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ELECTRIC VEHICLE RETROFITTING: A GUIDE TO POLICY-MAKING

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ACRONYMS & ABBREVIATIONS

AP	Air Pollutants
CAPEX	Capital expenditure
CO2	Carbon dioxide
EU	European Union
EV	Electric vehicle
GGGI	Global Green Growth Institute
GHG	Greenhouse gas
GM	General Motors
HDV	Heavy-duty vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
LDV	Light-duty vehicle
OEM	Original equipment manufacturer
OPEX	Operational expenditure
R&D	Research and development
RTOs	Region transport offices
TCO	Total cost of ownership
UK	United Kingdom
US	United States
ZEV	Zero-emission vehicle
ZEZ	Zero Emission Zones

CONTENTS

Executive Summary

Electric vehicles (EVs) have gained popularity as cleaner and more efficient solutions for achieving decarbonization objectives. More and more national governments have adopted electrification targets in their mobility strategies, while major original equipment manufacturers (OEMs) are prioritizing investments in the sector for its effectiveness, potential, and growing popularity of EVs among customers.[1] Despite the optimistic outlook, there are considerable challenges to the widespread adoption of EVs, such as high market costs, limited efficiency, scrappage production, and public acceptance.[2] Within the context of a global macro electrification agenda, EV conversion – or EV retrofitting – is a viable alternative to address the limitations of new EV technology, offering an innovative and adaptable green transportation solution.

With the potential to offer a more cost-effective, fast, and adaptable alternative to the purchase of new EVs, EV retrofitting is slowly being adopted by key countries as a complementary process to the electrification of transportation systems. Therefore, this report intends to explore EV retrofitting as a viable option for GGGI Members, focusing on market, technology, economic and policy insights that can render future development and investment opportunities.

The basic concept of vehicular retrofitting is the removal of the hardware systems of the combustion engine, including the motor, motor controller, battery, gearbox with differential, and wiring harness part. The process is then followed by the substitution with the basic parts of an EV: a steering system, suspension subsystem, braking system, traction motor (AC or DC), battery with battery management system, gearbox with differential, motor controller unit, and vehicle switching and controlling part.[3]

Undoubtedly, EV retrofitting has the potential to play an important middle-ground role in the complete electrification of transportation systems. Global economic and policy trends for green technology, transport electrification, and climate-friendly solutions provide an optimistic outlook of growth and development for the market over the next decade.[4] However, persisting challenges still need to be addressed for the industry to advance. Regulatory, technological, and enabling barriers must be addressed for the ICE-to-EV conversion industry to develop beyond its current infancy stage into an adaptable and reliable low-carbon strategy for governments worldwide.

The resolution of challenges is essential to facilitate wider adoption of technology. Public policies, incentives, and regulatory systems play a major role in the expansion of the EV retrofit market.[5] This report explores key enabling measures for the EV retrofitting industry and market's further development. It analyzes past experiences with similar technologies as well as countries' best practices to officially support EV conversion, focusing on safety and technical regulations, market incentives, R&D programs, and other measures for normalization and expansion of the practice.

Despite these barriers, several countries present a scenario with exemplary policy practices that acknowledge EV retrofitting as a feasible and worthwhile investment. The countries analyzed in this report show comprehensive examples of public policies that are specific to EV retrofitting, allowing the industry to develop and continue to grow. Among 46 GGGI members considered, five countries – Australia, Indonesia, Nepal, Sri Lanka, and the UK – were identified with having EV conversion legislation. When applying the division of Technical Regulation, Incentive Measures, and Environment Enabling Measures, only Indonesia possesses the three sets of regulations.

This report conducts comparative economic analysis of two-wheelers (2Ws), three-wheelers (3Ws), and four-wheelers (4Ws) retrofitting with the case of Indonesia, Sri Lanka, and Kenya respectively. This analysis is to fairly reflect the economic benefits of retrofitted electric vehicles. Capital expenditure (CAPEX) includes vehicle investment costs and partial replacement investment costs such as batteries. Operational expenditure (OPEX) mainly includes maintenance and energy costs including diesel for ICE vehicles and electricity for electric ones.

In this analysis, total cost of ownership (TCO) and unit travel cost (USD/km) indicators are used to determine the economic benefits. The following table shows the expected economic benefits of three types of retrofitted electric vehicles including 2Ws, 3Ws, and 4Ws.

1 IEA, ***Global EV Outlook***, last modified 2021.

2 Robbie Watts, Aritra Ghosh, and Justin Hinshelwood, "Exploring the potential for electric retrofit regulations and an accreditation scheme in the UK," ***Electronics*** 10, no. 24 (2021).

3 Arun C. Giriyapur and D. M. Karthik, "Retrofitting of an engine powered vehicle into an electric vehicle," ***International Conference on Smart System and Inventive Technology (ICSSIT)*** (2019), https://doi.org/10.1109/ICSSIT46314.2019.8987868.

4 Precedence Research, "Automotive retrofit electric vehicle."

5 Kukar, "Retrofitting for electric vehicles."

Table 1. The result of comparative Economic Analysis

		New ICE	New EV	Retrofitted EV
4Ws	TCO (USD)	100,736	82,913	65,217
	$/km	0.427	0.302	0.249
3Ws	TCO (USD)	27,487	16,162	15,250
	$/km	0.066	0.034	0.033
2Ws	TCO (USD)	3,134	1,700	2,436
	$/km	0.026	0.013	0.018

In addition, this report conducts environmental impact assessment of the retrofitted electric vehicles. The following table shows the expected environmental impact of the retrofitted electric fleet per annum. In terms of local pollutants, new E4W and retrofitted E4W options reduce $PM_{2.5}$ and NO_x emissions by 100%.

Table 2. Environmental Impacts of Retrofitted EV

		New ICE	New EV	Retrofitted EV
4Ws	CO_2 (kgCO2e)	3,777.91	1,844.23	1,844.23
	$PM_{2.5}$ (g)	1,991.206	0.000	0.000
	NO_x (kg)	348.068	0.000	0.000
3Ws	CO_2 (kgCO2e)	7,051.80	2,750.20	2,750.20
	$PM_{2.5}$ (g)	785.744	0.000	0.000
	NO_x (kg)	116.073	0.000	0.000
2Ws	CO_2 (kgCO2e)	387.89	292.52	292.52
	$PM_{2.5}$ (g)	68.326	0.000	0.000
	NO_x (kg)	10.093	0.000	0.000

The EV retrofitting market can be directly benefited by the promotion of decarbonization strategies and industry innovations and can be further expanded by the adoption of effective policies for the regulation and promotion of the practice. Given its potential as a more cost-effective, fast, and adaptable alternative to purchasing new EVs, retrofitting is slowly being adopted by countries **as a complementary process to the electrification of transportation systems**. Given this circumstance, this report proposes the following recommendations:

RECOMMENDATION 1: Establishment of EV conversion–specific technical legislation

With the increasing availability of EV retrofitting kits to the public, countries must prioritize specific legislation to regulate and oversee the EV retrofitting process. The adoption of an updated and robust regulation scheme helps guarantee the reliability of the process to the customer, constituting an important first step for the expansion of the market.

RECOMMENDATION 2: Inclusion of EV retrofits in existing EV incentives

As countries continue to invest in different decarbonization strategies for their transportation systems, electrification is a popular alternative for many. While it may be argued that EV retrofits can be automatically classified as EVs and, consequently, be given the same incentives granted to new EVs, an explicit inclusion of converted vehicles is essential for a truthful adoption of retrofitting as an electrification strategy.

RECOMMENDATION 3: Investment in R&D, capacity-building, and awareness campaigns

It is recommended to invest in manufacturers, start-ups, and companies through national R&D programs to continue to develop new EV conversion kits as well as for capacity building for the technicians who perform the conversion. Additionally, awareness campaigns are necessary to familiarize customers with the technology.

1. INTRODUCTION

1.1. CONTEXT

Growing concerns about rising global temperatures and the effects of climate change have led countries to develop strategies for the reduction of GHG emissions in different sectors.[6] The transportation sector, historically primarily reliant on fossil fuels[7] and responsible for considerably over a quarter of CO_2 emissions globally,[8] has been heavily affected by these trends. Major industry players have been prompted to embrace carbon-light solutions and formulate long-term strategies for decarbonization.

Electric vehicles (EVs) have gained popularity as cleaner and more efficient solutions to help achieve decarbonization objectives. Numerous national governments have adopted electrification targets for their mobility strategies, while major original equipment manufacturers (OEMs) have prioritized investments in the sector for its effectiveness, potential, and growing popularity of EVs among customers.[9] Despite the optimistic outlook, there are considerable challenges to the widespread adoption of EVs, such as high market costs, limited efficiency, scrappage production, and public acceptance.[10] In the broader context of a global macro electrification agenda, EV conversion or retrofitting is a viable alternative to the limitations of new EV technology, offering a fresh perspective to overcome the existing limitations and challenges.

New EVs are still considered luxury vehicles in many markets worldwide. Given the stage of the technology and of manufacturers, purchasing a new EV model is often not a financially viable option for many customers[11]. Furthermore, many customers face the high purchase costs for new EV models while still encountering the challenges of owning internal combustion engines (ICEs), such as restrictions on CO_2 emissions and rising oil prices.[12] In this context, EV

6 UNFCCC, ***Key aspects of the Paris Agreement***, accessed October 2, 2022, https://unfccc.int/most-requested/key-aspects-of-the-paris-agreement?gclid=CjwKCAjwrdmhBhBBEiwA4Hx5g4N4YHKwi1RaH_XUmZtdG7QdhuL8PgKRgc4Zzq0wtdtMJifxNxxjQxoCsIQQAvD_BwE.

7 IEA, ***Transport***, last modified 2023.

8 IEA, ***Transport***, last modified 2022.

9 IEA, ***Global EV Outlook***, last modified 2021.

10 Robbie Watts, Aritra Ghosh, and Justin Hinshelwood, "Exploring the potential for electric retrofit regulations and an accreditation scheme in the UK," ***Electronics*** 10, no. 24 (2021).

11 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

12 Gupta Kukar, "Retrofitting for electric vehicles: Status, potentials, and challenges," The City Fix Learn, last modified July 29, 2019, https://thecityfixlearn.org/webinar/retrofitting-electric-vehicles-status-potential-and-challenges.

retrofitting could be a possible alternative for democratizing access to electrification. It serves not only as a cost-efficient option for customers but also offers opportunities for engagement with EV parts industries and the expansion of EV infrastructure's outreach.[13]

While OEMs are adapting their productive systems to incorporate the different needs of EV consumers, the current market is dominated by popular vehicles from high-income countries and is unable to meet diverse demands of distinct geographical regions and niche clientele.[14] The adoption of more widespread EV conversion would allow (i) for owners of vehicles with a high inherent value to transition their ICEs into a technology fit for decarbonization, (ii) for owners of niche vehicles to participate in electrification despite the lack of alternatives for new EV models, and (iii) for governments and manufacturers to spread awareness and information about EVs and accelerate long-term electrification.[15]

EV retrofitting has the potential to be an environmentally friendly alternative to the purchase of new EV models. EV conversion not only reduces scrappage by reducing the number of potentially discarded vehicles in the transformation process, but also shows promise in diminishing GHG emissions. Recent studies show that retrofitted EVs exhibit reduced life cycle GHG emissions compared to both ICE vehicles and even new EV models.[16] While the technology is still new and its market is still advancing, EV retrofitting can tackle the challenges that new EV models face and has the potential to successfully integrate strategies for decarbonization. Consequently, the electric retrofitting of vehicles can play an important role in facilitating the electrification of transport and achieving the long-term goal of sustainable decarbonization.

Global economic and policy trends for green technology, transport electrification, and climate-friendly solutions provide an optimistic outlook of growth and development for the EV retrofitting market over the next decade.[17] However, persisting challenges still need to be addressed for the industry to advance. A lack of visibility and knowledge of retrofitting solutions among possible customers and policymakers alike, for instance, hinders the inclusion of such solutions in transport electrification strategies.[18] Without governmental support, the industry's capacity for developing better and cheaper technology is inhibited, restricting the existing EV conversion kits to a narrow number of vehicle models with limitations in terms of range and longevity.[19]

EV retrofitting has the potential to play an important middle-ground role in the complete electrification of transportation systems. As a solution to challenges such as the total cost of EV adoption and high scrappage levels of old ICE models, the expansion of EV retrofitting should be considered by governments within their long-term electrification strategies. Despite the EV conversion industry being in its initial stages, it can be a strong alternative for countries that cannot afford bold electrification initiatives due to high upfront costs. Retrofitting can be used to facilitate policy transitions for transport electrification, given its adaptability to regulations and incentives for EV adoption and can thus promote further visibility of electric transportation alternatives.[20] Additionally, it may provide environmental benefits through promoting reutilization of older vehicle parts and reducing the scrappage associated with the expansion of new EVs.[21]

1.2. OBJECTIVE AND SCOPE

With the potential of being a more cost-effective, fast, and adaptable alternative to the purchase of new EVs, EV retrofitting is slowly being adopted by key countries as a complementary process to the electrification of transportation systems. Therefore, this report intends to explore EV retrofitting as a viable option for GGGI Members, focusing on market, technology, economic and policy insights that can render future development and investment opportunities.

The report will be used to support the GGGI team and Members to facilitate the adoption of EV retrofitting. The report includes six chapters:

- Chapter 1 presents a general contextualization of EV retrofitting and the introduction of the report.

13 Fabian Hoeft, "Internal combustion engine to electric vehicle retrofitting: Potential customer's needs, public perception and business model implications," ***Transportation Research Interdisciplinary Perspectives*** 9 (2021), https://doi.org/10.1016/j.trip.2021.100330.

14 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

15 Hoeft, "Internal combustion engine to electric vehicle retrofitting"; Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

16 Eckard Helmers, Johannes Dietz, and Susanne Hartard, "Electric car life cycle assessment based on real-world mileage and the electric conversion scenario," ***The International Journal of Life Cycle Assessment*** (2017): 22, https://doi.org/10.1007/s11367-015-0934-3.

17 Precedence Research, "Automotive retrofit electric vehicle."

18 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

19 Neil Winton, "Electric cars are too expensive for many, but retrofitting could be the answer," Forbes, last modified January 20, 2022, https://www.forbes.com/sites/neilwinton/2022/01/20/electric-cars-are-too-expensive-for-many-but-retrofitting-could-be-the-answer/?sh=319bbc397583.

