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Systemic Design of Mobility: A Conceptual Framework for Electric Vehicle (EV) Conversions

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Abstract

The dominance of fossil-fuel-powered mobility presents a critical challenge to sustainability, especially in sub-Saharan Africa, where second-hand internal combustion engine (ICE) vehicles contribute significantly to environmental pollution. Addressing this issue requires systematically re-evaluating existing mobility infrastructures and vehicle technologies. This paper investigates the potential of retrofitting ICE vehicles into electric vehicles (EVs) through a systemic design approach. The paper is grounded in a systemic design approach, circular economy principles, and ideas of post-growth economic models. The paper highlights an ongoing ICE to EV conversion case study as an example to analyse the implications of mobility transitions in terms of resource efficiency, industrial adaptation, and inclusive innovation. The analysis emphasises the significance of integrating systemic design approaches with industrial transformation strategies in re-imagining mobility solutions for sustainability. The insights from this study can provide valuable guidance for policymakers, industry leaders and other stakeholders seeking to accelerate the transition to clean electric mobility technologies, particularly in sub-Saharan Africa.

1. Introduction

Globally, the transport sector contributes more energy-related emissions than other sectors, thus exacerbating climate change and environmental degradation (Dai et al. 2023; Jing et al. 2022; UNEP 2020; Aminzadegan et al. 2022). According to Pal et al (2023), the transport sector is responsible for 19.2% of the total carbon emissions. Although advanced economies are transitioning to cleaner energy sources, the rest of the world is still stuck with fossil-fuel-powered vehicles, thus fuelling global warming and air pollution, which affect public health and ecological systems. The importation of fossil-fuel-powered vehicles in sub-Saharan Africa is growing at an unprecedented rate, with a substantial portion of the vehicle fleet comprising second-hand imports from the USA, Europe and Asia (Farquharson 2019). These vehicles often lack modern emission control technologies, resulting in higher levels of pollutants and greenhouse gas emissions compared to newer models. In 2019, Europe was the largest exporter of second-hand cars to Africa, making 6.7 billion dollars, followed by Asia with 5 billion dollars, and the third was the USA with 3 billion dollars (Ayetor et al. 2021). Regionally, West Africa leads in second-hand car imports, bringing in over 900,000 vehicles annually and accounting for about 70% of Africa's total imported vehicles (Knoope & Terwindt 2023). This reliance on second-hand, fossil-fuel-powered vehicles contributes to environmental pollution and poses challenges for sustainable development in the region (Ezeoha et al. 2022).

According to Baskin (2018), 95% of vehicles on the roads in Burkina Faso, Cameroon, Niger, Sierra Leone, and Uganda are second-hand imports. Meanwhile, in Ethiopia, imported second-hand vehicles constitute 85% to the total fleet (Kebede 2021; UNEC 2020). In Uganda, approximately 95% of the vehicle fleet consists of relatively inexpensive used fossil-fuel-powered vehicles imported from Asia. It is reported that most of the engine oil from these imported cars is carelessly disposed of in the environment (Ssempebwa & Carpenter 2009). Harmful pollutants emitted by fossil-fuel-powered vehicles include

carbon monoxide, lead, hydrocarbons, oxides of nitrogen and sulfur, and particulate matter (Kebede et al. 2022). These pollutants pose serious challenges for the environmentalists, policymakers and government agencies tasked with maintaining air quality in Africa.

However, according to Schwela (2022), the introduction of the pedelec use in Uganda partially substituted fossil-fuel-powered vehicles such as passenger cars, boda-bodas, matatus and substantially reduced CO_2 emissions. That notwithstanding, most sub-Saharan Africa remains carefree of the detrimental effects of second-hand vehicle imports. Consequently, the need to develop a sustainable mobility solution in Africa is long overdue. This may require a deep understanding of the aspirations, needs, and daily realities of local communities in Sub-Saharan Africa, thus addressing regional disparities, infrastructure limitations, and economic inequalities that influence access to transportation. It is imperative to design solutions that reflect the aspirations of communities, ensuring that innovations empower both urban and rural populations.

Therefore, mobility solutions can be tailored to enhance accessibility, promote economic growth and drive environmental sustainability through prioritising inclusive and context-specific design and integrating principles of design justice. As discussed by Augenstein (2015), the success of an electric mobility system largely depends on the new functionalities around the vehicle. Design methods can potentially play a transformative role in shaping resilient, community-driven mobility ecosystems to promote a just and green transportation future for Africa. We know that systemic design goes beyond technical interventions to influence human behaviours for lifestyle change transitions. According to Van der Bijl-Brouwer and Dorst (2017), systemic design is a combination of systems thinking and design practice. Köhler et al. (2009) show that lifestyle transitions can greatly affect technological transitions in electric mobility systems.

In this regard, the urgency of transitioning to sustainable mobility extends beyond the mere adoption of electric vehicles and necessitates a critical examination of how design and industry contribute to resource efficiency (Augenstein 2015). The high costs and environmental impact of new EV production highlight the need for alternative solutions such as retrofitting existing ICE vehicles. However, this transition requires a new mindset, a conceptualisation that situates ICE-to-EV conversions within a broader discourse on systemic design, sustainability and post-growth economics (Jackson 2021).

