Competency Framework for the Electric Vehicle Industry in South Africa

March 2023

Executive Summary

The electric vehicle is the vehicle for the future and has a role in safeguarding humanity from the adverse effect of greenhouse gas emissions. The electric vehicle industry encompasses the automotive, energy and transport sectors; hence it is a priority industry for any economy. In essence, electric vehicles have significant economic and environmental impacts. In light of its strategic importance, a competency-based education framework is required for this industry. This report, therefore, presents a detailed overview & critical analysis of the competencies needed for the manufacturing of electric vehicles in the Republic of South Africa.

In detailing a competency framework for the electric vehicle industry in South Africa, this report addresses the knowledge and skill gap among Technical and Vocational Education and Training (TVET) college students being trained for the automotive industry. Also, the report recommends the appropriate competencies needed for the manufacturing, operation, and maintenance of electric vehicles in South Africa. The report utilized both qualitative and quantitative research methods for the analysis. The quantitative process involved surveying students through questionnaires, whilst the qualitative process entailed interviewing selected TVET lecturers and selected automotive industry stakeholders.

The report showed a competency deficiency in the electric vehicle industry in South Africa as it faces significant infrastructure and electricity challenges. Moreover, the report highlighted that from the analysis of the student survey, interview of the lecturers, and focus group discussion of the industry stakeholders, there is a vast knowledge and skill gap about Electric vehicle manufacturing and operation among TVET college students. The report also revealed that this skill and knowledge gap is driven by an obsolete TVET college curriculum, poor electric vehicle infrastructure, poor collaboration among stakeholders, changing dynamics of the business environment, and insufficient knowledge about electric vehicles by TVET teachers.

The framework is built on a competency-based education (CBE) philosophy, whereby educational systems are driven by changing competencies in the industry. Consequently, this report provides a comprehensive competency framework for the manufacturing, operation, and maintenance of electric vehicles in South Africa, encompassing pre-manufacturing knowledge, manufacturing knowledge, and post-manufacturing skills, distilled into the Technology - Integrated Competency Model and the Managerial Competency Model. The framework includes electric vehicle system engineering, design and manufacturing process, renewable energy and battery infrastructure operation, quality and standardization, electric vehicle maintenance, electric vehicle charging

infrastructure, cognitive and personal effectiveness competence, workplace behaviour competence, and green supply chain & logistics competence.

The report proffered recommendations for TVET students, the South African Government, and the TVET school management to ensure optimal utilisation of this framework. Furthermore, this report also advocates for ongoing robust engagement of all stakeholders with the TVET directorate in the Department of Higher Learning and Training (DHET) for collective interventions in Electric Vehicle related teaching and learning.

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1.0 Introduction

The permeation and indispensability of the technologies, systems and processes of the fourth industrial revolution and their widespread deployment make investments in human capital an urgent endeavour. Developing and positioning human capital is a veritable pathway to unearthing opportunities of the fourth industrial revolution. Furthermore, these investments are necessary for driving the socioeconomic development of a nation and optimising its manufacturing potential.

Balog & Demidova (2021) opined that due to the digital transformation occasioned by the fourth industrial revolution, academic knowledge and skills assessments have morphed and can now be assessed by evaluating competence. Thus, the evidence of adequate and optimal human capital investment is high expertise and competence.

It can also be postulated that the higher the level of investment in human capital, the higher the level of competence.

Mathematically,

$$\text{Competence Level (CL)} \ \alpha \ \text{Human Capital Investment (HCI)}$$

$$CL \ \alpha \ HCI \qquad (1)$$

$$CL = k \ HCI \qquad (2)$$

where k = constant and refers to innovative learning initiatives covering technology-enabled curricula and pedagogy

Succinctly, this mathematical postulation confirms the research of Mamabolo, Kerrin & Kele (2017) that investments in the human capital lead to skill development and, by extension, increase the individual's competence level. This is also in tandem with the recommendation of President Cyril Ramaphosa's Presidential Commission on the Fourth Industrial Revolution to leverage the revolution in tackling unemployment, brain drain, a stagnant economy, and the emigration of the highly skilled workforce (Marwala, 2020). Therefore, competence development and optimisation are prerequisite strategies for tapping directly from digital opportunities.

Human capital is a concept that covers investments in humans primarily via education and is transferable from one enterprise/endeavour to another. Skills and competencies are attained through specialised education or training and can promote economic development. One such example is competency-based education (CBE), which has become one of the most prominent "slogans" in academia today (African Development Report (2011).

CBE entails the development of clearly defined competencies, plotting the curriculum to achieve competencies linked to workforce needs, as stipulated by employers and the profession, i.e., specific knowledge, skills, and abilities (KSAs) valued by working practitioners in the field (Kim (2015).

Competence entails a high capability to deliver a task after possessing the needed knowledge, skills, attitudes, and attributes. Competence is the measure of the absorptive capacity of an individual on a particular vocation, task, or job (Cohen & Levinthal, 1990). Hager & Gonczi (1996) posits that competence is the possession of desirable attributes in terms of skills, knowledge, and abilities, evident in optimal performance. They further opined that competence entails the integration of general or vocational education, gives room for flexibility in work performance, and encourages high-quality work. Competence is at total variance with mediocrity.

The word competence originated from "***Compentia***", which means "has the right to speak" and "is authorised to judge" (Caupin et al., 2006). Consequently, competence-based education (CBE) is a game changer and a retooling reform for every nation (Acikgoz & Babadogan, 2021). As championed by the IYF, competence-based education has been the bedrock of the sustainable economic development of developed countries, where competence is the driving force of specific technical expertise and decision-making in developed economies. Houston (1974) opined thus, "*Competency–based programs include: (a) instruction is individualised and personalised, (b)the learning experience of the individual is guided by feedback, (c) the program as a whole is systemic, (d) the emphasis is on the exist, not on entrance, requirements, (e) instruction is modularised, (f) the student is held accountable for performance, completing the preparation program, when and only when he demonstrates the competencies that have been identified as a requisite for a particular professional role".* Also, Spady (1977) defined competence–based education as "*database, adaptive, performance–oriented set of integrated processes that facilitates, measure, record, certify within the context of flexible time parameters the demonstrations of known, explicitly stated, and agreed upon learning outcomes that reflects successful functioning in life role".*

Moreover, Albane et al. (2010) averred that competence-based education, CBE is "*more concerned with what students should do with what they learn than what they should learn".* Le et al. (2014) also posited that CBE focuses on students' professional, civic & academic success competencies with measurable learning objectives. Levine & Patrick (2019) view competency-based education from the following features: "*(a) students are empowered daily to make important decisions about their learning experience, how they will create and apply knowledge, and how they will demonstrate their learning, (b) assessment is a meaningful, positive & empowering learning experience for students that yields timely, relevant, and actionable evidence, (c) student receive timely, differentiated support based on their learning needs, (d) student progress based on evidence of mastery, not seat time (e) students learn actively using different pathways and varied pacing, (f) strategies to ensure equity for all students are embedded in the culture, structure, and pedagogy of schools, and education systems, (g) rigorous, common expectations for learning (knowledge, skills & disposition) are explicit, transparent, measurable, and transferable"*.

CBE demonstrates the knowledge, skills, and attitudes expected for the educational module before leaving the classroom (Hodges et al., 2019). Oroszi (2020) opined that competence–based education is an innovative advancement in higher education whereby academic content and curriculum are based on competencies required of a student rather than conformance with the traditional opaque system.

Therefore, with the increased penetration and permeation of the 4IR technologies in the transportation industry, competence-based education is a "must–have". Also, the OECD learning framework for 2030 described competence-based education as transformative competence that focuses on innovation and sustainability of development (OECD, 2018), which is revolutionising the transportation industry. Therefore, the sustainability of the transportation industry in terms of energy usage as a propellant needs a CBE approach. Hence, the need to develop a competence framework/ model for New Energy Vehicle (NEV), focusing on Electric vehicles (EV).

A CBE approach is also needed to bridge the skill gaps for electrification of the transportation industry, reduce inadequate information about jobs & opportunities in the sector, proffering solutions to educational problems in the industry, solve the inadequacy of incentives and support for educators in the sectors, and proffer solutions to the uncertainty of workforce development strategy in the industry (Williams et al., 2015).

The electric vehicle is the product of the interrelationship between the economy's transportation, energy, and environmental sectors. EVs use electricity as their primary and main fuel source, generating little or no emissions in contrast to vehicles using an Internal Combustion Engine (ICE). Electric vehicles include all vehicles using alternative energy other than fossil fuels, especially Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). The electric vehicle is chosen chiefly due to its strategic advantages over the ICE vehicles in terms of eco–friendliness, fuel cost savings, and the flexibility of fueling, which are all good for the economy. Hence, electric vehicles' rapid and continuous acceptance has led to considerable investments in producing different models by original equipment manufacturers (OEM) and Governments (Deloitte, 2020). According to Canalys (2021), global sales of electric vehicles increased by 39% year on year in 2020 to 3.1 million units, with a projection of 30 million units by 2028.

Furthermore, by 2030, nearly half of all passengers' cars will be electric. Many governments of different nations support this high projection to reduce environmental pollution caused by ICE vehicles, which is detrimental to human health and a major contributing factor to climate change. For instance, European governments, the United States, China, Canada, Japan, and New Zealand spent almost USD 14 billion on electric vehicle incentives, direct purchases, and tax deductions.

Furthermore, many car producers are focusing on producing only electric vehicles within the next (10) years: Volvo says it will only sell electric cars from 2030, Ford will only sell electric vehicles in Europe from 2030, Volkswagen will focus on 70% electric cars in Europe, 50% in China and 50% in the United States; General Motors plans to sell only electric LDVs by 2035, and Stellantis plans to sell 70% of electric cars in Europe and 35% in the United States. Moreover, the electric vehicle market is worth USD 250 billion and is forecasted to grow to USD 985.7 billion by 2027 (Fortune Business Insight, 2020). Also, the high acceptance of the electric vehicle is a major disruptor of the automotive supply chain, which is worth 91 billion euros with an objective of decarbonising the entire lifecycle of vehicles (McKinsey, 2021); this is even as the supply chain disruptor will alter more than 100, 000 jobs in 2030 in the German Automotive industry (Institute for Economic Research, 2020), a pointer to other nations. Moreover, in exploring the relationship between energy and the transportation industry, IRENA (2017) opined that the electric vehicle would lead to: a higher share of the variable renewable energy (VRE) in the power system within five (5) main areas of utilisation of mobile battery storage system in the vehicle, utilisation of second – hand batteries as 'second – life' role as a stationary battery storage system, the speed of charging technology and infrastructure, and the evolution in charging behaviours of owners of an electric vehicle. Therefore, the projection and positive interactions regarding electric vehicles make it the next big thing and a technological revolution in the transportation industry with positive multiplier effects on the economy. Thus, investment in developing human capital for electric vehicle production in competence-based education is visionary and championed by the IYF. This is also important considering the integration of 4IR technologies of Artificial Intelligence, Robotic technologies, Internet of Things (IoT), and Big Data drive the electric vehicle, evident in the production mechanism of self–driving cars.

Therefore, competence-based education for Technical and Vocational Education and Training (TVET) Colleges Engineering system plugs the educational loophole for electric vehicle production in South Africa, focusing on NATED 4 – 6 Cadres for Electrical, Electronic, and Mechanical Engineering students. This will revolutionise the automotive sector in South Africa, which contributes 4.9% to South Africa Gross Domestic Product as of 2020, 27.6% of manufacturing output, revenue of more than R500 billion, production of 600000 ICE indirect jobs in South Africa (GreenCape, 2022). The organisation also opined that EV production in South Africa is promising, with a major barrier of insufficient skills across the entire electric vehicle value chain. Also, it offers many opportunities for local manufacturing & electrification of public transport, lithium–ion battery production, local manufacturing of passenger vehicles, and EV use in retail, construction, and underground mining.

Consequently, in addressing the poor performance at TVET colleges, Badenhorst & Radile (2018) opined that this is due to blatant shortcomings of lecturers in their capabilities to meet the competencies required for effective lecturing. An analytical view of the Report 191 (Nated) programmes for TVET shows a need for a new curriculum. The programs don't reflect the realities of the fourth industrial revolution and sustainability practices upon which the electric vehicle curriculum will be built. Furthermore, Terblanche (2017) stated that there is a need for a curriculum design as the existing curriculum are plagued with challenges of: short duration, outdated design, contents, equipment & textbook, lack of practical technology & component, non–alignment of curriculum to changes in technology and industry, and lack of application to current work scenario.

The curriculum gap was also emphasised by the Minister of Higher Education and Training (DHET, 2018), stating thus "*Although the national technical education programs offered at our colleges are still formally set as a required component of an apprenticeship, in reality their content is seriously out of date, and employers who do train are forced to teach 'trade theory' again at their own expense'*. Furthermore, the 2018 evaluation of the TVET college expansion and capacity development programme (CECDP) revealed that it was a majorly administrative intervention and not curriculum oriented.

This report aims to design New Energy Vehicle (NEV) industry skills competency framework/ models for electrical, electronic, and mechanical engineering in NATED 4 – 6 levels for TVET educational system. The objectives are to:

1. Identify the specific skills and competencies required in the Electrical Vehicles Industries or for Electrical Vehicles Engineers
2. Identify skill gaps and competency mismatches for Electric Vehicle production.
3. Develop a Competency Priority Framework for Electrical Vehicles.

2.0 Research Methodology

This report utilises mixed-method research leveraging both quantitative and qualitative methods. According to Johnson & Onwuegbuzi (2004), a mixed method include "*the use of induction, which refers to the discovery of pattern, deduction, which involves testing theories & hypothesis, and abduction, which refers to uncovering and relying on the best set of explanations for undertaking one's result"*.

2.1 Quantitative Research Methods

This entails collecting and analysing numerical data to find patterns, test relationships, and generalise results. Therefore, for this report, the quantitative method will utilise survey research, which entails using a questionnaire to get data. A well–structured questionnaire will be utilised to collect data on identifying skill gaps and competency mismatches among TVET engineering students in South Africa, focusing on Electrical, Electronic & Mechanical engineering in NATED 4 – 6 Levels. The questionnaire will focus on skill gaps amongst the students, with the following proposed high-level constructs detailed in Table 1.

Table 1: Questionnaire content

S/N	Items	Measurement
1.	Demographic Information	● Gender ● Age ● School Grade ● Course
2.	Foundational Knowledge of Electric Vehicles	4 – To a Great Extent 3 – Somewhat 2 – Very Little 1 – Not at all
3.	Theoretical and practical knowledge of electric vehicles manufacturing	4 – To a Great Extent 3 – Somewhat 2 – Very Little 1 – Not at all
4.	Critical Awareness of Electric vehicles component	5 – Extremely Aware 4 – Moderately Aware 3 – Somewhat Aware 2 – Slightly Aware

		1 – Not at all Aware
5.	Knowledge of Electric Vehicle Maintenance	5 – Extremely Aware 4 – Moderately Aware 3 – Somewhat Aware 2 – Slightly Aware 1 – Not at all Aware
6.	Self – Assessment of Adaptive Electric Vehicle Skills	5 – Very High 4 – High 3 – Moderate 2 – Low 1– Very Low

2.2 Qualitative Research Methods

This is the collection of non–numerical data (text) to understand opinions, concepts, & phenomena to obtain in–depth insight into a problem. This report will utilise three qualitative methods: content analysis & bibliometric analysis, interview survey, and focus group. The content of existing IYF project documents and relevant literature on competency and skills in the automotive industry was analysed using content analysis and bibliometric analysis methods. In furtherance of the qualitative research approach, several key electric vehicle-related policy documents were perused. This includes the South African Automotive Master Plan (2021 – 2035), the Green Transport Strategy for South Africa (2018 – 2050) and the Auto Green Paper on the advancement of New Energy Vehicles in South Africa (DTIC 2021). Also, Table 2 details the ten related competency frameworks that were considered in formulating the EV Competency framework.

Table 2: Related Competency Frameworks

S/N	Frameworks/ Models	Constructs	Organisation/ Country	Authors
1.	National Electrification Skills Framework	● Supply chain & Logistics ● Circular Economy & Sustainability ● Technology Development & Deployment ● Battery Management ● Power Electronics, Motor & Drive	✔ Catapult ✔ University of Warwick ✔ The Faraday Institution (United Kingdom)	Howard et al. (2021)

		● Electrification		
2.	In – demand Automotive Manufacturing Competence	▪ Personal Effectiveness Competencies ▪ Academic Competences ▪ Workplace competencies ▪ Industry-wide Technical Competencies ▪ Industry – section Technical Competencies	✔ High Gear (South Africa)	
3.	Conceptual Key Competency Model for Smart Factories	● Openness to Learning ● Flexibility/ Adaptation to change ● Technical Literacy ● ICT Literacy ● Innovation & Creativity ● Soft skills	Journal Publication	Jerman, et al., (2020)
4.	Holistic Competence Model	▪ Cognitive Competence ▪ Meta Competence ▪ Functional Competence ▪ Social Competence	Journal Publication	Le Deist & Winterton (2005)
5.	Competence–in–use Framework	✔ Formal Competence ✔ Actual Competence ✔ Officially demanded Competence ✔ Competence required by Job	Journal Publication	Ellstrom (1998)
6.	Competence Framework for Bridging Skill gap in the European Li-ion Battery Industry	● Cognitive Competence ● Functional Competence ● Method and Process Competence ● Meta Competence	KTH Royal Institute of Technology	Zahiraldinni (2000)

		● Social Competence		
7.	APICS Supply Chain Manager Competency Model	▪ Personal Effectiveness competence ▪ Academic Competences ▪ Workplace & Leadership Competencies ▪ Operation Management Knowledge areas and technical competences ▪ Supply chain manager knowledge areas and technical competencies. ▪ Association membership & certification	The Association for Operation Management (USA)	
8.	Behavioural Competency Framework for supply chain team leaders	✔ Positivity ✔ Concern for standards ✔ Custom service focus ✔ Collaboration & Teamwork ✔ Motivating & Inspiring team ✔ Holding team to account ✔ Developing the team ✔ Reasoning	Co-Op Logistics	
9.	System Engineering Competency Frameworks	▪ System thinking ▪ Holistic lifecycle view ▪ System Engineering Management	UK International Council on System Engineering (INCOSE)	
10.	Regional Model Competency Standards for Manufacturing Industry	● Basic Manufacturing process ● Casting & Moulding ● Machine Operation &	International Labour Organization	

		Component Assembly ● Fabrication & Finishing ● Equipment Services & Maintenance		

Finally, selected TVET Lecturers were interviewed on the following aspects: the State of the Electric vehicle industry in South Africa, Perspectives on the need for Electric vehicle competency in TVET colleges, Electric vehicle skill and theoretical knowledge gap among TVET students, and electric vehicle gap in hard and soft skills among TVET students. Also, a focus group discussion was conducted for stakeholders in the automotive industry, which centres on the state of the electric vehicle industry in South Africa, the required electric vehicle competencies, and the perceived skill gap among TVET students for the industry. The qualitative research method will be conducted simultaneously with quantitative analysis to develop a competency priority model/ framework.

2.3 Sampling Technique

The report will utilise a convenience and purposive sampling technique during data collection from the population and samples.

2.4 Population

The population for the report is the entire fifty (50) Public TVET colleges in South Africa. These are grouped according to their province in Table 3.

