

STRATEGIES TO MITIGATE CARBON EMISSIONS FOR SUSTAINABLE SWITCHGEAR MANUFACTURING: A CRITICAL REVIEW FROM A LIFE-CYCLE ASSESSMENT PERSPECTIVE

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Abstract

The increasing demand for power infrastructure has intensified the need for sustainable switchgear manufacturing, particularly in emerging markets like India. This paper presents a critical review of carbon emission mitigation strategies in the switchgear industry, with a focus on life-cycle assessment (LCA) as a guiding framework. It explores the transition from sulfur hexafluoride (SF₆)-based systems to environmentally friendly alternatives such as clean air, vacuum, and solid insulation technologies. The review highlights global innovations by leading manufacturers including Siemens, Hitachi Energy, ABB, and Eaton, and contrasts these with the infrastructural, regulatory, and financial challenges faced by the Indian switchgear sector. Technological advancements—such as IoT-enabled monitoring systems, laminated bus plate designs, and hybrid switchgear—are examined for their role in reducing greenhouse gas emissions. The study underscores the importance of LCA in quantifying environmental impacts across product life cycles and calls for stronger policy support and investment in sustainable innovation to accelerate carbon neutrality in switchgear manufacturing.

Keywords: Sustainable Switchgear, Carbon Emission Reduction, SF₆ Alternatives, Life Cycle Assessment (LCA), Green Energy Technologies

Introduction

The growing demand for power supply and switchgear in the Indian market enhances the requirement to focus on sustainable switchgear manufacturing. The literature review focuses on existing research that reflect carbon emission mitigating strategies in the switchgear manufacturing industry. It provides examples of organisations which have adopted sustainable strategies for mitigating greenhouse gas emissions by switchgear. Findings of existing research related to the impact of the life cycle on carbon emission reduction measures are also explained in this literature review. It also helps to understand the technological innovation that took place in the switchgear industry for reducing carbon emissions. Further, it also highlights the barriers this industry faces in implementing carbon mitigation strategies.

Carbon emission mitigation strategies in switchgear manufacturing

The major carbon emission mitigation strategy in switchgear manufacturing is finding alternative insulating medium and equipment of SF₆. Non-switching gas-insulated busbars can use dry air insulation for up to 420kV voltages and vacuum interpreters can use it for up to 145kV (Ranjan *et al.*, 2022). It is also available for alternate gas circuit breakers up to 145kV voltage and it can be expanded up to 45kV by 2025. In addition, the key alternatives of SF₆ in switchgear are hydrogen and nitrogen along with clean air. However, these alternative insulator mediums can be used majorly for medium voltage switchgear. It has already been identified that high voltage switch gear with circuit breaker can only be used up to 145 KV which does not contain fluorine through utilising natural gases like carbon dioxide, oxygen and nitrogen. In 2022, GE and Hitachi Energy developed an SF₆ free 420kV circuit breaker which reflects the organisation's ability to create an environment-friendly high-voltage circuit breaker (Franck *et al.*, 2021).

These organisations also researched on finding a suitable replaceable gas for SF₆ in high-voltage switchgear. Further, Siemens Energy Transformer factory revealed that the organisation is utilising blue switching technology which is created based on clean air and it is utilised as the substitution of SF₆. Clean air consisted of 20% oxygen and 80% nitrogen (Iosifidou, 2023). Thus, it is completely carbon dioxide-free and it has zero global warming potential. Therefore, Siemens factory located in Maharashtra, India also manufactures blue technologies-based switchgear and circuit breakers. It is

expected that European countries will play a leading role in eliminating SF₆ usage in medium-voltage applications. Therefore, India is also required to create a framework that can support the country to effectively monitor and report the usage of SF₆ in different products. In addition, the UK Power Networks has collaborated with Siemens Energy to install its first SF₆ free switchgear and it is developed by using clean gas as an insulator medium. This switchgear can be operated at 132000 kV and the clean air consists of dehumidified nitrogen and oxygen (Kuschel *et al.*, 2019). Therefore, Siemens Energy was found to be the first manufacturer of environment-friendly clean air-based GIS. The clean air-based GIS is installed for upgrading the substation at East Sussex. This project took place because the UK Power Network targeted to reduce the application of SF₆ in switchgear of different voltages.