To do this, this paper explores the role of systemic design methods in shaping sustainable mobility solutions. To achieve this aim, section two discusses the theoretical frameworks of this study, section three discusses the conceptual analysis of ICE-EV conversions case study, as a design-led intervention, Section four presents the discussion and implications of this conceptual and theoretical contribution, and the last section concludes the work by summing up our framework for ICE-to-EV transitions.

2. Theoretical overview

2.1 Systemic Design and Sustainable Mobility

Systemic design is the integration of systems thinking and human-centred design to address complex, multi-stakeholder challenges that neither approach can fully resolve on its own (Jones 2014). Systems thinking provides a holistic perspective, making it possible to identify interdependencies within mobility ecosystems. Therefore, systems thinking via complex adaptive systems can provide a useful lens for understanding how sustainable mobility solutions evolve in Africa. This theory could explain how individual actors within the mobility ecosystem and populations connected thereto interact within a system, influencing the overall structure and behaviour of mobility (Stacey et al. 2002). Within the complex adaptive theories, utilising an agent-based approach analyses interactions amongst different stakeholders and formulates principles for adaptive, self-organising systems (Stacey 2003).

In the African context, interconnected organisations, governments, and communities need to establish collaborative structures that promote participatory decision-making in multi-stakeholder projects. This paper posits that instead of relying on rigid hierarchies, fostering self-organisation and adaptive governance can create more resilient, inclusive, and locally driven mobility systems that respond dynamically to the evolving needs of African societies (Burnes 2005). Human-centred design ensures that solutions remain inclusive, user-focused, and responsive to societal needs. Consequently, systemic design can help in developing adaptive, context-sensitive mobility solutions that evolve with economic and environmental conditions. This approach is particularly relevant in African contexts where mobility challenges are intertwined with infrastructural constraints, economic disparities, and policy limitations.

Systemic design combines agent-based and human-centred methods such as participatory and co-design to address the complexity of mobility systems (Jones & Kijima. 2018). The integration potentially allows for a dynamic approach to mobility innovation, where multiple stakeholders such as policymakers, transport operators, and local communities can collaborate to co-create solutions that are resilient, inclusive, clean and scalable. According to Blomkamp (2022), systemic design is often referred to as “systems (oriented) design, systems-led design, systems-aware co-design, design for complexity or system(s/ic) innovation” (p.13). These terms highlight the fluid, iterative, and multi-dimensional nature of systemic design, elaborating its ability to bridge disciplines, engage diverse actors and navigate uncertainty in mobility systems. The strength of co-design, participatory design and iterative learning makes systemic design eligible to foster a sustainable, equitable and future-ready mobility solutions that respond effectively to Africa’s socio-economic and environmental challenges.

In the context of ICE to EV conversions, the systemic design approach offers a methodology for rethinking existing automotive infrastructures as mobility ecosystems, while ensuring minimal disruption to supply chains and labour markets. In that regard, systemic design promises to integrate the holistic analysis and contextual adaptability of mobility. This can potentially enable the design discipline to create self-sustaining, open systems that leverage local resources, work culture insights and community-driven innovations. In other words, systemic design can stimulate context-aware design, thus facilitating the development of autopoietic systems which respond and evolve to environmental, social and economic challenges (Battistoni et al. 2019). This ensures that mobility solutions are rooted in the realities of African societies. Therefore, sustainable mobility in this context refers to the transformation

of fossil-fuel-based transport systems to zero-emissions alternatives (Hoppe & Michl. 2018). Africa is already facing an overwhelming volume of fossil-fuel-powered mobility, a situation exacerbated by the importation of second-hand vehicles from abroad. These vehicles often lacking modern emission control technologies, contribute significantly to air pollution and carbon emissions. What can be done about these challenges to promote sustainable mobility? To answer this overarching question, this paper explore cost-effective retrofitting solutions, such as converting existing internal combustion engine (ICE) vehicles into electric vehicles (EVs).

2.2 Circular Economy and Resource Efficiency

Before I address the research question, I need to explore how the circular economy and resource efficiency discourses can help us frame this problem. In comparison, the circular economy promotes material reuse and lifecycle optimisation instead of linear production-consumption-disposal models (Stahel 2016; Van Ewijk 2018). In MacArthur (2013), the circular economy is defined as "an industrial system that is restorative or regenerative by intention and design" (p.7). However, most of the circular economy definitions from literature are highly criticised for lacking broadness and inclusivity (Kirchherr et al. (2017; Corvellec et al. 2022). Thus, Kirchherr et al. (2017) offer the following definition of circular economy, which is much more encompassing:

"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations." (p. 224–225)

The above definition gives perspective to end-of-life concepts such as material reduction, re-use, recycle recovery in the production and consumption process and links these terms to economic prosperity for current and future generations. The key takeaway from the circular economy concept is that waste elimination should be planned at the early design stages to ensure waste returns as inputs in the production process. For instance, in sustainable construction, design for adaptation and design for repair principles are becoming integral to new building designs, and they are infused at the conceptual stages of the design process (Banihashemi et al. 2024). This is crucial for transitioning to an industrial model that separates economic growth from reliance on material inputs (Di Maio et al. 2017).