20 Hoeft, "Internal combustion engine to electric vehicle retrofitting"; Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

21 Hoeft, "Internal combustion engine to electric vehicle retrofitting"; Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

- Chapter 2 introduces a brief market analysis of EV retrofitting and presents an explanation of the composition and procedure of EV retrofitting of different modes of vehicles.

- Chapter 3 presents policy incentives and strategies to promote safe and inclusive EV retrofitting amongst public and private stakeholders.

- Chapter 4 showcases a financial assessment of ICE vehicles, new electric vehicles, and retrofitted electric vehicles of three different vehicle types in three different case countries to explore the possible economic and environmental benefits.

- Chapter 5 explores case studies that highlight countries' policy experiences with EV conversion and the lessons learned from previous chapters.

- Chapter 6 summarizes the information provided throughout the report.

2. EV RETROFITTING MARKET AND TECHNOLOGIES

2.1. EV RETROFITTING MARKET

The EV retrofitting market has the potential for a vast uptake among consumers, not only for its cost-effectiveness but also for its technology. EV retrofitting kits are simple in composition, and the conversion process is relatively straightforward for specialized technicians. While market analyses indicate that the EV retrofitting market is in its initial stages, the simplicity and accessible technology are a clear advantage for its expansion. However, caution is advised in inspections and supervision to guarantee a safe and optimal adoption of EV retrofitting.[22] As will be explored in following chapters, proper EV retrofitting regulations can allow for market growth and for EV technology to be further naturalized in society.

While the global EV retrofitting market currently presents a limited number of regularized retrofitting kits, popularization of the practice creates an avenue for the exploration of the technology in more specialized vehicles and in conjunction with other electrification technologies.[23] Current auto manufacturers already produce most of the parts composing retrofitting kits, making entry into the EV conversion business relatively cost-effective and resource-efficient. Major OEMs have an opportunity to expand into the electrification market without compromising a significant portion of their production capacity.

The **growing consumer demand for vehicle electrification** and **stricter government regulations on vehicle emissions** present key opportunities for the expansion of the electric conversion market, with demand predicted to grow for passenger vehicles and two-wheelers in the next decade. The global retrofit vehicle market was valued at an estimate USD 65.94 billion in 2023 and is projected to reach USD 125.37 billion by 2032[24]. The market presents signs of continuous growth, being dominated by the commercial vehicle segment (48%) and by market shares from Asia-

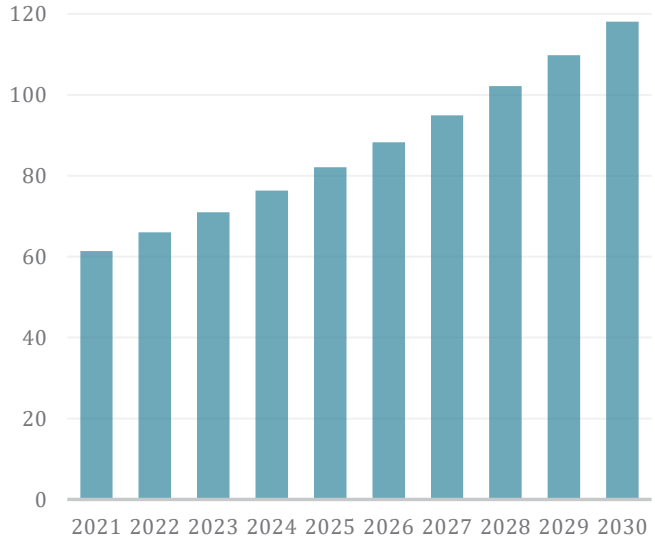
22 Nirmal Kumar, Navaneeth M, and Allan Sabu Joseph, "Retrofitting of conventional two-wheelers to electric two-wheelers," ***13th IEEE PES Asia Pacific Power & Energy Engineering Conference (PPEEC)*** (2021), https://doi.org/10.1109/APPEEC50844.2021.9687799.

23 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

24 Precedence Research, "Automotive retrofit electric vehicle powertrain market size, share, report by 2032," last modified June 2023, https://www.precedenceresearch.com/press-release/automotive-retrofit-electric-vehicle-powertrain-market

Pacific (62.5%), Europe (17.3%), North America (10.7%), Latin America (4%), and the Middle East and Africa (2.1%).[25]

Figure 1: Automotive retrofit electric vehicle powertrain market size, 2021 to 2030 (USD billion), Precedence Research, 2021

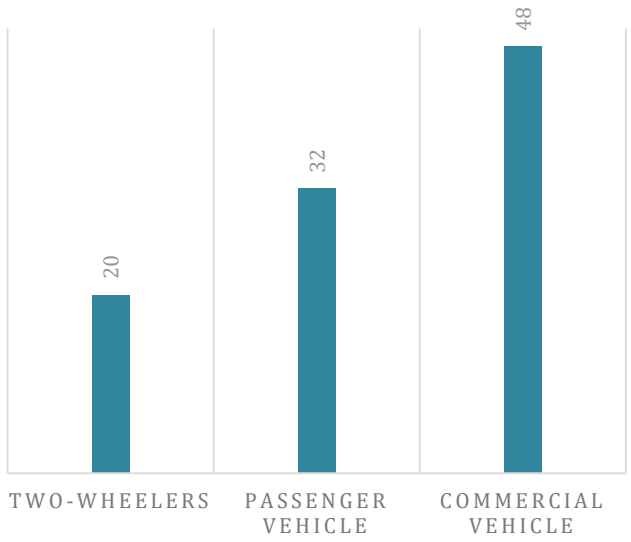


EV retrofitting can be an asset for the decarbonization of transportation systems—for users of professional-specific vehicles (e.g., ambulances or commercial mobiles) who wish to transition to EVs but cannot find available electric models of their vehicles.[26] Similarly, the technology appeals to collectors of classic models or other niche markets, facing restrictions on ICE vehicle use within zero-emission zones (ZEZ).[27] The conversion of specific models can guarantee optimal customer approval and present better performance compared to new EV models of the same category, with certain retrofit models having over 100 kilometers more autonomy than their new EV counterparts.[28]

The global EV conversion market defines different retrofitting demands according to the region. Asia-Pacific presents the largest share of the global EV powertrain conversion market, led by countries with strong investments in clean transportation research and development (R&D), such as China, India, Japan, and South Korea.[29] Increasing demand for EV retrofitting in the region is led by governments' determination to spur electromobility adoption, elevated prices of new EV models, and investments in R&D both in the public and private sectors. Retrofitting is presented as a cost-effective alternative, utilizing technology and expertise developed in conjunction with EV R&D. The exploration of EV retrofitting as a related market creates opportunities for the development of universal conversion kits of different small car models as well as other popular modes of transportation, such as two- and three-wheelers.[30]

Increased demand from European and North American economies is also affecting the development of new technologies in the EV retrofitting market. With new EV models being more financially accessible in these countries—through high investments in R&D and financial and fiscal incentives for the purchase and ownership of EVs—retrofitting targets the conversion of classic or labor-specific vehicles rather than most of the transportation fleet in these regions. In these cases, the development of new business models and vehicle model–specific conversion kits can contribute to the retrofitting market expansion.[31]

Figure 2: Automotive retrofit electric vehicle powertrain market share, by vehicle type, 2021 (%), Precedence Research, 2021



By vehicle type, the market is segmented into commercial vehicles, two-wheelers, and passenger vehicles. In 2021, the commercial vehicle segment held the largest electric conversion market share. A diverse set of countries, such as

25 Precedence Research, "Automotive retrofit electric vehicle powertrain market," last modified September 2022, https://www.precedenceresearch.com/automotive-retrofit-electric-vehicle-powertrain-market, Precedence Research, "Automotive retrofit electric vehicle powertrain market size, share, report by 2032," last modified June 2023, https://www.precedenceresearch.com/press-release/automotive-retrofit-electric-vehicle-powertrain-market

26 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

27 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

28 Luthereau, Alexandra, "Le retrofit électrique: L'avenir de la voiture propre?" Numerama, last modified June 28, 2020, https://www.numerama.com/tech/628645-le-retrofit-electrique-lavenir-de-la-voiture-propre.html.

29 Transparency Market Research, "Automotive retrofit electric vehicle powertrain market," last modified June 2022, https://www.transparencymarketresearch.com/automotive-retrofit-electric-vehicle-powertrain-market.html.

30 Transparency Market Research, "Automotive retrofit electric vehicle."

31 Transparency Market Research, "Automotive retrofit electric vehicle."

China and India, have facilitated the conversion of electric buses and heavy-duty trucks to decrease pollution along congested delivery routes.[32] The passenger vehicle segment is also anticipated to have the dominating market share by 2030. Market drivers—such as increases in fuel prices, the development of new motor and battery technologies, and the adoption of stricter carbon emission regulations—will fuel major investments in retrofitting passenger vehicles.

Major OEMs (e.g., GM[33] Ford,[34] and Toyota[35]) have announced their expansion toward the EV retrofitting market, disclosing the release of official conversion kits for their older models.[36] Further integration of retrofitting technology within the global automobile manufacturing system couldboost EV infrastructure development by making electrification cheaper and more accessible.[37] Consequently, EV retrofitting can play an important role in the automotive industry's transition.

The electric powertrain market plays a major role in the development of EV retrofitting as a decarbonization solution. Companies in this sector, such as Altigreen, Bharat Mobi, Continental AG, Dephi Technologies, Hitachi Astemo, Magna International, Mitsubishi, Robert Bosch, Transition One, etc. play a key role in the growth of the global market[38]. Despite the initial adoption of the strategy by some global players, local companies currently play a strategic role in the popularization of EV conversion kits in their areas. Local companies and manufacturers are more adaptable to their markets' needs in the development of retrofitting solutions, working with spare parts to create conversion kits[39].

A preliminary identification of ICE to EV retrofitting market was conducted on GGGI member countries. The result is as seen in Table 3:

Table 3: Preliminary mapping of ICE to EV retrofitting market in GGGI member countries

Region	Countries with Retrofitting Market
Asia	Indonesia, Republic of Korea, Nepal, Pakistan, Sri Lanka, Thailand
Africa	Kenya, Rwanda
Europe	Norway, UK
Latin America and Caribbean	Colombia, Ecuador, Mexico, OECS, Paraguay, Peru
Middle East	UAE
Pacific	Australia, Philippines
Total:	19

Out of the 46 official members of GGGI, 19 member countries and organizations have been identified with EV retrofitting markets at some level. EV retrofitting markets have been identified in all regions in which GGGI is present. A majority of these members are in the Asia region (6 out of 19), reflecting the organization of the current global retrofitting market. A similar quantity of members, however, was identified in the Latin American and Caribbean regions (6 out of 19). Fewer representations have been found in Africa (2 out of 19), Europe (2 out of 19), the Pacific (2 out of 19), and the Middle East (1 out of 19).

Limitations on the preliminary identification of EV retrofitting markets amongst GGGI members must be addressed. The mapping was conducted through desk-based research and review from the GGGI HQ and regional offices. This exercise was conducted to grant a brief understanding of the retrofitting market amongst GGGI members, to identify future opportunities and challenges for future expansion of the service in the regions, and to guide analyses of policy measures for market expansion. While the EV retrofitting market is still at an infancy level in a global scale, further investigation is necessary to fully understand each case country.

2.2. MAJOR CONVERSION KITS FOR RETROFITTING

The basic concept of vehicular retrofitting is the removal of the hardware systems of the combustion engine, including the motor, motor controller, battery, gearbox with differential, and wiring harness part. The process is then followed by the substitution with the basic parts of an EV: a steering system, suspension subsystem, braking

32 Precedence Research, "Automotive retrofit electric vehicle."

33 Paul A. Eisenstein, "GM set to join fast-growing EV conversion market," The Detroit Bureau, last modified July 22, 2022, https://www.thedetroitbureau.com/2022/07/gm-set-to-join-fast-growing-ev-conversion-market/.

34 Chris Randall, "Ford announces electric conversion motor." Electrive, last modified August 27, 2021, https://www.electrive.com/2021/08/27/ford-announces-electric-conversion-motor/.

35 Thom Taylor, "Toyota says it plans to convert old cars into EVs," Motor Biscuit, last modified January 13, 2023, https://www.motorbiscuit.com/toyota-says-plans-to-convert-old-cars-into-evs/.

36 Eisenstein, "GM set to join fast-growing EV conversion market."

37 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

38 Precedence Research, "Automotive retrofit electric vehicle powertrain market size, share, report by 2032," last modified June 2023, https://www.precedenceresearch.com/press-release/automotive-retrofit-electric-vehicle-powertrain-market

39 Hoeft, "Internal combustion engine to electric vehicle retrofitting"; Precedence Research, "Automotive retrofit electric vehicle."

system, traction motor (AC or DC), battery with battery management system, gearbox with differential, motor controller unit, and vehicle's switching and controlling apparatus.[40]

In general, EV conversion kits are comprised of the basic following parts:[41]

- Motor
- Controller
- Shunt
- Transmission adapter kit
- Charger
- Chill plate
- DC-DC converter
- Throttle controller
- Controller mount

EV conversions must be financially accessible to most car owners for their adoption to be effectively popularized.[42] In general, retrofitting is made available for vehicles that are five years or older. When performing the electric conversion, technicians and engineers must have a good understanding of the vehicle's daily operation cycle to size the battery capacity appropriately without impeding the existing passenger or load capacity.

The simplicity and relatively low prices of the component parts for an EV retrofitting process generate an opportunity for further development of the electric powertrain market. With predicted expansions and further interest in transport electrification, powertrain developers should continue to invest in versatile kits and products for conversion. The development of adaptable and accessible kits will allow for more flexibility in vehicle conversions.[43]

40 Arun C. Giriyapur and D. M. Karthik, "Retrofitting of an engine powered vehicle into an electric vehicle," ***International Conference on Smart System and Inventive Technology (ICSSIT)*** (2019), https://doi.org/10.1109/ICSSIT46314.2019.8987868.

41 Sandesh Kandagal, "EV retrofit technology? Conversion kit, cost & companies," e-Vehicle Info, last modified April 1, 2022, https://e-vehicleinfo.com/ev-retrofit-technology-conversion-kit-cost-companies/.

