR projects, especially from the companies that create a significant amount of low-value plastic waste, such as the noodle industry, seems like a feasible strategy. These smaller projects provide an opportunity to demonstrate the viability of the technology to the community and policymakers. Simultaneously, it establishes the infrastructure for low-value plastic processing and *EcoFlakes* production, creating a foundation for future expansion.

To meet the demand for *Plastic Roads* in all construction works, it is crucial to establish sufficient infrastructure for EcoFlakes production beforehand. Catering to the private sector as a minimum viable product allows for a gradual scaling up of the supply chain. This step addresses potential bottlenecks in the future when plastic waste becomes a mandatory component in road construction.

Training for engineers, operators and road construction workers

The municipalities showed itself open to change but requested an engineer familiar with the technology to instruct their municipality engineers in the first construction processes, especially for the calculations of percentage of plastic or additional requirements to keep in mind. The interviewed workers on a pre-mix pilot road were able to construct *Plastic Roads* themselves after quick instruction, therefore, training has to be kept in mind for low-skilled workers as well. In roads constructed with asphalt, the workers on-site do not need additional skills,

as the *EcoFlakes* come already mixed within the asphalt to the site. On the asphalt plant, the operator in charge of the computer-based controlling and mixing has to be instructed to add the *EcoFlakes*.

Policy Change on the governmental level

To implement *Plastic Roads* on a large scale, the change of the road standards is a prerequisite as they determine the input goods and quantities of future road construction. The market will remain limited without the use of EcoFlakes in public works. The involvement of the public sector is crucial, as it is the largest consumer of road construction. Advocating for policy changes that mandate the incorporation of plastic waste in public works can facilitate widespread adoption. For this step, we can collaborate with local plastic waste and environmental activists.

The Government of Nepal seeks to reduce import dependencies and decrease the use of imported bitumen from India (ShareSansar, 2023). Offering processed plastic waste as a partial substitution (6-10%) for bitumen while improving landfill lifespan presents high potential. By incorporating plastic waste as a required input in road construction, the market will create significant demand for *EcoFlakes*.

Adjusting Existing Asphalt Plants

Existing asphalt plants can be utilized for the new *Plastic Road* technology. Initially, a temporary arrangement using the existing conveyer belt for gravel as well as for EcoFlakes can bear certain quality risks, but it allows for gradual implementation. However, to fully integrate plastic waste into asphalt production, the largest plants, such as those manufactured by Ammann, need to undergo upgrading. The machines are already designed for this addition. New requirements based on updated policies will drive owners of asphalt plants to invest in this costly upgrade, ensuring their competitive advantage in the market.

The roadmap for market entry of *Plastic Roads* in Nepal outlines a phased approach that begins with private road construction and engagement with big industrial players. It emphasizes the importance of policy change to enable large-scale implementation and collaboration with existing asphalt plants. By involving the public sector and strategically positioning *EcoFlakes* as a valuable substitute for bitumen, the market offers significant potential for growth and sustainable waste management. The establishment of an efficient infrastructure will pave the way for a successful market entry and contribute to the transformation of Nepal's road construction practices towards a greener and more sustainable future.

Financing of the Technology Transfer

Using *EcoFlakes* in road construction is a suitable end-of-life destination for low-value plastics. Its macroeconomic benefit outweighs its cost when factoring in CO2 emissions and externalities. However, the current cost calculation does not include externalities, which is why the cost of production of *EcoFlakes* exceeds the market price. One promising approach to cover this financial deficit could be Plastic Credits, allowing the upscaling of this green technology by pricing external costs of plastic production of industrial enterprises.

Plastic Credits are transferable certificates representing the collection and recycling of specified amounts of plastic waste that would otherwise end up in the natural environment. By supporting projects that recover and recycle plastic waste, Plastic credits serve as a market-based financing tool to fund solutions to the global plastic pollution crisis, while encouraging responsible plastic waste management practices.