Governments around the world are promoting policies that drive waste as inputs for production to circulate materials. For instance, the 2008 circular economy promotion law of the People 's Republic of China provides incentives for using waste as inputs in production (Kirchherr et al. 2017). Although some scholars posit that sustainable product service systems-focused policies can contribute to circularity by intensifying the use of waste materials (Tukker 2015), there is still criticism on the extent it leads to a sustainable circular economy. That notwithstanding, there is evidence in existing literature and practice that circulating materials can reduce the volume and cost of new material consumption.

On the other hand, resource efficiency is about enhancing economic performance while minimising the strain on natural resources by utilising them more effectively (Van Ewijk 2018). This notion aims to reduce industrial activities and waste while producing more sustainable goods with fewer inputs (Delmas & Pekovic 2015). Nevertheless, this is a challenge since the world is continuously faced with the rise in human population, thus increasing demand for goods and services and consequently putting a strain on the available resources. At this point we know that our resources are scarce, particularly natural resources hence the need to use them sustainably (Hoang 2014). Some scholars have published work on how innovative tools can help corporations use resources wisely towards sustainability (Ngwakwe 2012; Bebbington and Thomson 2013). However, according to Bergmann et al. (2017), innovative tools face challenges such as measuring sustainability performance to ensure resource efficiency and management. Therefore, circular economy and resource efficiency are important concepts that can propel a sustainable ICE to EV transitions, which seems to be feasible for emerging economies already confronted with a load of second-hand ICE vehicle imports.

ICE-to-EV conversions represent a promising transition from fossil fuel-based to green transportation. This transition promises to extend the lifespan of existing second-hand vehicles, reducing waste, and promoting closed-loop industrial practices. It can also potentially foster low-carbon innovation within established industries while minimising the ecological footprint of new vehicle manufacturing. To answer the question of how we can promote sustainable mobility through ICE to EV transitions, it is apparent that the circular economy and resource efficiency concepts need to be considered first. In simple terms, how does converting an ICE to an EV vehicle promote circular economy and resource efficiency when it’s no longer serviceable?

2.3 Post-Growth Economics and Industrial Adaptation

The post-growth economics challenges the traditional narrative that economic growth is an unequivocal necessity for development (Spash 2015). In developing economies, where poverty and unemployment are skyrocketing and improving living standards is a priority, the dominant paradigm assumes that sustained gross domestic product (GDP) growth is the pathway to progress. However, post-growth perspectives argue that this approach ignores the deeper structural issues of unsustainable resource consumption (Johnsen et al. 2017; Bauwens 2021). Post-growth economics advocate for direct, localised solutions to poverty, equitable resource distribution, and ecological resilience (Schulz & Bailey 2014). Contrasting this with the steady-state economic principle of "sustainable scale," which posits that economies should only grow when benefits outweigh environmental and social costs (Splash 2015), post-growth thinkers highlight the incommensurability of many ecological and social factors.

Contrarily, conventional economics often presume that trade-offs can be efficiently managed, and external costs absorbed (Jackson 2019), yet this proves time and again that its unrealistic, particularly for global crises like climate change. Strategies that equate urbanisation and wage-based economics with progress frequently disregard the erosion of traditional livelihoods and the environmental harm they bring. Whereas post-growth perspectives advocate for alternative measures of well-being focusing on quality of life, community resilience and ecological sustainability rather than GDP growth (Lauer et al.

2025). I also argue that emphasis should be placed on redefining development through the principle of sufficiency, equity and long-term sustainability as opposed to enforcing a rigid path of expansionism. In simple terms, post-growth economic models critique conventional growth-centric paradigms, advocating for sustainability-driven prosperity over resource exploitation (Raworth 2017).

While post-growth economics advocates for equitable resource distribution and ecological resilience, industrial adaptation is a process by which industries adjust their structures, technologies and practices in response to environmental, economic and social changes (Murray 2008; Wilks 1984). This includes a paradigm shift towards sustainable production, resource efficiency, resilience to climate change and the adoption of circular economy principles to ensure long-term viability within ecological and societal limits (Murray 2012). With that in mind, post-growth economics and industrial adaptation both emphasise sustainability, resilience and operating within ecological limits. Post-growth economics challenges perpetual expansionism, advocating for efficiency, circularity and sufficiency, and industrial adaptation supports this through sustainable production models and regenerative manufacturing. Both these sustainable concepts prioritise resilience over growth models, promoting localised, resource-conscious industries that can withstand environmental and economic disruptions. To this end, industrial adaptation serves as a practical means to implement post-growth principles, shifting industries towards long-term sustainability.

Adopting the post-growth economics and industrial adaptation constructs, it is clear that the automotive industry's adaptation to EV retrofitting challenges the notion that technological progress necessitates perpetual resource extraction, instead proposing design-led degrowth strategies for sustainable mobility.