42 Robin Fearon, "Retrofitting older cars with electric motors could transform transport," ***Discovery***, last modified November 1, 2021, https://www.discovery.com/motor/retrofitting-older-cars-with-electric-motors-could-transform-tra.

43 Transparency Market Research, "Automotive retrofit electric vehicle."

2.2.1. Two-wheelers

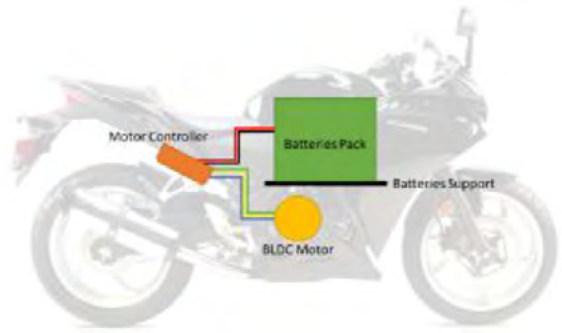
'L components, with companies offering variations of the following items:[44]

- Electric motor
- Motor controller
- DC-DC converter
- Lithium-ion phosphate battery pack

One of the main concerns of two-wheeler retrofitting is the placement of the electric battery and the motor. This positioning must be installed to maintain a safe weight distribution for the end user. Since many of the original components of ICE two-wheelers are not necessary in an electric conversion, the stability of the final product must be prioritized[45].

Battery capacity is one of the main challenges identified for two-wheeler ICE to EV conversion. Ideal batteries for this modal type must be compact in size, with high storage capacity, and high energy generation to be optimal for the range needs of consumers[46]. While challenges persist on providing battery packs with optimal range capacity, battery-swapping business models could potentially address consumers' range needs[47].

Figure 3: Arrangement of propulsion system in converted two-wheeler model, Zainor et al., 2019, p.73



44 Kumar, Navaneeth, Joseph, "Retrofitting of conventional two-wheelers to electric two-wheelers"

45 Kumar, Navaneeth, Joseph, "Retrofitting of conventional two-wheelers to electric two-wheelers"

46 Zainol, Toha, Kamisan, Bukhari, "Design and development of a retrofit electric motorbike"

47 Agarwal, Babbar, "Consumer's attitude towards retrofitting of existing internal combustion engine scooters with electric conversion in India"

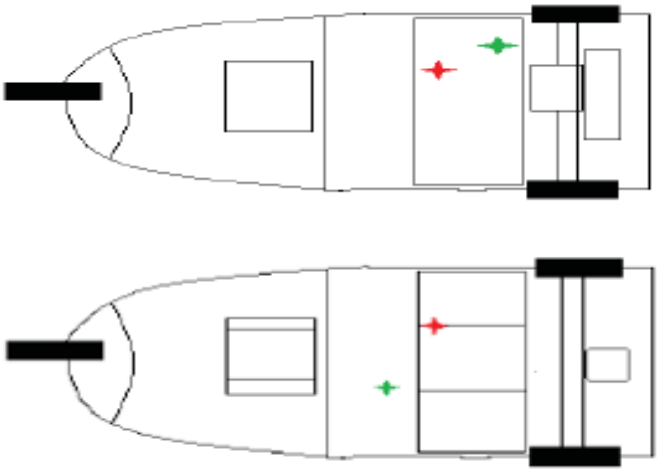
2.2.2. Three-wheelers

Three-wheelers' conversion kits closely resemble those for two-wheelers, demanding less components than retrofitting for conventional four-wheelers. The basic kit contains the following components:[48]

- Electric motor
- Motor controller
- DC-DC converter
- Lithium-ion phosphate battery pack

The removal of ICE parts during the conversion process will allow retrofitted three-wheelers to be lighter when compared to its ICE counterpart. Division of battery packs under the driver and passenger seats allows for stable weight distribution and safe vehicle operation[49]. Additional changes in secondary parts (such as wind screen glass, headlights, tail lamps, sunroof material, chassis, etc.) are recommended to reduce the weight of the three-wheeler further and optimize the range capacity of the retrofitted version[50].

Figure 4: Illustrative diagram of shift of center gravity of ICE three-wheeler (above) and of retrofitted three-wheeler (below), Kokate et al, 2020, p.232



2.2.3. Passenger vehicles

Battery capacities currently vary from 72 to 420 kilowatt hours. The electric range of current EVs can vary between 100 and 300 kilometers depending on weather and loads.[51]

Figure 5: Basic components for LDV electric retrofitting, Zemo, 2021

There might be variations in the components of retrofitting kits according to the necessities of different vehicles. Electric retrofitting of heavy-duty vehicles (HDVs), especially of buses, depends heavily on the structure of the chassis, with companies needing to adapt their specific demands to the models and their internal engine structure.[52]

2.3. RETROFITTING PROCESS

Similar to its technological aspects, the retrofitting process follows a general order for most vehicle types. Before beginning the conversion, an initial inspection of the vehicle must be performed to determine whether the chosen vehicle can be retrofitted. Since every vehicle has specific measurements and balancing conditions that must be met, conversion companies typically work with models for which they possess the expertise. These vehicles are often lightweight and spacious, which facilitates the installation of electric batteries.

After the initial inspection, the vehicle's thermal elements are removed, which mainly consist of the internal combustion engine, fuel tank, muffler, exhaust system, starter, and radiator. ICE vehicles frequently have unnecessary components necessary for electric operation, and their full removal renders space for the installation of the new components.

The integration of the retrofitting technology comes quickly after, consisting of the electric motor, the battery (usually

48 SL Mobility, "Conversion Kit," last modified June 27, 2016, https://www.slmobility.com/products/conversion-kit/conversion-kit/conversion-kit.

49 Kokate, Uttekar, Karandikar, Holmukhe, "Retrofitting of auto rickshaw to e-rickshaw – A feasibility study"

50 Kokate, Uttekar, Karandikar, Holmukhe, "Retrofitting of auto rickshaw to e-rickshaw – A feasibility study"

51 Daniel Hayes, ***The Clean Vehicle Retrofit Technology Guide***, Zemo Partnership, 2021.

52 Equipmake, ***EVR-B5 Overview***, last accessed January 13, 2023.

lithium-ion batteries, as they are the lighter models in the market), lithium cells, and a power controller to regulate the flow of energy. This step presents the most variation in terms of vehicle models, as the size of the electric motors and batteries will depend on the available size of each vehicle, their expected performance, and their weight.[53]

Two-wheelers require special attention due to the potential weight increase (approximately 15-20%) resulting from the installed electric technology. This alteration could impact stability, and, consequently, overall performance.[54] E-bus conversions also present more rigorous procedures during the integration of the retrofitting technology, as they generally involve the submission of details of changes, ideally with supporting evidence that the vehicle meets certain regulations.[55] Standardization of the popular bus chassis is necessary to develop technical expertise of the necessary steps for retrofitting that meets the balancing and performance needs of HDVs.[56]

The last step before delivering the final product involves conducting technical tests and verifying performance of the retrofitted technology. Although there is no global regulation for electric conversion inspections, most countries depend on legislation for inspections of general vehicular alteration and tuning. With the recent advancements of EV retrofitting, some countries have also started developing EV conversion–specific legislation to officially regulate the practice. This is an essential step to guarantee that the retrofitted vehicle not only operates within technical and safety parameters but also does not present any risks to the final user or to the environment.

Table 4: Retrofitting process

Initial Inspection	▪ Inspect the vehicle to determine its capability of being retrofitted.
Thermal Element Removal	▪ Remove thermal elements to secure space for the new components.
Technology Integration	▪ Install retrofitting technologies, including a motor, batteries, and a power controller, among others.
Technical Tests and Verifications	▪ Inspect the vehicle to guarantee it meets performance and safety requirements.

53 Kandagal, "EV retrofit technology?"

54 EV Reporter, "E-2Wheeler retrofitting: Scope and cost of conversion," last modified February 16, 2022, https://evreporter.com/e-2wheeler-retrofitting-scope-and-cost-of-conversion/.

55 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

56 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

3. POLICY MEASURES

3.1. GLOBAL BARRIERS FOR EV RETROFITTING EXPANSION

EV retrofitting has the potential to play an important middle-ground role in the complete electrification of transportation systems. Global economic and policy trends for green technology, transport electrification, and climate-friendly solutions provide an optimistic outlook of growth and development for the market over the next decade.[57] However, persisting challenges still need to be addressed for the industry to advance. Regulatory, technological, and enabling barriers must be addressed for the ICE-to-EV conversion industry to develop beyond its current infancy stage into an adaptable and reliable low-carbon strategy for national governments worldwide.

A major barrier identified concerns the lack of EV retrofitting-specific regulations within most countries. While EV conversion kits are generally domestically available in different markets – or, at the very least, the separate parts to enable EV conversion –, the absence of specific regulations and policies addressing the practice generates safety hazards to both drivers and pedestrians. Given that retrofitting alters the mobility, weight distribution, and electrical systems of the vehicle[58], proper guidelines and verification are necessary to assure its mechanical integrity[59]. Another considerable point is that the lack of safety guidelines or regulations compromises the expansion of the industry. With no official government strategy, industry leaders hesitate in financing the necessary R&D investments to make the technology accessible to consumers. Consequently, the lack of retrofitting regulation hinders the expansion of the industry into other markets and jeopardizes its reach in different consumer pools.[60]

A second major barrier concerns the current infancy level of the retrofitting industry and market. There is a restriction on the variety of conversion kits available for consumers, affecting the possible consumer pool for the technology.[61] Since ready-to-use conversion kits are made to be installed into specific ICE models, consumers must undertake specialized and costly individualized conversions if they do not want to be limited by the market offer of kit models. The market size also affects the total cost of ownership (TCO) of possible retrofitted vehicles. Without the necessary market

57 Precedence Research, "Automotive retrofit electric vehicle."

58 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

59 Kukar, "Retrofitting for electric vehicles."

60 Winton, "Electric cars are too expensive for many."

61 Kukar, "Retrofitting for electric vehicles."

investments and policy incentives, the technology might not be cost-efficient to customers when compared to the cost of the product and the cost of fuel for ICE vehicles.[62] While this report develops a financial tool for more accurate comparison between ICE, new EV, and retrofitted vehicles, the TCO of EV retrofitting might still be a considerable barrier to many possible consumers.

Lastly, there are environment-enabling challenges that constrain the full expansion of retrofitting solutions. The lack of information available about EV conversion in many countries, for example, generates hesitation and mistrust from potential customers[63]. While new EVs have slowly been gaining traction and popularity in the automobile market, retrofitting is still widely unknown by customers. The lack of accessibility, visibility, and informational campaigns and strategies leaves the solution out of consumers' knowledge and, consequently, underexplored. Additionally, this lack of information can also result in improper conversion practices that can present further risks to the technology's legitimacy and to users' safety[64].

Challenges must be addressed to allow the technology to be further popularized. Public policies, incentives, and regulatory systems play a major role in the expansion of the EV retrofit market.[65] Despite these barriers, several countries present a scenario of policy best practices for the recognition of EV retrofitting as a process that is both viable and worth investing in. The countries analyzed in this report show comprehensive examples of public policies that are specific to EV retrofitting, allowing the industry to develop and continue to grow.

3.2. ENABLING MEASURES

The following subchapter explores key enabling measures for the EV retrofitting industry and market's further development. It analyzes past experiences with similar technologies as well as countries' best practices to officially support EV conversion, focusing on safety and technical regulations, market incentives, R&D programs, and other measures for normalization and expansion of the practice.

3.2.1 Safety and Technical Regulations

Safety and technical regulations are official legislations and standards that oversee the safety of the general infrastructure and electrical systems of a vehicle. While many of these standards align with those governing manufacturing, retrofitted vehicles must have their own set of regulations to guarantee that the specific changes made to the vehicle's electric system, drivetrain, and other physical attributes will not cause safety hazards to the driver and to others within the vehicle's range.[66]

Ensuring a proper functioning of the electrical systems of a retrofitted vehicle is one of the main safety concerns after a conversion. If not properly performed, the high voltage of the newly inserted battery might cause sudden energy releases and fire hazards. Added batteries might also present chemical risks if not properly tested and installed. Another major concern is related to the drivetrain, which were not initially projected to carry weighty batteries. If installed without a proper engineering study, the battery may cause weight distribution issues and later-set structural damages to the vehicle's drivetrain.[67]

Currently, there is no standardization for retrofitted EV safety and technical standards. While individual components can be acquired, the industry is still at infancy level in many countries. Retrofitting of old classic cars, for instance, might be possible, but it is not strongly regulated beyond what mandated for traditional EVs[68]. Some countries recognize the potential of EV conversion for their decarbonization goals and are creating the necessary legislation to oversee and give incentives to its expansion[69].

Some countries are taking a pioneer role on creating regulatory standards. Taking inspiration from already existing vehicular modification and tuning regulations, they are working both on creating retrofitting-specific technical and safety standards as well as a simplification of the certification process. Instead of testing all converted vehicles, for example, a strategy many countries are adopting are certifying mechanics and model-specific retrofitting kits[70].

This strategy is being adopted more frequently amongst countries, requiring the regularization of testing agencies and the registration of specialized mechanics and technicians. However, it is still common to find regulations that demand vehicle verification after the conversion process, testing areas such as weight balancing, brake performance, temperature resistance, noise levels, and

62 Kukar, "Retrofitting for electric vehicles."

63 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

64 Meixner, "Electric vehicles enthusiasts convert their own petrol cars, but engineers warn the risks of retrofitting."

65 Kukar, "Retrofitting for electric vehicles."

66 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

67 Watts, Ghosh, and Hinshelwood, "Exploring the potential for electric retrofit regulations."

68 Berggreen, "What was I thinking? A tale of an EV conversion that was over before it began" last modified May 18, 2023 https://cleantechnica.com/2018/06/02/what-was-i-thinking-a-tale-of-an-ev-conversion-that-was-over-before-it-began/.

69 Santiago, "La CDMX invertirá 20 mdp em conversión de autos de combustión a eléctricos" last modified May 18, 2023 https://politica.expansion.mx/cdmx/2022/02/03/cdmx-inversion-20-mdp-innovacion-motores-electricos.