It focused on using alternatives of SF₆-free switchgear that are available in the market and support the country to accomplish net zero carbon emission without compromising on the effective power supply. In addition, Hitachi Energy declared that it also created SF₆-free GIS at 420kV which has been utilised in Germany's TenneT's power grid to accomplish its goal of carbon neutrality (Pietrzak *et al.*, 2022). It is also part of upgrading grid connections like the UK Power Network. SF₆-free GIS is also beneficial for increasing the operating life of power assets. It is one of the scalable solutions for generating the lowest carbon footprint. Both UK Power Network and TenneT are responsible for supplying power to millions of homes and businesses across the UK and Germany respectively. Therefore, it is crucial to adopt technology that can decrease greenhouse gas emissions and support the country in developing a carbon-free energy system. The installation of SF₆-free GIS in Germany successfully neglected the emission of approximately 2300 kg of SF₆ which is equal to 1150 passenger vehicles' carbon emissions each year (Hitachi Energy, 2023). Therefore, it can be determined that few organisations have been successful in implementing clean air-based GIS.

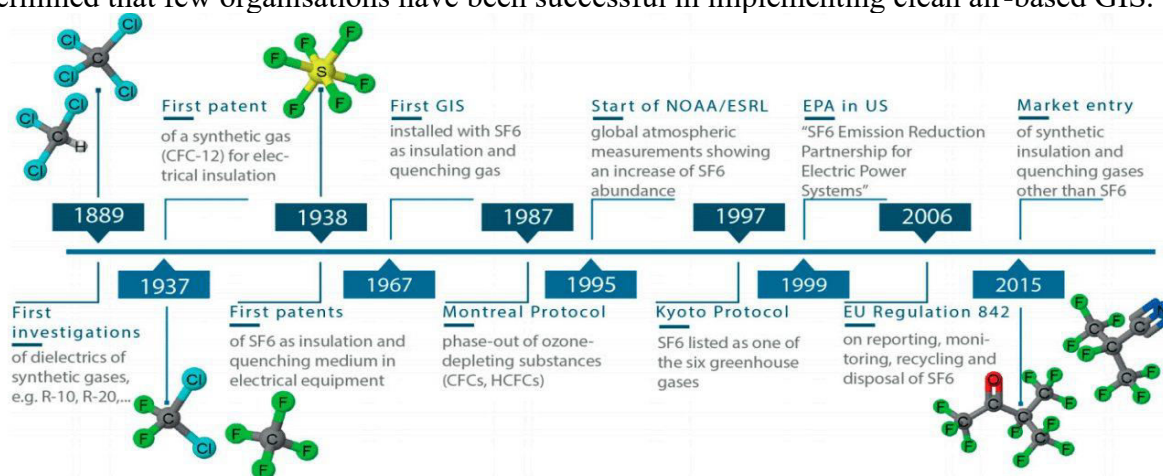


Figure 1: SF₆ Alternative Gases in Switchgears
 (Source: Switchgear Content, 2019)

There are different alternatives to SF₆-based switchgear including air-insulated switchgear, vacuum-insulated switchgear and solid insulation solution. Air-insulated switchgear is dependent on air as the major's insulating medium which eliminate the requirement of SF₆. It is simple to maintain and provides reliable performance (Tan *et al.*, 2022). However, it has drawbacks concerning compactness and capability to deal with high voltages. Vacuum-insulated switchgear applies vacuum as an insulator. It consists of an efficient dielectric feature which makes switchgear an effective alternative. It also had a compact design and low maintenance along with high reliability. However, it operates at a lower pressure which is the limitation of using vacuum insulated for high voltage (Węgierek *et al.*, 2023). Research is going on in developing solid insulation to use as a mediator in switchgear. It also has effective insulation properties and does not emit greenhouse gasses. It supports switchgear manufacturers to accomplish long-term sustainability and decrease carbon footprint on the