3. Conceptual Analysis: ICE-to-EV Conversions

To contextualise this study to real-world applications, the study highlights an ongoing case study on electric mobility in Botswana. This is an initiative by the government to convert existing internal combustion vehicles to electric vehicles. I am part of the team tasked with retrofitting two sedan vehicles and one pickup truck. The project team is made up of two universities, one research and development institute and two colleges of vocational education. I have identified this case study as an example of an ongoing ICE to EV transition in an emerging economy. I find this case significant to provide a conceptual lens based on a real-world project aimed at transitioning from ICE vehicles to EVs. Figure 1 shows the ICE to EV conversions design approach used during the three conversions, and Fig. 2 shows some conversion activities carried out during the EV mobility project.

Although the purpose of this article is not to dwell on the nitty-gritty of this ongoing electric mobility project, the case study example aims to provide context for the conceptual analysis section of this paper.

3.1 Design as an Agent of Industrial Transition

The transition from ICE-to-EV vehicles is a significant step towards achieving sustainable mobility. The Botswana mobility case study is currently using systemic design via co-design approach, which plays a critical role in enabling this transition. Co-design is about involving all relevant stakeholders in the design and development process (Sanders and Stappers, 2008; Nthubu et al. 2022). Although the project is both upskilling existing automotive technicians and conducting retrofitting activities, I am particularly applying design techniques to provide a structure for our teams to retrofit existing ICE vehicles to electric vehicles. Co-design tools employed help users to communicate, co-create ideas and work together in design and manufacturing teams. As demonstrated by our successful conversion of the three vehicles, the retrofitting approach shows how design methods can be leveraged to reconfigure vehicle architecture without requiring entirely new materials or manufacturing infrastructure. This aligns with the principle of industrial adaptation discussed above, in which existing assets are repurposed to extend their lifecycles and improve environmental outcomes. ICE-to-EV conversion systems illustrate the potential of design in reshaping industry practices.

From the Botswana case study, retrofitting ICE vehicles through a systemic design approach enhanced resource efficiency, minimised industrial waste and ensured economic feasibility in emerging economies where purchasing new vehicles is financially challenging. In comparison to traditional mass production models, which depend on large-scale manufacturing, the retrofitting approach embraces a localized, circular economy by enabling small businesses and skilled labourers to contribute to the sustainable mobility transition. In our case study, some retrofitting tasks were outsourced to local manufacturers as a way of involving them in the new mobility ecosystem. For example, achieving precise adjustment for the electric motor transmission shafts exceeded our in-house capabilities, requiring collaboration with local machine shops. This participatory systemic design approach promoted inclusive design and accelerated the growth of the green mobility ecosystem across various socio-economic sectors.

3.2 The Role of Emerging Technologies

Recent advancements in computer-aided design (CAD), artificial intelligence applications, additive manufacturing, and digital prototyping have revolutionised the industrial transitions. The ICE to EV conversion process is not spared from this industrial transition either. Since the conversion process is largely about designing spaces in the existing ICE chassis and engine bay, some of these technologies enabled us to precisely develop custom conversion kits. These kits optimise the integration of critical EV components such as battery packs, electric motors, motor control systems, vacuum pumps and onboard chargers. The integration of paper-based and 3D modelling tools allows us to simulate and refine component placement, minimising the need for extensive structural modifications to the vehicle chassis. In fact, in all our three conversions, we did not modify the chassis at all except to drill holes to secure our new frames and brackets for securing electric vehicle components.

During the space conceptual and detailed design stages, as shown in Fig. 1, the team predominantly used sketch-based modelling in co-design workshops, 3D space modelling in SolidWorks software, and iterative prototyping, which played a crucial role in the design validation process. The use of digital fabrication techniques ensured that custom brackets and support structures were efficiently

manufactured to fit the constraints of the existing ICE vehicle design. These emerging technologies facilitate the decentralization of EV conversion, making it possible to establish regional retrofitting hubs that cater to localised demands and empower regional supply chains and labour markets.

This case study demonstrates the need to further use automated manufacturing techniques where skilled and semi-skilled technicians and engineers develop expertise in sustainable vehicle conversions. This is important to create a scalable conversion model that can be adapted to various vehicle types, contributing to a broader industrial shift towards a sustainable mobility solution.

3.3 Systemic Implications of ICE-to-EV Conversions

During the Botswana case study, I found that using a systemic design approach in ICE-to-EV conversions underscores the potential to bridge the gap between post-growth economics and industrial adaptation. In comparison to conventional vehicle replacement models, which are driven by perpetual industrial expansionism, the retrofitting strategy aligns with sufficiency-based design principles, thus maximising the utility of existing second-hand vehicles as assets rather than relying on continued resource extraction. This approach potentially reduces environmental impacts and democratizes access to green mobility solutions, especially in regions where electric vehicle adoption remains slow due to financial constraints. So far, from our case study, converting ICE to EVEs seems to be a viable option for emerging economies to accelerate sustainable access to mobility services. For instance, most people who own second-hand ICE vehicles keep coming to our site to ask for help with converting their vehicles, hence the need to expand this initiative to make it accessible to many people who cannot afford to buy new cars.

