AI-Powered Inputs for Causal Loop Diagrams versus Human-driven inputs on Factors Affecting Electric Vehicle Adoption in South Africa

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Abstract: Electric vehicles (EVs) have gained immense popularity, especially in highly industrialized nations that are keen on reducing their dependency on fossil fuels. Most of these vehicles have been adopted through regulatory measures, offers of subsidies, and/or a set of related measures that tend to tip the economic balance of EVs in favour of the users. South Africa, as a developing economy, faces unique challenges in adopting EVs, including limited infrastructure, high upfront costs, and an unreliable electricity supply. Despite these challenges, the potential for EV market penetration in South Africa is expected to be substantial if the barriers to adoption are well understood and measure put in place to support the uptake of EVs. This qualitative study investigated the driving forces which impact EV adoption in south Africa through artificial intelligence (AI)-driven approach using multiple AI-engines. The results were then compared to those factors identified from workshop engagements (Human intelligence - HI). This resulted in the development of a comprehensive set of variables that could be used to develop a causal loop diagram (CLD). Through the use of AI models, it was possible to identify other factors for further stakeholders engagement workshops, however results indicate that HI identified far more factors than the AI-driven models.

Keywords: Electric vehicle adoption, artificial intelligence, human intelligence, factors.

1. INTRODUCTION

The evolving electric vehicle (EV) industry has aroused significant interest in modelling its market penetration and the associated profound impacts. That involves not only the changes in the transportation sector, such as market growth and the choice of vehicles by consumers, but also its potential long-term impacts on different sectors. These impacts might include carbon emission reductions, an outlook on petroleum consumption, changes in electricity demand, adaptations for current power market designs, and the corresponding investment plans for future power systems. The transportation sector is a significant contributor to greenhouse gas emissions and is the third largest emitting sector, with almost 55 Mt CO_2 emissions in South Africa (BCG, 2023). Electric vehicles (EVs) have been identified as a key solution to reduce emissions and combat climate change (Tongwane & Moeletsi, 2021).

The EV market growth might receive strong governmental support in some countries, including financial subsidies, rebates, and exemptions, while other countries might choose to focus more on improving the affordability of private automobiles by creating a more extensive public transportation system. Such concerns have become increasingly important for policymakers and key stakeholders due to the global advances in technological breakthroughs in transportation sectors, shifting away from consumption of fossil fuels. The rapid EV market penetration has a significant effect in alleviating environmental issues and coherence in broader

policy lines however, systems and interactions can be very complex between the key role players in the electric vehicle (EV) landscape. The complexities can be difficult to understand, particularly in the form of long-term behaviour.

The behaviour of a dynamic system can be the result of many interacting systems. Often the cause of a behaviour can best be described as a set of interacting feedback loops, and that many actions that affect systems, or policies of systems, do not have an immediate impact. To best manage changes, it is important to understand systems and interactions. Causal Loop Diagrams (CLDs) allow people to see visually the dynamic systems and interactions. In a complex form, testing hypotheses, identifying interventions, creating discussion, and clarifying mental models is an aid wherever long-term behaviour can be predicted or influenced (Haraldsson, 2004). Critical to the process of developing CLDs is the identification of key variables.

Given that, the core objective of this paper was to identify key influences that would impact the uptake of electric vehicles in south Africa through an AI driven approach and then compared it to those factors that were identified through multiple engagement sessions hosted by South Africa's Presidential Climate Commission. The workshops included stakeholders from Government departments, private and public enterprises, representatives from the taxi unions, as well as academia. The difference and similarities between the key variables/ drivers was then summarised and analysed. This approach would result in a comprehensive CLD which policymakers can use to deepen their understanding of market development; the industry's agent to learn the possible dynamics and assess the impact of their actions.

2. METHODOLOGY

2.1 A summary was concluded of the key factors influencing EV adoption after sessions were hosted by the South Africa's National Climate Commission where stakeholders were engaged from the automobile associations, eMobility Programs, private industry, charging station companies and energy modellers from academia and government.

2.2 A literature review was completed to further discuss these factors.

2.3 The next step was to use multiple AI programs to identify factors that were perceived to affect EV adoption in South Africa, analysing the commonalities between programs and relevance to the South African environment. The same question was posed to all the AI-driven search engines: "What are the factors that affect EV adoption in South Africa?"