environment (Xing *et al.*, 2022). Therefore, it can be determined that the alternative of SF6 free switchgear consisted of different limitations which raises the requirement of finding the substitution of SF6 that can support operating high voltage switchgear efficiently. Furthermore, Dullni et al (2015) explained that the carbon emission from electrical switchgear can be reduced by making improvements in its design. There are different design rules for reducing SF6 emission including maximizing SF6 filling pressure and decreasing the feeling mass of this gas per unit. The greenhouse emission can also be decreased by optimising and decreasing the gasket length along with selecting and ensuring gasket material is appropriate to the environment. It also includes facilitating SF6 recovery by neglecting dead internal volumes. Therefore, greenhouse emissions can be prevented by focusing on the design aspect of SF6-based GIS. However, De Vito *et al* (2024) argued that maintenance of switchgear whether it is air-based or gas-based is crucial for reducing carbon emissions because faulty and dirty insulators cause more carbon emissions into the environment. Therefore, an IoT system-oriented ozone sensor can be created to monitor switchgear as it is beneficial for screening and identifying the condition of switchgear. Therefore, it supports the manufacturer in maximizing maintenance activities related to the switchgear component. It supports manufacturers in considering air pollution by switchgear and predicting faulty conditions. Therefore, an effective monitoring system through integrated advanced technology is beneficial for reducing carbon emissions in switchgear manufacturing.

Impact of life-cycle on carbon emission reduction measures

Life cycle assessment is a common greenhouse gas protocol to control carbon emissions to the environment. It helps to develop a standard greenhouse emission reporting system in the organisation. It supports organisations in adopting reliable and transparent approaches for quantifying greenhouse emissions and taking sustainable action to reduce those (Serres, 2022). It increases the credibility and accountability of organisations towards their sustainable action. It enables organisations to develop a framework for harmonizing greenhouse gas programs and initiatives. Therefore, it can support switchgear manufacturers in tracking greenhouse emissions and also support them in determining the impact of different categorical products that are used as alternatives. The carbon footprint of a high-voltage GIS needs to be investigated in its all life cycle phases including filling, operation, recycling or recovering (Billen et al., 2020). The phases of filling and recycling or recovering involve instant emission and the threat of operational leakage. However, sometimes there is a lack of data that tracks the emission of carbon or greenhouse gas from switchgear in different life cycle phases. Therefore, life cycle assessment plays a crucial role in determining the threat of carbon emission which is important for taking appropriate preventive action.

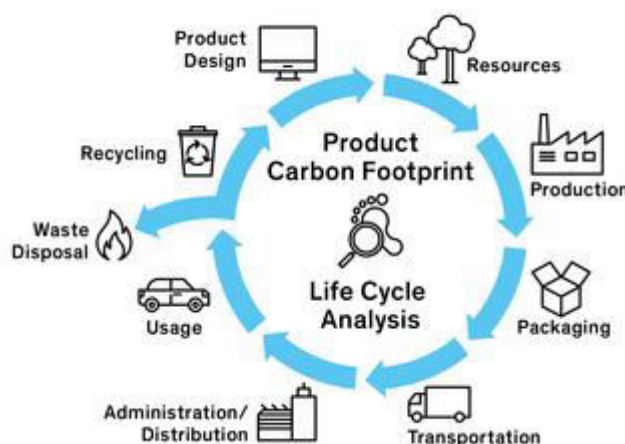


Figure 2: Life cycle assessments
(Source: My Climate, 2024)