Looking at systemic implications from a policy and regulatory perspective, integrating conversion technologies into existing vehicle markets requires the development of standardised retrofitting protocols, incentives for converted vehicles and training programs for mechanics and engineers involved in the mobility ecosystem. Through this case study project, we have mostly managed to develop training programs to upskill existing automotive technicians with EV skills and retrofitting capabilities. However, more efforts need to be made towards developing policies and regulations to manage the EV mobility ecosystem. The success of this industrial transition depends on collaborative design and innovation between designers, manufacturers, policymakers, and end-users, ensuring that sustainable mobility solutions are both technically viable and economically inclusive.

This conceptual analysis positions ICE to EV conversions as a viable industrial transition mechanism that leverages design thinking, digital fabrication, and systemic sustainability approaches to transform existing transport infrastructures. The study of vehicle conversions highlights the need for interdisciplinary collaboration and the adoption of localized, adaptive solutions to accelerate the transition to a sustainable mobility future. Therefore, integrating emerging technologies, industrial adaptation strategies and retrofitting presents a scalable, cost-effective alternative for decarbonizing transport systems in both developed and developing economies.

4. Discussions and Implications

Figure 3 represents the conceptualisation of how EV conversions can lead to a transition to sustainable mobility. This is indeed a complex and multifaceted challenge that requires a balance between systemic design, industrial adaptation, circularity and disruptive innovation. The framework depicted in Fig. 3 highlights how ICE-to-EV conversions play a crucial role in this shift, acting as a bridge between existing automotive infrastructure and future sustainable transportation solutions. EV conversions are positioned within the broader context of circular economy principles and post-growth economics, thus reducing waste and supporting long term environmental and economic sustainability. We can also see from Fig. 3 that policy interventions guide this transformation; a strategic approach that integrates both systemic and industrial perspectives is important to foster innovation. In the next sub-sections, the article discusses this conceptulisation in more detail.

4.1 Systemic Design as a Driver for Sustainable Mobility

This conceptual framing shows that systemic design is crucial in addressing the complex challenges of transitioning from fossil-fuel-powered vehicles to sustainable mobility solutions (Jones 2014; Van der Bijl-Brouwer & Dorst 2017). Using participatory co-design and iterative learning, systemic design enables the co-creation of inclusive, resilient and adaptive mobility solutions tailored to specific socio-economic and environmental contexts (Jones & Kijima 2018). This is important for African urban mobility ecosystems, where infrastructural constraints and economic disparities demand flexible and context-sensitive interventions (Burnes 2005).

In the context of ICE to EV conversions, systemic design facilitates the optimisation of existing vehicle architecture rather than relying on resource-intensive new manufacturing. This approach minimises industrial waste and reduces material extraction, aligning with sustainable development goals (Stahel 2016; Hoppe & Michl 2018). Moreover, the case study in Botswana illustrates that systemic design promotes local engagement, skill development, and economic participation, further reinforcing its role as an enabler of sustainable mobility transitions. This approach also fosters resilience and long-term sustainability through the integration of self-organising and adaptive governance models and policies (Stacey 2003; Battistoni et al. 2019).

4.2 Circular Economy and Resource Efficiency in ICE-to-EV Transitions

The integration of circular economy principles into the ICE to EV conversion process ensures that mobility transitions align with broader sustainability objectives (MacArthur 2013; Kirchherr et al. 2017). Therefore, we have seen that repurposing existing vehicles that have reached their ICE vehicle end-of-life extends their life cycle, reduces waste generation, and minimises the demand for new raw materials (Di Maio et al. 2017). The circular economy concept highlights the importance of designing for reuse, repair, and remanufacturing, ensuring that waste is reintegrated into the production cycle (Stahel 2016; Corvellec et al. 2022).

The retrofitting process fosters resource efficiency by leveraging locally available waste materials, i.e. used ICE vehicles, and skills, thus creating decentralised retrofitting hubs that enhance industrial sustainability. This model is particularly relevant for emerging economies, where the high cost of new EVs and inadequate infrastructure hinder widespread adoption (Tukker 2015). Furthermore, circular economy strategies embedded within ICE to EV conversions support closed-loop production models, reinforcing the shift from linear industrial practices to regenerative mobility systems (Van Ewijk 2018).

4.3 Post-growth Economics and Industrial Adaptation in Sustainable Mobility

Post-growth economic principles emphasise sufficiency, equity and long-term resilience over perpetual expansionism (Spash 2015; Bauwens 2021). The ICE to EV conversion model challenges the conventional growth-driven automotive industry by offering a more sustainable alternative, design-led degrowth. Instead of relying on continuous vehicle production, this approach prioritises reconfiguration of existing assets to meet environmental and economic objectives (Jackson 2019; Raworth 2017). Industrial adaptation plays a critical role in supporting post-growth ideals by reshaping manufacturing processes to focus on sustainability, circularity and efficiency (Murray 2012). Our case study highlights how industries can integrate new technologies such as digital prototyping and AI-driven optimisation to retrofit vehicles efficiently. Further, this model creates opportunities for workforce development, ensuring that automotive technicians and engineers transition to new skills that align with the evolving mobility landscape (Wilks 1984). Implementing circular production methods and emphasising localised industrial development fosters economic resilience while reducing environmental degradation (Schulz & Bailey 2014).