Table 3: Public TVET Colleges in South Africa

Province	Name of TVET Colleges
Western Cape	● Boland TVET college ● **College of Cape Town for TVET** ● False Bay TVET college ● Northlink TVET college ● South Cape TVET college ● West Coast TVET college
Eastern Cape	▪ Buffalo City TVET college ▪ **Eastern Midlands TVET college** ▪ Ikhala TVET college ▪ Ingwe TVET college

	▪ King Hintsa TVET college ▪ King Sabata Dalindyebo TVET college ▪ Lovedale TVET college ▪ Port Elizabeth TVET college
Northern Cape	● Northern Cape Rural TVET College ● **Northern Cape Urban TVET college**
Kwazulu Natal	▪ Coastal TVET college ▪ **Elangeni TVET college** ▪ Esayidi TVET college ▪ Majuba TVET college ▪ Mnambithi TVET college ▪ Thekwini TVET college ▪ Umfolozi TVET college ▪ Umgungundlovu TVET college
Free State	● Flavius Mareka TVET college ● Goldfields TVET college ● **Maluti TVET college** ● Motheo TVET college
North West	▪ **Orbit TVET college** ▪ Taletso TVET college ▪ Vuselela TVET college
Gauteng	● Central Johannesburg TVET college ● Ekurhuleni East TVET college ● Ekurhuleni West TVET college ● **Sedibeng TVET college** ● South West TVET college ● **Tshwane North TVET college** ● Tshwane South TVET college ● Western TVET college
Mpumalanga	▪ **Ehlanzeni TVET college**

	▪ Gert Sibande TVET college ▪ Nkangala TVET college
Limpopo	● **Capricorn TVET college** ● Lephalale TVET college ● Letaba TVET college ● Mopani South East TVET college ● Sekhukhune TVET college ● Vhembe TVET college ● Waterberg TVET college

Source: DHET Website (2022).

2.5 Sample Size

Table 3 shows no uniformity in the number of TVET Colleges across the nine (9) provinces. Hence, based on the convenience sampling technique, at least one (1) TVET College was selected from each province for the research since the Northern Cape has the least number of TVET Colleges, which is two (2). This gives us a total of nine (9) TVET colleges. The colleges selected are highlighted in Table 3 and are chosen based on the population of students enrolled in the TVET colleges (Khuluvhe & Mathibe, 2021).

Based on the purposive sampling technique (Khuluvhe & Mathibe, 2021), a total of hundred and twenty-six (126) TVET students were the respondent for this report. The respondents filled out the questionnaire using an online Google Form. Also, based on the purposive sampling technique and following the recommendation of Cresswell (2007) and Marshall et al. (2015), four (4) TVET lecturers were interviewed. Furthermore, according to the popular research convention of focus group discussion recommended by Krueger & Casey (2014), who suggested between five (5) and eight (8) participants, seven (7) Industry stakeholders were selected.

2.6 Method of Analysis

The quantitative data collected via a well–structured questionnaire was analysed using descriptive frequency and percentage analysis. It was also analysed using inferential statistics of multiple regression, all using the Statistical Package for Social Science (SPSS V.25) for the analysis. The interview data and focus group discussion data were recorded, logically/structurally transcribed and then subjected to theme analysis using the recommendations of O'Connor & Gibson (2003), Rabiee (2004), Kruegar & Casey (2000), Krueger (1994) and Lacey & Luff (2007).

2.7 Report Ethics

All participants in the research of this report participated willingly without compulsion. Also, all data collection and information generated were treated with the utmost confidentiality, as no names of the participants were recorded.

2.8 Report Stakeholders

This report will be a collective decision of various relevant stakeholders for absolute comprehensiveness. The stakeholders are:

a. **Students in TVET colleges:** These are students that are in Electrical Engineering, Mechanical Engineering, Electronics Engineering and computer science/ information technology. Essentially, one hundred and twenty–six (126) students were used for the survey to understand their skill level, skill gaps, and competence mismatch in Electric vehicle production.
b. **STEM Educators**: These are lecturers in Science, Technology, Engineering, and Mathematics (STEM) sections in TVET colleges.
c. **TVET Directorates:** These are the departmental staff in the DHET domicile in three TVET directorates, namely; programme & curriculum innovation, curriculum development and support; and lecturer development. After a successful quantitative and qualitative analysis research, the competency model developed will be vetted with these three directorates for curriculum synchronisation.
d. **The National Association of Automotive Component and Allied Manufacturers (NAACAM):** These are the members of the automotive industry who participated in the focus group discussion.
e. **Green Technology/ NEV Technology Organizations:** These organisations are within the green technology or green energy space. They were consulted for their input regarding environmental sustainability & performance.

3.0 Results, Data Analysis and Discussions

3.1 TVET Students' Electric Vehicle Knowledge and Skills Gap: Results

To ascertain the level of knowledge about electric vehicles and the related skill gap among TVET learners, one hundred and twenty (126) TVET students filled out an online questionnaire (See Annexure A). The results of the subsequent respondent analysis are detailed below:

a. Gender

Table 4 details the gender distribution of the respondents, which is also represented graphically by Figure 1.

Table 4: Gender distribution of the respondents (TVET Students)

Gender	Frequency	Percentage
Male	75	59.5
Female	51	40.5
Total	126	100

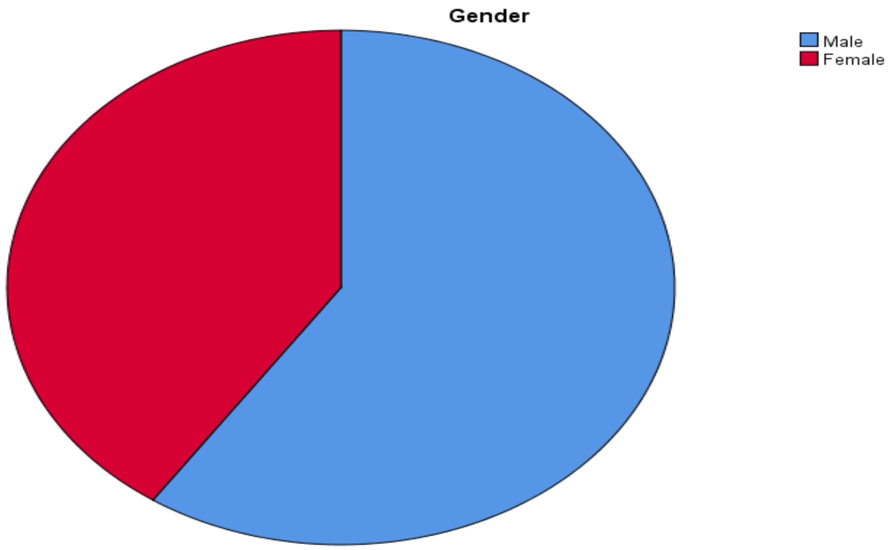

Figure 1: Gender distribution of the respondents (TVET Students)

b. Age

Table 5 details the age distribution of the respondents, which is also represented graphically by Figure 2.

Table 5: Age distribution of the respondents (TVET Students)

Age Range	Frequency	Percentage
15 – 20 Years	13	10.3
21 – 26 Years	97	77.0
27 – 32 Years	16	12.7
33 – 38 Years	0	0
Above 38 Years	0	0
Total	126	100

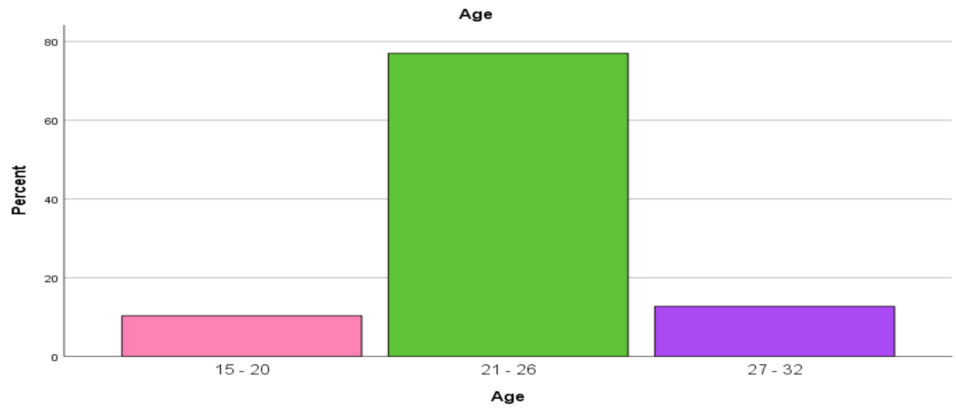

Figure 2: Age distribution of the respondents (TVET Students)

c. School Grade

Table 6 details the school grade distribution of the respondents, which is also represented graphically by Figure 3.

Table 6: School grade of the respondents (TVET Students)

Levels	Frequency	Percentage
Level 1	0	0
Level 2	3	2.4
Level 3	7	5.6
Level 4	52	41.3
Level 5	64	50.8
Total	126	100

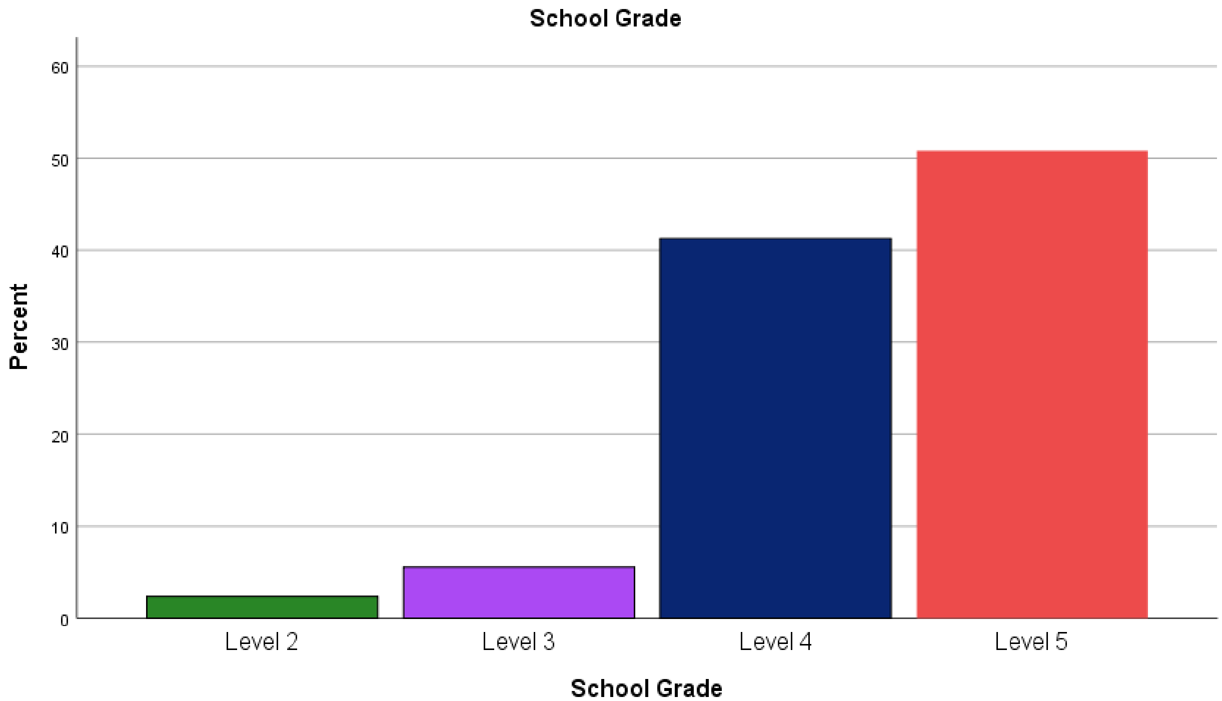

Figure 3: School grade of the respondents (TVET Students)

d. Course of study

Table 7 details the distribution of the courses the respondents are studying, which is also represented graphically by Figure 4. The School of Engineering grouping covers all courses not explicitly captured by the questionnaire, like engineering science, electrical machines, etc

Table 7: Course of study of the respondents (TVET Students)

Courses	Frequency	Percentage
Electrical Infrastructure	38	30.2
Engineering and Related Design	32	25.4
Information Technology and Computer Science	0	0
Mechatronics	0	0
Process Instrumentality	0	0
Process Plant Operation	0	0
School of Engineering	56	44.4
Total	126	100

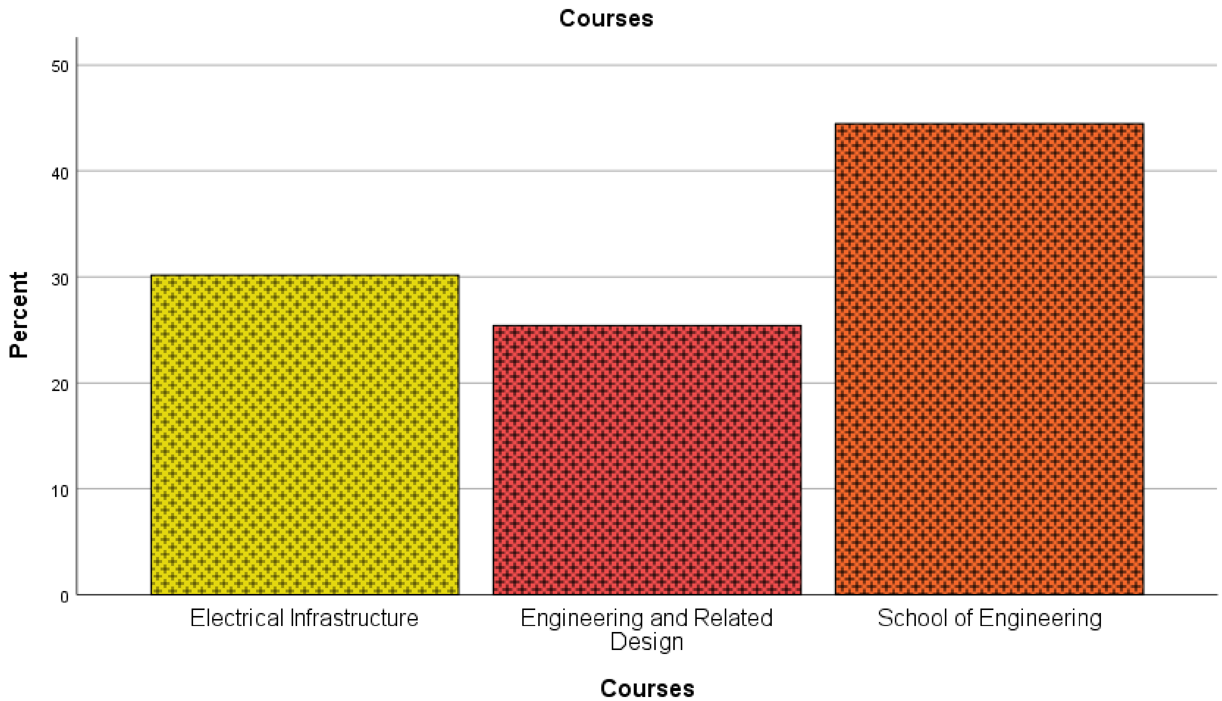

Figure 4: Course of study of the respondents (TVET Students)

e. Enjoying the Course

Table 8 details the distribution of the student's responses to the question: are you enjoying your course of study, which is also represented graphically by Figure 5.

Table 8: Students' response to the question: are you enjoying your course of study?

Item	Frequency	Percentage
Yes	126	0
No	0	0
Total	126	100

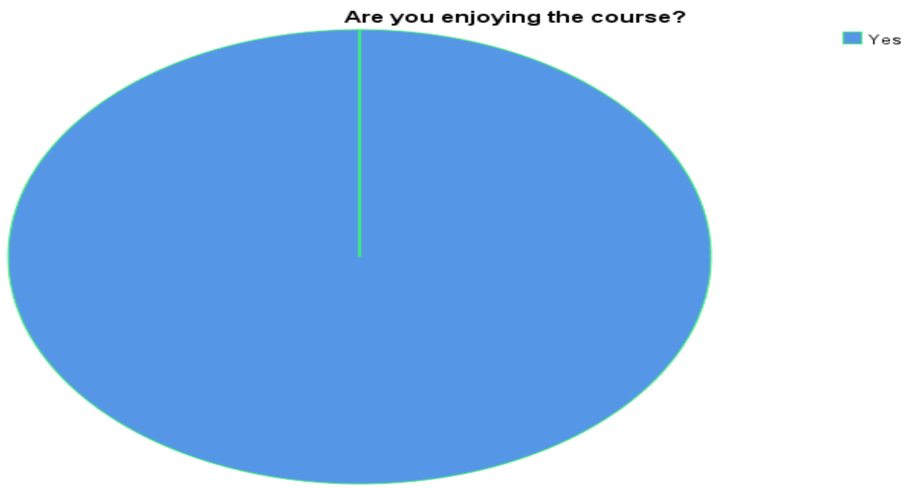

Figure 5: Students' response to the question: are you enjoying your course of study?

Section B to Section F assesses several elements of TVET's students' knowledge and skills using various Likert scale configurations. (Please see Annexure A). The results are further detailed in the subsections:

f. Section B: Foundational Knowledge of Electric Vehicles

This section used a 4-point Likert scale to assess the student's knowledge of electric vehicles. The results are detailed thusly:

Table 9: TVET students' foundational knowledge of electric vehicles

Items	Mean	Standard Deviation	Ranking
I understand the impact of electric vehicles on society (Power systems, transportation networks, etc.)	3.21	0.755	1
I understand the different energy sources for Electric Vehicles	3.05	0.920	2
I understand how electric vehicle batteries are charged.	3.03	0.929	3
I have heard of electric vehicles in a class	2.98	0.996	4
I have participated in a class discussion on electric vehicles	2.75	1.019	5
Average	**3.004**	**0.9238**	

g. Section C: Theoretical and Practical Knowledge of Electric Vehicles Manufacturing

This section used a 4-point Likert scale to assess the student's theoretical & practical knowledge of electric vehicle manufacturing. The results are detailed thusly:

Table 10: TVET students' theoretical and practical knowledge of electric vehicle manufacturing

Items	Mean	Standard Deviation	Ranking

I understand the electric vehicle design process	2.60	0.922	1
I know and understand the various electric vehicles components	2.58	1.015	2
I understand the electric vehicle manufacturing and assembly process.	2.52	0.986	3
I have practical experience with electric vehicle subsystems (braking, battery, converters, etc.)	2.17	1.056	4
I have practical experience with the electric vehicle manufacturing process	1.98	0.942	5
Average	**2.37**	**0.9842**	

h. Section D: Critical Awareness of Electric Vehicles Components

This section used a 5-point Likert scale to assess the student's critical awareness of electric vehicle components. The results are detailed thusly:

Table 11: TVET Student's Awareness Level of Electric Vehicle Components

Items	Mean	Standard Deviation	Ranking
Charging Stations	3.39	1.326	1
Battery Pack	3.37	1.401	2
Electric Traction Motors	3.29	1.321	3
Power Inverter/ Controller	3.20	1.420	4
Onboard Charger	3.07	1.438	5
Thermal Management Systems	2.98	1.365	6
Average	**3.217**	**1.3785**	

i. Section E: Knowledge of Electric Vehicle Maintenance

This section used a 5-point Likert scale to assess the student's knowledge of electric vehicle maintenance. The results are detailed thusly:

Table 12: TVET Student's Knowledge level of Electric Vehicle Maintenance

Items	Mean	Standard Deviation	Ranking
Knowledge of Electric Vehicles Maintenance tools, services, and activities	3.40	1.432	1
Knowledge of Electric vehicle maintenance approaches	2.92	1.489	2
Knowledge of Electric vehicle general inspection and fault diagnosis	2.91	1.403	3
Knowledge of Electric vehicle spare parts	2.83	1.430	4
Knowledge of Remote diagnostics for electric vehicles	2.71	1.391	5
Average	**2.954**	**1.429**	

j. Section F: Self-Assessment of Adaptive Electric Vehicles Skills

This section used a 5-point Likert scale to evaluate the student's self-assessment of their adaptive hard and soft skills pertaining to the electric vehicle industry. The results are detailed thusly:

Table 13: TVET Student's Self-Assessment of Adaptive Electric Vehicle Soft and Hard Skills

Soft Skills	Mean	Standard Deviation	Ranking	Expected Mean	Mean Difference
Team work	4.52	0.616	1	5.00	-0.48
Attention to details skills	4.31	0.843	2	5.00	-0.69
Problem-solving skill	4.14	0.756	3	5.00	-0.86
Interpersonal skill	4.11	0.782	4	5.00	-0.89
Decision-making skills	4.10	0.757	5	5.00	-0.90
Creativity	4.00	0.790	6	5.00	-1.00
Abstract thinking	3.98	0.753	7	5.00	-1.02
Leadership skill	3.92	0.977	8	5.00	-1.08
Critical thinking skill	3.90	0.784	9	5.00	-1.10
Analytical skill	3.88	0.786	10	5.00	-1.12
Average Soft skills	**4.086**	**0.7844**			
Hard Skills	Mean	Standard Deviation	Ranking	Expected Mean Level	Mean Difference
ICT and Mathematical skills	3.52	0.961	1	5.00	-1.48
System Design	3.13	0.915	2	5.00	-1.87
Trouble Shooting Skills	3.13	1.145	3	5.00	-1.87
Equipment and Engine Repair	3.02	1.110	4	5.00	-1.98
Engineering Drawing	3.00	1.246	5	5.00	-2.00
Diagnostics Skills	2.95	1.065	6	5.00	-2.05
Average Hard Skills	**3.125**	**1.0737**			
Average Total Skills	**3.726**	**0.8929**			

k. **Regression Analysis: Correlation between "Foundational Knowledge of Electric Vehicles" and "Theoretical and Practical Knowledge of Electric Vehicle Manufacturing"**

This section used regression analysis to determine the relationship between TVET students' "Foundational Knowledge of Electric Vehicles" and "Theoretical & Practical knowledge of Electric Vehicle Manufacturing". Table 14 gives the regression model results, and Table 15 details the ANOVA analysis.