The AI-driven search engines used were the free versions and included the following eight tools based on a query to find the best "conversational AI tools similar to ChatGPT" (ClickUp, 2024). Results were then compared to HI:

1. ChatGPT (https://chatgpt.com/)
2. DeepSeek (https://www.deepseek.com/)
3. EverAsk (https://everask.ai/)
4. Blackbox (https://www.blackbox.ai/)
5. Google Gemini (https://gemini.google.com/)
6. Claude (https://claude.ai/new)
7. Microsoft Copilot (https://copilot.microsoft.com/)
8. Chatsonic (https://writesonic.com/)

2.4 An analysis of the differences between the factors identified through workshops (Human intelligence inputs) and the AI generated factors was concluded and an analysis of the similarities and differences in results.

3 BACKGROUND

3.1 Electric vehicles in South Africa

Most countries, including South Africa, are seeking a less polluted and sustainable mode of transport to replace traditional Internal Combustion Engine Vehicles (ICEVs). This was the key motivation to the compilation of the Green Transport Strategy compiled by the Department of Transport (DoT, 2018). Although South Africa's EV market is still in its infancy (Figure 1) (Jansen van Rensburg, 2024), with limited models available (GreenCape, 2024) and high import costs, government has shown interest in promoting EVs through policy initiatives and partnerships with private sector stakeholders.

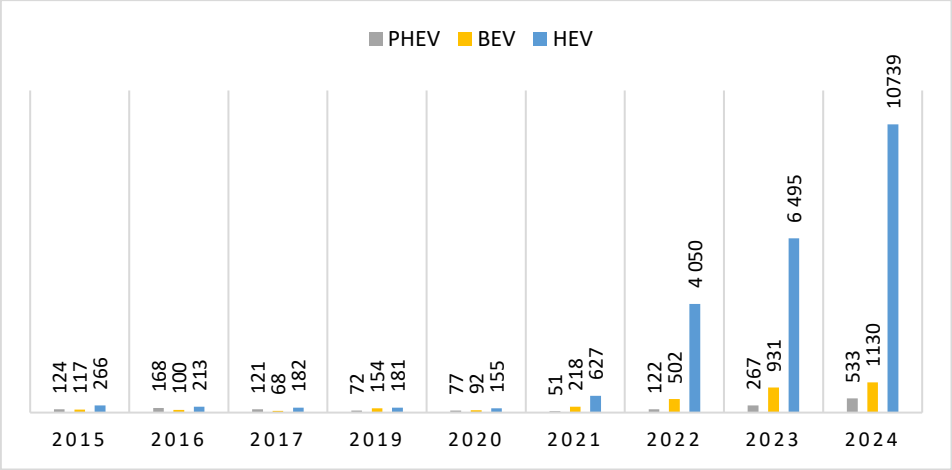

Figure 1: Number of electric vehicles in South Africa where BEV are full Battery Electric Vehicle, HEV are conventional Hybrid Electric Vehicles and PHEV are Plug-in Hybrid Electric Vehicles

The potential for EV growth in South Africa is significant, given the country's large urban population and increasing environmental concerns (DTIC, 2023).

3.2 Factors impacting the EV market penetration in South Africa

1. *Affordability*: The price of vehicles with electric drivetrains is more than that of their conventional counterparts (Manu & Krygsman, 2021) largely due to an ad valorem tax (up to 30%) on EVs which are considered part of luxury goods (Panchia, 2024). Electric vehicle battery cost reduction is also crucial, and the realization of scale economies coupled with technological advances will be sufficient to drive costs down over this period. Reduction in the price of electric vehicles increases the total amount of external factors involved in

the decision to purchase or not to purchase. Workshop engagements confirmed this factor to have a positive correlation with EV adoption (Presidential Climate Commission, 2023).

2. *Charging infrastructure*: A positive correlation has been found between the number of EV chargers and EV adoption (Automobile Association, 2024). Both private and public entities are reluctant to allocate resources towards the establishment of charging stations, thus adding to the concern about the practicality of driving an EV (Pamidimukkala , Kermanshachi, Rosenberger, & Hladik, 2023). After workshop engagements, this became a much-debated issue since some stakeholders believed that there were adequate charging infrastructure and others believed it was still not conveniently accessible and remained a barrier (Presidential Climate Commission, 2023).