70 MMA, "Tuning auto: Que dit la loi en France?" last modified October 29, 2020, https://www.mma.fr/zeroblabla/tuning-auto-reglementation-france.html#:~:text=EST%20PAS%20PERMIS-,La%20personnalisation%20d'un%20v%C3%A9hicule%20est%20libre%20dans%20la%20mesure,%C3%A0%20la%20l%C3%A9gislation%20en%20vigueur.

wiring harnesses[71]. Other verification simplifications commonly seen are on the environmental certifications – which, if the vehicle is fully converted to electrical, should be nullified[72].

Despite the recent advances in legislation, there is still room for improvement. EV retrofitting regulations are often based on pre-existing EV regulations, which make them inflexible to the realities of different retrofitting solutions. Standards are usually designed according to procedures from countries with major OEMs, such as the US, the European Union, and Japan, and are, therefore, unfit to the local needs for vehicles in different areas[73]. Comprehensive safety and technical regulations must be designed according to the local environment and through consultations with the local technical authorities and representations.

3.2.2. Market Incentives

Market incentives are common policy mechanisms to reduce prices and promote more competitiveness to strategic but expensive technologies[74]. Governments show experience on adopting different market incentives to EV retrofitting, with policies differing according to their end goal.

Some market incentives contemplate expanding and diversifying the industry. Initial applications of EV conversion should be adapted to popular vehicle models of local markets, requiring active modeling from the local industries and technicians[75]. While some countries have strong OEMs that are taking the lead in developing new retrofitting technologies[76], all governments that recognize the decarbonizing potential of EV conversion must create policy incentives to develop the local market.[77]

The market expansion of EV retrofitting can serve as a support for the long-term electrification of the transportation sector. It offers more varieties to how consumers choose to electrify their mobility, thereby promoting the development of charging infrastructure to make EVs cheaper and more convenient to use[78]. Similarly, countries with long-term EV strategies should investigate retrofitting as a complementary strategy to generate more jobs in the maintenance market, which may otherwise shrink due to the cost-efficient nature of EV services when compared to ICEs.[79]

Another essential incentive measure is identifying the key stakeholders for EV retrofitting expansion and engagement. The stakeholders are usually startups that enable the implementation of the solution in the market, and car suppliers and manufacturers that contribute for the know-how and the supply of the necessary parts for the retrofitting kits in the market[80]. Major OEMs, universities, and research centers also play a major role in the development and enhancement of the technology – these stakeholders will be further explored in the next subchapter.

Many governments choose to shift their focus to promotion of a wider consumer base. The adaptable nature of retrofitting allows seamless integration within already established financial incentives, subsidies, rebates, and other policy incentives in place for traditional EVs[81]. While these measures are simple to be adopted, they must explicitly include EV retrofitting to avoid confusions from consumers on the possible incentives to ICE-to-EV conversion[82]. Governments may either include retrofitted vehicles in the already-existing policies, or officially register retrofitted vehicles as EVs after their conversion.[83] Ideally, however, is the design and implementation of retrofitting-specific consumer incentives to strengthen and market the solution to potential customers.

3.2.3. R&D Programs

A key area for EV retrofitting expansion is investing on research and development (R&D) programs. Some major automobile OEMs have recently announced their expansion plans into EV retrofitting kits[84], projecting market expansion for the solution soon. R&D is essential for the growth and diversification of the market, for the improvement of the

71 EV Reporter, "Regulatory framework for retrofitting in India", last modified May 18, 2023 https://evreporter.com/regulatory-framework-for-retrofitting-in-india/.

72 EV Reporter, "Regulatory framework for retrofitting in India", last modified May 18, 2023 https://evreporter.com/regulatory-framework-for-retrofitting-in-india/.

73 Republic of Kenya, "Electric vehicle standards in Kenya: Draft summary report." https://www.transport.go.ke/department/images/climate/Electric_mobility_standards.pdf

74 Hardman, Chandan, Tal, Turrentine, "The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence."

75 Hoeft, "International combustion engine to electric vehicle retrofitting: Potential customers' needs, public perception, and business."

76 Paul Myles, "Toyota joins retrofit EV powertrain push," Automotive, last modified January 16, 2023, https://www.tu-auto.com/toyota-joins-retrofit-ev-powertrain-push/.

77 Libeau, "Retrofitting: A frugal, circular, and inclusive solution do decarbonize our vehicle fleet."

78 Paul Myles, "Toyota joins retrofit EV powertrain push," Automotive, last modified January 16, 2023, https://www.tu-auto.com/toyota-joins-retrofit-ev-powertrain-push/.

79 Libeau, "Retrofitting: A frugal, circular, and inclusive solution do decarbonize our vehicle fleet."

80 Hoeft, "International combustion engine to electric vehicle retrofitting: Potential customers' needs, public perception, and business."

81 Scooter Doll, "Electric vehicle tax credits and rebates available in the US, sorted by state," Electrek, last modified October 5, 2022, https://electrek.co/2022/10/05/ev-tax-credit-rebate-states-electric-vehicles/.

82 République Française, Le retrofit électrique: Quel cadre legal? Quelle prime à la conversion? 2022.

83 République Française, Le retrofit électrique: Quel cadre legal? Quelle prime à la conversion? 2022.

84 Takewaza, "Tesla escapes niche position."

retrofitting process, and for guaranteeing the safety and positive experience of the customers[85].

As a globally nascent industry, EV conversion's main actors have been start-ups and specialized technicians aiming to electrify old or classic vehicles[86]. However, for the industry to continue to expand and for retrofitting to become a competitive solution in clean transportation, more investment is needed in powertrain technology, engineering adaptation solutions of popular vehicles, and cost reduction of the essential parts for retrofitting, especially lithium-ion batteries.

While these challenges might initially appear as big barriers for the nascent market, a positive insight is that most of these barriers are shared with the EV automobile industry. R&D investments in EV retrofitting solutions can be incorporated within already existing or future electrification strategies in the value chain of the major automobile OEMs. Recent announcements from Ford[87], GM[88], and Toyota[89] of solutions' development in line with their decarbonization strategies might help popularize retrofitting amongst other key transportation players.

Despite the positive outlook brought by recent private sector engagements, more attention must be brought to the role governments and public actors have on the expansion and popularization of the industry. EV retrofitting is a solution closely related to adapting the real transportation needs of a population[90], and thus cannot be solely led by major international players. Local capacity-building and technology development are essential for the retrofitting market's expansion.

Some countries have started working closely with their local players to further develop retrofitting solutions according to their population's needs. Local and regional governments have developed incentive schemes for two- and three-wheeler conversions in India[91] and Sri Lanka[92], reflecting the real mobility needs of their population. Major conversion strategies identify and engage with local partners to improve and promote EV conversion, creating new R&D opportunities in the local markets.

Earmarked EV retrofitting R&D investments are still essential to signalize more active engagement of the private sector in the industry. An important example comes from France's EUR 20 million investment in scaling up industrial solutions for EV retrofitting kits[93]. Combining R&D investments with adaptations to national legislation send strong signals of the country's industries' strategy of expansion to other EU markets.

3.2.4. Other Measures

The last policy measures focus on the capacity-building and information promotion of EV retrofitting technologies. Often being categorized as an indirect type of incentives, these play a key role in the popularization of infant industries and markets. Their incorporation into official electrification strategies is central for the long-term adoption of new technological solutions amongst customers.

Customer surveys conducted in markets with integrated retrofitting technologies show that there is still a high level of skepticism amongst the population[94]. The lack of information on the safety and reliability of EV conversion caused mistrust with potential customers, who changed their opinions after they were exposed to reliable marketing strategies. Industrial investments and market expansion plans must thus be aligned with information strategies to shift skepticism from the solution.

While each set of policy measures has it inherit value to contribute to the expansion of the retrofitting market in one direction, it is their combination that will guarantee its comprehensive adoption. Technical and safety regulations should be adopted in conjunction with marketing campaigns, while market expansion cannot be unlinked from technological and innovation investments. Despite the industry's early global stage, countries have started adopting successful strategies that must be analyzed for their best practices.

85 Hoeft, "International combustion engine to electric vehicle retrofitting: Potential customers' needs, public perception, and business."

86 Banerjee, "EV powertrain retrofitment market gains traction with influx of organized players", Money Control, last modified May 9, 2023 https://www.moneycontrol.com/news/technology/auto/ev-powertrain-retrofitment-market-gains-traction-with-influx-of-organised-players-8899181.html

87 Chris Randall, "Ford announces electric conversion motor." Electrive, last modified August 27, 2021, https://www.electrive.com/2021/08/27/ford-announces-electric-conversion-motor/.

88 Paul A. Eisenstein, "GM set to join fast-growing EV conversion market," The Detroit Bureau, last modified July 22, 2022, https://www.thedetroitbureau.com/2022/07/gm-set-to-join-fast-growing-ev-conversion-market/.

89 Thom Taylor, "Toyota says it plans to convert old cars into EVs," Motor Biscuit, last modified January 13, 2023, https://www.motorbiscuit.com/toyota-says-plans-to-convert-old-cars-into-evs/.

90 Libeau, "Retrofitting: A frugal, circular, and inclusive solution to decarbonize our vehicle fleet". OECD Forum, last modified May 19, 2023 https://www.oecd-forum.org/posts/retrofitting-a-frugal-circular-and-inclusive-solution-to-decarbonize-our-vehicle-fleet.

91 EV Reporter, "FAQs about retrofitment of electric 3Ws."

92 Hamza, "Sri Lanka partners with USAID to convert petrol-run tuktuks to electricity." Economy Next, last modified May 19, 2023 https://economynext.com/sri-lanka-partners-with-usaid-to-convert-petrol-run-tuktuks-to-electricity-98704/.

93 Gouvernement Française, La concertation sur le retrofit électricque est lancée, 2022

94 Hoeft, "Internal combustion engine to electric vehicle retrofitting."

3.3. EV RETROFITTING POLICIES AMONGST GGGI MEMBERS

Among 46 GGGI members considered, five countries – Australia, Indonesia, Nepal, Sri Lanka, and the UK –have enactedEV Conversion legislation. When applying the division of Technical Regulation, Incentive Measures, and Environment Enabling Measures, only Indonesia possesses all three sets of regulations.

All countries identified present technical legislation to oversee the technical retrofitting procedures and certify the proper registration of newly converted vehicles. The five countries require a newly retrofitted vehicle to undergo technical assessments to verify the full operation of safety systems. This procedure is either done by a certified technician or by each designated office. After the technical verification, converted vehicles are registered as EVs in Australia and the UK, and as a converted vehicle in Indonesia.

Official EV conversion incentives were identified in Indonesia, Nepal, and the UK. The Indonesian government recognized EV retrofitting as a favorable strategy for the decarbonization of their 2-wheelers fleet and adopted subsidies for its promotion. Nepal and the UK have instead chosen to explicitly include EV conversion within some of their EV policy incentives, granting tax reductions to converted vehicles.

The last set of EV retrofitting regulations are those policies to promote enabling environments. Within the identified countries, only R&D policies were present amongst the members. The Indonesian government has deducted R&D costs for the development of EV parts in-country as an attempt to lower prices for future EV production. On the other hand, the Sri Lankan government has recently signed a MoU with the United States to promote the research and conversion of ICE three-wheelers to electric in the country.

The limited number of EV retrofitting legislations amongst GGGI members reflects the infancy level in which the global market is currently at. However, following prior identification of 19 members having EV retrofitting solutions in their domestic markets, it is advisable for countries to develop ICE to EV retrofitting-specific standards and legislations. Market stakeholders in key countries have been pushing for a broader adoption of the solution to secure market growth in line with the popularization of other electric mobility solutions[95].

A mapping of EV retrofitting policies and regulations amongst GGGI members was performed to identify the level of experiences. The result is as seen below:

95 Asociación Latinoamericana de Retrofit, "Movilidad, cambiar motores de combustión por eléctricos y cómo reducir emisiones a um menor costo". Last modified June 13, 2023. https://plataformaurbana.cepal.org/sites/default/files/2022-04/Movilidad%2C%20cambiar%20motores%20de%20combusti%C3%B3n%20por%20el%C3%A9ctricos%20y%20c%C3%B3mo%20reducir%20emisiones%20a%20un%20menor%20costo.pdf.

Table 5: EV Retrofitting Policies by GGGI Members**

GGGI Countries	Region	EV Retrofitting Legislation	Technical Regulations	Incentive Measures	Environment Enabling Measures
Angola	Africa	•	•	•	•
Australia	Pacific	•	•	•	•
Bahrain	Middle East	•	•	•	•
Burkina Faso	Africa	•	•	•	•
Cambodia	Asia	•	•	•	•
Colombia	Latin America	•	•	•	•
Costa Rica	Latin America	•	•	•	•
Côte d'Ivoire	Africa	•	•	•	•
Denmark	Europe	•	•	•	•
Ecuador	Latin America	•	•	•	•
Ethiopia	Africa	•	•	•	•
Fiji	Pacific	•	•	•	•
Guyana	Latin America	•	•	•	•
Hungary	Europe	•	•	•	•
Indonesia*	Asia	•	•	•	•

Jordan	Middle East	•	•	•	•
Kazakhstan	Asia	•	•	•	•
Kiribati	Pacific	•	•	•	•
RoK	Asia	•	•	•	•
Kyrgyz Republic	Asia	•	•	•	•
Lao PDR	Asia	•	•	•	•
Mexico	Latin America	•	•	•	•
Mongolia	Asia	•	•	•	•
Nepal	Asia	•	•	•	•
Nicaragua	Latin America	•	•	•	•
Norway	Europe	•	•	•	•
OECS	Latin America	•	•	•	•
Pakistan	Asia	•	•	•	•
Papua New Guinea	Asia	•	•	•	•
Paraguay	Asia	•	•	•	•
Peru	Latin America	•	•	•	•
Philippines	Pacific	•	•	•	•
Qatar	Middle East	•	•	•	•
Rwanda	Africa	•	•	•	•
Senegal	Africa	•	•	•	•
Sri Lanka*	Asia	•	•	•	•
Thailand	Asia	•	•	•	•
Tonga	Pacific	•	•	•	•
Turkmenistan	Asia	•	•	•	•
UAE	Middle East	•	•	•	•
Uganda	Africa	•	•	•	•
UK	Europe	•	•	•	•
Uzbekistan	Asia	•	•	•	•
Vanuatu	Pacific	•	•	•	•
Vietnam	Asia	•	•	•	•
Kenya*	Africa	•	•	•	•

* The countries marked have been selected as case studies for the financial assessment chapter

** Refer to Appendix for further information on each policy identified

4. FINANCIAL ASSESSMENT

4.1. ECONOMIC BENEFITS FOR LDVs

Kenya's 2018-2022 National Climate Change Action Plan (NCAP) identifies the development of domestic e-mobility technology as a strategy for cutting GHG emissions and adapting Kenya's infrastructure to climate change[96]. Key companies including Roam Electric have been leading the e-mobility market in the country, working with the government to create sustainable policy and market conditions for the growth of the adoption rates in the years to come[97]. Retrofitting EV has been considered as an option to accommodate the decarbonization demand while maintaining accessible costs for the population[98]. In Kenya, the conversion of passenger vehicles was adopted with special attention to utility vehicles for the mining, safari, and tourism industries[99]. Considering more than 95% of registered cars being secondhand[100], EV retrofitting technologies will play a prominent role of decarbonation in Kenya transport sector.