Table 14: Regression Analysis Model of "Foundational Knowledge of Electric Vehicles" and "Theoretical & Practical knowledge of Electric Vehicle Manufacturing"

Model Summary[b]										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.520[a]	.270	.265	.67597	.270	45.956	1	124	.000	1.987
a. Predictors: (Constant), FoundationalKnowledge										
b. Dependent Variable: TheoreticalandPractical										

Table 15: ANOVA Analysis of "Foundational Knowledge of Electric Vehicles" and "Theoretical & Practical Knowledge of Electric Vehicle Manufacturing"

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.999	1	20.999	45.956	.000[b]
	Residual	56.661	124	.457		

	Total	77.660	125			
a. Dependent Variable: TheoreticalandPractical						
b. Predictors: (Constant), FoundationalKnowledge						

l. Regression Analysis: Correlation between Students' self-assessment of their soft and hard skills on their theoretical and practical knowledge of electric vehicle manufacturing

This section used regression analysis to determine the relationship between TVET students' self-assessment of their soft and hard skills and "Theoretical & Practical knowledge of Electric Vehicle Manufacturing". Table 16 gives the regression model results; Table 17 details the ANOVA results, and Table 18 the coefficient analysis results.

Table 16: Regression Analysis Model of Students' self-assessment of their Soft and Hard skills on "Theoretical & Practical knowledge of Electric Vehicle Manufacturing"

Model Summary[b]										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.601[a]	.361	.351	.63497	.361	34.807	2	123	.000	2.181
a. Predictors: (Constant), HardSkills, SoftSkills										
b. Dependent Variable: TheoreticalandPractical										

Table 17: ANOVA Analysis of Students' self-assessment of their Soft and Hard skills on "Theoretical & Practical knowledge of Electric Vehicle Manufacturing"

ANOVA[a]					
Model	Sum of Squares	df	Mean Square	F	Sig.

1	Regression	28.068	2	14.034	34.807	.000[b]
	Residual	49.592	123	.403		
	Total	77.660	125			
a. Dependent Variable: TheoreticalandPractical						
b. Predictors: (Constant), HardSkills, SoftSkills						

Table 18: Coefficient Analysis of Students' self-assessment of their Soft and Hard skills on "Theoretical & Practical knowledge of Electric Vehicle Manufacturing"

Coefficients[a]										
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	.876	.422		2.077	.040	.041	1.711		
	SoftSkills	-.066	.115	-.047	-.577	.565	-.293	.161	.795	1.257
	HardSkills	.563	.073	.621	7.684	.000	.418	.708	.795	1.257
a. Dependent Variable: TheoreticalandPractical										

3.2 TVET Students Electric Vehicle Knowledge and Skills Gap: Analysis of Participant's Responses

a. Social Demographic Information

Table 4 and Figure 1 reveal the gender distribution of TVET college students who were respondents to the study. It shows more male students (59.5%) than female students (40.5%). This gender representation conforms to the fact sheet on gender for TVET students in Post School Education and Training (PSET) institutions in South Africa. (DHET 2021a). Also, the TVET students, as shown in Table 5 and Figure 2, reveals the following age distribution: 10.3% are between 15 – 20 years, 77% are between 21 – 26 years, and 12.7% are between 27 – 32 years. This shows that most TVET students fall within the age bracket of 21 – 26 years. These statistics mirror the fact sheet on the age of TVET students in PSET institutions by DHET (DHET 2021b).

Furthermore, most (92.1%) of the respondents are TVET students in Grade levels 4 and 5, showing the reliability of their opinions in filling the questionnaires, as they are returning students with college experiences. Table 6 and Figure 3 show that 2.4% of the respondents are in level 2, 5.6% are in level 3, 41.3% are in level 4, and 50.8% are in level 5. Also, of the seven (7) main courses in TVET colleges, the respondents studied Electrical Infrastructure (30.2%), Engineering and Related Design (25.4%) and the school of engineering (44.4%). As shown in Figure 4 and Table 7, these courses are relevant for producing Electric Vehicles. Consequently, Figure 5 and Table 8 show that the students enjoy the courses they are studying, signifying a conducive learning environment.

b. Foundational Knowledge of Electric Vehicles

This report develops a Competency framework for producing electric vehicles, thus the need to evaluate the foundational knowledge of electric vehicles among TVET students. This knowledge level was assessed using a four (4) point Likert scale of 4 – To a Great extent, 3 – Somewhat, 2 – very little, and 1 – Not at all. Table 9 reveals that the average mean ranking of EV foundational knowledge among TVET students is 3.004, with a Standard Deviation (S.D) of 0.9238. These statistics show that the students have moderate knowledge about electric vehicles, with most of them knowing the impact of electric vehicles on society (Mean = 3.21; S.D = 0.755). Also, Table 9 reveals that discussion on Electric vehicles is low in classes, with a mean score of 2.75 and a standard deviation of 1.019. Table 9 portrays that TVET college students are aware of the existence of electric vehicles and that the students will assimilate teachings on electric vehicles.

c. Theoretical and Practical Knowledge of Electric Vehicles Manufacturing

Table 10 was obtained using a 4-point Likert scale: 4 – to a great extent, 3 – somewhat, 2 – very little, and 1 – not at all. The average mean score of 2.37 and standard deviation of 0.9842 reveals that TVET students don't have the required theoretical and practical knowledge about electric vehicle manufacturing. The students have little understanding of the electric vehicle design process (Mean = 2.60; S.D = 0.922), which is the starting point of EV manufacturing. Likewise, Table 10 shows that the students don't have practical EV manufacturing process experience (Mean = 1.98; S.D = 0.942). This reveals a knowledge gap in the electric vehicle manufacturing process. Therefore, a competency framework on electric vehicle manufacturing will fill this knowledge gap.

d. Critical Awareness of Electric Vehicles Component

Table 11 shows the impact of the student's awareness and knowledge of electric vehicle components. The students, evaluated based on a Five (5) point Likert scale of 5 – Extremely Aware, 4 – Moderately Aware, 3 – Somewhat Aware, 2 – Slightly Aware, and 1 – Not at all aware, have an average awareness level of 3.217 (mean score rating) and standard deviation of 1.3785. However, juxtaposing Table 11 with Table 9 shows that students are conscious of automotive industry events and open-minded to learning new things. Therefore, the developed electric vehicle competency will quickly reverberate among the students and achieve the intended objectives.

e. Knowledge of Electric Vehicle Maintenance

Using a five (5) point Likert scale: 5 – extremely aware, 4 – moderately aware, 3 – somewhat aware, 2 – slightly aware, and 1 – not at all aware, Table 12 shows that the students are somewhat aware of electric vehicle maintenance with a mean score rating of 2.954 and standard deviation of 1.429. Table 12 reveals that with a mean ranking of 3.40 and a standard deviation of 1.432, the student is somewhat aware of electric vehicle maintenance tools, services, and activities. It also shows they are slightly aware of remote diagnostics for electric vehicles, with a mean ranking of 2.71 and a standard deviation of 1.391. The Table suggests a need for maintenance model knowledge for electric vehicles.

f. Self-Assessment of Adaptive Electric Vehicles Skills

Table 13 details the soft and hard skills TVET students possess following a Likert scale of 5 – very high, 4 – high, 3 – moderate, 2 – low, and 1 – very low. Table 13 shows that TVET students possess relatively moderate skills, with an average mean score of 3.726 and a standard deviation of 0.8929. The Table shows that the top three skills are soft skills (teamwork, attention to detail, and problem-solving), and the last three are hard skills (diagnostic Skills, engineering drawing ability, and equipment & engine repair). Table 13 shows that the students possess more soft skills, with an average mean score rating of 4.086 and a standard deviation of 0.7844, than hard skills, with an average mean score rating of 3.125 and a standard deviation of 1.0737. Moreover, considering the skill gap analysis of Adepoju and Aigbavboa (2020), Table 13 shows a high skill gap among TVET students regarding electric vehicles. The high skill gaps are in diagnostics skills, engineering drawings, equipment & engine repair, troubleshooting skills, system design, ICT & mathematical skills, analytical skills, critical thinking skills, leadership skills, and abstract thinking and creativity. Thus, necessitating an electric vehicle competency framework for TVET colleges.

g. Regression Analysis

Given the skill gap among TVET students on Electric vehicles, as shown in Tables 9- 13, there is a need to analyze the effect of foundational knowledge of electric vehicles and adaptive electric vehicles skills on theoretical and practical "understanding" of electric vehicle manufacturing. The Regression model of Table 14 shows that having a foundational knowledge of EV as possessed by TVET students does have a statistically significant effect on acquiring a theoretical and practical knowledge of EV with R = 0.52, Durbin – Watson value of 1.987 and a significant difference of 0.000. The ANOVA Table of Table 15 reveals that the relationship between foundational knowledge and theoretical & practical knowledge is statistically significant. Therefore, Table 14 and Table 15 show that TVET students with a moderate foundational knowledge of electric vehicles will have a high assimilation rate from the theoretical and practical "understanding" of electric vehicles obtained from the competency framework.

Furthermore, the Regression Model of Table 16 reveals that possessing soft and hard skills statistically significantly affects the development of theoretical and practical knowledge of electric vehicles at R = 0.601, Durbin – Watson = 2.181, and a significant difference of 0.000. Table 17 reveals that there is a statistical relationship between having EV adaptive skills and EV theoretical and practical skills for electric vehicle manufacturing. Therefore, there is a need to concentrate on developing hard and soft skills to ensure that students have an adequate understanding of theoretical and practical knowledge of electric vehicle manufacturing. However, Table 18 reveals that developing hard skills in electric vehicles significantly affects theoretical and practical knowledge of EV than soft skills at 0.621 standard coefficients and 0.000 significance difference. Hence, the concentration should be on developing hard skills in the form of technological competence for a thorough understanding of electric vehicle manufacturing.

3.3 TVET Lecturers Interview: Results

To ascertain the level of electric vehicle knowledge and commensurate skills gap amongst TVET learners as facilitated by TVET lecturers, TVET lecturers were sought for interviews. Following Cresswell's (2007) recommendation of three (3) to five (5) interviewees for case studies and the saturation paradigm of Marshall et al. (2015), Four (4) TVET lecturers were interviewed. The lecturers were interviewed virtually using Microsoft Teams. The interviews are analyzed per the research of O'Connor & Gibson (2003) and Lacey & Luff (2007), who opined that analyzing interviews entails transcribing the recorded data into a text, mapping out the responses following the questions, and then charting for recurring themes and interpreting them.

The Lecturers were asked the following questions:

a. Introduction

2. Please describe your background, job title, and current job responsibilities in relation to the automotive industry.
3. What are your views about the state of the Electric Vehicle industry in South Africa?
4. Kindly give your perspective on the need to develop competencies amongst TVET learners for the production & maintenance of electric vehicles in South Africa.

b. Perspectives on Competency for EV in South Africa

1. What are your views about the teachings on EV in TVET College?
2. What can you say about the level of knowledge on EV among TVET College teachers/ lecturers?
3. Does the TVET College curriculum incorporate EV teachings?

c. EV Skill Gap Theoretical Knowledge among TVET Learners

1. What is the knowledge level of TVET Learners on EV Car manufacturing
2. What is the knowledge level of TVET Learners on EV Car components?
3. What is the knowledge level of TVET Learners on EV Machining and fabrication for car production?
4. What is the knowledge level of TVET Learners on installing the electrical and electronic components of Vehicles?
5. What is the knowledge level of TVET Learners on Technical Drawings?
6. What is the knowledge level of TVET Learners on car maintenance, general inspection and fault diagnosis?

d. EV Skill Gap (hard and soft skills) among TVET Learners

1. What are the soft skills that TVET Learners lack?
2. What is the current level of soft skills that they lack?
3. What are the hard skills that TVET Learners lack?
4. What is the current level of hard skills that they lack?
5. What do you think are the drivers of the skill gap on Electric vehicles among TVET Learners

3.4 TVET Lecturers Interview: Analysis of Participant's Responses

3.4.1. Mapping out Responses

a. Respondents Background

Lecturer 1 is a mechanical engineering lecturer who studied mechanical engineering and currently teaches at the highest level of TVET College. He has been in the teaching profession for about ten years. Lecturer 1 teaches courses on motor trade, motor trade fitting, machines, machining, electrical and welding from N 1 - N3. He also teaches mechanical engineering from N4 to N6, including courses on power machines, mechanical techniques, and power-generating systems. Lecturer 2 is an aircraft engineer and an engineering lecturer in one of the TVET colleges, mainly teaching electrical engineering courses, with more than eight years of experience in teaching. Lecturer 2 teaches digital electronics, mathematics, power machines, and thermodynamics power machines. Lecturer 3 is a lecturer and a Registrar for vocational programs, in charge of implementing the TVET curriculum of ministerial programs and training of employees. The fourth lecturer has over twenty (20) years of experience in the automotive industry and has taught for the past eight (8) years at a TVET college.

b. Perspectives on the South African Electric Vehicle Industry

Lecturer 1 opined that the electric vehicle industry in South Africa is still very young, and the challenges of load shedding hamper its adoption, as the country still relies on the internal combustion engine, which will be faded out soon. The lecturer opined thus, "***For us as South Africans, we've been mostly exposed to the internal combustion engines, which is not very far from the electric vehicle. The electric vehicle has a different power source which is currently a problem in the country. Currently, we are having what is called load shedding***". Also, Lecturer 1, viewing the electric vehicle industry from the educational perspective, opined that the academic curriculum does not favour the electric vehicle industry compared to advanced economies, where technology is at the fingertips of the students. The lecturer further stated thus, "***From my point of view, the development of the electric vehicle industry is still slow in South Africa. If you go to countries like the United States or China, technology is at kids' fingertips. If you go to South Africa's government or public schools, you'll observe that it's very difficult for our kids to do basic computer literacy***".

Moreover, in his response to the state of the electric vehicle industry in South Africa, Lecturer 2 opined that the industry is capital-intensive and will require a lot of money to develop. Lecturer 3 stated that the electric vehicle industry in South Africa is at a developing stage in South Africa, saying thus, "***the electric vehicle industry is a developing stage in South Africa***". The lecturer described electric vehicles as the future that will benefit the Republic of South Africa but faces dual issues of obsolete curriculum and electricity issues in South Africa. The Lecturer stated thus, "***I think that's the future. The only disadvantage we have relates to our curriculum offering. Our curriculum is a bit behind in innovation and takes time to review. Otherwise, I see it as something that will be very successful and will improve our economy. Electric vehicles are linked to electricity, which is a problem because the car needs to be charged. But I think through solar energy; they can be charged. So, for me, it's a huge opportunity for South Africa***".

Lecturer 4 opined that South Africa is still at the entry stage compared to European countries and still faces infrastructural issues. The lecturer said, "***Currently, we are just at the entry stage of the EV market. We are very far behind our European counterparts concerning everything regarding EVs. We currently lack the basic infrastructure to cater for EVs at this time. There are a few charging stations around in upmarket areas***".

c. Perspectives on EV-related teaching in TVET Colleges

Lecturer 1 opined that there are no teachings on Electric vehicles in TVET colleges, as the curriculum is focused on internal combustion engines (ICE). However, he opined that a significant lacuna relates to converting the ICE to an Electric vehicle. Lecturer 2 opined that electric vehicle teachings should be incorporated into the TVET curriculum, as there is a lot of research on the subject, but it will need government funding. The lecturer opined thus, "***My view is it should be incorporated into the TVET space, and it would be easier if the government provides the financial muscle. The government is not investing money into the EV space because they are currently investing money in old technology. With EVs, you would be putting money into the future technology*** ". Lecturer 3 opined that EV teachings in TVET colleges are needed, starting from training the staff and the students. However, the lecturer opined that electric vehicle teachings should be introduced into TVET ministerial and occupational programs. The lecturer stated thus, "***Even though we are not offering a program that is designed for EVs, it's something that we have to venture into because it must start with us having the infrastructure and all those things. And also to capacitate the trainers regarding the curriculum concerning electric vehicles. That's the space that I can say we'll be able to implement the electric vehicles project. It's on the more, on the occupational side first, before we take it on the ministerial side***". The Lecturers explained further, "***Some of our students start by doing ministerial programs like the NCV, which is a three-year program. Once they complete them, they go to the occupational field to do artisanship programs to become an electrical engineer, a motor mechanic, and all that stuff. So most students cross and do some occupational programs after they're done with the ministerial***".

d. Need for Electric Vehicle Competency Development for TVET students

Lecturer 1 sees the need to develop EV competencies in TVET Colleges as the world progresses towards that direction, especially as the world focuses on carbon emission reduction. The lecturer opined thus, "***We are forced to move onto electric vehicles because of carbon emissions. We need***

to make sure that in the TVET space, we introduce EV-related courses". Lecturer 2 averred that developing EV competencies for TVET students is a need for the students, which might help reduce unemployment in the future, and also because the world is talking about greenhouse emissions. The Lecturer state thus, "***There is a need for students actually to understand what it is. I think there is a huge need for schools. The biggest thing in the world right now is greenhouse emission reduction. With the current state in South Africa, as far as employment is constrained, it looks like a saviour for their jobs in the future***". Lecturer 3, contributing from the perspectives of renewable energy development, opined that EV competencies should be developed in the TVET system, as the Republic of South Africa is into Renewable energy technology. However, the lecturer cum Registrar recommends that the EV competencies should be introduced into the curriculum through the TVET occupational programs. The lecturer stated thus, "***But on the other side of occupational programs where we are doing, we run some programs and projects through SITAS. There is a faster rate of curriculum innovation in that side. That's the angle where we are making bigger and faster strides towards renewable energy innovation as compared to the other leg of vocational ministerial programs***". To contribute to the Net zero emission goal of the United Nations; Lecturer 4 opined that EV competencies should be introduced to TVET students, stating thus "***There will be a need to train learners in the field of EVs whether it is in the manufacturing process or the maintenance process. If we can introduce it in manufacturing, that could make it more sustainable and affordable to the general public, allowing for zero-emission***".