4.4 Industry Disruption and Policy Considerations

The large-scale adoption of ICE-to-EV conversions raises questions about regulatory frameworks, automotive labour markets and industrial restructuring. Traditional manufacturers focus on producing new EVs, but retrofitting offers a viable and complementary pathway to accelerate sustainable mobility transitions. Governments and policymakers must establish clear regulatory guidelines that ensure the safety, reliability and efficiency of converted EVs while incentivising adoption through financial subsidies, tax incentives and support for small and medium enterprises engaged in retrofitting.

Moreover, the shift towards conversion-based mobility solutions has profound implications for workforce transformation. Automotive technicians, mechanics, and engineers will need reskilling programs to adapt to the new demands of EV technology. Collaborative efforts between governments, educational institutions, and industry stakeholders can facilitate workforce development through targeted training programs and apprenticeship opportunities, ensuring that labour markets evolve alongside technological innovations.

4.5 Challenges and Future Directions

Despite the benefits of ICE-to-EV conversions, they still face several challenges including the following observed during our case study project:

- Standardization and Safety Regulations

Establishing and enforcing universal safety and performance standards to ensure compliance with evolving EV regulations and consumer confidence remains a huge challenge.

- Battery Sourcing and Lifecycle Management

We also had challenges to do with addressing supply chain limitations, ensuring ethical sourcing of raw materials and developing robust recycling infrastructure to handle end-of-life battery disposal. In other words, we still don't know where and how to dispose of these batteries in 10 to 15 years.

- Scalability and Consumer Adoption

There is also a problem of overcoming economic and behavioural barriers that hinder widespread adoption, such as the upfront costs of conversions and the need for greater public awareness of its benefits.

Therefore, future research needs to focus on refining design methods, enhancing digital prototyping workflows, and developing policy frameworks that integrate conversion systems into mainstream sustainability agendas. The development of modular, cost-effective conversion kits can help scale retrofitting efforts and reduce conversion costs, making sustainable mobility more accessible to lower-income populations.

Additionally, the role of emerging technologies such as AI blockchain for supply chain transparency, and advanced battery technologies must be explored to optimize conversion efficiency and sustainability. Expanding research on consumer behaviour and market dynamics will also help identify strategies to drive public acceptance and demand for retrofitted EVs.

The ICE-to-EV conversions can serve as a scalable cost-effective solution for decarbonising transport systems, particularly in emerging economies where new EV adoption is financially and infrastructurally challenging. Strategic industry collaborations, policy innovation, and continued technological advancement will be critical in realising the full potential of this transition towards sustainable mobility.

5. Conclusions

This article conceptualises ICE to EV conversions as a systemic design-led intervention within post-growth economic models. Our mindsets and approach challenge the conventional automotive industry practices while fostering a more sustainable, inclusive mobility ecosystem through the integration of systemic design, circular economy principles and industrial adaptation strategies. The research underscores the necessity of design innovation in bridging technological progress with ecological and

social imperatives, ultimately positioning EV retrofitting as a viable complement to new EV production in the transition to sustainable mobility.

Furthermore, the findings highlight the potential for ICE-to-EV conversions to disrupt traditional automotive industry structures, offering a pathway to resource-efficient, economically viable, and socially inclusive mobility solutions. Future studies should focus on scaling conversion efforts, developing standardised policies and leveraging digital tools to optimize design efficiency. Through policy support, industry collaboration, and technological advancements, ICE-to-EV conversions can serve as a transformative strategy in global decarbonization efforts and sustainable transport development.