3. *Energy security*: South Africa has implemented extensive loadshedding in the last 2 years than in all of history combined due to lack of generating capacity resulting in supply shortfalls (VerofySOLAR, 2024). Fears have arisen that there may not be sufficient power supply to charge the EVs (IT Web, 2022). Based on the workshop engagements, this was not considered to be a barrier since renewable powered charging stations were considered as well as charging during periods when there would be no loadshedding.

4. *Government Policies*: Supply side and demand-side incentives would have to be implemented (Bharadwaj, 2023). These would include incentives for local component and electric vehicle manufacture as well as rebates on EV purchases. The localised production of parts and components and possibly even assembly would bring down the overall retail price of EVs thus making it more attractive to the average consumer. The National Treasury has released details of a proposed tax amendment (Section 12V) that will grant automotive Original Equipment Manufacturers (OEMs) a 150% tax allowance on expenses related to buildings, as well as new and unused machinery, plant, and equipment primarily used for producing electric vehicles, for investments that come into use between 1 March 2026 and 1 March 2036 (Chipfupa, 2024). Based on workshops held, these factors were well recognised due to the representation by the automotive industry.

5. *Grid Capacity*: The monitoring, control, and management of utilities and supporting infrastructure solutions when electric vehicle drivers connect to the grid to charge their vehicles is also important. During the workshops, it was not recognised as a barrier but input from South Africa's electricity utility highlighted this as a possible barrier if the network was not adequately prepared for a high penetration of EVs (Venter, 2023).

6. *Consumer Awareness and Perception*: For consumers, changing their views for adopting and using electric vehicles and associated technologies, their awareness and perception of these vehicles and the environment, and supporting regulatory and public infrastructure need to be managed.

7. *Vehicle range*: Having a long vehicle range can influence consumers' decision-making in purchasing an electric vehicle. Owners may have range anxiety, and as a result, may want

to select a vehicle that can travel longer without recharging. In addition, the further an electric vehicle can travel before recharging, the fewer public charging stations will be required. Many motor companies have developed electric vehicles that have a longer range compared to older models to encourage customer buy-in (Jaguar, 2023).

8. *Environmental benefits*: Electric vehicles have fewer or no tailpipe emissions and contribute no greenhouse gases and air pollution (Aderibigbe & Gumbo, 2023).

9. *Fuel levy and carbon tax on fuel*: The fuel levy is the further largest source of income for the South African government, with a 49% increase in the basic fuel price from 2011 until 2021 (Sustainable Energy Africa, 2022). The government charges a vehicle emissions tax on new cars based on how much CO^2 they emit per kilometre, and this is payable by manufacturers of these vehicles in the country (R144 per tonne of CO2 as of January 2022) (Mthethwa, 2023). The increasing fuel levy and carbon tax on fuel would certainly be incentives to switch to EVs.

10. *Electricity tariffs*: The National Energy Regulator of South Africa (NERSA) recently approved a 12.7% tariff for 2025, with another 5.36% in 2026 and 6.19% in 2027 (Ellis, 2025), which means that EV owners will see higher electricity bills, making electric mobility less attractive.

Broadly speaking, a review of the factors influencing the EV market indicate that not only is the automotive market an intricate and complex system, but it is subject to the effects of several types of influences that lie outside its borders, and also beyond the ability of car manufacturers to control. With due consideration of both categories of influence, an analysis is undertaken of those that impinge on the transformation of the South African car market by the introduction of an initial consumer-targeted and driver-oriented technology, EVs themselves connected as a stand-alone technology to the grid.

A broad understanding of the many factors influencing the demand and supply of EVs was obtained through engagements and workshops held with several stakeholders active in the EV space. Together with insights and qualitative discussions, similar insights were gained through a review of the literature. By examining the key factors, a gradual understanding of the interconnectedness of those discrete insights was anticipated, and through the systemic view of the overall market landscape, the most salient insights to be incorporated in constructing a CLD could be identified.