e. Incorporation of Electric Vehicle teachings in TVET Curriculum

Lecturer 1 opined that the TVET curriculum, even the updated curriculum, currently lacks anything on Electric vehicles except teachings on mechanical engineering. The Lecturer stated thus, "***There is nothing that speaks about electric vehicles in the updated curriculum***". Lecturer 2 opined that the curriculum contains aspects of decentralization for vehicle production but definitely lacks content on the production mechanism of electric vehicles, stating thus, "***Yes, actually, we have information on EVs. It's not in one box; we know the motors and that it has a power control unit. We all know those things; we teach students about converters. We know it has a charge point, but if you put individual components together, it doesn't form an EV. So what is required is technology integration. That is, how do you take the different components***

and make an EV". Lecturer 3 averred that electric vehicle is inferred in the automotive engineering curriculum but is not presented in detail. The lecturer opined thus, "***Like, you know, it is just a general concept in the curriculum, but not detailed. Our curriculum is not aligned with the latest developments. That's why I'm hesitant to say the electric vehicle is fully covered within the offering, even though the contents are there to say if it is an electric vehicle, those are the parts that power the vehicle. For an EV, it's the DC from a battery. These are general concepts that a person who has studied automotive engineering will have a general understanding of. But I think that curriculum needs to be reviewed to go deeper into the mechanism of electric vehicles***". Lecturer 4 opined that the curriculum contains nothing relating to Electric vehicles, stating thus, "***We at this time have nothing related to EVs***".

f. Knowledge Level of TVET Lecturers on Electric Vehicle

Lecturer 1 stated that there is a low level of electric vehicle competency and knowledge among TVET lecturers, ranking their knowledge level a two out of ten, stating that even with short courses, the competency levels are inadequate. In the lecturer's words -"***I would say that on a scale of 1 to 10, I would say that we are at 2. We recently went for a short course at Nelson Mandela University here in PE. Still, it was only a handful of lecturers we had here. Only very few had a clear idea of what was going on with the technology. So there are several courses that lecturers can go to, but they are short courses: five-day courses, three-day courses etc.***". Lecturer 2 opined that even though they teach the various aspect of vehicles and courses in the automotive industry, they still lack understanding on Electric vehicles stating thus - "***As far as EV technology, I don't think any of us understand what makes an electric vehicle, a Tesla electric vehicle***". Lecturer 3 opined that the lecturers possess general knowledge of electric vehicles and residual expertise from what they studied in their university days. The Lecturer's words are as follows "***My understanding is that those trainers, the level of knowledge they have is limited to what they studied. Most of them studied eight to ten years ago. And obviously, there is current knowledge and technology due to the latest developments. I'm saying for lecturers, there will be a need for top-up training in terms of the electric vehicle***". Lecturer 4 opined that the level of knowledge of TVET staff is limited to the training they have gone through on Electric vehicles, which is quite limited.

g. TVET students' knowledge level of General Vehicles and Electric Vehicles

Lecturer 1 opined that the Knowledge level of TVET students on Electric vehicles is deficient and limited to what they get online but not in class. In the lecturer's words – "***to be honest with our syllabus, there is no time to go that far. Our students are only getting an education on EVs from the web, where they are exposed to what is happening in the industry. But their knowledge is only limited to what the internet offers. I don't believe that our students are well equipped when it comes to the manufacturing of the EVs***". Furthermore, Lecturer 1 said that the TVET students have low knowledge about the electrical circuitry on ICE vehicles, stating thus, "***I want to be honest. Their knowledge is shallow on the electrical aspects".***

However, the Lecturer stated that the students have a high knowledge level of internal combustion engine (ICE) vehicles, especially on various machines, assembling and fittings. In the lecturer's words - "***Yes. They understand the fitting. That is another course. They learn a lot about those types of machines. The milling machine and so many others are on the syllabus. But remember that expertise is quite difficult to obtain. They know and understand those machines, but from a theoretical perspective. After the theory, they go for the practical experience where they use what they've learned***."

Lecturer 1 stated that the students understand technical drawings, saying, "***That is a core mechanical engineering skill and its part and parcel of their qualification. They must understand technical drawing as, without the understanding of technical drawing, you can't call yourself an engineer. So drawings form the basics: from N1 to N4, they deal with drawing. So they can draw mechanical components***". In assessing the maintenance competencies of TVET students, Lecturer 1 opined that they have moderate maintenance services knowledge, as they can do basic servicing of vehicles but not major servicing. The lecturer stated thus, " ***they can do minor service on the car; that is part of their curriculum. They can do that, but because of what is happening in our country, I want to be honest, there are problems. I want you to understand the problems that we are having in our country. The workshop is designed to produce a perfect mechanic. However, that is very difficult in our country because these workshops lack equipment and other assets. So it's challenging to clearly state that a student can do major repairs on your car. They can do a minor service. They can change brakes and other minor service items. Still, when it comes to major service, they cannot***". Lecturer 2 affirmed that TVET students do have a low knowledge level about electric vehicles, stating thus - "***I think their knowledge is quite low. They do know it's a car that uses electricity. That's that. They probably know it needs to be charged. Still, not many of them will tell you that it has an electric motor". In assessing their general knowledge of ICE vehicles, Lecturer 2 opined that the student knowledge is quite high, stating thus, "We are in a space where we are surrounded by automobile engine cars. Hence, their knowledge of ICE is quite high***". Lecturer 2 further stated that the students do have high knowledge about technical drawing, saying - "***Some understand electrical technical drawings, and others understand mechanical drawings. So their level of knowledge is high regarding the technical drawings (either mechanical or electrical)***". Also, Lecturer 2 opined that the student has high maintenance knowledge of ICE vehicles but not electric vehicles. The Lecturer stated thus, "***yes, they can service an ICE vehicle. Most of them can conduct mechanical maintenance on any vehicle. But maintenance for EVs, I think that sort is specialized and not many students understand it***". Moreover, Lecturer 3 opined that TVET students do have low knowledge about electric vehicles but have high knowledge about ICE vehicles, as the curriculum is ICE focused. The Lecturer stated thus, "***Technically, they are knowledgeable about manufacturing vehicles from engineering, electrical, and mechanical perspectives. But they don't know about electric vehicles because it's not included in the curriculum. They know just the basics, nothing deep, you know. When our curriculum was developed, the focal points were either persons focusing on the electrical, i.e. the petrol or the diesel engine mechanic or maybe the persons specializing in the auto side of a motor vehicle, i.e. the auto electricians. So the electric vehicle is a new concept, and the curriculum doesn't cover it. It doesn't go into the deepest details of the electric vehicles***". Lecturer 3 scored the students hundred per cent on their knowledge level about maintenance and servicing an ICE vehicle but not that of electric vehicles. The lecturer stated thus, "***When we train students, it's as a motor mechanic who can perform diagnostic maintenance, everything with regards to vehicles that are using fuel. When it comes to EV, our students should be able to distinguish that they don't have the skills. Our students have general maintenance knowledge, but our curriculum does not cover EV maintenance. That is a challenge***".

h. Electric Vehicle Knowledge and Skill Gap Analysis

Lecturer 1 stated that there is a wide skill gap among TVET students on Electric Vehicles, stating thus, "***There is a gap on electric vehicles. The students don't have knowledge on electric vehicles. The lecturers as well. A hundred per cent. There is a wide gap***". Also, Lecturer 1 opined that the students do not have soft skills, as they are not exposed to them from the curriculum. In the lecturer's words, "***They do not have soft skills. They have passion, but they've never been exposed to teamwork. They've never partnered and seen what the other departments are doing as part and parcel of their curriculum. So that gap is there***". However, on the technical and hard skills, Lecturer 1 opined that the students have a moderate level of skills, as it is part of their syllabus, stating thus, "***Yes, the technical skills are part of their syllabus. So they have moderate hard skills, but low soft skills***". Also, on the cause of the skill gap among TVET students, he stated that the factor responsible for this is the old and outdated nature of the curriculum. Lecturer 1 states thus, "***We are currently in the fourth industrial revolution. According to the syllabus given to us by the Department of Higher Education, who are the experts, some of the module contents we are lecturing the students are old. It's not talking to the industry now. The industry includes robotics and is very technical. It also includes Information Technology (IT), programming, etc. I feel that the syllabus needs to be infused with current content for the industry now and not from 20 years ago. Because now we are outdated. I want to be honest. We are outdated when it comes to the content of the syllabus. A new syllabus just came out last year but doesn't include things happening in the industry now***". Lecturer 2 opined that there is a skill gap among TVET students. Regarding soft skills, the students only possessed problem-solving skills but lacked communication, critical thinking, interpersonal skills and teamwork. The lecturer stated thus, "***I think communication is one of the skills lacking. Critical thinking is one of them. I think problem-solving also is just something that they need to be taught a lot. Those will probably be what they can think of in the TVET space. They lack communication skills, critical thinking, interpersonal skills and teamwork***". In assessing the level of hard skills among TVET students, Lecturer 2 opined that the students have moderate and half-built hard skills but lack system design skills. The lecturer stated thus, "***Well, I think at the moment with the way we were teaching them in the TVET space it's sort of someone else who will design. We are there to ensure that when it breaks, they'll fix it. We train them to be artisans; that's what we are moulding them for. They don't have to be able to design anything..... So at the moment, we are teaching kids who will not design a light bulb. We're just teaching them that when the light bulb refuses to come on, go***

and buy another one and you must put it in like this. That's basically what we're doing. We will not break them out of that mould as long as they think that university students will do all their thinking for them". Moreover, on the cause for the wide skill gap among TVET students, Lecturer 2 stated that lecturers are the major cause as they don't know about electric vehicles. The lecturer also stated that an obsolete curriculum is another cause of the EV skill gap among TVET students. Excerpts from the Lecturer are as follows "***I think at the top of the list there are the facilitators, which is to ask the lecturers themselves. If you ask most of them that have been in the industry, you'll probably find only about 20%, 30% of them. Starting from my college, it's me, and it's probably about three of us who were in the industry and came back to teach. And that makes it very difficult, if you are taught by someone who only knows the theory and is teaching you technical stuff, you will not understand more than what they are teaching you.......So on top of that list, the drivers will probably be the lecturers themselves, and from there, the curriculum is not communicating with what already is in the industry. And we are busy teaching old things. If you even look at the curriculum, I teach the students about power machines or electronics; it doesn't talk to what is currently in the industry***". Furthermore, Lecturer 3 averred that there are skill gaps among TVET college students. The lecturer further stated that students have moderate soft skills in how they conduct themselves but lack communication skills, presentation skills, and teamwork, saying thus, "***So it's moderate. I think the presentation skills are moderate; they lack presentation skills and teamwork; no, it might not be that much. Even when they're in workshops, they sometimes work as a team. Still, interpersonal communication is challenging, especially when we get students from a deep background where communication is in the vernacular. So, to some extent, presentation and communication skills are lacking***". Also, the lecturer stated that TVET students have high hard skills because it is part of their curriculum, saying, "***I can say that the hard skills are good. Because it's part of the main curriculum that we train them on. Okay, So technically, they have high hard skills and moderate soft skills***". Lecturer 3 stated that the rigid curriculum and slow pace of reviewing curriculum is the major cause for the EV skill gap among TVET students. The Lecturer stated thus, "***Let me say, rigid curriculum and slow pace of curriculum innovation. Yes, to start training our students in EVs, it must start with reviewing the curriculum where you change, incorporate the electric vehicle modules or bring a course that is a full qualification that speaks to EVs; then, we can start to train students. But the pace of doing that is slow***". Lecturer 4 averred that there is a skill gap in

Electric vehicles among TVET students. He highlighted the following as key gaps: "***The understanding of the entire electrical process, from generation to usage. The calculations required to calculate the power required through the electrical drivetrain regarding the chassis used. The understanding of power management and control of the sub systems***". On assessing the level of soft skills among the students, the Lecturer opined that the students lack certain soft skills that their ready access to the internet can remedy. Also, on the hard skills, the lecturer opined that the students lack certain hard skills. The excerpt from the lecturer is "***Knowing the basic tooling required when working on EVs and the process involved when doing certain jobs. Included will also be the application of using diagnostic tools to solve issues. The biggest aspect will be the safety component, which deals with high AC and DC voltages. Next will be the basics of electricity and basic layout of vehicles***". Lecturer 4 stated that the lack of basic resources to develop EV skills is the major cause of the EV skill gap among TVET students.

3.4.2 Charting out themes and interpretation

The responses from the lecturers' covers have been categorized into the following themes with interpretations: Respondent background, South Africa Electric Vehicle Industry, TVET Colleges' teachings on Electric vehicles, Level of TVET student's skills and knowledge of Electric vehicles, and the Electric vehicle skill and knowledge gap analysis.

a. Respondents Background

The interview survey shows that the respondents have an educational background and qualification in Engineering, focusing on mechanical and electrical engineering. This indicates that the lecturers have adequate foundational knowledge allied to the manufacturing and operation of electric vehicles. Also, the Lecturers have an average of eight (8) years of experience, with thirty (30) plus cumulative experiences in teaching at TVET colleges. Hence, their years of experience show they understand the working dynamics and operational activities of TVET colleges. Also, the TVET lecturers are from different provinces and know about TVET colleges in other provinces, demonstrating balanced answers to questions on TVET colleges. However, most of the TVET lecturers are males, with one female, showing that the engineering profession is dominated mainly by men, confirming the research of Jagacinski (2006).

b. South African Electric Vehicle Industry

The lecturers agree that the electric vehicle industry is at an infant stage which is growing slowly. However, they stated the electric vehicle industry is the industry of the future, and government must make an appreciable investment in the industry. However, all the lecturers lamented the challenges responsible for the industry's slow growth, which are obsolete educational curricula in building the necessary workforce for the industry. To the lecturers, the obsolete school curriculum has enabled the internal combustion engine to grow more than electric vehicles. Another challenge bedevilling the industry is the issue of electricity in charging electric vehicles. The lecturers opined that the energy crisis and load shedding is crippling the industry. Another challenge is the lack of electric vehicle infrastructure and technology. The lecturers lamented the scarcity of EV infrastructure in South Africa, especially the manufacturing and charging station infrastructure. As stated by the lecturers, these challenge points out the need for a drastic reconfiguration of the existing educational curriculum to reflect the future. The lecturers agreed that EVs are the vehicle of the future, and South Africa, as the shining star of Southern Africa, can't be left out. Hence, an Electric vehicle competency framework is needed to guide academics and the industry. Also, the challenges open up a huge investment deficit in the electric vehicle industry, thereby calling for both public and private sector investment.

c. TVET Colleges Teachings on Electric Vehicle

The lecturers citing "Net zero agenda', "Carbon emissions", "Greenhouse gas emissions", and "Renewable Energy" opined that there is a need for the electric vehicle to be incorporated into the TVET educational system. This shows that the lecturers focus on preserving the environment and deeply understand environmental sustainability. Also, it shows the willingness and optimism of the lecturers to inculcate into their teaching philosophy the concept of sustainable development, revealing that they want the educational system of South Africa to be in conformance with global issues. Also, the Lecturers opined that introducing electric vehicles into the TVET system is a means for reducing the unemployment rate in the Republic, as these EV competencies are the competencies for the future. Moreover, the lecturers advocating for a competency framework for Electric vehicles bemoan the obsolete curriculum focused on ICE vehicles, even though they agree that some of the content of the curriculum can be transformed with added competency for electric vehicles. This further buttressed the need for electric vehicle competency frameworks.

d. Level of TVET Students' Knowledge about Electric vehicles

In assessing the level of competency on electric vehicles among themselves, the lecturers opined that TVET lecturers have very low-level knowledge about electric vehicles. They stated that the little knowledge about EVs stems from environmental awareness, residual knowledge from courses in the automotive industry, and short learning courses. These justify the popular statement, "*one can't give what one does not have*". Hence, in assessing the knowledge level of the students, the lecturers opined that the students do not possess any knowledge about electric vehicles except general knowledge of ICE vehicles. The lecturers opined that students understand the general knowledge of vehicles in machining, fittings, assembling, technical drawing, and other mechanical engineering. However, the lecturers said the students possess low electrical engineering knowledge of ICE vehicles. They also opined that the students could perform simple and minor maintenance services for ICE vehicles. These show that the students have foundational knowledge and a fertile mind for understanding teachings on electric vehicles. This shows that TVET colleges lack electric vehicles competencies framework, which the lecturers can use to teach the students.

e. Electric vehicle skills and Knowledge Gap Analysis

The interview with the TVET lecturers and their contributions shows a broad skill and knowledge gap of Electric vehicles among TVET students. These gaps depict knowledge deficiency by the lecturers and the TVET college system. It also shows a lack of collaboration with both industry and organizations in the automotive industry. Furthermore, these skills reflect the educational walk of isolation from other Post School Education and Training (PSET) such as Universities, private institutions, and colleges. The lecturers agreed that the students have a moderate level of hard/ technical skills acquired from the obsolete curriculum and a low level of soft skills. The lecturers opined that the student's level of hard skills is just to know what has already been produced but lack the mental agility in system design and basic manufacturing processability for designing a typical ICE vehicle, let alone electric vehicles. As highlighted by the lecturers, some of the soft skills that TVET students lack are teamwork, programming, communication, critical thinking, interpersonal, and presentation skills. These skills deficiency shows the rigidity in the teaching philosophy of TVET colleges. It prepares the student for working in isolation, without the necessary managerial capability for efficiency and long-term effectiveness.

Moreover, the lecturers identified the causes and drivers of the knowledge and skill gap among TVET students. These include obsolete curriculum, lecturers without knowledge of Electric vehicles knowledge, rigid curriculum, slow pace of curriculum review, and lack of resources to develop Electric vehicles skills. These drivers and causes show that the TVET Directorates in charge of curriculum review are oblivious to global issues, especially regarding technological advancements. It also shows the lack of progress among the TVET College teachers in demanding constant curriculum review. Also, these causes show rigid bureaucratic bottlenecks in the Department of Higher Education and Training (DHET), as lamentations about obsolete curricula have always been but nothing to show. All these suggest a more than Government approach in rejigging the TVET educational curriculum to cater to contemporary automotive industry changes. Also, these causes show the need for pragmatic and transformational leadership at the TVET educational directorate, where necessary financial resources and human resources can be mobilized to make sure students are fit for purpose and for the future. This will undoubtedly benefit environmental, social, and economic sustainability of the Republic of South Africa.

3.5 Industry Focus Group: Results

In developing a competency framework for manufacturing electric vehicles, seven (7) stakeholders in the Automotive industry were engaged in a focus group discussion, following the recommendation of Krueger & Casey (2014), who suggested between five and eight participants as an ideal size for a focus group. The questions of the focus group for the stakeholders are as follows:

a. **Introduction**

1. Please describe your background, job title, and current job responsibilities in relation to the automotive industry.
2. What are your views about the state of the Electric Vehicle industry in South Africa?
3. Kindly give your perspective on the need to develop competencies amongst TVET learners for the production & maintenance of electric vehicles in South Africa.

b. **Required Competencies**

4. What core competencies are necessary to work in the EV Industry for a manufacturing & maintenance role?
5. What do you generally look for amongst students/recent graduates?

6. What educational background is required?
7. What core theoretical knowledge is necessary to have?
8. What practical skills or experiences are necessary to have?
9. Are there any specific personality traits you believe are necessary to have?

c. Perceived Skills Gap

10. What is your current talent shortage, and do you think it also applies to the EV components manufacturing and maintenance
11. What primary skills do you feel most recent graduates lack?
    a. What are the main theoretical knowledge gaps?
    b. Which are the main practical skill gaps?
    c. Are there any skill gaps related to machines or equipment?
    d. Are there generally any soft skills that you feel candidates are lacking?
    e. Have you experienced any other types of skill gaps?
12. What do you believe are the main drivers for these skill gaps?

In analyzing the focus group discussion data, the recording was transcribed in conformance to Rabiee (2004) to generate the necessary themes and achieve the dual objectives of analyzing the skill gap in the industry and mapping out the required competency for manufacturing electric vehicles. The interpretation of the focus group discussion transcribed data was based on the seven criteria framework for focus group interpretation by Rabiee (2004), Kruegar & Casey (2000), and Krueger (1994). These criteria are Consideration of the actual words used and their meaning; consideration of the context; consideration of the frequency and extensiveness of comments; the intensity of the comments; internal consistency; specificity of responses in relation to personal experience; and big ideas. Therefore, the focus group analysis will be based on two approaches: A summary of the participant's responses to the questions; and an interpretation of responses.