In this line, this report conducted comparative economic analysis of four-wheelers retrofitting with the case of Kenya. For the economic assessment of passenger vehicles in Kenya, this report mainly refers to the 2019 GIZ report "Updated Transport Data in Kenya 2018". Additional data were retrieved from the main EV retrofitting company, Roam Electric[101] - former Opibus –, and local data.

This analysis is to fairly reflect the economic benefits of retrofitted electric passenger vehicles. The baseline internal combustion engine (ICE) passenger vehicle Landcruiser 70 Series 2023) is defined as the current 4W operating in Nairobi that would be standard model in compliance with all legal requirements and in accordance with standard current business practices.

96 Government of Kenya, "National Climate Change Action Plan: Second Implementation status Report for the FY2019/2020".

97 Wachira, "Kenya's electric vehicle market is raring to go". Last modified June 06, 2023. https://chinadialogue.net/en/transport/kenyas-electric-vehicle-market-is-raring-to-go/

98 Siele, "Electric conversion: How Kenyan motorists are cutting costs", last modified May 02, 2023. https://businesstoday.co.ke/electric-conversion-how-kenyan-motorists-are-cutting-costs/.

99 Page, "Opibus: The mobility startup converting Kenya to electric vehicles". Last modified June 06, 2023. https://edition.cnn.com/2022/03/01/africa/opibus-kenya-electric-mobility-bus-motorcycle-car-spc-intl/index.html

100 UNEP, "Used vehicles and the environment: A global overview of used light duty vehicles-flow, scale, and regulation".

101 Roam Electric. "Off Road", last modified June 06 2023. https://www.roam-electric.com/off-road

Capital expenditure (CAPEX) includes vehicle investment costs and partial replacement investment costs such as batteries. The projection of real battery prices for electric 4W is 2,131.5 USD based on local data. Operational expenditure (OPEX) is mainly including maintenance and energy costs including diesel for ICE vehicles and electricity for electric ones. The market electricity price for E4Ws is taken with the assumption of 9,221.16 kWh annual consumption.

Comparative analysis of new ICE 4W vehicle, new electric 4W vehicle and retrofitted electric 4W vehicle over the lifespan of 15 years is conducted. The following table shows key parameters utilized for financial calculations.

Table 6. Key parameters for comparative Economic Analysis of 4Ws

Parameters		New ICE 4W	New E4W	Retrofitted E4W
CAPEX	Vehicle cost	USD 45,363.00 (KES 6,394,000)	USD 57,595.40 (KES 8,000,000)	USD 39,900.00* (KES 5,542,110)
	Battery Replace-ment Cost	N/A	USD 2,131.50 (KES 300,000)**	USD 2,131.50 (KES 300,000)**
	Subsidy	N/A	N/A	N/A
OPEX	Fuel Cost per year	Diesel: USD 2,959.89/year (USD 1.244/l)	USD 1,189.53/ year (USD 0.129/ kWh)	USD 1,189.53/ year (USD 0.129/ kWh)
	Annual Mainte-nance cost	USD 3,500 (KES 488,250) ***	USD 1,247.82 (KES 173,956)	USD 1,247.82 (KES 173,956) ***
	Annual Insurance	N/A	N/A	N/A
	Interest rate	9.5%	9.5%	9.5%
TECH-NICAL	Lifespan	15 years	15 years	15 years***
	Driving Distance	60.8km/day (22,223 km/year****)		
	Fuel efficiency per km	9.34 km/L	2.41 km/kWh	2.41 km/ kWh
	Emission factor	0.17Kg CO2e/ km ****	0.2kgCO2e/ kWh	0.2kgCO2e/ kWh*****

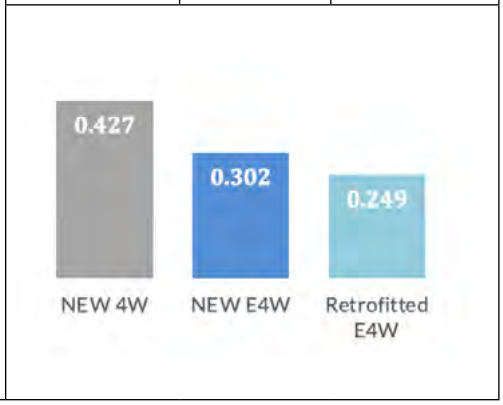
* Cost of retrofitted E4W: Used ICE vehicle cost + conversion kit + service fee (obtained from roam-electric.com)
** Retrieved from Subbru, 2022 (https://ke.opera.news/ke/en/auto/f17a8c2cee84cd8b34bec2919e6611b4)
*** Retrieved from Roam Electric website (roam-electric.com)
**** Retrieved from GIZ, 2019
***** Retrieved from Our World in Data, 2023 (https://ourworldindata.org/co2/country/kenya#carbon-intensity-how-much-carbon-does-it-emit-per-unit-of-energy)

Economic analysis is to estimate the economic benefits of adopting retrofitted E4Ws by comparing them with second-hand ICE 4Ws and new E4Ws. In this analysis, total cost of ownership (TCO) and unit travel cost (USD/km) indicators are used to determine the economic benefits. The economic analysis is carried out according to the methodology presented in this report, utilizing 9.5% of the interest rate set by Trading Economics. The following table shows the expected economic benefits of retrofitted electric 4W vehicles. TCO of incremental economic benefits from 3 types of vehicle options is calculated as USD 100,736 per new ICE 4W vehicle, USD 82,913 per new E4W, and USD 65,217 per retrofitted E4W respectively. The unit travel cost of retrofitted E4W is 0.249 USD/km, which is comparatively lower than the other two options.

Table 7. The result of comparative Economic Analysis of 4Ws

	New ICE 4W	New E4W	Retrofitted E4W
Total Cost of Ownership (TCO)	100,736	82,913	65,217

Travel Cost per km	0.427	0.302	0.249



The following table shows the expected environmental impact of the retrofitted E4W fleet per annum. In terms of local pollutants, new E4W and retrofitted E4W options reduce $PM_{2.5}$ and NO_x emissions by 100%.

Table 8. Environmental Impacts of 4Ws

GHG Emissions		New ICE 4W	New E4W	Retrofitted E4W
CO_2 (kgCO2e)	Per km	0.17	0.08	0.08
	Annual	3,777.91	1,844.23	1,844.23
	Lifespan	56,668.65	27,663.49	27,663.49
$PM_{2.5}$ (g)	Per km	0.090	0.000	0.000
	Annual	1,991.206	0.000	0.000
	Lifespan	29,868.083	0.000	0.000
NO_x (kg)	Per km	0.016	0.000	0.000
	Annual	348.068	0.000	0.000
	Lifespan	5,221.018	0.000	0.000

4.2. ECONOMIC BENEFITS FOR 3Ws

Sri Lankan mobility patterns are heavily reliant on private vehicle ownership, with three-wheelers accounting for the third most recurrent vehicle type[102]. Converting the transportation fleet to electric is strategic not only to reduce the country's emissions and reach its mitigation goals but also to reduce Sri Lanka's dependency on fossil fuels[103]. This is specifically important in the face of recent severe economic crises caused by fuel shortages[104]. Three-wheelers in Sri Lanka are a key transportation mode for passenger carriers, benefitting specifically the elderly, the children, middle-income families, and women[105]. With the advancement of mobile taxi apps and services[106], the three-wheelers fleet is expected to expand in the years to come, creating a promising market for three-wheeler retrofitting services and technologies.

For the financial analysis of **three-wheelers** retrofitting, the case of Sri Lanka was chosen. The data used for the financial assessment of 3-wheeler vehicles in Sri Lanka was mainly based in the Thilakshan, Sugathapala, and Bandara (2019) report "Electric Vehicles as a Sustainable Mode of Transportation – The Sri Lankan Context" and the Gajanayake et al (2020) report "Study of the Impact of Electric Vehicle on Fuel Consumption and Carbon Dioxide Emission Scenarios in Sri Lanka". Other additional data were retrieved from the main EV retrofitting company identified, SL Mobility[107].

This analysis is to fairly reflect the economic benefits of retrofitted electric passenger vehicles. The baseline internal combustion engine (ICE) 3W vehicle is defined as the currently operating model in Colombo city in compliance with all legal requirements and in accordance with standard current business practices.

CAPEX includes vehicle investment costs and partial replacement investment costs such as batteries. The projection for real battery prices for electric 3W is 1,500 USD based on UNDP data. OPEX is mainly including maintenance and energy costs which differ relative to the technology used. The market electricity price for E3Ws is taken with the assumption of 4,701.2 kWh annual consumption.

Comparative analysis of new ICE 3W vehicle, new electric 3W vehicle and retrofitted electric 3W vehicle over the lifespan of 10 years is conducted. The following table shows key parameters used for financial calculations.

102 Madhuwanthi et al, "Factors influencing to travel behavior on transport mode choice"

103 Gajanayake et al, "Study of the impact of electric vehicles on fuel consumption and carbon dioxide emission scenarios in Sri Lanka"

104 Kurukulasuriya, "Sri Lanka's energy crisis is a glimpse of what's coming". Last modified June 12, 2023. https://www.undp.org/blog/sri-lankas-energy-crisis-glimpse-whats-coming

105 Madhuwanthi et al, "Factors influencing to travel behavior on transport mode choice"

106 Goldstein Market Intelligence, "Sri Lanka three-wheeler market trends, challenges, key players, demand & growth drivers analysis with regional outlook for forecast period 2016-2024". Last modified June 12, 2023. https://www.goldsteinresearch.com/report/sri-lanka-three-wheeler-market-analysis

107 SL Mobility. "Conversion Kit", last modified June 07 2023. https://www.slmobility.com/products/conversion-kit

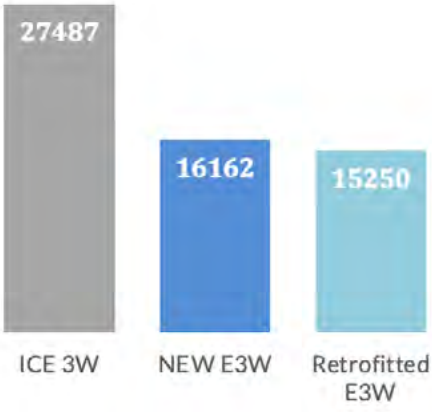
Table 9. Key parameters for comparative Economic Analysis of 3Ws

Parameters		New ICE 3W	New E3W	Retrofitted E3W
CAPEX	Vehicle cost	USD 3,259* (LKR 1,000,000)	USD 4,562* (LKR 1,400,000)	USD 3,650* (LKR 1,120,000)
	Battery Replace-ment Cost	N/A	USD 1,500*	USD 1,500*
	Subsidy	N/A	N/A	N/A
OPEX	Fuel Cost per year	USD 3,464.19 (LKR 1,005,903.43)	USD 1,209.60 (LKR 367,584)	USD 1,209.60 (LKR 367,584)
	Annual Mainte-nance cost	USD 207.33 (LKR 60,204) **	USD 144.97 (LKR 42, 097)	USD 144.97 (LKR 42, 097)
	Annual Insurance	N/A	N/A	N/A
	Interest rate	15.5%	15.5%	15.5%
TECH-NICAL	Lifespan	10 years	10 years	10 years
	Driving Distance	161km/day (58,765 km/year**)		
	Fuel efficiency per km	20 km/L**	12.5 km/kWh	12.5 km/ kWh ****
	Emission factor	2.4 Kg CO2e/ km*** Kg C/kgOE	0.585kgCO2e/ kWh*****	0.585kg-CO2e/ kWh*****

* Retrieved from the financial-economic analysis on Tuktuk conversions in SL done by the UNDP
** Retrieved from Thilaskhan, Sugathapal, Bandara (2019)
*** Retrieved from SL Mobility (slmobility.com)
**** Retrieved from UNEP, 2019 (https://www.unep.org/news-and-stories/story/taming-sputtering-tuk-tuk-sri-lankan-innovator-develops-affordable-electric)
***** Retrieved from Central Bank of Sri Lanka (2017)

Economic analysis is to estimate the economic benefits of adopting retrofitted E3Ws by comparing 3 types of 3W vehicles. In this analysis, total cost of ownership (TCO) and unit travel cost (USD/km) indicators are used to determine the economic benefits. The economic analysis is carried out according to the methodology presented in this report, utilizing 15.5% of the interest rate set by Trading Economics. The following table shows the expected economic benefits of retrofitted electric 3W vehicles. TCO of incremental economic benefits from 3 types of vehicle options is calculated as USD 27,487 per new ICE 3W vehicle, USD 16,162 per new E3W, and USD 15,250 per retrofitted E3W respectively. The unit travel cost of a retrofitted E3W is 0.033 USD/km, which is comparatively lower than an ICE 3W (0.066 USD/km) and a New E3W (0.034USD/km).

Table 10. The result of comparative Economic Analysis of 3Ws

	New ICE 3W	New E3W	Retrofitted E3W
Total Cost of Ownership (TCO)	27,487	16,162	15,250
			
Travel Cost per km	0.066	0.034	0.033
			

The following table shows the expected environmental impact of the retrofitted E3W fleet per annum. In terms of local pollutants, new E3W and retrofitted E3W options reduce $PM_{2.5}$ and NO_x emissions by 100%.