3.3 AI-driven Models

Numerous applications of AI to system dynamics are available in the literature (Armenia, Franco, Iandolo, Maielli, & Vito, 2024). Pertaining AI, machine learning, neural networks, Bayesian networks, fuzzy logic, and genetic algorithms are attractive in improving prediction accuracy or better interpreting insights. The selection of AI algorithms intended to capture the underlying complex relationships hypothesized within the modelling objectives is diverse, but the practical limits associated with maintaining computational efficiency is important to

understand. AI has been used in cases where large datasets are available which allows patterns to be identified in order to make predictions and optimize solutions, so finding relationships between variables is largely based on statistics and measurable methods. When dealing with subjective or qualitative problems, it is not known how effective AI would be in specific case studies when compared to group model building where there may be nuances, tacit knowledge and experience that present mental models that AI may not access.

This study aimed to find non-linear relationships and hidden patterns through traditional methodologies (HI), and then using AI programs, which then culminated in the development of a causal loop diagram of the dynamics around EV adoption in South Africa.

4. RESULTS

The factors were divided into the following categories:

a) Government policies and incentives,
b) Consumer awareness & perception,
c) Automotive industry & local manufacturing,
d) EV charging infrastructure,
e) Social & environmental factors, and
f) Other Factors.

Table 1 presents results where "X" indicates the identification of a particular factor/variable.

Table 1: Comparison of results for AI-generated and HI-generated factor identification

	SEARCH ENGINE								HI
	ChatGPT	DeepSeek	EverAsk	Blackbox	Gemini	Claude	MS Copilot	Chatsonic	Workshops
Government Policies & Incentives									
Lack of ta1 rebates or subsidies	X	X	X	X			X	X	X
No clear national policy or EV roadmap		X							X
Regulatory frameworks						X			X
Support for local manufacture							X	X	X
Electricity tariffs	X	X							X
High import duties and ta1es	X	X	X			X			X
Urbanization & traffic congestion		X							X
ICEV fuel costs			X					X	X

	SEARCH ENGINE								HI
	ChatGPT	DeepSeek	EverAsk	Blackbox	Gemini	Claude	MS Copilot	Chatsonic	Workshops
Consumer Awareness & Perception									
EV maintenance cost uncertainty	X	X	X	X		X			X
Cultural preference for ICE		X		X					
Range an1iety	X	X	X			X			X
Benefits of driving EVs					X	X	X	X	X
EV resale value						X			X
Preference for larger vehicles						X			
Unreliable electricity supply	X	X			X	X	X		X
Effort expectancy to adopt EV technology				X					
EV battery life	X	X	X				X		X
Automotive Industry & Local Manufacturing									
Local automotive manufacturing sector focused on petrol and diesel vehicles	X								X
Underdeveloped supply chains for EV maintenance & repairs		X							X
Limited production of EV parts	X	X							X
Second-hand EV market	X	X							
Limited models		X			X	X			X
High battery costs				X					X
High retail price								X	X
EV export market								X	
Vehicle subscription services								X	
Ev Charging infrastructure									
Solar powered chargers	X								X
Home charging installation cost						X			X
Limited Charging Infrastructure	X	X	X	X	X	X	X		X
Social & environmental factors									
Economic inequality / affordability		X						X	X
Peer influence				X					
Corporate sustainability goals are pushing for greener fleets	X								X
Environmental Concerns & Sustainability	X	X	X	X		X		X	X
Marketing campaigns that leverage community influence and testimonials from early adopters can enhance acceptance.				X					X
Other factors									
Competition with HEVs		X							
Temperatures impacting conference						X			
Grid capacity constraints						X			X
Global conditions							X	X	

Based on the results above, the following insights were gained. **Figure *2*** shows the percentage of variables that was identified through each method (from a total of 38 variables).