A. Summary of Participant's Responses

i. Participants Background

The participant's backgrounds, experiences, and relevancy in the automotive industry and concerning electric vehicle production are summarized in Table 19.

Table 19: Participants' Background

S/N	Gender	Job title	Specialization	Industry
Participant 1	Male	HR Merchant	Training and development of employees. Production of steel bus, car seat frames, etc.	Automotive industry
Participant 2	Female	Skills Transformation	Manufacturing of volta, brake pad, bolts and filters.	Component manufacturing
Participant 3	Female	Future Skills Developer	ESG Skills development	Consulting
Participant 4	Female	Skills Developer	Competency and skills required for the future.	Consulting
Participant 5	Female	Supply chain skills	Supply chain skills development	Automotive
Participant 6	Female	People Management	Management of employees in manufacturing, industrial manufacturing, and Automation.	Consulting
Participant 7	Male	Commercial Activator in the value chain	Sales Management in I.T, Project and Production; Production of Automotive chips, electrical equipment and exhaust exchanger for vehicles.	Phoenix Industries

ii. State of the Electric Vehicle Industry

Furthermore, the participants discussed the state of the electric vehicles industry in South Africa. In giving her perspectives on the electric vehicle industry in South Africa, Participant 6 opined that the electric industry in South Africa focuses on the post-manufacturing aspect of the electric vehicles value chain. Still, more skills are required to ramp up the production of various electric vehicle parts in the country. Participant 4 opined that the electric vehicle industry in South Africa and Africa is lagging behind the rest of the world, even though there is a desire for increased uptake of EVs. The participant further posited the need to prepare for increasing EV demand and develop the prerequisite skill set. The respondent stated thus: "***Basically, I'm saying we need to start creating the readiness for EVs because there would be an uptake of the technology***". Participant 3 posited that the EV industry is an enabler for South Africa to fulfil its commitment to the Net Zero carbon emission by 2050 policy of the United Nations, as the policy can serve as an enabler for producing electric vehicles. In light of this looming target, the participant opined that there is a need to quickly accelerate the necessary skills for manufacturing EVs & her components as the country currently lacks this stating that "***we need to do it quickly so that we can enable the net zero transition***".

Participant 7 opined that the electric vehicle industry in South Africa requires concrete plans and actions. The participant further stated that the industry has a plethora of plans that are yet to be concretised. The participant believes that more work is required to create an enabling environment and supporting infrastructure to ensure EVs are produced in South Africa. The participant further stated that the biggest challenge to the feasibility of a prosperous electric vehicle industry in South Africa is the inability to manufacture EV batteries locally. The participant said thus, "***The best way ahead is to achieve battery manufacturing in this country. We should focus on attracting the best available battery technology and providing the necessary materials, people, skills and machinery to make those batteries***".

iii. Need for Developing Competencies in TVET Students

Participant 4 opined that there is a need for developing competencies for TVET students, suggesting that "***when we look at competencies, we are looking at problem-solving abilities, we are looking at critical thinking skills, we are looking at predictive analytics*. Those are some of the key competencies that we see going forward in the industry**". Also, the participant stated that there is a need for software engineers in the electric vehicle industry alongside the predominant roles of electrical engineers, electronic engineers, and mechanical engineers. The participant opined that there is a huge need for software development competencies. The participant stated thus, "***I need to mention that software developers would play a huge role in the future electric vehicles because the next step is autonomous vehicles, and the key element here is that we will want high-tech software programs in electric vehicles. So, my understanding is that we are looking at software development as one of the core competencies that are required***". Participant 4 says there is a need to break down these roles and determine their competencies to enable the industry to have the required right skills to be relevant and competitive, stating thus: " ***what we need to do then is to break down the roles and determine the skills, abilities, competencies, mindset that are required for each of those roles or professions***" According to Participant 1, there is a need to develop electric vehicle competency for TVET students, with a focus on what skills companies in the industry requires. The participant opined thus, "***we need a pool of people that will also help companies to meet the changing market needs***".

Furthermore, in an exchange of opinions with Participant 7, Participant 1 stated the critical skills and competency needed from TVET students includes welding skills, robotics manufacturing, and innovative skills. In contributing to the discussion and addressing Participant 4 submissions, Participant 7 stated that the competency required for electric vehicles would be battery technologies skills, robotics, battery software, and machine learning. The participant said thus: "***It is important to develop competencies for TVET learners and students. Students need to be focused on building prerequisite technical skills. In addition to that, we also need to introduce them to system thinking because I also hear that we've got robotics, machine learning, artificial intelligence, and whole numbers of technology that need to come together to work effectively***". Also, contributing to the discussion, Participant 5 opined that from experience with TVET students, there is a need to develop their competencies, as what they have is not up to standard, especially basic computer skills, stating thus "….***students need to have the basic computer skills and many require training and exposure to brush up their skills because they are very teachable if I can put it that way***".

iv. Necessary Electric Vehicle Competency Skills

Participant 4 stated that critical thinking skills are needed for electric vehicle manufacturing, stating thus "...***critical thinking skills…. in South Africa we have a deficit in that particular area***". The participant further noted that problem solving is a necessary competency, stating thus "***if we're looking at designs and maintenance of electric vehicles, problem solving ability will have to be quite high on the agenda in terms of the approach that you use to problem solving, how do you actually get to a solution, how do you consider the various scenarios, scenario thinking is actually quite important as well as a subset of problem solving***". Also, Participant 4 opined that there is a need for data analytic competencies, stating thus ***"…the whole element around data analytics, predictive analytics, our interpretation of the data that is coming through all the technology and digitalizing data is something to be benefitting from***". Also, Participant 4 also stated that there is a need to develop business and commercial skills to complement technical skills for the electric vehicle industry saying that "***if you are quite creative, if you are able to optimize cost, if you can produce some commercial viable solutions. Those are some of the skill set industry is looking for out there and that cut across all the various sectors, you know, the commercial acumen, the business acumen needs to complement some of the technical skills as well***". Moreover, Participant 7 opined that some of the essential skills needed in the electric vehicle industry are critical thinking ability, which will stimulate their ability to learn by themselves and be confident, irrespective of their background. Participant 7 also detailed the skills that the TVET student should possess. At the same time, work integration training will do the rest of the training for the student when they are absorbed into an organization. In stating the skills, the participant stated thus, "***To me what I see as important is data analytic skills, communication skills, research or internet skills, to me if that's done, your employer can do the rest in the form of training. However, we need certain things in the industry; we need basic numerical competence and programming skills. I think both are important***".

v. Workplace Competencies required

Participant 7 opined that the competencies required in the workplace are somewhat related to the Electric vehicle competencies, stating thus "…***competency to us will mean communication, basic research and data handling and in terms of the skills we need from them, mechatronic, electrical, mechanical that is still needed, and it would be good to get some information***

technology skills too there as well". Moreover, Participant 6 stated that the workplace competencies needed are interpersonal communication skills stating thus "***we will also look at some interpersonal skills, how you convey messages, the effective means of communication, we talked about the value that is derived from been being a thinker***". Also, Participant 6 opined that there is need to develop flexibility as a competence, in working across various manufacturing plant and understanding diversity in the workplace as it in line with environmental, social and governance (ESG) Agenda, stating thus ***"….you know if we bring the ESG agenda back, it's really around being transparent, being open, sharing information, inclusivity is a very big one as well, you know we have to make sure that we are bringing in together all the diverse background being inclusive with people with different background, Participant 7 also talk about you know the impact that different background have only the work place, it really about making sure they understand the contribution that they are making***". Participant 6 furthered opined that understanding the value chain in the workplace and how they fit in is a competency that will ensure effective performance. The participant opined thus "***when people understand the full value chain, when we starting up with the design process and we go through manufacturing process to the finish product; something people need to understand, what their contribution in that value chain is, how do they fit in? What impact the work is having on the finished product and the commercials of the plant, we find that the more empowered they are with information, the more effective the contribution will be from that particular individual***".

vi. Competencies Required among Graduates

According to Participant 1, the competencies and skills required from graduates do not differ from those applicable to TVET students. These include technical skills, interpersonal skills, critical skills, and the ability to practice what they learned in college. The participant stated thus - "***it is important to ensure that when they get to the workplace, they can practice what they have learnt from the technical institution or TVET college. It's just the technical skills from our side. Interpersonal skills is also one of the critical skills that you need because if one cannot correlate or interact with superiors and subordinate then it becomes a problem, especially in design areas whereby there is high level of expectation on precision, accuracy and all that, those are the two skills I will mention from my side".*** According to Participant 3, a major competence that is needed from graduates is resilience, stating that ***"I think one of the key skills that we see that is very***

important, that hasn't been raised is that of resilience. As we move into the future world, that is one of the pivotal skills we need. To bounce back from a difficult situation, to be able to learn, keep trying, to be able to win things the right way, to perfect, to change, this is an enabling skill across all industries, so I think I will add that to the list". Also, Participant 5 emphasized that technical skills are most needed among graduates, followed by teamwork, in working with people from different spaces. The participant opined thus "***one thing we are finding out is that when these graduates come into the work place, they might have the technical ability. Still, they really struggle in terms of leading people and collaborating as a team*** ". Also, Participant 5 stated that presentation skills and adaptive capability are needed among graduates, stating, "***And we also found that graduates needed to be able to stand before a room and present to people at the more senior level. So I will also add presentation skills, and you know, the use of computer packages, data collection, and analyzing of the data, which we have now incorporated into our graduate program. And also on the important skills these graduates need to function in the department and be part of the department***".

vii. Electric Vehicle Skill Gap Analysis among TVET Students

According to Participant 4, there is a noticeable skill gap among graduates, even TVET graduates, but this can be appropriately determined during workplace integration training in the various department to see the level of the gap. The participant stated thus, "***we have a foundation program where we employ graduates in the program. These individuals are qualified and have either a basic or an undergraduate degree but have no opportunity for work experience. All I can say is that during the year or the 18 months that they spend on the program, they go through to various departments like the customer support department, operations department, finance, HR, etc. What we do is to have this structured program where the student spends time with the various teams. Through these, you can see where their passions lie, how they can apply themselves and what contribution we can expect*** ". According to Participant 7, current skills from TVET students are inadequate, suggesting a wide skill gap. The participant stated thus, "***Regarding TVET, what we know is, the current skills we are getting from TVET Colleges are inadequate for the current dispensation. We rely heavily on automotive learning academies or apprenticeships, so we do not have a position where we place fresh TVET graduates. When they come to us, we retrain them, and in two years' time, we base our employment decision on the two years of training we***

have given them". However, participant 7 further opined that there is a need for TVET students to have the necessary workplace competencies, such as workplace readiness skills, so that work integration in retraining TVET students can be easy and efficient.

viii. Factors Driving Electric Vehicle Industry Skill Gap

Participant 1 opined that changes in the business environment are driving the skill gap, stating thus: "***I will say this is driven by changing demands expected from human resources. There is the urgent need for the business to adapt and simultaneously develop people to be able to keep the business running now and in the future***". Participant 3 opined that Technological changes in the world are driving the skill gap, saying, "***I also think it is just the upgrade of technology, how the world is changing, the French president once said that change has never been as fast and will never be this slow again***". Participant 5 agrees that technological changes are driving skill gap in the industry and among students, stating "***I agree with the statement on technological changes. The fast-changing world of technology like robotics is disrupting current processes both now and in the future***". Also, Participant 4 opined that lack of collaboration is driving skill gap and allowing technical problems to fester. He stated thus " ***when we work in isolation, we bring about the biggest challenges. Today was incredibly powerful because it is really about partnerships, collaboration, getting the right stakeholders and the right call, and providing various input. Even in the very simple discussion today, I picked up a really sterling thing I wouldn't have realized: challenges for our students. So I think that the more we collaborate, the more we come together, the more power we will have to make positive contributions***". Participant 7 agreed with everyone and suggested that adding workplace integration into the curriculum for the student will bridge the skill gap, saying that " ***I think there is a need for work place integration to be part of the curriculum***".

3.6 Industry Focus Group: Analysis of Participant's Responses

a. Participants' Background in the Automotive Industry

Table 19 shows that all seven (7) participants in the focus group discussion work within the automotive industry and consulting for automotive organizations. It also indicates that the participant falls into four (4) categories: human resource manager, skill developer, supply chain manager, and manufacturer. Also, the gender categorization of the participant shows that there are five females and two males, reflecting that the skills development discourse is mostly dominated by women, confirming the research of Reichel et al. (2020). Furthermore, Human resources is a specialization that women traditionally dominate, whilst Ainsworth & Pekarek (2021) opined thus "*it is perceived matching women's stereotypically assumed talents of dealing with people and showing a concern for others*". Also, Table 19 revealed that most participants are engaged in the automotive industry. Therefore, the choice of the participants aligns with the criteria for choosing participants for the focus group, as noted by Rabiee (2004); given their experience, relevance to the subject matters, and willingness to discuss with each other and share similar socio-characteristics, as all of them are within the South African Automotive industry.

b. State of South Africa Electric Vehicle

According to the respondents' perspectives, the South African electric vehicle industry is developing. However, like the rest of Africa, it is still behind compared to advancements in other countries. Furthermore, the participant highlighted that the electric vehicle industry in the country is mostly into producing components but not manufacturing vehicles. This means the electric vehicles industry imports and assembles electric vehicles in South Africa instead of manufacturing them. The participants noted that in line with the United Nations Net Zero policy, the required competency for manufacturing is needed. That is, emphasis should be placed on the manufacturing process and activities, not just on pre-production components and post-production activities. They noted that emphasis should be placed on the electric vehicles' battery technology, which differentiates the vehicles from internal combustion engine vehicles. Therefore, from the focus group discussion, participants believe that for the growth of the electric vehicle industry in South Africa, there is a need to develop the necessary competencies across a typical electric vehicle. This aligns with the analysis of Daniel (2022) that the South African Government is focusing on producing electric vehicle components and possibly on the manufacturing of electric vehicles as stated in the DTIC Auto Green Paper of the Government. According to (Daniel, 2022), the government plans to reduce the ad valorem tax and eliminate the 25% import duties on the components for electric vehicles, which is higher than the 18% import duties for the internal combustion engine. This will allow a local manufacturer of ICE vehicles to produce Electric Vehicles. Therefore, as a complement to the government’s policy on electric vehicles, there is a need to develop the needed competencies required for manufacturing among TVET students.

c. Electric Vehicle Competencies for TVET Students

Based on their knowledge level and years of experience in the automotive industry, the participants highlighted various competencies and skills that need to be developed among TVET students regarding workplace skills, electric vehicle competencies and expected graduate skills. The focus group discussion raised forty-three (43) competencies and skill sets needed for producing electric vehicles in South Africa. These skills are highlighted in Table 20. The Table shows that the participants want technologically oriented and managerial skills, whereby the TVET students can function in any EV organization. It also emphasized the need to be a sound and brilliant student in understanding the different courses taught in class, mostly engineering. These competencies and skills proffered by participants from the focus group discussion align with competencies developed by Howard et al. (2021); High Gear (2020) for the automotive industry; Jerman et al. (2020); INCOSE (2015); International Labor Organization (2007); Le Deist & Winterton (2005); Zahiraldinni (2000); and Ellstrom (1998).

Table 20: Electric Vehicles Competencies and Skills

Electric Vehicle Competencies	**Workplace skills**	**Expected Skills from Graduates**
Manufacturing skills	Problem-solving skills	Communication skills
Understanding Electric vehicle infrastructure	Critical thinking skill	Research skill
Battery Technology	Market competitive skill	Basic Hand skill
Problem-solving skills	Teamwork	Adaptability
Predictive analysis	Scenario thinking	Critical thinking
Software Engineering competencies	Data Analytics	Presentation skill
Electrical & Electronic Engineering competencies	Predictive analysis	Interpersonal skills
Mechatronic Engineering competencies	Creativity	Work integration ability
Chemical Engineering competencies	Cost management	

General competency for the automotive industry	Business acumen	
Robotic technology	Commercial skill	
System thinking	Understanding value chain	
Machine Learning	Flexibility & Diversity	
Artificial Intelligence	Resilience ability	
Computer skills	Openness and Inclusivity	
Predictive analysis	Communication skills	
Programming skills	Workplace readiness skills	
Basic EV technical skills		

d. Electric Vehicle Skill and Knowledge Gap

The participants all agreed that there is a skill and knowledge gap among TVET students regarding manufacturing Electric Vehicles, stating that the current skills and competencies delivered by TVET colleges are inadequate. In discussing the skill and knowledge gap, the participants noted that this gap has resulted in unnecessary training and work integration. They agreed that some competencies need to be developed before coming into an EV organization, which will aid and reduce the period of work integration. To the participants, retraining and graduate training program shows a competence mismatch between what is taught in colleges and what is obtainable in the industry (workplace). Therefore, the curriculum should be rejigged with necessary electric vehicle manufacturing competencies and skills to make entry easy, effective, and rewarding for the recipient organization. Also, the focus group noted that competencies issues with TVET graduates are not the same as University and College graduates, showing a lacuna in teaching philosophy, TVET college structure, and synchronization of curriculum offerings and industry needs. Therefore a developed competency framework for Electric Vehicle manufacturing will close the skill and knowledge gap, restructure TVET College's teaching philosophy, rejigged TVET college curriculum, reskill TVET students, and repurpose the students for easy entry into the Electric vehicle industry.

e. Factors Driving EV Skill Gap

In concluding the focus group discussion, the participants highlighted factors driving the electric vehicle skill Gap. These are a competitive nature and changing dynamics of business, rapid technological advancements, lack of collaborations, poor stakeholder management, and lack of workplace integration into the curriculum. These factors reflect the dichotomy between educational stakeholders and industry stakeholders. It shows poor preparation for adapting the curriculum to changes in the business and technological world. It also reveals a lack of exposure or underexposure of TVET students to the industry. In other words, internships in TVET colleges should be with organizations that are abreast with modern technological advances and can adapt rapidly to these changes, thus reflecting poorly on the students.

4.0 Electric Vehicle Competency Framework

4.1 Framework Development Overview

In developing a competency Framework for Electric Vehicle manufacturing, operation, and maintenance for TVET students, a quantitative survey was done to ascertain the knowledge level of the students. Also, through qualitative research methods, lecturers from different TVET colleges were interviewed, and stakeholders in the automotive industry were engaged using a focus group discussion. The student survey analysis showed that the TVET students have a moderate foundational knowledge of electric vehicles, insufficient theoretical and practical knowledge (understanding) of electric vehicles, and inadequate knowledge of electric vehicle maintenance. Also, the student survey shows that there are high skill gaps among the students in the following EV adaptive skills: diagnostics skills, engineering drawings, equipment & engine repair, trouble shooting skills, system design, ICT & mathematical skills, analytical skills, critical thinking skills, leadership skills, and abstract thinking and creativity.

Moreover, the interview survey analysis from TVET lecturers confirms the high skill gaps and poor knowledge level about electric vehicles among TVET students, emphasizing the obsolete curriculum as the driver. The skill gaps are system design, basic manufacturing skills, teamwork, programming skills, communication skills, critical thinking skills, interpersonal skills, and presentation skills. Furthermore, the stakeholders from the automotive industry confirm the knowledge and skill gaps of electric vehicles in the TVET educational system based on their interaction with TVET graduates. The stakeholders recommended forty-three (43) Electric vehicle competencies and skills for TVET students, which covers the skills identified by the lecturers and the students.

Consequently, the TVET lecturers and the industry stakeholders opined that the electric vehicles industry in South Africa is at a growing stage that needs a rejigged curriculum for TVET students from an Electric Vehicle competencies framework, which will repurpose TVET students for the future of work in the automotive industry and also for the development of the industry. This will undoubtedly address the knowledge and skill gap drivers the TVET lecturers and stakeholders raised. Also, a competency framework will aid TVET students in understanding both the practical and theoretical knowledge of Electric vehicles as suggested by the regression models.