Table 11. Environmental Impacts of 3Ws

GHG Emissions		ICE 3W	New E3W	Retrofitted E3W
CO_2 (kgCO2e)	Per km	0.12	0.05	0.05
	Annual	7,051.80	2,750.20	2,750.20
	Lifespan	70,518.00	27,502.02	27,502.02
$PM_{2.5}$ (g)	Per km	0.013	0.000	0.000
	Annual	785.744	0.000	0.000
	Lifespan	7,857.438	0.000	0.000
NO_x (kg)	Per km	0.002	0.000	0.000
	Annual	116.073	0.000	0.000
	Lifespan	1,160.729	0.000	0.000

4.3. ECONOMIC BENEFITS FOR 2Ws

For the financial analysis of **two-wheelers** retrofitting, the case of Indonesia was chosen. Despite its archipelago formation, Indonesia's transportation is dominated by the road subsector – with over 90% of the modal shares for passengers being in-road[108]. Particularly motorcycles, consistuting over 80% of the country's land transportation mods,have gained increasing popularity.[109]. In a move to attempt to curb GHG emissions, the Indonesian government implemented legal frameworks and tax incentives to increase the adoption rates of electric vehicles – specifically electric motorcycles[110]. The E2W conversion is an innovative solution that holds promising potential for expansion in the Indonesian market.

The data used for the financial assessment of passenger vehicles Indonesia was mainly based in the Afraah et al (2021) report "Comparing Total Cost of Ownership of Electric and Conventional Motorcycles in Indonesia".

This analysis is to fairly reflect the economic benefits of retrofitted electric two wheelers. The baseline internal combustion engine (ICE) two-wheeler is defined as the current two-wheeler operating in the West Java Province that would be standard model in compliance with all legal requirements and in accordance with standard current business practices.

CAPEX includes vehicle investment costs and partial replacement investment costs such as batteries. The projection of real battery prices for electric 2W is 149.28 USD. OPEX primarily covers maintenance and energy costs which vary based on the technology used. The market electricity price for E2Ws is taken with the assumption of 361.13 kWh annual consumption.

Comparative analysis of new ICE 2W vehicle, new electric 2W vehicle and retrofitted electric 2W vehicle over the lifespan of 15 years is conducted. The following table shows default parameters used for financial calculations.

Table 12. Key parameters for comparative Economic Analysis of 2Ws

Parameters		New ICE 2W	New E2W	Retrofitted E2W
CAPEX	Vehicle cost	USD 1,187.58 (IDR 17,650,000)	USD 1,277.74 (IDR 18,990,000)	USD 1,914.26 (IDR 28,450,000) million*
	Battery Replacement Cost	N/A	USD 149.28 (2,203,260 IDR)**	USD 149.28 (2,203,260 IDR)**
	Subsidy	N/A	USD 471 (IDR 7,000,000)	USD 471 (IDR 7,000,000)
OPEX	Fuel Cost per year	USD 160.21 (USD 0.95 per litre)	USD 28.89 (USD 0.08 per kWh)	USD 28.89 (USD 0.08 per kWh)
	Annual Maintenance cost	USD 8.10 (IDR 119,000)	USD 4.76 (IDR 70,000) per service***	USD 4.76 (IDR 70,000) per service ***
	Annual Insurance	1.5% of vehicle price	1.5% of vehicle price	1.5% of vehicle price***
	Interest rate	5.75%	5.75%	5.75%****
TECHNICAL	Lifespan	15 years	15 years	15 years
	Driving Distance	28km/day (10,220 km/year)***		
	Fuel efficiency per km	60.6 km/L	28.3 km/kWh	28.3 km/kWh
	Emission factor	2.3g CO2e/km	0.81kgCO2e/kWh	0.81kg-CO2e/kWh*****

108 Asian Development Bank, "Indonesia: Transport sector assessment, strategy, and road map"

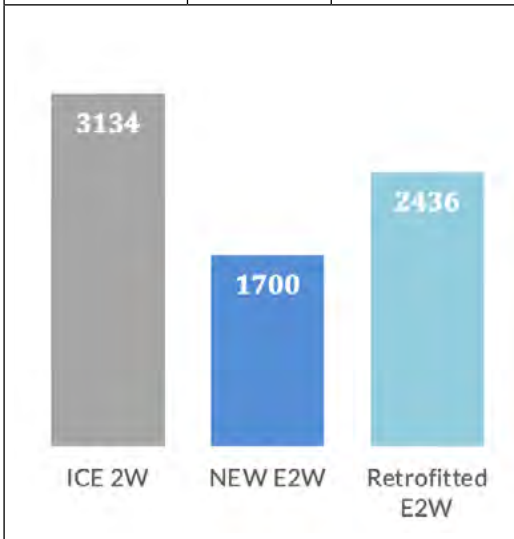
109 Asian Development Bank, "Indonesia's Summary Transport Assessment".

110 Habibie, Sutopo, "A literature review: Commercialization study of electric motorcycle conversion in Indonesia"

* Cost of retrofitted E2W: Used ICE vehicle cost + conversion kit + service fee (calculated from data available by Afraah et al, 2021)
** Retrieved from Afraah et al, 2021
*** Retrieved from Afraah et al, 2021
**** Retrieved from Trading Economics, 2023
***** Retrieved from Climate Transparency, 2021

Economic analysis is to estimate the economic benefits of adopting retrofitted E2Ws by comparing 3 types of 3W vehicles. In this analysis, total cost of ownership (TCO) and unit travel cost (USD/km) indicators are used to determine the economic benefits. The economic analysis is carried out according to the methodology presented in this report, utilizing 5.75% of the interest rate set by the trading economics. The following table shows the expected economic benefits of retrofitted electric 2W vehicles. TCO of incremental economic benefits from 3 types of vehicle options is calculated as USD 3,134 per New ICE 2W vehicle, USD 1,700 per New E2W, and USD 2,436 per retrofitted E2W respectively. The unit travel cost of a retrofitted E2W is 0.018 USD/km, which is lower than an ICE 2W (0.026 USD/km), but higher than a New E2W (0.013 USD/km).

Table 13. The result of comparative Economic Analysis of 2Ws

	New ICE 2W	New E2W	Retrofitted E2W
Total Cost of Ownership (TCO)	3,134	1,700	2,436
			

Travel Cost per km	0.026	0.013	0.018
			

The following table shows the expected environmental impact of the retrofitted E2W fleet per annum. In terms of local pollutants, new E2W and retrofitted E2W options reduce $PM_{2.5}$ and NO_x emissions by 100%.

Table 14. Environmental Impacts of 2Ws

GHG Emissions		New ICE 2W	New E2W	Retrofitted E2W
CO_2 (kgCO2e)	Per km	0.04	0.03	0.03
	Annual	387.89	292.52	292.52
	Lifespan	5,818.32	4,387.74	4,387.74
$PM_{2.5}$ (g)	Per km	0.007	0.000	0.000
	Annual	68.326	0.000	0.000
	Lifespan	1,024.883	0.000	0.000
NO_x (kg)	Per km	0.001	0.000	0.000
	Annual	10.093	0.000	0.000
	Lifespan	151.399	0.000	0.000

5. CASE STUDIES

5.1. FRANCE

While not the first in the European Union to adopt specific strategies and regulations to enable the expansion and popularization of EV retrofitting, France's policy profile and history provide a relevant case for analysis. The country already had strict laws for vehicular tuning and modifications, requiring any transformative modification (i.e., modifications that affect the vehicle's descriptive characteristics, or categorization) to be officially registered and altered in the vehicle's documentation.[111] EV retrofitting previously followed a similarly strict process, requiring each individual vehicle to be re-registered and verified by specialists before being given authorization for circulation—a costly and time-consuming process.[112]

A modification in the legislation in 2020, however, allowed for a simplification of the certification process. Rather than focusing on the certification of each vehicle, the new legislation allows for the homologation of EV kits by model. The EV conversion kits must be submitted to the authorities for technical verification and, after approval, can be installed in vehicles that i) are roadworthy, ii) are registered in France, and iii) are over five years old.[113] Customers must seek government-certified technicians for the installation of government-approved EV conversion kits, warranting a Certificate of Conformity and a modification of the vehicle's registration card to an EV.[114]

Converted EVs are officially registered not only as EVs but also as new vehicles under insurance companies, allowing for older vehicles to be given greater benefits for insurance after conversion.[115] Additionally, because converted EVs are registered as EVs, with no differentiation given to their converted hardware, they benefit from other government incentives for EV acquisition and ownership. An important example is the explicit consideration of EV conversion in France's EV rebate scheme, since April 2022, making vehicles eligible for rebates of EUR 1,100 for two- and three-wheelers, EUR 2,500 to 5,000 for four-wheelers, and EUR 5,000 to 9,000 for HDVs.[116]

Regularization of the EV conversion process and the inclusion of EV conversion within the country's

111 MMA, "Tuning auto: Que dit la loi en France?" last modified October 29, 2020, https://www.mma.fr/zeroblabla/tuning-auto-reglementation-france.html#:~:text=EST%20PAS%20PERMIS-,La%20personnalisation%20d'un%20v%C3%A9hicule%20est%20libre%20dans%20la%20mesure,%C3%A0%20la%20l%C3%A9gislation%20en%20vigueur.

112 Luthereau, "Le retrofit électrique."

113 Transition One, Homepage, accessed October 3, 2022.

114 République Française, ***Arrêté du 13 mars 2020 relatif aux conditions de transformation des véhicules à motorisation thermique en motorisation électrique à batterie ou à pile à combustible***, 2020.

115 TOLV, ***Choisir la meilleure assurance pour son véhicule après retrofit***, accessed January 20, 2023.

116 République Française, ***Le retrofit électrique: Quel cadre legal? Quelle prime à la conversion?*** 2022.

electrification incentive schemes follow the national strategy of decarbonizing the transportation system and investments in the innovation of the national automobile sector.[117] EV retrofitting is regarded as a complementary solution to new EVs, and start-up companies focused on the French market are first investing in the development and homologation of EV retrofit kits of popular French vehicle models to, in a second phase, expand the technology to the wider European Union market.[118]

The French legislation was officially changed in 2020, allowing companies to adapt their production system for the new challenge of EV conversion. Since then, the government has not only promoted direct EV retrofitting incentives but has also announced an investment of EUR 20 million to retrofitting professionals "to finance industrial solutions that allow the technology to be scaled up in order to lower the unit cost" of each EV conversion kit.[119] With the purpose of democratizing EV retrofitting, France is actively financing and exploring innovative solutions and technologies within its automobile sector to adapt to the decarbonization ambitions of the European Union, giving EV retrofitting the policy portfolio required for its development.

Figure 6: Transition-One electric Renault Twingo II conversion[120]

5.2. UNITED STATES

Despite already existing for many years, the United States' EV retrofitting market mainly targets the conversion of classic and alternative vehicles, enabling their transformation to an electrified automobile system.[121] EV conversion companies operate on a small scale, usually working on a custom model basis to allow for more adaptability of older classic vehicles. Although customization remains a popular form of EV retrofitting in the US, recent state-level regulations and policies toward a possible transition of the market, with modern retrofitting alternatives becoming more common for the usual customer.[122]

The United States requires federal legislation certifying the safety and regulating the procedure for EV conversion. Official safety standards and regulations of the US Environmental Protection Agency and the National Highway Traffic Safety Administration dictate that vehicle conversions requiring the addition of heavy battery systems or additional fuel tanks—which may alter a vehicle's center of gravity, payload capacity, or handling characteristics—need to be crash-tested and certified.[123] Similarly, vehicle owners interested in converting their vehicles must work with the manufacturer or an authorized representative. The conversion is performed by a technician associated with the manufacturer, who holds the relevant emissions and tampering certifications.[124]

While national legislation governs conversion procedure and safety certification, states possess the jurisdiction to promote additional safety standards and EV conversion incentives. Examples of state-level incentives are ownership tax exemptions in Arizona, an income tax credit in Washington, D.C.,[125] and a rebate system for EV conversion in California.[126] In addition to the rebate incentive, California developed guidelines for qualifying conversion types and eligible motors, power systems, and parts.[127]

During a time of decarbonization and modernization of transportation fleets, the United States' automobile market and customer base faces the challenge of trading older vehicles—many of them associated with collectors—for newer, more expensive EV models. While national legislation provides clear guidelines to ensure the safety and optimization of EV conversion, state-level incentives and guidelines are essential for adapting the country's

117 Luthereau, "Le retrofit électrique."

118 Luthereau, "Le retrofit électrique."

119 Gouvernement Française, ***La concertation sur le retrofit électricque est lancée***, 2022.

120 Eric C. Evarts, "French company makes EV conversions easy for old clunkers," ***Green Car Reports***, last modified 2019, https://www.greencarreports.com/news/1124381_french-company-makes-ev-conversions-easy-for-old-clunkers.

121 David M. Kuchta, "Best EV conversion companies," Treehugger, last modified December 12, 2022, https://www.treehugger.com/electric-vehicle-ev-conversion-companies-85249.

122 Hybrid Center, "12 Great Electric Car Conversion Companies Reviewed," last modified May 13, 2021, https://www.hybridcenter.org/electric-car-conversion-companies/.

123 U.S. Department of Energy, "Propane Laws and Incentives in Federal" accessed January 12, 2023, https://afdc.energy.gov/fuels/laws/LPG?state=US.

124 U.S. Department of Energy, "Conversion and tampering regulations."

125 Scooter Doll, "Electric vehicle tax credits and rebates available in the US, sorted by state," ***Electrek***, last modified October 5, 2022, https://electrek.co/2022/10/05/ev-tax-credit-rebate-states-electric-vehicles/.

126 Openstates, "Vehicular air pollution: Zero-emission aftermarket conversion project," AB-2350, last modified 2022, https://openstates.org/ca/bills/20212022/AB2350/#:~:text=This%20bill%20would%20require%20the,been%20converted%20into%20a%20zero%2D.