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Figures

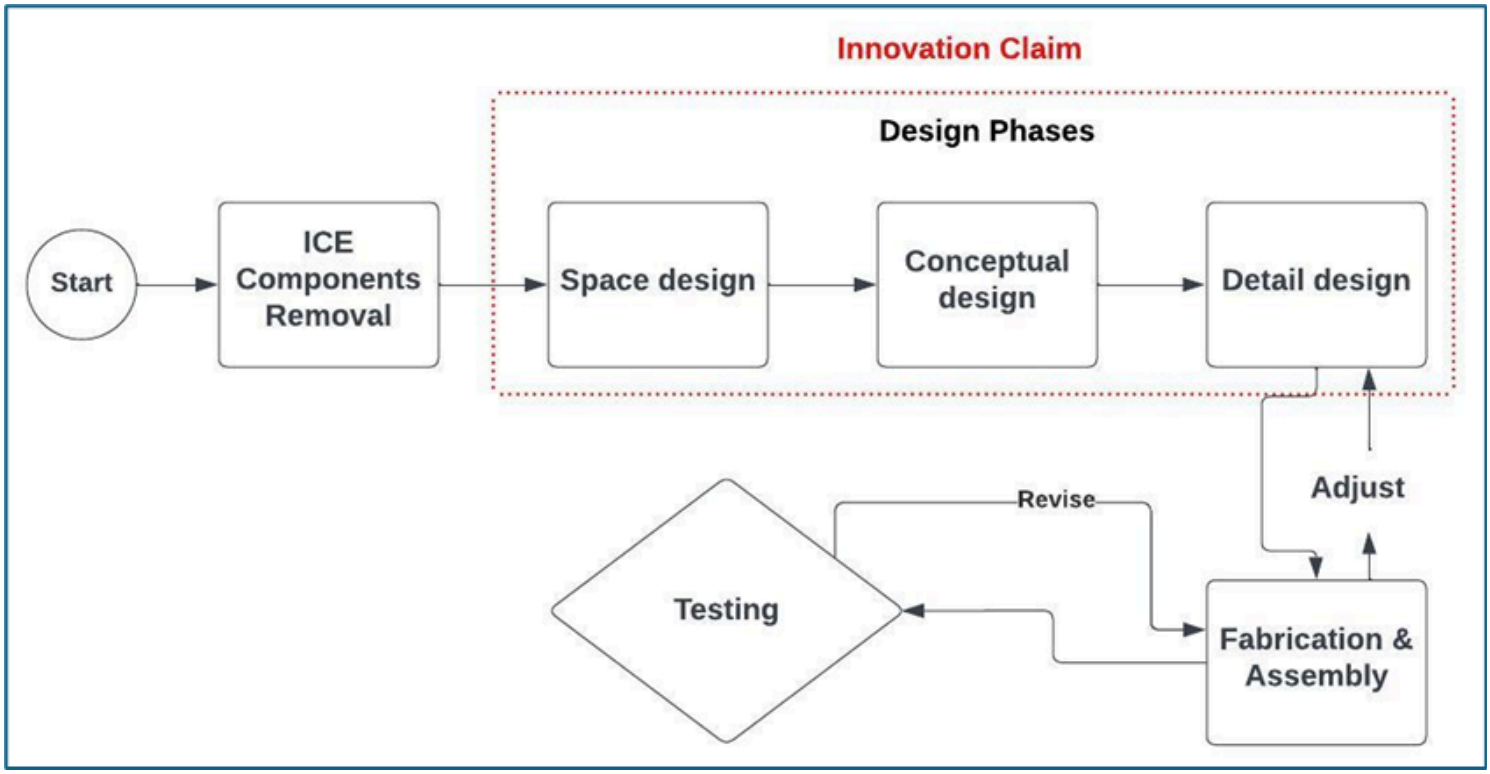


Figure 1

ICE-to-EV Conversion Design Process