Life cycle assessment provides a holistic view regarding the environmental impact of switchgear. It is one of the best methods for quantifying global impact indicators. Therefore, it supports switchgear manufacturers to consider the indicators while designing sustainable switchgears to reduce its negative impact. It also supports switchgear manufacturers to consider sustainable development goals while conducting life cycle assessments (Moon *et al.*, 2022). At each phase of the life cycle assessment, the consideration of the most relevant interaction between the switchgear and the environment helps to identify the function that needs to be focused on creating sustainable switchgear. Therefore, it supports switchgear manufacturers to invest in sustainable solutions. LCA calculation needs to be applied to the sustainable switchgear product to determine their carbon neutrality. For example, Hitachi Energy aimed to develop a carbon-neutral energy future by creating its high voltage technology EconiQ GIS of 145kV (Abb, 2024). The product has a lifespan of 50 years and the organisation determines environmental impact in terms of global warming potential, acidification potential, ozone layer depletion potential, photochemical ozone creation potential and blue water use at different phases including equivalent unit, materials, assembly, use phase, transport and end of life. It has been determined that the organisation has accomplished zero ozone layer depletion at all phases. It has supported the organisation to identify that the use phase provides a maximum contribution to global warming potential among all the stages of the life cycle as it consists of 72% of total global warming potential values (Liu *et al.*, 2024). Therefore, Hitachi Energy has determined that the use phase is a major driver for creating the life cycle environmental impact of its switchgear product. Thus, life cycle assessment is crucial for measuring actions related to carbon emission reduction.

Mode/fuel	Equivalent unit	Materials	Assembly	Use phase	Transport	End of life	Total
Global Warming Potential (GWP 100 years), excl. biogenic carbon	kg CO ₂ eq.	154,308	23,300	502,238	2,806	16,724	699,376
Abiotic Depletion (ADP elements)	kg Sb eq.	7.67	0.01	0.17	0.00	0.03	7.87
Abiotic Depletion (ADP fossils)	MJ	1,638,775	303,000	5,570,000	37,460	72,700	7,621,935
Acidification Potential (AP)	kg SO ₂ eq.	663.62	22.30	973.00	4.57	15.50	1,678.99
Eutrophication Potential (EP)	kg PO ₄ ³ eq.	35.65	4.36	115.00	0.70	2.72	158.42
Ozone Layer Depletion Potential (OLDP)	kg R11 eq.	0.00	0.00	0.00	0.00	0.00	0.00
Photochemical Ozone Creation Potential (POCP)	kg C ₂ H ₄ eq.	39.41	1.96	70.60	0.10	1.58	113.64
Primary energy demand from ren. and non ren. resources (net cal. value)	MJ	2,564,083	427,000	13,000,000	39,700	107,537	16,138,320
Blue water use (excl hydropower)	Kg	3,602,869	831,000	34,100,000	5,670	226,360	38,765,899

Figure 3: Application of LCA by Hitachi Energy
(Source: abb, 2023)

Further, Meinrenken *et al* (2020) explained that LCA provides information regarding greenhouse emissions that are emitted during the production, transportation and distribution of a product. Therefore, it also supports Switchgear manufacturers in determining greenhouse emissions for product disposal. Thus, carbon footprint analysis can be implemented efficiently by adopting this assessment tool and it is crucial for designing product value chains to reduce carbon emissions. The breakdown of carbon emission as per the product's life cycle phase is helpful to understand in which phase the organisation needs to focus on designing new sustainable switchgear. Manufacturers of Sustainable Switchgear can also understand the climate change impact due to their product by adopting LCA. The product's carbon footprint determination process has been standardized by developing this framework. In addition, the life cycle assessment of AIS and GIS 20kV helps to identify that GIS substations create lower environmental impact compared to AIS substations by considering major environmental indicators (TREIER *et al.*, 2022). It occurs because GIS loses four times less electricity compared to AIS substation. On the contrary, GIS more negatively affects global warming indicators because of containing SF₆. Thus, LCA is beneficial for measuring carbon

emissions along with determining the overall environmental impact of switchgear. Furthermore, LCA allows switchgear manufacturers to consider environmental impact factors while developing their products. In India, the organisation follows ISO standards for adopting LCA (Gouveia *et al.*, 2022). Therefore, organizations like Siemens can make different environmental declarations regarding their product including switchgear. The organisation can adopt environmental product declarations which support the organisation to provide quantified environmental data related to the life cycle of the product. The organisation can apply different kinds of environmental product declarations including environmental labelling and self-declared environmental claims (Siemens, 2024). It also needs to consider product category rules for determining environmental product declaration (EPD). As per ISO standards, product category rules refer to the consistent approach that sets a minimum quality standard for LCA in terms of EPD (Piasecka *et al.*, 2020). EPD supports switchgear manufacturers to communicate the product's environmental impact and performance with customers. Therefore, it can be determined that switchgear manufacturers can present how effectively it has reduced carbon emissions by developing sustainable switchgear through their EPD declaration.