127 Openstates, "Vehicular air pollution."

transportation system and enhancing public perception of EVs to greener and cleaner alternatives.[128]

Figure 7: Zelectric, a conversion of `50s and '60s Beetles and Porsches[129]

5.3. INDIA

EV retrofitting services are available across India, with different companies working in the retail of retrofitting kits and in the technical procedure for the conversion itself. Most of the current market players are scattered, composed mainly of a diverse start-up collective that does not operate with state- or federal-level boosts.[130] The maturity of the EV conversion market can increase with the further development of policies and regulations, which can also benefit from a consumer environment that seeks new, clean alternatives for variousvehicle types.[131]

The Indian national government promulgated amendments to the AIS 123 regulation, with Amendment N. 3 providing the guidelines for pure electric conversion kits.[132] The guidelines establish the technical, mechanical, and safety tests and procedures that retrofitted vehicles must undergo[133]—excluding environmental tests to reduce costs.[134] Additionally, the guidelines clarify that EV conversion kits must be submitted for approval and validation by the manufacturers, with certification issued after approval.[135] Once certified, the manufacturers are allowed to appoint dealers to sell the kits, and retrofit vehicles must later be reregistered in their region transport offices (RTOs) as EVs.[136]

Delhi, in particular, presents a prominent market for EV retrofitting, with the city already accounting for over six times the number of EVs compared to the rest of the country.[137] With a National Green Tribunal 2015 ruling that bans diesel vehicles older than 10 years from city roads, EV-converted vehicles have recently been allowed to bypass the decision.[138] With concomitant investments in public charging infrastructure, EV conversion is now officially recognized as a cost-effective and increasingly popular alternative.

An important factor of the Indian retrofitting market is its inclusivity of other types of vehicles, especially three-wheelers. There is an increasing number of start-ups focused on the conversion of three-wheelers that have already received certification, with a big share of the country's market being destined to these vehicles.[139] Additionally, some states have already recognized the potential of three-wheeler conversion and are promoting incentives to democratize the practice. The state government of Karnataka, for example, encourages the conversion of existing ICE rickshaws in the city of Bengaluru for its 2030 decarbonization goals, while the state of Telangana includes subsidies of 15% of up to INR 15,000 for the first 3,000 retrofitted general three-wheelers.[140]

In India, EV retrofitting has found fertile ground—with a growing demand for decarbonization and cost-effective solutions. The regularization of start-ups already present in the market will allow for further expansion of the customer base, with incentives (e.g., the bypassing of diesel bans in Delhi) working in favor of the popularization of the practice. An interesting factor, however, is the adaptation of EV retrofitting to the local demand of three-wheeler users—an opportunity recognized by Karnataka and Telangana. Further policies must be developed to both organize the current market and promote EV retrofitting for different

128 David Tracy, "California may soon pay you to convert your car to an EV and I hope the federal government follows suit," The Autopian, last modified May 5, 2022, https://www.theautopian.com/california-may-soon-pay-you-to-convert-your-car-to-electric-power-and-i-hope-the-federal-government-follows-suit/.

129 Roy Furchgott, "A trip to the garage, for an electric switch," ***The New York Times***, last modified April 23, 2020, https://www.nytimes.com/2020/04/23/business/electric-car-conversions.html.

130 Avishek Banerjee, "EV powertrain retrofitment market gains traction with influx of organised players," ***Money Control***, last modified July 30, 2022, https://www.moneycontrol.com/news/technology/auto/ev-powertrain-retrofitment-market-gains-traction-with-influx-of-organised-players-8899181.html.

131 Banerjee, "EV powertrain retrofitment market."

132 Indian Government, ***AIS-123*** Amendment 2, 2018.

133 Indian Government, ***AIS-123***.

134 EV Reporter, "Regulatory framework for retrofitting in India – compiled by ARAI," last modified February 28, 2022, https://evreporter.com/regulatory-framework-for-retrofitting-in-india/.

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137 Sunainaa Chadha, "Why Delhi is on track to emerging as the EV capital of India," ***The Times of India***, last modified December 15, 2021, https://timesofindia.indiatimes.com/business/india-business/why-delhi-is-on-track-to-emerging-as-the-ev-capital-of-india/articleshow/88298208.cms.

138 Chadha, "Why Delhi is on track."

139 EV Reporter, "FAQs about retrofitment of electric 3Ws – answered by Avinash Reddy," last modified May 19, 2021, https://evreporter.com/faqs-about-retrofitment-of-electric-3ws/.

140 EV Reporter, "FAQs about retrofitment of electric 3Ws."

vehicle types as a safe, cost-effective, and efficient alternative.

Figure 8: Conversion of an old car to electric in India[141]

5.4. JAPAN

Despite the historical relevance the country has had in the passenger vehicle market, Japan has seen a slow growth in EV adoption throughout the years.[142] Some automobile giants, such as Nissan and Toyota, already have experience developing and producing low-emission vehicles in the global market, such as the Nissan Leaf and Toyota's hybrid model Prius. However, with EVs accounting for less than 2% of new vehicle sales in the domestic market by the end of 2022, drivers face a challenging low amount of public charging infrastructure that compromise further public acceptance for EV models.[143]

However, Japan's potential influence in the global automobile transition is not lost, and the country seems to have changed its strategy to enable the expansion of carbon-free transportation. The Japanese government has announced its pledge for carbon neutrality by 2050 and a ban on sales of domestic ICE vehicles by the mid-2030s.[144] As companies expect the government to announce further policies to facilitate the electrification of road vehicles, they are disclosing new EV plans. Japanese OEMs have recently announced EV strategies that match the commitments of other foreign giants and infrastructure investments to enable a conducive environment for the transition.[145]

Such a commitment came from Japanese giant Toyota, with an investment announcement of USD 70 billion in the electrification of its vehicles and the production of batteries by 2030.[146] However, instead of focusing on the production of new EV models, Toyota has chosen to focus on developing EV conversion for their old ICE vehicles. Akio Toyoda, the company's chief executive, argues that retrofitting would give customers a wider variety of choices and allow some markets that are not yet adapted for EVs to gradually transition into electrification.[147]

Toyota seeks to provide alternatives to new EV models in the market, basing their EV strategy on the creation of retrofitting solutions. The company's "conversion" strategy was announced in January 2023 with the exhibition of both a battery electric vehicle and a hydrogen-powered version of the Toyota AE86 series to display the variety of possibilities they are willing to develop.[148] Despite being at an initial stage, Toyota's push into the EV retrofitting market has the potential of igniting similar responses from other automobile giants in the years ahead.

Figure 9: Toyota CEO Akio Toyoda at the Tokyo Auto Salon[149]

5.5. KENYA

EV retrofitting gained a special focus in Kenya as a viable solution to introduce electrification in the country's transportation system. The Kenyan government pledged to

141 Akshat Ajeya, "Why scrap your old car? Convert it to electric, here's how!" ***Go Mechanic Blog***, last modified January 4, 2020, https://gomechanic.in/blog/convert-your-old-car-to-electric/.

142 Ko Fujioka, "Japan to relax rules on fast EV chargers, jump-starting rollout," ***Nikkei Asia***, last modified January 4, 2023, https://asia.nikkei.com/Business/Automobiles/Japan-to-relax-rules-on-fast-EV-chargers-jump-starting-rollout.

143 Fujioka, "Japan to relax rules on fast EV chargers."

144 Shiho Takewaza, "Tesla escapes niche position as Japan starts to embrace EVs," The Japan Times, last modified February 7, 2022, https://www.japantimes.co.jp/news/2022/02/07/business/corporate-business/tesla-future-japan/.

145 Takewaza, "Tesla escapes niche position."

146 Paul Myles, "Toyota joins retrofit EV powertrain push," Automotive, last modified January 16, 2023, https://www.tu-auto.com/toyota-joins-retrofit-ev-powertrain-push/.

147 Bethany Biron, "Toyota says it plans to transform older cars into eco-friendly models to reduce carbon emissions, as the carmaker faces increased criticism for EV hesitancy," ***Business Insider India***, last modified January 16, 2023, https://www.businessinsider.in/thelife/news/toyota-says-it-plans-to-transform-older-cars-into-eco-friendly-models-to-reduce-carbon-emissions-as-the-carmaker-faces-increased-criticism-for-ev-hesitancy/articleshow/97012468.cms.

148 Taylor, "Toyota says it plans to convert old cars into EVs."

149 Biron, "Toyota says it plans to transform older cars."

fully transition to ZEVs during the COP26[150] but accounted with only 350 registered EVs by the end of 2022[151]. Intending to explore the opportunities that arise from the country's mainly renewable energy matrix – with over 90% of Kenya's power coming from sources such as solar, wind, and thermal[152] –, the Kenyan government is slowly introducing EV-friendly regulations to boost the market and attract domestic and foreign investments in the sector[153].

One of the main companies of the sector is Roam Electric (former Opibus). Founded in 2017, Roam first introduced their EV solutions in Kenya to fill an identified gap in the domestic market by providing EV conversion to 4x4 vehicles[154]. Targeting the safari and tourism industries, Roam was able to grow its client-base by focusing on vehicles with specific routes, predictable range capacity, and without other cheap electrification alternatives in the domestic market[155]. A kickstart through 4x4 EV conversion allowed Roam to expand their portfolio to include domestically produced electric two-wheelers and to invest in EV conversion solutions to public transportation[156].

Roam's focus on four-wheeler EV conversion is particularly interesting to the Kenyan market. Despite its renewable-focused energy sources, urban centers such as Nairobi present high levels of air pollution due to GHG and air pollutants (AP) emissions by transportation[157]. This is partially due to a combination of high rates of importation of second-hand vehicles – with over 95% its light-duty fleet coming from this origin[158] - and lack of air quality or emission standards[159]. Stricter standards are necessary on vehicle importations and GHG and AP emissions, but the available second-hand vehicles already in circulation in Kenya possess the ideal conditions for EV conversion[160].

Roam's market strategy for EV conversion not only utilizes the already-existing second-hand four-wheeler fleet and the safari and tourism sectors but also emphasizes using most of the retrofitting components from local sources[161]. The company reports incorporating at least 35% of the components necessary for the conversion from local sources and productions and envisions battery production in-country to lower the retrofitting prices further[162]. This measure contributes to the development of a domestic value chainthat supports future EV initiatives in Kenya.

After Roam's inception in the market, other companies have arisen and are expanding EV conversion as a viable solution for ICE vehicles in the country. Kenya's sole power supplier, Kenya Power, for example, has announced plans to convert over 2,000 vehicles from ICE to EV in the next four years[163]. Other companies, such as Knights Energy, have received approval from the Kenya Bureau of Standards (Kebs) to convert vans and buses into hybrid and electric vehicles in the country[164]. Despite existing challenges[165], domestic and international factors are highly favorable to the expansion of the Kenyan EV retrofitting market to Africa. Public and private stakeholders are addressing the barriers through

150 Nyabira, Muigai, Onyango, "Why Kenya could be getting ahead of itself in electric vehicle drive". Last modified June 20, 2023, https://www.businessdailyafrica.com/bd/opinion-analysis/columnists/why-kenya-could-be-getting-ahead-in-electric-vehicles-drive--4167214

151 ESI Africa, "Kenya making great strides to become Africa's electric vehicle hub". Last modified June 14, 2023, https://www.esi-africa.com/east-africa/kenya-making-great-strides-to-become-africas-electric-vehicle-hub/

152 ESI Africa, "Kenya making great strides to become Africa's electric vehicle hub". Last modified June 14, 2023, https://www.esi-africa.com/east-africa/kenya-making-great-strides-to-become-africas-electric-vehicle-hub/.

153 ESI Africa, "Kenya making great strides to become Africa's electric vehicle hub". Last modified June 14, 2023, https://www.esi-africa.com/east-africa/kenya-making-great-strides-to-become-africas-electric-vehicle-hub/.

154 Page, "Opibus: The mobility startup converting Kenya to electric vehicles". Altered June 14, 2023, https://edition.cnn.com/2022/03/01/africa/opibus-kenya-electric-mobility-bus-motorcycle-car-spc-intl/index.html

155 Kuhudzai, "Opibus scaling electric vehicle conversions for mass transit vehicles to make electric mobility more accessible in Africa". Last modified June 14, 2023, https://cleantechnica.com/2021/03/01/opibus-scaling-electric-vehicle-conversions-for-mass-transit-vehicles-to-make-electric-mobility-more-accessible-in-africa/

156 Kuhudzai, "Opibus scaling electric vehicle conversions for mass transit vehicles to make electric mobility more accessible in Africa". Last modified June 14, 2023, https://cleantechnica.com/2021/03/01/opibus-scaling-electric-vehicle-conversions-for-mass-transit-vehicles-to-make-electric-mobility-more-accessible-in-africa

157 Kirago, Gatari, Gustafsson, Andersson, "Black carbon emissions from traffic contribute substantially to air pollution in Nairobi, Kenya"

158 UNEP, "Used vehicles and the environment: A global overview of used LDVs".

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160 Roam Electric, "About". Last modified June 14, 2023. https://www.roam-electric.com/about

161 Kuhudzai, "Opibus scaling electric vehicle conversions for mass transit vehicles to make electric mobility more accessible in Africa". Last modified June 14, 2023, https://cleantechnica.com/2021/03/01/opibus-scaling-electric-vehicle-conversions-for-mass-transit-vehicles-to-make-electric-mobility-more-accessible-in-africa

162 Kuhudzai, "Opibus scaling electric vehicle conversions for mass transit vehicles to make electric mobility more accessible in Africa". Last modified June 14, 2023, https://cleantechnica.com/2021/03/01/opibus-scaling-electric-vehicle-conversions-for-mass-transit-vehicles-to-make-electric-mobility-more-accessible-in-africa

163 ESI Africa, "Kenya making great strides to become Africa's electric vehicle hub". Last modified June 14, 2023, https://www.esi-africa.com/east-africa/kenya-making-great-strides-to-become-africas-electric-vehicle-hub/.

164 Kariuki, "Kebs licenses electric vehicles conversion companies". Last modified June 14, 2023, https://www.businessdailyafrica.com/bd/markets/market-news/kebs-licenses-electric-vehicles-conversion-companies--2459954

165 Page, "Opibus: The mobility startup converting Kenya to electric vehicles". Altered June 14, 2023, https://edition.cnn.com/2022/03/01/africa/opibus-kenya-electric-mobility-bus-motorcycle-car-spc-intl/index.html, ESI Africa, "Kenya making great strides to become Africa's electric vehicle hub". Last modified June 14, 2023, https://www.esi-africa.com/east-africa/kenya-making-great-strides-to-become-africas-electric-vehicle-hub/

policy and market instruments to ensure the continued success of this venture.