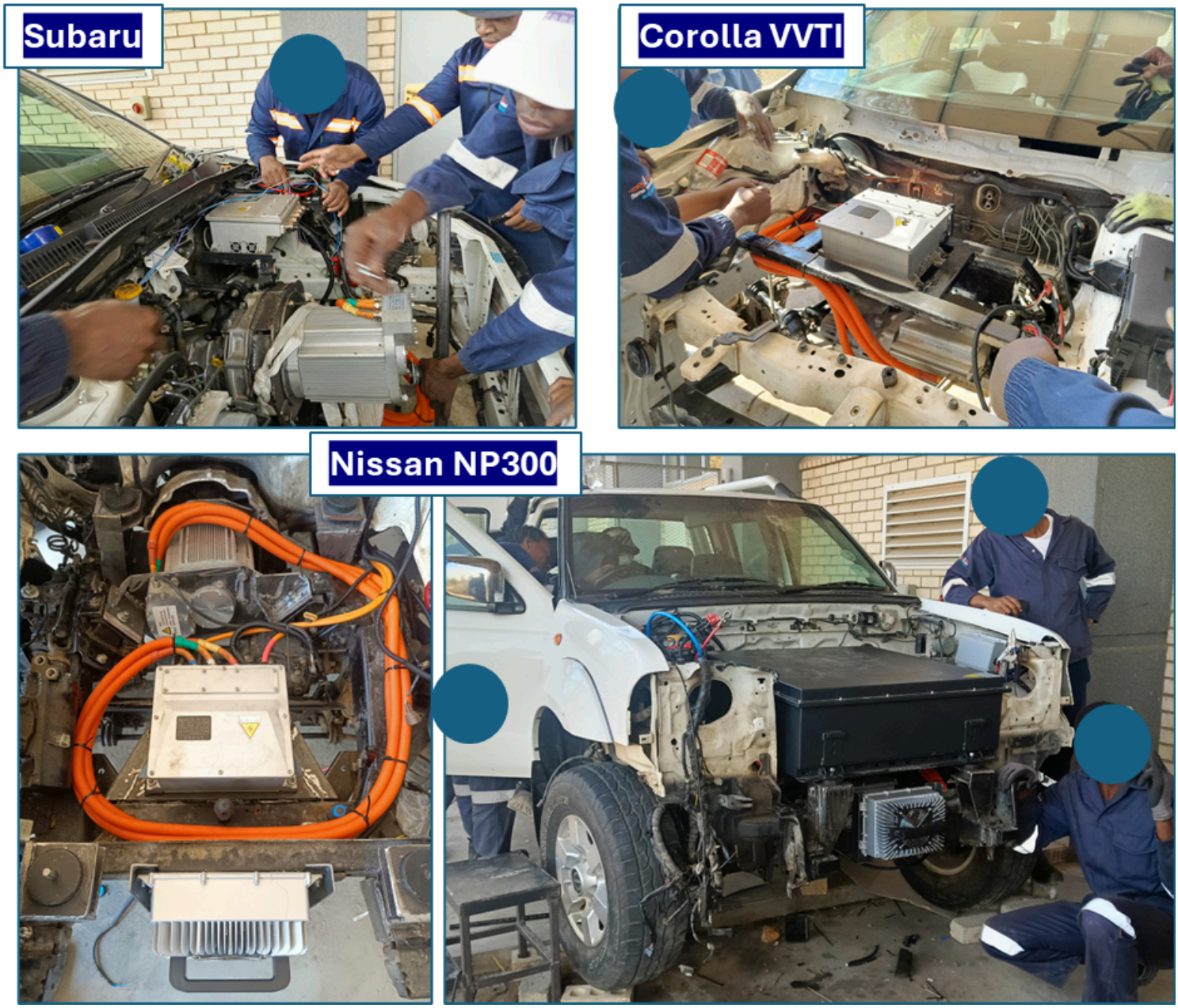


Figure 2

ICE-to-EV Conversion activities

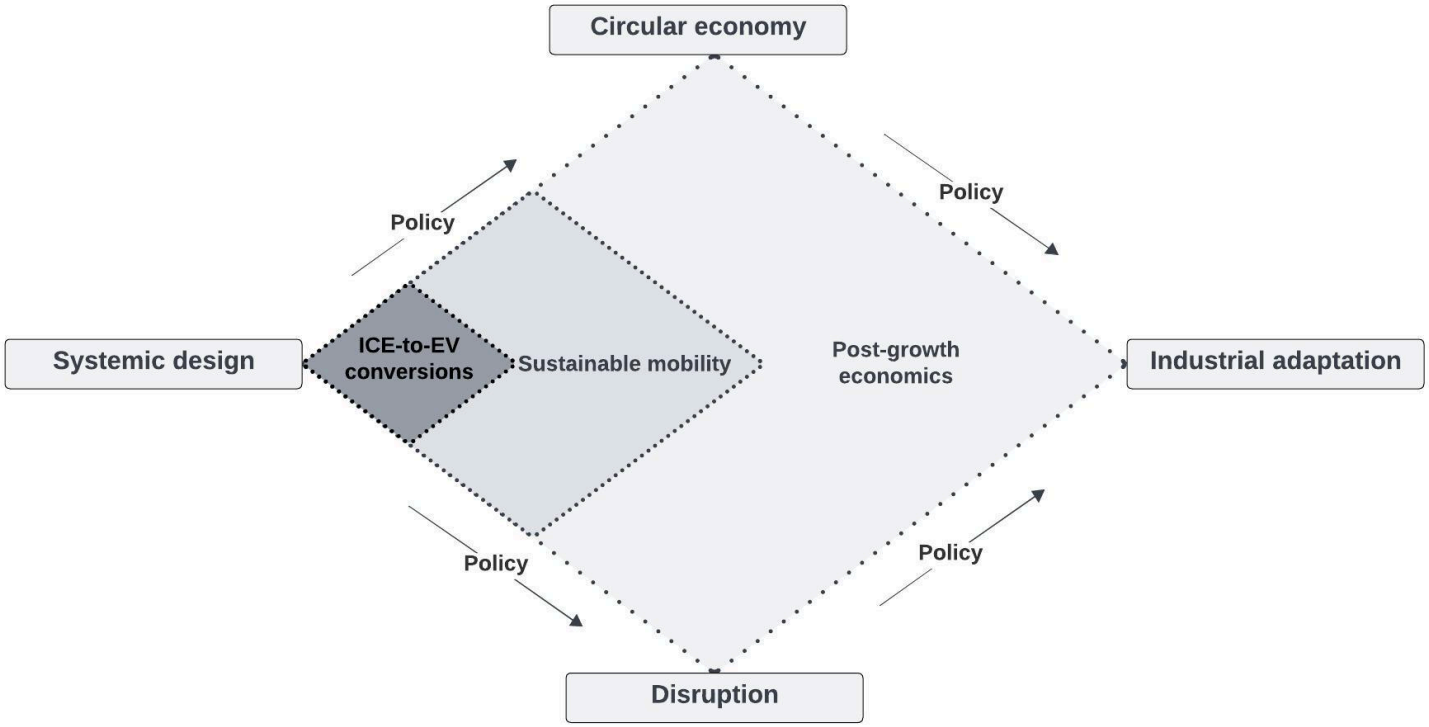


Figure 3

A Theoretical framework for EV Conversions