Therefore, from the perspectives of the TVET student's needs, the concern of the TVET lecturers, the recommendation of the automotive industry stakeholders, and a comprehensive systematic and bibliometric literature review, the Electric Vehicle Competency framework is grouped into two: Technology - Integrated Competency Model and Managerial Competency Model. This is diagrammatically shown in Figure 6, followed by a concise explanation of each of the constructs of the framework.

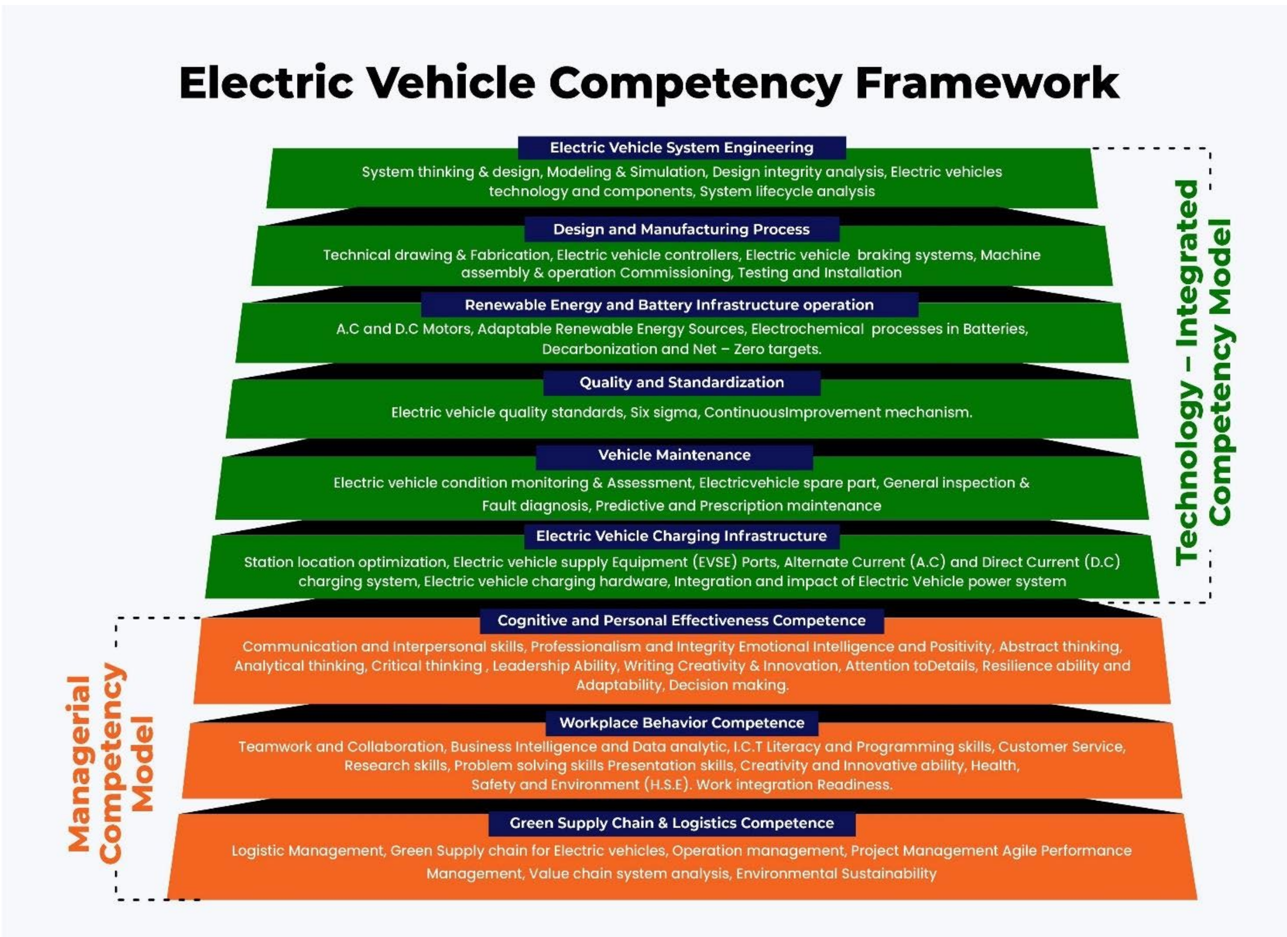

Figure 6: Electric Vehicle Competency Framework

4.2 Constructs of Electric Vehicle Competence Framework

A. TECHNOLOGY – INTEGRATED COMPETENCY MODEL

These are the technical know-how competencies that TVET students should know and understand in both theory and practical for the production of Electric Vehicles.

1. Electric Vehicle System Engineering

According to the International Council on Systems Engineering (INCOSE), system engineering is an interdisciplinary approach that promotes team efficiency and aids the success of systems, thereby forming a structured development process that starts from concept to production to operation. According to the council, system engineering defines the need of a customer, the needed functionality in a product development cycle, documenting requirements, and engaging in design synthesis & system validation, with consideration to costs & schedule, performance, test, manufacturing, training & support, operation and integration of different systems of a product over their lifestyles, whilst the system is the combination of product, people, and processes that provide a capacity or solution to solve a need or achieve an objective.

Consequently, in-depth knowledge of system engineering involved in automotive manufacturing and battery storage system makes production possible for the production of electric vehicles. This also entails understanding the dynamics in the lifecycle of electric vehicles, which encompasses electric vehicle technologies, infrastructure dependencies, energy management & control, customer usage patterns, and electric vehicle system modelling. Therefore, the entire lifecycle systems, processes, and technologies needed for electric vehicle production must be understood, and the knowledge of their integrative approach is system engineering.

However, in developing competencies for electric vehicle system engineering, based on Electric Vehicle stakeholders, students must understand these five aspects: system thinking & design, modelling & simulation, design integrity analysis, electric vehicle technology & components, and system lifecycle analysis.

a. **System Thinking & Design:** This entails envisioning and visualizing the system within an environment, its boundaries and interfaces, and its lifecycle. Hence, for electric vehicle production, the student must understand the system lifecycle of an electric vehicle, the hierarchy of systems, system contexts, the various interfaces, and the interactions among all the systems. Succinctly, the student must understand all the fundamental and internal components of an electric vehicle, its functionality, interfaces, lifecycle of each component, and working mechanism with other components. This will develop the system thinking needed for EVs and understand the various designs forming the electric vehicles' foundation. Generally, understanding these multiple systems and processes of EV components aids in analyzing problems that may arise from them and how to design an EV. This also brings into perspective the need of the customer based on the various interactions of the EV systems; the student can envisage the need of an EV user.

b. **Modelling & Simulation:** This is the process of using data generated by a given system to make informed decisions and predictions about the systems. According to Shannon (1992), modelling & simulation is "*the process of designing a model of a conceptual system and using it to conduct experiments to understand the performance of the system and/or evaluate alternatives management strategies and decision-making process using simulation results*". Hence, knowledge about EV components can be processed into data, modelled, and simulated into various outcomes and options to make informed decisions. According to Yin & McKay (2018), modelling & simulation aid in understanding real world systems, thus bridging the gap between model design & development and verification & validation. Furthermore, the authors opined that modelling and simulation procedure entails the following: Define research problem, specifying the purpose, collecting data & information, building up a conceptual model, selecting the simulation method, choosing the simulation tool, developing the simulation model, conducting verification experiments, verify the simulation model, conduct validation experiments, validate the simulation model, simulation experiment and documentations. However, considering the educational context of modelling & simulation for TVET students, Brigas (2019) opined that model and simulation "*can provide alternative collaborative and interactive environments that foster personal discovery and help students to act and think, assuming the role of researcher, allowing them to build their own knowledge*". Brigas(2019) further opined that simulation and modelling aid the development of skills such as decision-making, reflection, generalization, and creativity.

   Moreover, Miller (2021) opined that software such as MATLAB, Simulink, and Simscape aid in modelling and simulation for electric vehicles in the following areas:

   i. **Exploring Electric Power Train Architectures:** the options and tradeoffs in selecting the right architecture for an electric vehicle are somewhat challenging in terms of electrical motors, battery cooling systems, sources of power and combustion engine, which must then be evaluated according to performance, acceleration, range & price, thus requiring simulations. This can be done using SimScape software.

ii. **Tune Regenerative Braking Algorithms**: To maximize the efficiency of electric vehicles in recapturing kinetic energy and storing them in battery, there is a need for alignment of the powers converters, driveline, and battery design within battery management algorithm. Hence, simulation aids in understanding and balancing requirements for optimal passenger comfort & safety and maximization of the range of the vehicle.

iii. **Modification of Suspension Design**: This entails managing the tradeoffs between vehicle handling and passenger comfort, which depends on parameters such as bushing stiffness, hard point locations, and spring rates. This can be done using MATLAB simulation and models.

iv. **Optimization of Vehicle Level Performance:** Simulation and modelling is needed for the performance of independently developed systems of electric vehicles. This is because different engineering areas handle different systems in a typical electric vehicle. For example, control engineers develop braking system algorithms, and hydraulics engineers develop valves, master cylinder, and pumps. Engineers and manufacturers are responsible for designing electrical motors and mechanical drive trains. Thus, the integration and efficiency of integration require simulation and modelling. Also, in ensuring optimal vehicle performance, simulation verifies that battery capacity, brake caliper pressure, and motor power requirement are in ranges that permit smooth deceleration and acceleration.

v. **Development of Active Chassis controls:** Simulation aids in testing and modelling different safety features, fault tolerance or physical conditions of icy surfaces or poorly loaded trailers using chassis control algorithms like torque vectoring, anti – lock braking, and electronic stability.

vi. **Validate ADAS Algorithms**: The ADAS algorithm aids in modelling and simulating the safety requirements of passengers, especially through harsh steering and braking manoeuvres. Miller (2021) explained thus: "*you can model passengers as 3D mechanical humanoids with joints and instrument them with accelerators to capture the acceleration and jerk that passengers feel as the vehicles move through a manoeuvre guided by an ADAS algorithm. You can then post-process the accelerator data in MATLAB to derive an index of discomfort*".

vii. **Test using Hardware – in – the – Loop:** According to t Miller (2021) using Simscape model in Hardware – in – the – loop enables the testing of the embedded control unit, both hardware and software, in real-time simulation considering worst-case scenarios such as short–circuited electrical networks and overheated batteries.

c. **Design integrity Analysis:** According to Stapelberg (2009), this entails the integrity of engineering designs, which must be analyzed comprehensively for a marketable, comfortable and need – based electric vehicle. The design integrity entails analyzing the design criteria for reliability, availability, maintainability, and safety of various systems, otherwise known as RAMS analysis. According to FSES (2019), RAMS analysis used in design integrity is a decision-making tool that increases a system's availability, reduces the system lifecycle costs and increases its overall profit. This explanation conforms to ByHon (2021) that RAMS analysis ensures that a process, product or system fulfils the objectives it was designed to meet under the conditions of Reliability, Maintainability, Availability and well-defined Safety. RAMS is briefly defined as follows:

   i. **Reliability:** This is the amount of time that a product or design is available to response in accordance with a demand placed on it. That is the measure of how the performance of a design/ device will remain unchanged over a specific period. This can be done using fault tree analysis (FTA) and Reliability Block Diagrams (RBD).

   ii. **Availability**: This is the fraction of the time an item or design has not failed but is available when demanded.

   iii. **Maintenance** includes active and reactive maintenance of a system to ensure the reliability and availability of a system or product.

   iv. **Safety**: this entails avoiding an unacceptable risk using risk analysis techniques such as HAZOP (Hazard and operability analysis), LOPA (Layer of Protection analysis), and PHA (Process Hazard analysis).

d. **Electric Vehicles Technology and Components:** understanding the various components and technology for electric vehicles makes system engineering easy. The components of electric vehicles include electric traction motor, power electronics controller, DC/AC controller, thermal system, reduction gear, auxiliary battery, battery management system, onboard charger, transmission, charging port, and traction battery pack. They are explained thus:

   i. **Electric motor** converts electric energy into kinetic energy, which also minimizes noise and vibrations, thus making the electric vehicle quiet and comfortable, unlike internal combustion engine vehicles.

ii. **Reduction gear:** it is a kind of transmission that reduces the revolution per minute (RPM) to an appropriate level, which conveys the motor's power to the wheel, and the EV power train takes advantage of higher torque.

iii. **Battery:** This is the storage of electrical energy, similar to a fuel tank of an internal combustion engine vehicle. However, the higher the capacity of a battery of an electric vehicle, the higher the distance it can cover.

iv. **Battery Management System (BMS):** This manages the hundreds of mini cells of an electric vehicle's battery.

v. **On board charger:** This is used to convert alternating current (AC) from portable chargers or slow chargers into direct current (DC).

vi. **Electric Power Control Unit (EPCU):** This comprises of all the devices that controls electric power in electric vehicles, which includes inverters (used to convert battery DC into AC and regulate motor speed), low voltage DC–DC converter (conversion of high voltage electricity from high voltage battery of an electric vehicle to low voltage, then supplies it to the electronic system inside the electric vehicle); and vehicle control unit (this overseas the electric vehicle power control mechanisms such as the regenerative braking control, A/C load management, motor control, and power supply for electronic systems).

vii. **Charge port**: it connects the electric vehicle to an external supply, thus changing the battery pack.

viii. **Auxiliary Batteries**: This is a source of electrical energy for accessories of an electric vehicle which charges the car in the absence of the main car, and prevents voltage drop.

ix. **Thermal System cooling:** it ensures the maintenance of an operating temperature for components of an electric vehicle.

e. **System Lifecycle Analysis**: this entails a comprehensive evaluation of the lifecycle of each system that would make up the electric vehicle. This describes the inputs, outputs, procedures, materials, resources, and requirements from the beginning to the end. This is also known as the system development life cycle (SDLC), which includes the following phases:

i. Planning: Obtaining the approval for the system, and factoring system requirements, design, implementations, testing, deployment, operation and maintenance.

ii. Analysis: This entails understanding the business needs and processing needs of the system or product.

iii. Design: this is the system's solution or representation based on analysis and system requirements.
iv. Implementation entails executing the design, constructing the product, and testing it.
v. Maintenance: This is constantly checking the systems' performance to keep it healthy for a purpose.

2. Design and Manufacturing Process

This aspect of the Technology – integrated competency model entails bringing to life the result of the system engineering for electric vehicles. This involves designing the various parts and components needed for electric vehicles and manufacturing them. Hence, for TVET students, this entails understanding technical drawing & fabrication, electric vehicle controllers, electric vehicle braking systems, machine assembly & operation, commissioning, testing and installations. These are explained below:

a. **Technical Drawing & Fabrication:** This is a two-dimensional approach with a technical drawing before fabrication. Fabrication entails manufacturing a product's components by combining different other parts using a standardized method or process. For instance, fabricating the door of an electric vehicle encompasses bringing together different parts or materials. However, before fabricating the door, there must have been technical drawings to envisage how it would look and fit with other components. Technical drawing is a diagram conveying information about components, objects, or products.
b. **Electric Vehicle Controllers**: This is an electric package with batteries and an electric motor that controls the acceleration and speed of an electric vehicle. Like other EV components, developing competency for EV production requires knowledge about designing and manufacturing the components or about assembling the different parts of the EV components. For instance, an EV controller is made up of key switch operation, electromagnetic holding brake, adjustable command ramping, adjustable dead band, forward/ reverse input with push features, speed limit input, selectable throttle command inputs, standard & vehicle specific I/O for over 60 events and signal, compact, rugged & vehicle mount designer, watertight access panel for drive configuration & setup, and selectable modes of operation (Electromate, 2023).

c. **Electric Vehicle braking systems:** The braking system used in electric vehicles is called regenerative braking. It slows down a car, but most importantly, captures 70% of kinetic energy from braking and converts it to electrical energy, which then charges the vehicle's high voltage battery. In understanding the dynamics of electric vehicles, the student must understand the working dynamics of the regenerative braking system for Electric vehicles, which can only be learned by knowing the brakes' design and manufacturing process. The regenerative braking system includes the following component: brake drum, hydraulic pump/ motor, friction lining, controller, electric generator (DC Motor), and linking mechanism (Gyanesh, 2022).

d. **Machine Assembly & Operation:** This aspect of the competency model buttresses the fact that to know how electric vehicles can be produced, one must understand how to assemble and operate machines. Assembly machines involve mechatronics systems, which assemble fabricated parts/components. Hence, a student must know the maintenance routines of different assembly machines, learn how to set up devices, replace damaged or worn tools in the machines, know how to set up a job, that is component for assembly, and knows the following operation of machine assembly: planning, parallel cutting, knurling, slottry, drilling, cutting flats, and non – precision surface grinding operations. Also, the operation of the following machine assembly must be understood: Mills, Lathes, Planers, Radial arm drills, Shapers, Surface Grinder, and Slotters.

e. **Commissioning, Testing and Installations**: These are three manufacturing processes executed after a product has been manufactured. It starts with the commissioning process, which entails engineering procedures to check and inspect the product's functionality and its individual system. This is followed up by testing, which in manufacturing is called functional testing (FCT), the final quality control test and ensures all necessary functions of the manufactured product are carried out and perfected. The final stage is the installation of the manufactured product, which entails the utilization of the product, which in this case is the utilization of the electric vehicle manufactured.

3. Quality and Standardization

This aspect entails the qualities and standards needed to produce environmentally sustainable and socially acceptable electric vehicles. They are usually in the form of requirements, guidelines, characteristics or specifications. That is, students of TVET should understand the quality requirements and standards to be met in producing the different components of electric vehicles. According to the American Society for Quality, the objectives of quality standards are as follows: satisfaction of customer quality requirements, ensuring safe products & services, compliance with regulations, meeting environmental objectives, protecting products against climatic or other adverse conditions, and ensuring that internal processes are defined and controlled. Furthermore, understanding standards and quality aids in designing different types of electric vehicles for different customers and uses.

Therefore, in understanding the standards and quality set for the electric vehicle, students should digest these three aspect model for this competency framework: Electric Vehicle Quality Standards, Six Sigma process, and continuous improvement mechanism:

a. **Electric Vehicle Quality Standards:** According to Arrow Electronics (2023), quality standards for electric vehicles are in four areas with relevant organizations: International organizations for standardization (ISO) codes, the Electrotechnical commission (IEC) standards, the Society for Automotive Engineers (SAE), and the South African Bureau of Standards (SABS). The areas are:

    i. **Safety and Security Standards:** These standards cover privacy, occupant injury prevention, information management, installation, and insulation against electric shock. This is shown in Table 21.

Table 21: EV safety and standards

Standard Name	Description
ISO/ IEC 27000	Provision of best practice recommendations on information security management, including confidentiality, privacy, confidentiality, and IT/ Technical/ Cyber security issues.
ISO 6469	These standards cover persons' protection against electrical hazards, functional safety against failures, and onboard electrical energy storage.
IEC 60364 – 7 – 722	Low-voltage electrical installations

SAE J1766	Ensures adequate barriers between users and the battery system to protect from potentially harmful materials and factors within the battery system that can injure occupants during a crash.
ISO 17409	Safety requirements for conducive connection of EVs to external electric circuits.
IEC 61140	Protection against electric shock
IEC 62040	Uninterruptible Power systems (UPS)
IEC 60529	Degrees of protection by enclosures (IP Code)

ii. **Connectors Standards:** These standards ensure a conducive charging system architecture for electric vehicles, including operational, functional, and dimensional requirements. Across different models and geographic, the standards are the SAE International SAE J1772 (IEC 62196 Type 1), covering the electrical, physical and communication protocol. The Japanese CHArge de MoVe (CHA de Mo) and China's GB/T Technology among others.

iii. **Communication standards:** these are standards for charging stations with electric vehicles for the vehicle to communicate with the charging point management systems (CPMS), enabling a seamless end–to–end charging process. The standards are shown in Table 22. Table 22 also contains new standards for electric vehicles in South Africa under the newly revised South African Bureau of Standards (SABS) posited by the Department of Trade, Industry and Competition, gazetted in Notice 1367 of 2022, Standards Act, 2008, with standard codes as SANS.