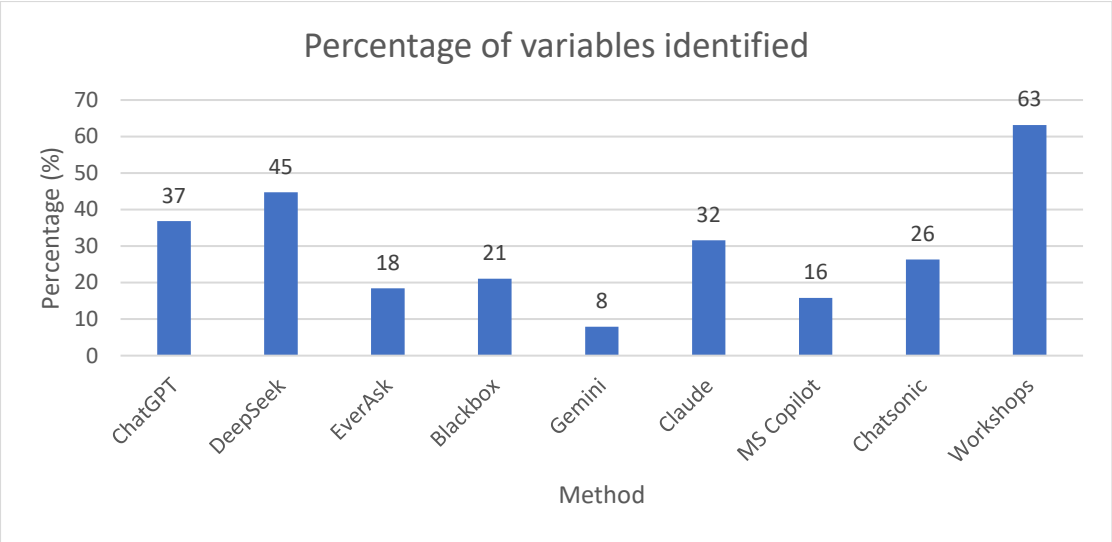

Figure 2: Percentage of factors identified by various methods of those listed in Table 1

An analysis on the number of AI-generated models which identified the various factors in each of the categories is shown in **Figure 3 - Figure 8.**

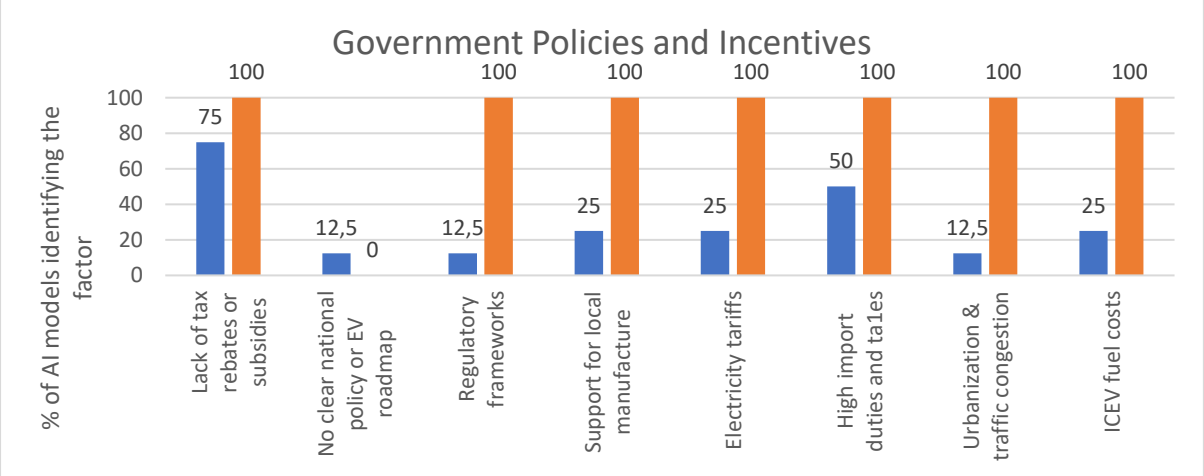

Figure 3: Percentage of AI tools which identified each factor compared to those picked up through HI (Government policies and incentives category)

The lack of government policies supporting incentives such as tax rebates and subsidies was the factor most AI-models identified (75%). All of these factors (100%) were identified through the HI-driven method. DeepSeek indicated that South Africa did not have a clear EV roadmap which is not true. The Green Transport Strategy and the White Paper on EVs outlines the strategies for EV roll-outs and identifies transport options to reduce road carbon emissions. Workshop engagements recognised that there are frameworks for EV roll-out in South Africa. but implementation is more the challenge.

For this ***Government policies and incentives*** category:
Worst scoring AI-models: Gemini.
Best scoring AI-model: DeepSeek.