Conclusion

In conclusion, the feasibility of establishing *Plastic Road* technology in Nepal appears promising. It is driven by an abundance of low-value plastic waste, a pressing demand for infrastructure improvement. The necessary plants for implementation are already in Nepal and can be upgraded for our needs. However, several key barriers must be addressed to ensure successful adoption. The primary challenges lie in the cost aspect, necessitating the implementation of Plastic Credits to subsidize *EcoFlakes* and make them cost-competitive with bitumen. Additionally, policy changes are indispensable to create an enabling environment for the widespread adoption of *Plastic Roads*. Simultaneously, efforts must be made to establish the essential infrastructure for low-value plastic waste processing to ensure a consistent and substantial supply of EcoFlakes for road construction projects. By proactively addressing these challenges, the implementation of *Plastic Road* technology in Nepal can offer a sustainable and innovative solution to address waste management and infrastructure development needs in the country.

While NIDISI ReValue initially concentrated its efforts on lobbying with municipalities and instructing road construction companies in the new technology, the research has shown that a focus on policy change is the key to large-scale introduction of *Plastic Roads* in Nepal. Municipalities and road construction companies are willing to implement the innovation, yet they are bound by national road construction standards and have little incentive to deviate from those. Regulations for the Strategic and Local Road Networks set fixed standards for the input quantities in road construction. On the municipality level, the local engineers have a certain leeway when creating the tender for new roads, yet they usually follow national guidelines and refrain from taking risks by unilaterally changing their road technology. Smaller roads can be constructed with pre-mix as *Plastic Roads* pilot projects. However, as Nepal is heavily investing in infrastructure development and the improvement of the road network, the number of roads constructed with asphalt will augment in the future.

The current machines in asphalt mixing are adjustable for the new technology. While manual adding is a short-term option, modern machines on the largest batch mixing plants already have the possibility to add a specific feeder for the *EcoFlakes* input. This investment on the side of the asphalt companies will require previous policy change to make it economically viable.

There are no significant socio-cultural barriers that would hinder the introduction of the technology to Nepal. At the same time, improving safety standards during small-scale *Plastic Road* construction projects will benefit road construction workers in general. Dangers are unmonitored fumes and particles of shredded plastic entering the environment around the mixing site, either on-site with a pre-mix or on the asphalt plant. Necessary precautions and securement of the storage must be foreseen, and workers ought to be trained adequately.

The technology promises a positive impact on the waste management in Nepal, offering an appropriate end-of-life destination for low-value plastic waste. The substitution of bitumen as an input good by an already existing petrol constitutes a more environmentally and resource friendly approach. Nonetheless, a life-cycle assessment and a study on microplastic and leaching of other chemical components for the climate and context of Nepal has to be conducted to determine possible negative externalities. The improved quality of roads will create safer traffic conditions, reducing accidents and travel time, while also reducing the maintenance costs by lowering renovation needs.

Finally, to kickstart the technology transfer collaboration with the industry to build private roads and setting up the infrastructure is recommended. Policy change is a vital step for which partnering up with local actors in the environmental sector and convincing the asphalt companies of the cost-saving advantage is advised to jointly work on establishing new road standards.

To effectively implement *Plastic Roads* technology in Nepal, a strategic approach is essential. Initiating the process with municipalities and the private sector to achieve pilot roads is crucial, as these projects serve as

compelling examples to convince major contractors and other important stakeholders to advocate for the necessary policy changes. Once the policy changes are successfully instituted, the focus should shift to engaging big contractors, as this approach minimizes training efforts while simultaneously maximizing demand for *EcoFlakes*, ensuring consistency and reliability in the demand. Collaboration with like-minded partners, such as Green Road Waste Management, can be explored to establish joint ventures that leverage their local knowledge and network, expediting the achievement of common goals and fostering accelerated progress in the implementation of *Plastic Road* technology in Nepal.

The *Plastic Roads* technology provides a great potential to be introduced in Nepal. Small projects are feasible within the current political framework; however, policy change is necessary for conquering Nepal's market. Price competitiveness remains a key challenge with the financial deficit incurred through the additional steps required for processing the low-value plastic. Plastic Credits offer a possible solution that needs to be further evaluated from an economic point of view. Likewise, substantial endeavors and capital investments are indispensable for the establishment of the vital infrastructure for low-value plastic waste processing. This includes collection infrastructure, machinery, and processing facilities to guarantee a consistent and robust supply of *EcoFlakes*. Setting up the infrastructure without the prospect of constructing larger public roads and a validation of financial feasibility through Plastic Credits bears risks. Confirmation that policy makers have an interest in changing the road guidelines to include and incentivize *Plastic Roads* together with robust cost calculations on the production of *EcoFlakes* remains crucial to justify investments and expand operations.

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