Table 22: EV Communication standards

Standard Name	Description
ISO/ IEC 15118	Communication interface for bi-directional charging/ discharging of electric vehicles
SAE J2847	Communication between plug-in vehicles and off-board DC Charger
IEC 61851-24	Digital communication between a DC electric vehicle charging station and an electric vehicle for control of DC Charging.

SAE J2931	Security requirements for digital communication between the electric vehicles supply equipment (EVSE) and Advanced metering Infrastructure (AM) utility ESI and/ or Home Area Network (HAN).
IEC 61850	Communication networks and systems for power utility automation
SANS 15118-3	Vehicles to grid communication interface – Part 3: Physical and data link layer requirements. This standard specifies the physical and data link layer requirement for high-level communication of electric vehicles, mostly between battery electric vehicles (BEV) or plug–in hybrid electric vehicles (PHEV). This communication is based on the electrical installation of electric vehicle supply equipment (EVSE) and wired communication technology.
SANS 15118-4	Road vehicles – vehicle to grid communication interface – Part 4: Network and application protocol conformance test. This standard is about conforming to the Abstract Test Suite (ATS) for a System Under Test (SUT), thus implementing an EVCC or SECC following ISO 15118-2

iv. EV charging standards: these standards cover charging topologies for electric vehicles, which are described in IEC 61851.

Furthermore, the US National Renewable Energy laboratory codes and standards for electric vehicles according to different areas are shown in Table 23.

Table 23: General EV standardization code

Areas	Standards	Description
Vehicle Systems	SAE J – 1634	Electric vehicle energy consumption and Range test
	SAE J – 1711	Recommended practice for measuring the exhaust emissions and fuel economy of Hybrid electric vehicle

	SAE J – 1715	Hybrid electric vehicles and electric vehicle terminology
	SAE J – 2344	Guidelines for electric vehicle safety
	SAE J – 2464	Electric and hybrid electric vehicle recharge energy storage system (RESS)) safety and abuse testing.
	SAE J – 2711	Recommended practice for measuring fuel economy and emissions of hybrid electric and conventional heavy-duty vehicles.
	SAE J – 2758	Determination of the maximum available power from a rechargeable energy storage system on a hybrid electric vehicle.
	SAE – J – 28899	Measurement of minimum sound levels of passenger vehicles.
	SAE J – 2894	Part 1: power quality requirement for plug-in vehicle chargers requirements
	SAE J – 2894	Part 2: Power quality requirements for plug-in vehicle chargers – Test methods
	SAE J – 2907	Power rating method for automotive electric propulsion motor and power electronics sub – system
	SAE J – 2908	Power rating method for Hybrid electric and battery electric vehicle propulsion
	ISO/FDIS 6469-1:2009 (E)	Electrically propelled road vehicles – safety specification Part 2: Vehicle operational safety means and protection against failures.
	ISO/ CD 6469-33	Electrically propelled road vehicles – safety specifications. Part 3: protection of persons against electric shock

	ISO/WD 23274-2	Hybrid electric road vehicles – Exhaust emissions and fuel consumption measurements Part 2: externally chargeable vehicles.
Batteries	SAE J – 1766	Recommended practice for electric and hybrid electric vehicle battery system crash integrity testing.
	SAE J – 1797	Recommended practice for packaging of electric vehicles battery modules.
	SAE J – 1798	Recommended practice for performance rating of electric vehicle battery modules
	SAE J – 2288	Lifecycle testing of electric vehicle battery modules.
	SAE J – 2289	Electric drive battery pack system: functional guidelines
	SAE J – 2380	Vibration testing of electric vehicle batteries
	ISO/ CD 12405-1	Electrically propelled road vehicles – test specification for Lithium–ion traction battery packs and systems – Part 1 "High Power Applications".
Interface	SAE J – 1772	SAE electric vehicle conducive charge coupler
	SAE J – 1773	SAE electric vehicle inductively coupled charging
	SAE J – 1850	Class B data communications network interface
	SAE J – 2293	Part 2: Energy transfer system for EV part 2: Communications requirements and network architecture.
	SAE J – 2836	Part 1: use cases for communications between plug–in vehicles and the utility grid.
	SAE J – 2836	Part 2: use cases for communications between plug – in vehicles and the supply equipment (EVSE).

	SAE J – 2836	Part 3: use cases for communication between plug – in vehicles and the utility grid for reverse flow.
	SAE J – 2847	Part 1: Communications between plug–in vehicles and the utility grid.
	SAE J – 2847	Part 2: Communications between plug–in vehicles and the supply equipment (EVSE).
	SAE J – 2847	Part 3: Communications between plug–in vehicles and the utility grid for reverse power flow.
Infrastructure	SAE J – 2293	Part 1: Energy transfer system for EV part 1: functional requirements and System Architecture.
	SAE J – 2841	Utility factor definitions for plug–in hybrid electric vehicles.

Moreover, specific standards for the electric vehicle are categorized under South Africa's National Regulator for Compulsory Specifications Act, Act 5 of 2008 of the Department of Trade and Industry. The lights fitted into the electric vehicles shall comply with the requirements of SANS 20050, SANS 20056, SANS 20057, SANS 20072, SANS 20076 or SANS 20082. Also, retro-reflecting electric vehicle devices shall be per SANS 20003, whereby side retro-reflectors shall be amber irrespective of their position. Consequently, the installation of lighting in electric vehicles shall be in accordance with the stipulated requirements in SANS 20074. Furthermore, rear-view mirrors shall be fitted in the electric vehicles in accordance with SANS 20081, windscreens and windshields shall be in accordance with SANS 20043, glass partition and glass windows should be of safety glass in accordance with SANS 20043, and brakes and braking equipment should be in accordance with SANS 20078.

Moreover, every electric should have at least one audible voice, which should be in accordance with SANS 20028, which should not exceed 112 dB(A) for vehicles with a power less than or equal to 7kW. Also, tell-tale fitted in an electric vehicle shall be in conformance with SANS 20060. Devices that prevent the unauthorized use of an electric vehicle shall conform with SANS 20062, whereas fitted speedometer equipment shall be done according to the requirements of SANS 20039.

Furthermore, components that generate and radiate electromagnetic energy in an electric vehicle should be in accordance with the provisions of the electronic communications Act, 2005 (Act No. 36 of 2005) and its Regulations. Also, particulate and gaseous emissions from electric vehicles should be in accordance with SANS 20040 or SANS 20047, depending on the applicability. In addition, vehicle noise should comply with and not exceed the values stated in SANS 20009, SANS 20041 or SANS 20063. Moreover, the engine and exhaust systems of hybrid electric vehicles should conform to the specification of the South Africa National Road Traffic Act, 1996 (Act 93 of 1996). Also, tyres in electric vehicles should comply with the provisions in SANS 20075.

b. **Six Sigma:** This methodology defines and improves quality standards of products, processes and services. According to Krishnan & Prasath (2013), six sigma is a methodology that advocates for 99.9997% accuracy for improving key processes, eliminating defects and ensuring excellence. The six sigma methodology can be used in designing and producing electric vehicles, considering different specifications, needs and requirements. Krishnan & Prasath (2013) further opined that six sigma, which Motorola Company first used, is done using the DMAIC (Define, Measure, Analyze, Improve and Control), which is explained thus:

   i. **Define:** This entails defining the project goals and the deliverables of customers. This can be achieved by defining customers' requirements, developing a problem statement, benefits & goals, identifying champions, team & process owners, determining resources, evaluating critical organizational support, developing project plans & milestones, and developing a high-level process map. Moreover, the following tools can aid in this define phase: Project Charter, stakeholder analysis, and process flow chart.

   ii. **Measurement:** This entails measuring the process to determine the product's performance and quantifying the problem. This can be done by defining defects, opportunities, metrics & units; detailing the process map appropriately; developing a data collection plan; validating the measurement system and collecting & analysing data. The following tools can be used: data collection plan, process flowchart, bench marking and process sigma calculation.

iii. **Analyse**: This analyses the root causes of defects, problems and data collected during the measurement phase. These analysis steps include defining performance objectives; identifying value/ non value added process steps, identifying sources of variation, and determining root causes. The analysis tool includes: a Pareto chart, Histogram, scatter plot, time series/ run chart/five whys, regression analysis, cause & effect/ fishbone diagram, statistical analysis, process map review & analysis, and hypothesis testing.

iv. **Improvement:** This phase entails improving the outcome from the analysis, thus eliminating defects from the product. The steps include designing experiments, developing potential solutions, defining operating tolerance of potential solutions, assessing potential solutions' failure modes, validating potential improvement pilot studies and re–evaluating/correcting potential solutions.

v. **Control:** This phase control all performance of future process using the following steps: definition and validations of monitoring & control system; development of standards & procedures; implementation of statistical control; determination of process capability, development transfer plan and handoff to process; verifications of benefits, profits, cost savings & avoidance; growth, close project, and finalize documentation and communication to business. The tools utilized in this phase include: control charts, cost-saving calculations, a control plan and process sigma calculation.

c. **Continuous Improvement Mechanism:** This is a quality enhancement mechanism where each component is periodically evaluated for improvement. According to the American Society for Quality (2023), continuous improvement is "*the ongoing improvement of products, services or processes through incremental and breakthrough improvements*". According to Sundqvist & Backlund (2014) in ensuring continuous improvement, there are five strategic themes which are Leadership (commitment of managers to continuous improvements), Strategic focus (this entails focusing on the needs of the customer and strategic goals of the organizations); Organizational culture (this involves entrenching a culture of continuous improvement among employees and encouraging innovation); Process and Standardization (critical process should be enabled and all process should be standardized with appropriate feedback system); and Learning from Result (this is capturing feedback into the system for improvements).

4. Renewable Energy and Battery Infrastructure Operations

This aspect of the competency framework deals with the core aspect of an electric vehicle, which is the significant difference from the internal combustion engine. This competency construct focuses on building a battery storage system with renewable energy for electric vehicles. This entails understanding battery cell manufacturing, electrochemistry, and renewable energy choice. Subsequently, for a comprehensive understanding of this model, students must thoroughly know the following constructs: AC & DC motors, Adaptable renewable sources, electrochemical processes in batteries, electric vehicle battery manufacturing processes, decarbonization & net-zero targets.

a. **A.C and D. C Motors:** Electric motors in a vehicle convert electrical energy into kinetic energy for car movement. Therefore, in understanding the manufacturing mechanism of batteries for electric vehicles, the interactions between Alternating current (A.C) and Direct Current (D.C) must be understood. An electric motor comprises winding, a central motor shaft, bearing, terminals, brushes, and frame and end shields. All these components set up an electric field and magnetic field in the electric motor, which aids conversion from electric energy to kinetic energy. In an electric motors, there are Direct current motors (usually with 96 – 192 volts) and Alternating current (usually at 240 volts), which are used in an electric vehicle, whereby electric energy gotten from charging stations in form of AC are stepped down via on – board changers into DC for electronics inside the electric vehicles. Hence, during the production of batteries, one must be familiar with the needed capacity of voltage for both A.C and D.C inside the electric vehicle.

b. **Adaptable Renewable Energy sources:** The major essence of the electric vehicle is the optimization of environmental sustainability, which aids in reducing carbon emissions from vehicles. However, the charging process for electric vehicles, especially in South Africa, still depends firmly on fossil fuels; that is, fossil fuel power charging stations for electric vehicles. Hence, an adequate competency for electric vehicle production integrates renewable energy sources in charging the batteries. The most adaptable renewable energy source is solar energy, whereby solar panels can be integrated with electric vehicles to charge the batteries. Hence, in producing EV batteries, integrating solar energy as a source of charging the battery should be integrated into the manufacturing mechanisms.

c. **Electrochemical Processes in Batteries:** This is the internal mechanism of batteries. In chemistry, it is known as electrolysis and electrochemical reactions, where ions react to generate electric energy. Bertrand (2011) opined thus, "*A battery consists of one or more electrochemical cells. Each cell contains two metal electrodes and at least one electrolyte solution (a solution containing ions that can conduct electricity). The battery operates through electrochemical reactions called oxidations and reduction".* Therefore, the electric energy stored inside a battery is powered by electrochemical reactions, also called redox reactions. This is the case irrespective of the battery type, which depends on the metal used in the production. Common batteries for electric vehicles: Lithium–ion batteries, Nickel metal hydride batteries, and Lead acid batteries. However, the most commonly used EV battery with many cells is the Lithium-ion battery, whereby Lithium ions form the critical component for the electrochemical reactions.

d. **Decarbonization and Net zero target:** This aspect entails sustainable production of the component of the battery packs, in line with the Decarbonization agenda and the United Nations Net – Zero targets of 2050, whereby there is no green emission in the whole product lifecycle of a product. Therefore, students should be taught about being sustainable – innovative in finding alternative materials for battery packs, as well as cells (i.e Lithium ions), electrical connections (wires or busbars), thermal interface materials (adhesives, gap fillers & paste), and the housing (Melancon, 2022).

5. Vehicle Maintenance

This competency model encompasses the knowledge of servicing and repairing electric vehicles. The student should be able to provide maintenance services to electric vehicles. Hence, in doing this, they must have sound knowledge about the following: Electric Vehicle condition monitoring & assessment, Electric vehicle spare parts, General inspection & fault diagnosis, and predictive & prescriptive maintenance. This will aid in the safety of the vehicles, enhance fuel efficiency, maintain the vehicle's economic value, and prevent unplanned vehicle breakdowns.

a. **Electric Vehicle Condition Monitoring & Assessment:** This entails monitoring the various components of an electric vehicle and assessing its performance. According to Watkins and Wong (2012), electric vehicle motors and generators needs consistent condition monitoring due to high stress on the winding insulation system, ageing effects and load variation on the components. Furthermore, according to Donaldson (2018), other electric vehicle aspects that need condition monitoring are inverters, batteries, and onboard chargers. However, according to the two authors, for condition monitoring of the major component of the electric vehicle, sensors and technology is needed to gather the necessary data.

b. **Electric Vehicle Spare Part:** In maintaining an electric vehicle, a student should understand the nature, type, size, and compatibility of various spare parts that can be replaced in an electric vehicle. Also, a student should understand the quality makeup of different spare parts vis–a–vis the seller.

c. **General Inspection & Fault Diagnosis:** This aspect entails periodic inspection of the various functional part of the electric vehicles to detect problems. However, the inspection may not bring the required problem to visibility, hence, a need for diagnosis of the fault, which is technical. Students should have various technical knowledge of diagnosing faults in electric vehicles. The research of Zhang, Yao & Rizzoni (2016) and Yang et al. (2021) shows that diagnosing faults in electric vehicles entails computational knowledge of electric vehicle algorithms like deep learning algorithms and structural models from MATLAB/ Simulink. Also, Offer et al. (2012) opined that fault diagnosis should be conducted on electric vehicles to check their mechanical and thermal integrity, which could be done using MATLAB/ Simulink modelling.

d. **Predictive and Prescriptive Maintenance**: These are significant types of maintenance management that are needed in maintaining electric vehicles, as it deals with analyzing the usability of Electric Vehicles. Predictive Maintenance entails the analysis of data from the usage of EVs in predicting needed areas that need maintenance in terms of repairs, changing of parts, and servicing. It provides insights into the state of performance of electric vehicles. Consequently, prescriptive maintenance is a maintenance mechanism based on certain conditions and periodic criteria that must be met for the optimal performance of an electric vehicle. It is also a "What – If" maintenance by ensuring necessary repairs or servicing.

6. Electric Vehicle Charging Infrastructure

This is the infrastructure needed to charge the electric vehicle; hence, a student should develop competency in the whole process of charging electric vehicles. This entails understanding the following: Station location optimization, Electric vehicle supply equipment (EVSE), Alternate

Current (AC) and Direct Current (DC) charging systems, electric vehicle charging hardware, and integration and impact of electric vehicles on the electric system.

a. **Station Location optimization:** This is understanding how to install electric vehicle charging stations, which involves the following: infrastructural requirements, installation of a transformer, safety equipment, cables for equipment & meters, and land & charger models (Lendingkart, 2022). Furthermore, there are three types of charging stations that can be used in building an EV charging station, which are Level 1, Level 2, and Level 3 charging stations. Level 1 charging station is a basic and low charging station, with 120 volts using an AC plug, and it takes 8 – 12 hours to charge a battery fully. Level 2 charging station is a standard charging station with 240 volts AC plug, taking 4 – 6 hours to charge a battery fully. Level 3 charging stations are rapid charging stations with 480 volts in a DC plug, which takes about 40 minutes to charge a battery fully.
b. **Electric Vehicle Supply Equipment (EVSE):** This device is used to charge electric vehicles. Students should understand how to set up an EVSE in connection with the different types of charging stations.
c. **Alternate Current (AC) and Direct Current (DC) charging systems:** These are the two charging systems in electric vehicles, depending on the charging station level. The AC charging stations are used to charge electric vehicles, which is converted into DC with inbuilt onboard chargers in EV, as the vehicle stores power as DC. Moreover, a DC charging system doesn't need a converter, as the converter is inbuilt inside the charger. Hence, students should understand how the built-up EV is respective to the charging system, especially with integration with renewable energy.
d. **Integration and Impact of Electric Vehicle Power System:** This entails understanding the relationship between electric motors and the controllers, which constitute the power system of electric vehicles. However, recent development has led to different vehicle connectivity affecting the power system, which a competent EV manufacturer should understand. These include Vehicle to Building (V2B), Vehicle to Home (V2H), Vehicle to Grid (V2G), Vehicle to Vehicle (V2V), and Vehicle to Everything (V2X). The various connectivity shows how electric vehicles can be charged from buildings, vehicles, homes, and the grid.

B. MANAGERIAL COMPETENCY MODEL

These are various managerial competencies that a TVET student in the EV domain must possess.

1. Cognitive and Personal Effectiveness Competence

These are inbuilt and personal traits and skills that a TVET student must possess. They include the following: communication & interpersonal skills, professionalism & integrity, emotional intelligence & positivity, abstract thinking, critical thinking, analytical thinking, leadership capability, writing, creativity & innovation, attention to detail, and decision-making.

a. **Communication & Interpersonal Skills**: These skills entails a respectful way of sharing one's idea or information with others in a coherent, clear and calm means, irrespective of age, social status and economic background. This also entails being empathetic to people, demonstrating flexibility for change and deepening trust. This is necessary for working with co-workers, supervisors, and subordinates during the manufacturing of electric vehicles.

b. **Professionalism and Integrity:** This entails adhering to a professional code of conduct set by the EV manufacturing organization, mainly relating to ethics, professional appearance, organizational culture, positive attitude at work and maintaining a professional demeanour.

c. **Emotional Intelligence & Positivity:** Being optimistic about a situation and managing one's emotions. This also entails being self–aware and demonstrating self-control, conscientiousness, and trustworthiness. In a typical EV organization, many workers from different backgrounds face different issues at work; hence, being conscious of one's emotion and being positive goes a long way in ensuring good performance from oneself and colleagues.

d. **Abstract Thinking**: This is higher-order thinking, which is the ability to connect thoughts and feeling from our senses, environment, and organizations with physical issues. The EV manufacturing process is an evolving field that needs high-order thinking in designing, conceptualizing and manufacturing in line with the constantly changing patterns of customers and users.

e. **Analytical Thinking**: The technological model of the EV competency framework shows that many analyses are needed during the entire manufacturing, maintenance and charging process. Hence, students should develop their analytical skills, which entails deconstructing data into information to make logical conclusions and informed decisions.

f. **Critical Thinking**: This involves inductive and deductive reasoning about accomplishing a task, which connects situations, reviews the information, and analyses issues to make an informed judgment. This is necessary due to the various assembling of parts needed in the manufacturing process of Electric Vehicles.
g. **Leadership Ability:** This is the capability to influence and inspire people to take action or perform a task using different leadership styles of transformational, democratic, bureaucratic, strategic or Laissez – Faire leadership. This is needed because in an EV factory, irrespective of the factory layout, workers operate in a team, whereby leadership ability aids an individual in bringing efficiency to the operation at hand.
h. **Writing:** This represents one's thoughts in a text that is legible and understandable to read. In manufacturing an Electric Vehicle, writing is necessary to note figures, progress, and pass information around.
i. **Creativity & Innovation:** This entails generating creative ideas, processes and mechanisms and then turning them into solutions during the entire production cycle of an EV.
j. **Attention to Detail:** This entails concentration, focus and keen observation of issues, tasks, writings, figures, drawings, processes, and designs during the manufacturing of Electric Vehicles.
k. **Resilience ability and Adaptability:** Students should be trained to get things done and not give up, as this is required in an EV organization with complex and rigorous activities. Also, TVET students should develop their adaptability skills to adapt to a new organization, department, or section in an organization or with a new set of teammates.
l. **Decision Making:** This is the ability to select between options based on comprehensive information at one's behest.