Figure 10: Last installations of electric conversion system at Roam Electric[166]

5.6. SRI LANKA

The electrification of Sri Lanka's transportation system is strategic for the country's economy and environment. Heavily reliant on oil importations, Sri Lankan transportation is estimated to be the most polluting sector in the country[167], using around 70% of Sri Lanka's total oil consumption[168]. This trend reflects an acute increase of two- and three-wheelers' registrations in the country for the past two decades[169]. These modes of transportation are often highly polluting due to either outdated or poorly maintained combustion systems[170].

In addition to the related environmental constraints it presents, oil importations generate a considerable constraint to Sri Lanka's economy[171]. Despite petroleum being the main its energy source, the country is not a producer of fossil fuel resources[172]. Sri Lanka's energy systems are heavily dependent on imported oil, with demand coming especially from its transportation sector. The increased demand for gasoline and diesel is one of the major factors that negatively affect Sri Lanka's economy[173], as the government directs many of its import bills on the acquirement of petroleum-derived products[174].

High oil-importation demands devalued the Sri Lankan currency and led to a petroleum supply crisis in 2022, resulting in the banishment of vehicle imports to the country[175]. The economic crisis particularly impacted three-wheeler's owners and drivers. Tuk-tuks, as three-wheelers are commonly known in Sri Lanka, are mainly used in urban centers for self-employment, contributing to the informal economy and transportation of the Sri Lankan population[176]. Without the means of refueling their vehicles and of importing new versions, half a million people have reportedly lost their income activity during 2022, exacerbating the country's dependency on oil importation[177].

Within this context, EV conversion has gained popularity as a viable mobility opportunity in Sri Lanka. The solution provides the opportunity for the government to achieve its NDC targets and goals[178], contributing to GHG mitigation and air quality levels. Electrification of three-wheelers has particularly caught attention of domestic and international stakeholders. Coming behind motorcycles as the most popular registered vehicles in the country[179], tuk-tuks' expansion rate amongst user has increased over 12-fold in the last decade[180]. As most tuk-tuks in Sri Lanka are ICE models imported from India[181], start-ups and small-scale mechanics have started exploring EV retrofitting in the past decade, developing simple and affordable conversion kits to attract potential consumers[182].

With the recent economic crisis and with the oil and ICE vehicles importations' ban[183], tuk-tuk conversion

166 Roam Electric, "6 Benefits of converting your vehicle to electric". Last modified June 20, 2023, https://www.roam-electric.com/post/6-benefits-of-converting-your-vehicle-to-electric

167 US Embassy Colombo, "U.S. partners with David Pieris Motor Company to boost electric mobility in Sri Lanka". Last modified June 26, 2023, https://lk.usembassy.gov/u-s-partners-with-david-pieris-motor-company-to-boost-electric-mobility-in-sri-lanka/

168 Sugathapala, "Assessment of skills and knowledge gap in energy efficiency within the transport sector in Sri Lanka"

169 Sugathapala, "Assessment of skills and knowledge gap in energy efficiency within the transport sector in Sri Lanka"

170 SL Mobility, "Vision & Mission". Last modified June 26, 2023, https://www.slmobility.com/about/vision-&-mission

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173 Top Car News, "Sri Lanka to electrify 500,000 tuk-tuks". Last modified June 26, 2023, https://topcarnews.net/sri-lanka-to-electrify-500000-tuk-tuks-s244513.html

174 Sugathapala, "Assessment of skills and knowledge gap in energy efficiency within the transport sector in Sri Lanka"

175 Top Car News, "Sri Lanka to electrify 500,000 tuk-tuks". Last modified June 26, 2023, https://topcarnews.net/sri-lanka-to-electrify-500000-tuk-tuks-s244513.html

176 SL Mobility, "Vision & Mission". Last modified June 26, 2023, https://www.slmobility.com/about/vision-&-mission

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181 UNEP, "Taming the sputtering tuk tuk: Sri Lankan innovator develops affordable electric conversion kit". Last modified June 26, 2023, https://www.unep.org/pt-br/node/24335

182 UNEP, "Taming the sputtering tuk tuk: Sri Lankan innovator develops affordable electric conversion kit". Last modified June 26, 2023, https://www.unep.org/pt-br/node/24335

183 Sugathapala, "Assessment of skills and knowledge gap in energy efficiency within the transport sector in Sri Lanka"

gained a larger interest from the Sri Lankan government. Partnerships and technical exchanges with foreign donors have recently been established to assist in tuk-tuk conversion[184] and on the establishment of more advanced charging facilities for the new EVs in the streets[185]. Recognizing the strategic opportunities of tuk-tuk conversion, the Sri Lankan government aims to facilitate the conversion of half a million vehicles in the next five years, hoping to mitigate air pollution in urban centers and to revive micro- and informal economic activities in the country[186].

Challenges remain on the road for electrification of the Sri Lankan transportation fleet. Mainly, charging infrastructures in the country continue to present a challenge to current EV owners[187], and energy systems must be decarbonized to support EV expansion[188]. However, the recognition of the strategic role tuk-tuks have in the country's economy and transportation is a key factor for future environmentally friendly ventures[189], and further investments in technical know-how are essential for driving domestically led EV conversion efforts in the country.

Figure 11: CEO of SL Mobility posing next to converted three-wheeler[190]

184 Hamza, "Sri Lanka partners with USAID to convert petrol-run tuktuks to electricity". Last modified June 26, 2023, https://economynext.com/sri-lanka-partners-with-usaid-to-convert-petrol-run-tuktuks-to-electricity-98704/

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6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

With many countries taking active measures to transition their transportation systems from ICEs to electric vehicles, the inclusion of EV retrofitting within their strategies creates the possibility of further accessibility of transportation electrification to the population. The simplicity of the technology, the opportunities made available through decarbonization efforts within the EV agenda, and the positive initial experiences presented by some countries highlight the potential expansion of EV retrofitting technology. While the EV market is still in its initial stages, it can grow significantly when integrated into national strategies.

Many countries have employed different policy measures to accelerate the adoption of EVs by the population but do not explicitly include retrofitted vehicles in their strategies. As an emerging global industry still in its initial phase, EV retrofitting requires technical regulations and safety guidelines for its growth and popularization among customers. Developing appropriate legislation for regulating the process is not only important for the expansion of the market but also for guaranteeing its safe practice. Another area that requires specific policy involvement is the continuous development of available models of the retrofitting kits through further R&D engagements.[191]

Similarly, the EV retrofitting market must also be included in indirect strategies for transportation electrification promotion. Misconceptions about the technology and the retrofitting process are common amongst potential customers, who lack reliable information about the retrofitting kits and services available in the market[192]. Investments in awareness campaigns and branding are important for wider customer popularity.

While these policies are important for immediate EV retrofitting promotion strategies, they must be employed with a broader and long-term strategy of charging infrastructure promotion. The potential of EV retrofitting within a wider electrification agenda can promote a more inclusive and flexible transformation of the transportation

191 Transparency Market Research. "Automotive retrofit electric vehicle."

192 Transparency Market Research. "Automotive retrofit electric vehicle."

sector, reducing the cost barriers and contributing to decarbonization efforts. Inclusive electrification policies of different populational needs and leverage transportation alternatives to customers of new and retrofitted EVs are crucial to promote true inclusion of the population within electrification strategies.

6.2. RECOMMENDATIONS

The EV retrofitting market can be directly benefited by the promotion of decarbonization strategies and industry innovations and can be further expanded by the adoption of effective policies for the regulation and promotion of the practice. With the potential of being a cheaper, faster, and more adaptable alternative to purchasing new EVs, retrofitting is slowly being adopted by countries **as a complementary process to the electrification of transportation systems**. Given this circumstance, this report proposes the following recommendations:

RECOMMENDATION 1: Establishment of EV conversion–specific technical legislation

With the growth of EV retrofitting kits available to the public, countries must prioritize specific legislation to regulate and oversee the EV retrofitting process. While general guidelines for vehicular modifications exist, the process for EV retrofitting directly affects the weight, balancing, braking, suspension, and power generation of vehicles. The adoption of an updated and robust regulation scheme ensures the process's reliability to the customer, constituting an important first step for the expansion of the market.

Technical guidelines must be the comprehensive conversion procedure, which include the safety requirements, environmental regulations, and registration and insurance certifications. Additionally, the guidelines must be clear on the homologation requirements of EV retrofitting kits, certification of qualified manufacturers, and accreditation of specialized sellers and technicians for installment. To accelerate the adoption of EV retrofitting as a complementary option for the electrification of transportation, EV conversion must be comprehensively and explicitly included in the country's vehicular legislator system, enabling its monitoring and regulation.

RECOMMENDATION 2: Inclusion of EV retrofits in existing EV incentives

As countries strive to transition their transportation systems towards decarbonization, electrification is a popular alternative for many. While it may be argued that EV retrofits can be automatically classified as EVs and, consequently, be given the same incentives granted to new EVs, an explicit inclusion of converted vehicles is essential for a truthful adoption of retrofitting as an electrification strategy.

Direct incentives for EV retrofitting may facilitate awareness and the initial popularization of the practice, allowing customers to become familiarized with the practice and to invest in an alternative to new EV acquisition—which might not be financially accessible to many. Additionally, permitting converted vehicles to bypass carbon-zero or ICE-banned zones can potentially democratize vehicle electrification and, consequently, promote further awareness and acceptance of the practice.

RECOMMENDATION 3: Investment in R&D, capacity-building, and awareness campaigns

The EV market is still in its initial stages worldwide, and the EV conversion market is no exception. Despite being an affordable alternative to new EV acquisition, EV retrofitting faces the challenge of being model-specific, requiring the development of a particular EV conversion kit for each vehicle model. Thus, investments are necessary for manufacturers, start-ups, and companies to continue to develop new EV conversion kits, focusing on popular models that have a wider range of customers.

Similar investments must be directed to the technicians who perform the conversion. Given the safety risks that exist in any vehicle modification, continuous capacity-building is necessary to keep up with the fast-transforming market. Additionally, awareness campaigns are necessary to familiarize customers with the technology available for their vehicles and the potential incentives and benefits that are connected to EV retrofitting.

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APPENDIX: EV RETROFITTING POLICIES BY GGGI MEMBER

A detailed look into each member's EV retrofitting policies divided between **Technical Regulations, Incentive Measures,** and **Environment Enabling** Measures are as follows:

Technical Regulations	
Australia	The National Guidelines for the Installation of Electric Drives in Motor Vehicles offers the general technical guidelines for the conversion of ICEs into EVs. However, each jurisdiction must be consulted to certify that their procedures are also being followed. Nationally, once the conversion is performed, a certified engineer must perform an assessment of the vehicle to check if all safety systems are fully operational and that the brakes are working. A detailed report must be submitted to the Department of Transport for review and approval, which will grant the vehicle authorization to be registered as an EV.
Indonesia	2W conversion: • Motorcycles that have been converted from ICE to electric must undergo inspection and approval from a specialized technician and receive the proper certification. The certification requires each vehicle to be tested and approved by the specialized technician. • After the certification is obtained, motorcycles must be registered as converted to the Transportation Official. Documents to be presented include the Vehicle Number Certification, the test report, a list of EV system installations, the Conversion Certificate, the technical drawings of the converted motorcycle, and any other requirements in accordance with the regulatory provisions legislation. After the procedure is completed, the applicant must pay a registration fee. Other motorized vehicles' conversion: • Conversions can only be performed by approved and registered technicians and certified mechanics. Every vehicle must be individually tested and certified within the technical and road-worthy requirements. The responsible technician and mechanics must directly apply for the certification and approval with the Indonesian National Police. After application, every vehicle must be tested and receive approval. • Converted vehicles are required to have periodic tests in addition to being proven by registration and identification.
Nepal	EV retrofitting must receive verification from a responsible officer at the Transport Office.
Sri Lanka	Fuel conversion can be performed only after 3 years from the date of vehicle registration and before the vehicle is older than 25 years of age. Prior approval for the conversion should be obtained from the Commissioner General of Motor Traffic. A Vehicle Conversion approval must be requested, and, after the procedure, a Weight Certificate and a Fuel Conversion of Vehicle Certificate must be obtained from the Department of Motor Traffic.

UK	Registration: • Under the Vehicle Excise and Registration Services act 1994, a vehicle converted from a petrol engine to an electric one must be then registered as an electric car. This is done by taking down the V5C registration document and substituting it with the EV documents. Generally, any vehicle must be registered with the DVLA, which might follow an in-person inspection. Insurance: • The insurance company must be notified of the EV conversion. Vehicle owners must obtain an insurance certificate from their insurance company after providing the necessary paperwork for the conversion process. Safety Certification: • A crash performance test might be done by the DVLA to certify that the vehicle's weight did not suffer considerable alterations during the conversion procedure compared to the registered weight on its VIN plate
Incentive Measures	
Indonesia	2W Conversion Subsidy: • Electric motorbike conversion assistance for the 2023 fiscal year is set at a maximum of 50,000 units of electric motorbikes and for the 2024 budget it is set at 150,000 electric motorbikes. The size of the number of convertible electric motors can be evaluated every year.
Nepal	Registration Fee Exemption: • Environment-friendly and energy-efficient modifications (including retrofitting ICE vehicles into electric) have been granted exemption of the 50% rate of the registration fee upon approval from the responsible officer from the verification of the vehicle after said alteration.
UK	Tax Reductions: • After being certified and accredited by the DVLA, EV converted cars less than 40 years old are eligible for EV tax reductions. Conversion Subsidies: • The UK government have invested in several initiatives and public funds to support the conversion of government and public fleets to adapt to Clear Air Zones and mitigation targets. Funds include the Clean Bust Technology Fund, the Clean Vehicle Technology Fund, the Clean Air Fund, and the Annual Air Quality Grant. While these incentives have been significant, they are not exclusive to EV conversion, and are mostly focused on converting old fleets to fit the European Air Standards.
Environment Enabling Measures	
Sri Lanka	International Cooperation: • USAID + Pieris Motor Company 2022 MoU: Sri Lanka's energy ministry has partnered with a local motor mechanics company and USAID to convert three-wheelers run on petrol to electric three-wheelers. Under this partnership, DPMC will convert internal combustion engine three-wheelers to electric three-wheelers and offer after sales services through their island wide service centers. Meanwhile USAID will provide technical assistance to DPMC and establish a network of charging stations for three-wheelers.
Indonesia	R&D Investments: • The Indonesian government has announced a deduction of up to 300 percent on research and development costs in the fields of power generation, batteries, and power tools to promote lower prices of EV parts in the country

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