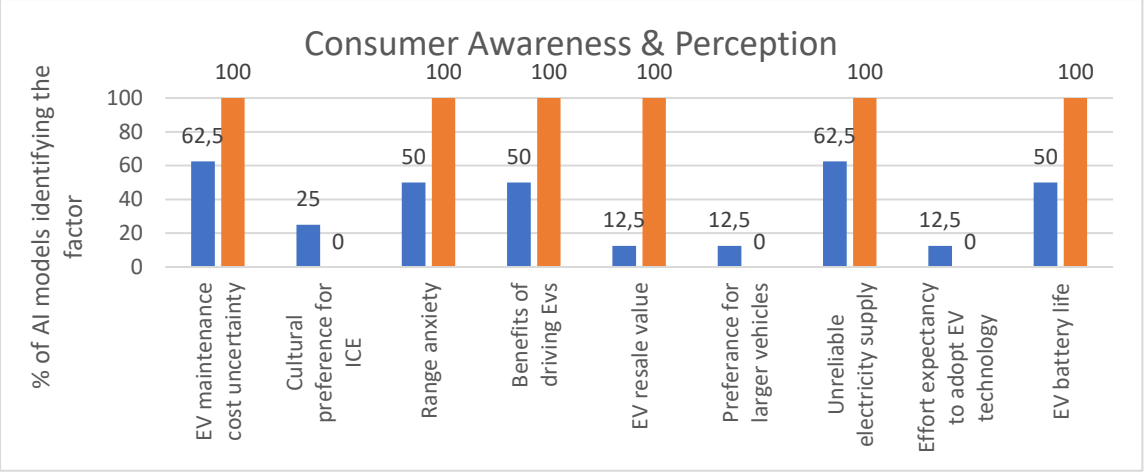

Figure 4: Percentage of AI tools which identified each factor compared to those picked up through HI (Consumer awareness & perception category)

In terms of consumer awareness and perception, the two factors picked up by most of the AI models was the lack of understanding of the maintenance requirements that would be required for EVs, as well as the unreliable electricity supply (loadshedding) in the country – both factors scoring 62.5%. Most of these factors were identified through the HI-driven method except for the consumer preference on driving larger vehicles, with bigger EV models being too expensive to purchase; the cultural preference for ICE vehicles; and the amount of effort consumers would have to make in order to switch to EVs.

For this ***Consumer awareness & perception*** category:
Worst scoring AI-models: Chatsonic.
Best scoring AI-model: Claude.

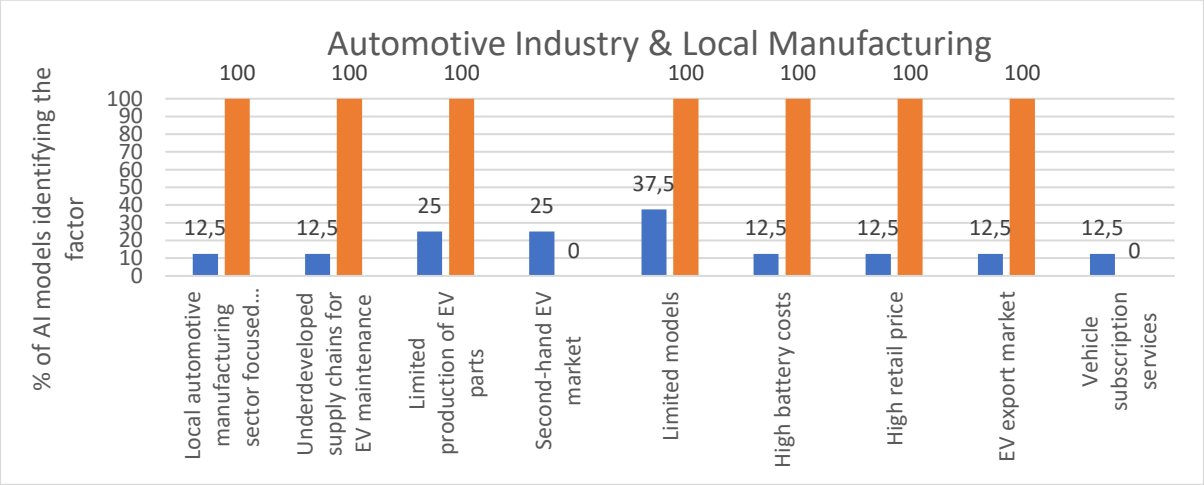

Figure 5: Percentage of AI tools which identified each factor compared to those picked up through HI (Automotive industry & local manufacturing category)

A very low percentage of AI-models were able to identify all the factors in the automotive & local manufacturing category. The HI-approach did not identify or discuss vehicle subscription options to gain access to an EV as an alternative mechanism to purchasing it, and the second-

hand EV market was not included due to the low population of EVs in the country and not enough second hands.