2. Workplace Behavior Competence

These are skills, abilities and attitudes an individual or student must exhibit in a workplace. These are required for employees to perform well within the ambit of a workplace's rules, regulations, and professional conduct. These include teamwork & collaboration, Business Intelligence & Data Analytics, I. C. T literacy, Customer service, problem-solving skills, creativity & innovation, and Health, Safety & Environment (H.S.E) knowledge.

a. **Teamwork and Collaboration:** This skill entails working with others, irrespective of background or perception, to achieve a specific purpose or goal. Workers in a typical electric vehicle company are grouped into teams, necessitating collaboration to get a job done. In enhancing the skill, a student must understand their various roles in the team, understand how productive relationships can be achieved, the team's objectives and the mechanism for resolving conflicts among one another.
b. **Business Intelligence and Data Analytics**: This is the ability to utilize data from the business environment and work environment to make an informed decision about the business and make necessary business strategies. Therefore, TVET students should understand the concept of data analytics in the electric vehicle industry in making informed decisions about production, maintenance, battery management and customer/ user of electric vehicles.
c. **I.C.T Literacy and programming skills:** This entails having basic knowledge about information and communication technology (ICT) and using this knowledge in the workplace. TVET students should be able to handle computers in a typical Electric Vehicle workplace. However, considering the sophistication of an electric vehicle's entire product lifecycle, there is a need for deep ICT knowledge of programming, mainly in Simulation and Modeling techniques of MATLAB and Simulink software.
d. **Customer Service:** This entails providing support, assistance, and information to actual and potential customers respectfully and dignifiedly. TVET students can develop this skill by enhancing their interpersonal and emotional intelligence ability and putting themselves in customers' shoes. This is needed because of the demographics of customers that use electric vehicles in South Africa.
e. **Research Skills:** Students should be curious and able to source knowledge from the library, books and online. This is needed as changes are inevitable in the automotive industry; hence, research capability gives an individual edge over others.
f. **Problem-solving skills:** The ability to proffer workable and realistic solutions to a challenge after identifying the root cause, brainstorming the various options in a scenario-

thinking endeavour, and logically picking the best option. This skill aids in analyzing multiple issues that can be associated with a given task during the production process of an electric vehicle.

g. **Presentation Skills**: This is the ability to make a crystal clear presentation of a task, issue, problem, or solution to a group of people without fear or nervousness. Thus, TVET students should understand the usage of presentation software like Microsoft Powerpoint.

h. **Creativity and Innovative ability:** The workplace environment is a dynamic climate where different issues, challenges, and problem arises; hence, new idea and approaches are needed. Therefore, TVET students should be trained to be creative and innovative by developing the ability to think outside the box, look for new ways to solve issues and develop dynamic approaches to recurring operational inefficiency.

i. **Health, Safety & Environment (H.S.E):** A manufacturing workplace like an electric vehicle factory is prone to all occupational hazards. Hence, having adequate knowledge about the processes, mechanisms, technology, equipment and procedures for safety and protecting one's health in the workplace is a required competency. TVET students should familiarize themselves with H.S.E policy of an EV organization, understand how to set up safety equipment & code, and have knowledge of potential hazards that arise from different work operations.

j. **Workplace Integration Readiness:** Integration into an EV organization starts with work integration, whereby the new intern or employee is taught about the process, culture, and mechanism of doing things in the organization. Hence, a student should be trained to be mentally prepared and emotionally ready to assimilate and quickly adapt to the new environment, which will speed up their performance and learning curve.

3. Green Supply Chain & Logistics Competence

Electric vehicle production is a multilateral process with multiple stakeholders, requiring an efficient supply chain system and logistic management. Therefore, building competency in the supply chain and logistics in line with green initiatives for electric vehicles will aid in understanding the length and breadth of the production mechanism of electric vehicles in terms of pre–production, production and post–production activities. These Green supply chain and logistics competence can be developed via knowledge of logistics management, the Green supply chain for electric vehicle components, operation management, project management, agile performance management, value chain system analysis, and environmental sustainability.

a. **Logistic Management:** This is the capability to manage the flow of resources, materials, supplies and equipment needed to produce an electric vehicle's various components and parts. This also entails having profound knowledge about warehousing, inventory process & techniques, packaging, material handling and transportation of the resources needed for production. It is also a process that entails managing the purchase of production supplies, equipment and machines. Therefore, TVET students should know the logistics of all the materials that will aid in supply planning, production planning, distribution methods, worker collaboration and schedule management in an EV workplace. The student should also be cognizant of the seven (7) R's of Logistics: Right Cost, Right Product, Right Customer, Right Time, Right Place, Right Condition, and Right Quantity (Dovetail Business Solutions, 2023).
b. **Green Supply Chain for Electric Vehicle:** The supply chain entails the linkage among different stakeholders, organizations, and activities regarding the production or sale of a product. It involves everyone, every resource and everything involved in producing the electric vehicle, from the supply of different raw materials to the user of electric vehicles. However, since the electric vehicle seeks to reduce greenhouse gas emissions, its supply chain should be green. Therefore, a green supply chain for electric vehicles entails reducing or removing processes or procedures along the chain with adverse environmental impact. That is, alternative measures or practices along the EV supply chain should be eco–friendly. Hence, TVET students should be taught all the available means, strategies, practices and digital platforms for the decarbonisation of the supply chain of electric vehicles.
c. **Operations Management**: Electric vehicle manufacturing process comprises different operations, which requires adequate knowledge to navigate them successfully. According to Hayes (2023), operation management is "*the administration of business practices to create the highest level of efficiency possible within an organization"*. It is concerned with the various processes, strategies, production plan & control, plant layout, material management, quality planning & control, inventory management, scheduling planning,

material control and production efficiency of electric vehicles. Hence, TVET students should be introduced to a typical EV organisation's operational setting and management.

d. **Project Management:** This is the application of established processes and methods to achieve project objectives designed by relevant stakeholders. The project itself is a temporary endeavour with a beginning and an end. In a typical EV company, there are several projects, even sub–projects regarding EV production, which need sound project management knowledge to lead the project to success along with its deliverables. Hence, TVET students must understand how to manage a project, which stimulates a better understanding production process of an EV. In understanding Project Management, the students should be taught about the two major schools of thought in Project Management, which are the nine (9) knowledge areas of project management by Project Management Institute (PMI) and Project IN Controlled Environments (PRINCE 2) methodology.

e. **Agile Performance Management:** Most workplaces are becoming flexible with schedules, deliverables, and team management, including EV companies. However, this flexibility must be guided by best practices, of which Agile management guides the whole process. Agile performance management is the coordination of the various processes and operations that undergo changes and flexibility to align with organisational goals and adapt to the accompanying innovations. According to Verlinden (2023), Agile Performance Management is an agile methodology that breaks a project into smaller units for easy management and also encompasses evaluating employees for growth. Elements of Agile performance management entail frequent feedback and regular check–ins, engaging multiple sources of feedback, being employee-centric and focusing on skill development. TVET students should be trained on agile performance management in an electric vehicle organization as changes, flexibility and dynamics are always introduced.

f. **Value Chain system analysis:** According to Tardi (2022), value chain is "*a series of consecutive steps that go into the creation of a finished product, from its initial design to its arrival at a customer's door. The chain identifies each step at which value is added, including its production's sourcing, manufacturing, and marketing stages*". Hence, in the production of electric vehicles, there are different stages of adding value, from production to aesthetics to branding and selling. Students should develop the competency of using creativity and innovations in determining the appropriate value that needs to be added or omitted along the entire chain of production to the user.

g. **Environmental Sustainability:** This entails the assurance, planning and promoting eco–friendliness along with the sourcing and utilization of raw materials, parts and components used for producing electric vehicles, thus ensuring those resources are also available for utilization in the future. Students in the EV industry should be able to identify practices that promote environmental sustainability along the entire supply chain, production cycle/ stages and value of an electric vehicle. Also, this may differ from one organization to another; hence, the student should understand the peculiarity of organization strategies and eco–friendliness approach for properly integrating environmental sustainability practices into an EV organization.

4.3 Summary

This comprehensive framework encompasses all aspects of electric vehicles, catering to TVET students within TVET Colleges and when they start applying EV knowledge and skills in an organization. The framework includes Electric vehicle system engineering, Design & Manufacturing process, Renewable Energy and Battery Infrastructure operation, Quality and Standardization, Vehicle Maintenance, Electric Vehicle Charging Infrastructure, Cognitive and Personal Effectiveness Competence, Workplace Behavior competence, and Green supply chain & Logistics competence. Therefore, a robust engagement with the TVET directorate and allied partners is needed to ensure optimal framework utilization.

5.0 Recommendations

The quantitative and qualitative analysis shows a knowledge and skills gap amongst TVET students in the South African electric vehicles and automotive industries. However, via surveys, interviews, and focus groups, the report has developed a comprehensive two–model approach competency framework for teaching TVET students and preparing them for the future electric vehicle industry in South Africa. Consequently, we proffer high-level recommendations for the effectiveness of the developed framework. The recommendations are categorized for three key stakeholders: TVET students, the South African Government, and the TVET Schools.

a. TVET students

The students are the capstone of the Electric vehicle industry, and their knowledge level today determines the industry's continued existence tomorrow and the competitiveness of the South Africa Automotive industry in the Global market. Hence, for the effectiveness of the developed framework, students who are the knowledge recipient of the framework should adhere to the following:

i. Develop a positive attitude towards learning.
ii. Enhance their level of curiosity and inquisitive nature for learning.
iii. Engage in collaborative learning.

b. South African Government

The Government is a pillar for driving up learning policy in the country and making funds available for institutions of learning. Given the economic and environmental role of Electric vehicles in the country and the global economy, this EV framework's utilisation depends on Government collaboration and willpower. Therefore, it is recommended thus:

i. Government should organize training for TVET teachers on electric vehicles, as most know the Internal Combustion Engine manufacturing process but not Electric Vehicles.
ii. Purchase EV software and technology for simulation and modelling needed for training TVET students, such as MATLAB, Simulink, and Simcar.
iii. Provision and setting up of a mini electric vehicle factory in each province for practical teaching on electric vehicles.

iv. Introduce teachings on the Fourth Industrial Revolution (4IR) technologies to TVET colleges, especially on artificial intelligence, virtual reality, big data analytics, and sensor technology.
v. Formulate a policy on internships for TVET students with electric vehicle production or distribution companies.
vi. Formulate a policy on practicum for solar energy and photovoltaic as it relates to Electric vehicles.
vii. The TVET curriculum should be rejigged to accommodate this EV production framework, as many stakeholders opined that the current curriculum is obsolete and has no place for EV production teachings.

c. TVET School Management

TVET colleges' management has an internal role to play before and after utilizing this EV framework. This is summed up in the following recommendations:

i. TVET colleges have to introduce physics and chemistry practicals into teachings, as this is vital to the battery management system of electric vehicles (i.e., electrochemistry from chemistry and circuit systems from physics are the foundation of EV batteries).
ii. TVET colleges should introduce the following courses or subjects into the curriculum or teaching modules of the school;
    - Electric Vehicles System Engineering (Introduction/Advanced)
        - Risk analysis and management (such as hazard and operability analysis, HAZOP; layer of protection analysis, LOPA; and process hazard analysis, PHA).
    - Electric Vehicles Design and Manufacturing Process (Introduction/Advanced)
    - Electric Vehicles Renewable Energy and Battery Infrastructure Operations (Introduction/Advanced)
    - Electric Vehicles Maintenance & Vehicle Charging Infrastructure (Introduction/Advanced)
    - Electric Vehicles Quality & Standardization (Introduction/Advanced)

- Introduction to the working mechanisms and codes of the International Organizations for Standardization (ISO) and Electrochemical Commission (IEC).

- Introduction to the qualitative, quantitative and technological analysis of Six Sigma (using its software)
- Introduction of data analytics (descriptive, predictive and prescriptive data analysis).
- Introduction of Health, Safety & Environment (H.S.E) practices, codes and tools.
- Introduction to Operation management in the supply chain, project management, logistics management, and production planning & strategy.

iii. TVET colleges should form a partnership with automotive parts suppliers, whereby students can practically understand the value chain and supply chain of electric vehicles and local content sourcing.

iv. TVET colleges should organize monthly debates and leverage class presentations, team projects and term papers to enhance their students' soft skills.

v. Electric vehicle industry experts should be invited to interact with the students to boost their self-confidence and give them a bird's eye view of the future.

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Appendix A: Questionnaire for TVET College Students

Research Objective: To examine the skills gap among STEM students in TVET Colleges for the production and maintenance of Electric Vehicles (EVs) in South Africa

Dear Students,

Kindly tick (✓) the most appropriate responses, as your response will enable us to conduct a comprehensive analysis that will equip you with competence for the production of electric vehicles for Southern Africa and the African continent in general.

Thanks for your time and participation.

Signed:
Ngawethu Consulting for IYF South Africa

Section A: Demographic Information

Kindly tick as appropriate

1. **Gender:** Male [ ] Female [ ]
2. **Age:** 15 – 20 [ ], 21 – 26 [ ], 27 – 32 [ ], 33 – 38 [ ], above 38 [ ]
3. **School Grade**: Level 1 [ ], Level 2 [ ], Level 3 [ ], Level 4 [ ], Level 5 [ ]
4. **Courses:** Electrical infrastructure [ ], Engineering and Related Design [ ], Information Technology & Computer Science [ ], Mechatronics [ ], Process Instrumentation [ ], Process plant operations [ ], School of Engineering [ ].
5. **Are you enjoying the course:** Yes [ ], No [ ]

Section B: Foundational Knowledge of Electric Vehicles

Kindly tick (✓) as appropriate your response to the following statements using the following scale:

4 – To a Great Extent, 3 – Somewhat, 2 – Very Little, 1 – Not at all

S/N	Items	To a Great Extent 4	Somewhat 3	Very Little 2	Not at all 1
1.	I have heard of electric vehicles in a class				
2.	I have participated in a class discussion on electric vehicles				
3.	I understand the different energy sources for electric vehicles				
4.	I understand how electric vehicles' batteries are charged				
5.	I understand the impact electric vehicles have on society (power systems, transportation networks etc.)				

Section C: Theoretical & Practical Knowledge of Electric Vehicle Manufacturing

Kindly tick (✓) as appropriate your response to the following statements using the following scale:

4 – To a Great Extent, 3 – Somewhat, 2 – Very Little, 1 – Not at all

S/N	Items	To a Great Extent 4	Somewhat 3	Very Little 2	Not at all 1
1.	I understand the electric vehicle design process				
2.	I understand the electric vehicle manufacturing and assembly process				
3.	I know and understand the various electric vehicle car components.				
4.	I have practical experience with the electric vehicle manufacturing process				
5.	I have practical experience with electric vehicle subsystems (braking, battery, converters, etc)				

Section D: Critical Awareness of Electric Vehicles Components

Kindly tick (✓) as appropriate your critical awareness of the following Electric Vehicle Components using the following scale:

5 – Extremely aware, 4 – Moderately aware, 3 – Somewhat aware, 2 – Slightly aware, 1 – Not at all aware.

S/N	Items	Extremely Aware (5)	Moderately Aware (4)	Somewhat Aware (3)	Slightly Aware (2)	Not at all Aware (1)
1.	Electric traction motors					
2.	Power inverter/ Controller					
3.	Battery Pack					
4.	Thermal management systems					
5.	Charging stations					
6.	Onboard charger					

Section E: Knowledge of Electric Vehicle Maintenance

Kindly tick (✓) as appropriate your critical awareness of the following Electric Vehicle maintenance concepts using the following scale:

5 – Extremely aware, 4 – Moderately aware, 3 – Somewhat aware, 2 – Slightly aware, 1 – Not at all aware.

S/N	Items	Extremely Aware (5)	Moderately Aware (4)	Somewhat Aware (3)	Slightly Aware (2)	Not at all Aware (1)
1.	Knowledge of electric vehicles maintenance tools, services & activities.					
2.	Knowledge of electric vehicle general inspection and fault diagnosis					
3.	Knowledge of electric vehicle spare parts					
4.	Knowledge of remote diagnostics for electric vehicles					
5.	Knowledge of electric vehicle maintenance approaches					

Section E: Self-Assessment of Adaptive Electric Vehicle Skills

Kindly tick (✓) as appropriate your self-assessment of the following Electric Vehicle skillsets using the following scale:

5 – Very High, 4 – High, 3 – Moderate, 2 – Low, 1 – Very Low

A.	Soft Skills	Very High (5)	High (4)	Moderate (3)	Low (2)	Very Low (1)
1.	Abstract thinking					
2.	Creativity					
3.	Problem-Solving					
4.	Teamwork					
5.	Interpersonal Skill					
6.	Critical Skill					
7.	Leadership Skill					
8.	Decision-making Skills					
9.	Analytical Skills					
10.	Attention to details					
B.	**Hard Skills**					
1.	Systems design					
2.	Engineering Drawing					
3.	Equipment and engine repair					
4.	Diagnostic skills.					

5.	Troubleshooting skills					
6.	ICT & Mathematics Skills					

Thank You

Appendix B: Focus Group/ Interview Survey for Industry Stakeholders

Research Objective: To ascertain the needed competency and skills for the production and maintenance of Electric Vehicles in South Africa

Dear Stakeholder,

This interview is to get your view on the skills and competency required for producing and operating electric vehicles in South Africa. Your choice as an interviewee is based on your knowledge level and experience in the automotive industry.

Kindly give us the needed answers, which will enable us to conduct a comprehensive analysis that will equip the country with the competence to produce electric vehicles for Southern Africa and the African continent.

Thanks for your time and participation.

Signed:
Ngawethu Consulting for I.Y.F. South Africa

Semi-Structured Interview Questions

Introduction

1. Please describe your background, job title and current job responsibilities in relation to the automotive industry.
2. What are your views about the state of the Electric Vehicle industry in South Africa?
3. Kindly give your perspective on the need to develop competencies amongst TVET learners for the production & maintenance of electric vehicles in South Africa.

Required Competencies

4. What core competencies are necessary to work in the EV Industry for a manufacturing & maintenance role?
5. What do you generally look for amongst students/recent graduates?
6. What educational background is required?
7. What core theoretical knowledge is necessary to have?
    a. Can you think of any specific TVET college whose students/graduates have exceptional EV-related propositional or experiential knowledge
8. What practical skills or experiences are necessary to have?
9. Are there any specific personality traits you believe are necessary to have?

Perceived Skills Gap

10. What is your current talent shortage, and do you think it also applies to the EV components manufacturing and maintenance? Please elaborate
11. What primary skills do you feel most recent graduates lack?
    a. What are the main theoretical knowledge gaps?
    b. Which are the main practical skill gaps?
    c. Are there any skill gaps related to machines or equipment?
    d. Are there generally any soft skills that you feel candidates are lacking?
    e. Have you experienced any other types of skill gaps?
12. What do you believe are the main drivers for these skill gaps?
13. In your view, does South Africa have a competitive advantage in producing or maintaining electric vehicles?

Thank You.