For this ***Automotive industry & local manufacturing*** category:
Worst scoring AI-models: EverAsk.
Best scoring AI-model: DeepSeek.

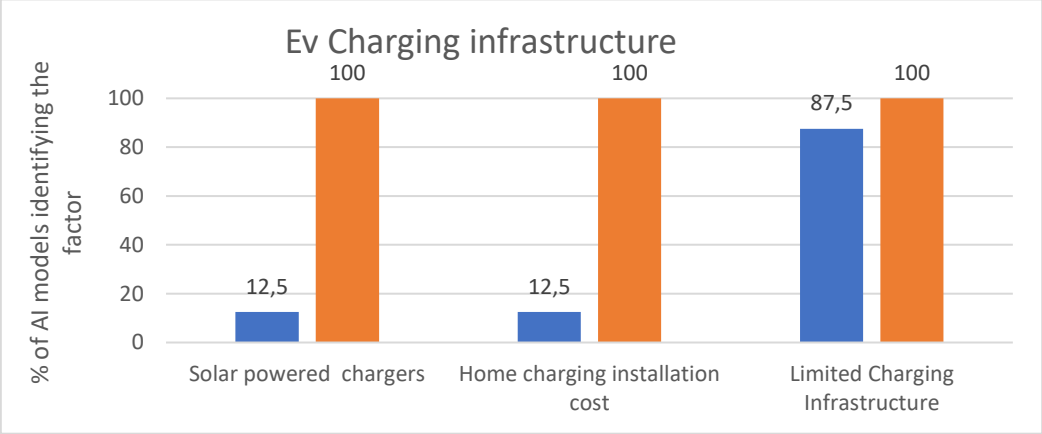

Figure 6: Percentage of AI tools which identified each factor compared to those picked up through HI (EV charging infrastructure category)

Almost all of the AI-models picked up the limited charging infrastructure in South Africa as being a factor affecting adoption while a much lower percentage identified solar home chargers as an option or the high installation cost. The HI-driven approach considered home charging using conventional grid-connected power but did not see it as a barrier because many households would have access to affordable Level 1 AC charging.

For this ***EV charging infrastructure*** category:
Worst scoring AI-models: Chatsonic
Best scoring AI-model: ChatGPT & Claude.

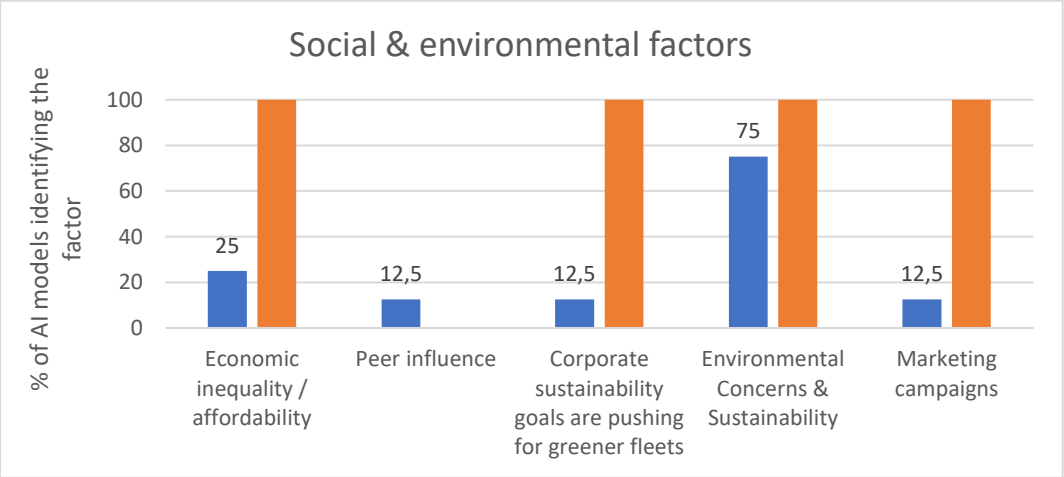

Figure 7: Percentage of AI tools which identified each factor compared to those picked up through HI (Social and environmental factors)

The only factor not identified by HI was peer influence. If anything, there would be pressure from government on industry and fleet owners to electrify to meet sustainable development goals but not peer pressure to coerce individuals into EV purchases. Due to data on South Africa's Gini coefficient being available as well as income groups and related monthly incomes, it is surprising that only 2 of the 8 AI-models identified the correlation.

For this ***Social and environmental*** category:
Worst scoring AI-models: Gemini & MS Copilot
Best scoring AI-model: Blackbox

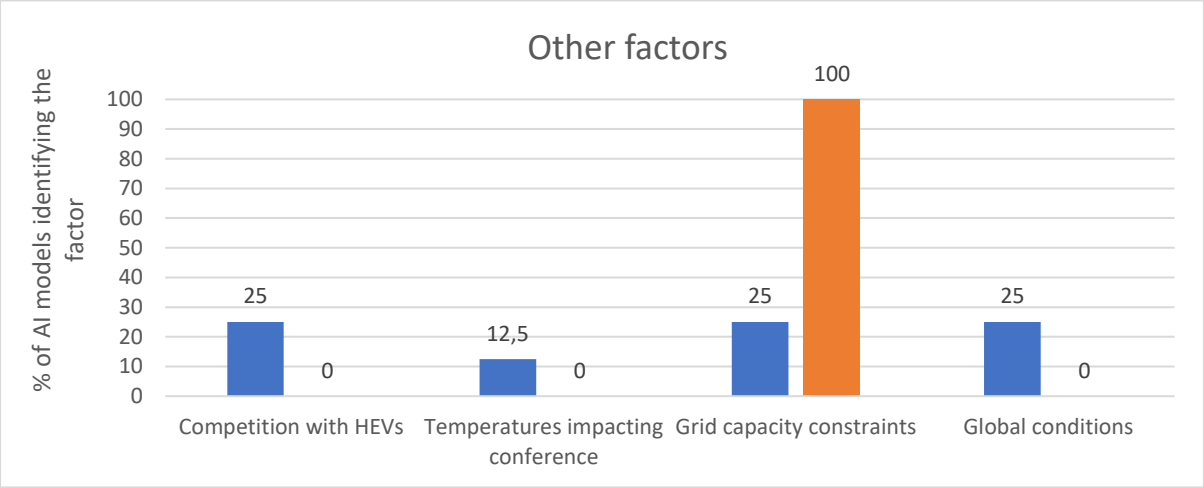

Figure 8: Percentage of AI tools which identified each factor compared to those picked up through HI

In this category, HI only identified grid capacity constraints due to representation from the energy utility during the workshops. The country has a very high fraction conventional hybrid electric vehicles (HEVs) compared to full battery EVs and plug-in hybrids but this was not identified as a barrier for adoption through workshop discussions. Temperatures were not identified as a factor except by the AI models (Claude) and that would most likely speak to the international market.

For this category:
Worst scoring AI-models: EverAsk, Blackbox & Gemini
Best scoring AI-model: ChatGPT & Claude.

CONCLUSIONS

In summary, the best to worst performing AI model is listed below where 1 is the best and 8 is the worst in terms of the number of factors it identified:

1. DeepSeek
2. ChatGPT
3. Claude
4. Chatsonic

5. Blackbox
6. EverAsk
7. MS Copilot
8. Gemini.

The factors that the HI-models did not pick up which were obtained through AI include:

- Cultural preference for ICE
- Preference for larger vehicles
- Effort expectancy to adopt EV technology
- Second-hand EV market
- Vehicle subscription services
- Peer influence
- Competition with HEVs
- Temperatures impacting conference and
- Global conditions.

Through the use of AI models, it was possible to identify other factors that stakeholders can be engaged on in upcoming workshops and which can be included in a CLD or system dynamics model.

The problems noted with the AI modelling process is:

- The process is often automated and lacks human interaction, which may limit stakeholder buy-in and shared understanding.
- Does not allow iterative refinement through discussion, incorporating lived experiences and tacit knowledge that AI may overlook.
- The output may still require expert interpretation to validate and make it actionable.

AI-generated CLDs are faster and data-driven, but they may lack contextual depth and stakeholder consensus. In contrast, HI-based models are collaborative, contextually rich, and more actionable for decision-making, though they take longer to develop. Ideally, a hybrid approach could combine AI's analytical power with human expertise for the best results.

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