Technological innovations for carbon reduction from switchgear

Sustainability is one of the driving factors behind the technological innovation of switchgear. In the 21st century, every industry focuses on sustainability to improve the efficiency of their business operation to decrease greenhouse gas emissions and similarly, the switchgear industry also focuses on this aspect. High-voltage switchgear produces heat because it needs to maintain an ambient temperature in the electrical room (Usman, 2023). Therefore, high-voltage switchgear cannot be substituted by low-voltage switch gear as it has a particular application. Thus, different switchgear manufacturer focuses on developing sustainable switchgear by emphasizing technical innovation. For example, ABB created technically advanced switchgear NeoGear which is beneficial for decreasing carbon footprint on the environment by integrating laminated bus plate technology (ABB, 2024). Traditional bus bar systems can create heat due to AC losses which does not take place in laminated bus plate technology. Therefore, this switchgear generated heat up to 30% which indicates more sustainable functioning of switchgear. This switchgear reduces the requirement of total energy for the room conditioning system. A reduction in the heat generation by NeoGear in the electrical room creates a more sustainable solution for switchgear. In addition, low-voltage switchgear is converted into compact and closed modular types from completely large open types to reduce the physical footprint of switchgear (Thippana *et al.*, 2021). This transformation brings more safety in terms of switchgear usage. The development of laminated bus plates Technology support switch gear not only helps to decrease its food print but also decreases the space required for switch gear to install. Therefore, NeoGear reduces the size of low-voltage switch rooms by using this technology. Electronic houses can be converted into containers by using this switchgear which is beneficial for reducing costs. This kind of switchgear is also appropriate for refurbishment projects. Thus, technological innovation creates more sustainable and positive switchgear.

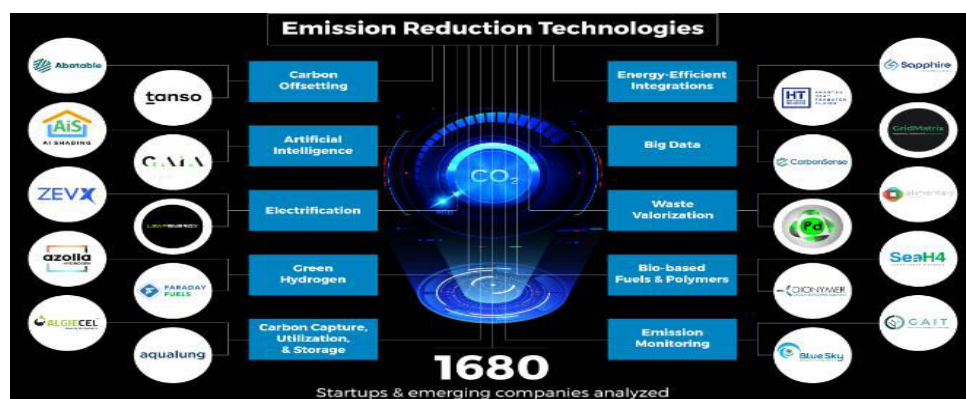


Figure 4: Emission Reduction Technologies
(Source: Insights, 2023)

The switchgear industry has also made developments in creating environment-friendly solutions to reduce greenhouse emissions to the environment. Therefore, it becomes important to create switchgear without using SF₆ (Kim and Kim, 2021). One of the well-known organisations in this market Schneider Electric brought changes in this industry because it created revolutionary switchgear SM AirSeT by using pure air instead of SF₆ (SchneiderElec, 2024). It drastically decreases carbon emission of electrical systems and meets both the purpose of high voltage switchgear as well as environmental concerns. However, the technology of switchgear is focused on security and dependability. Thus, the advanced technology of switchgear also needs to consider these factors. One of the popular power management organisations Eaton Corporation created Arc Quenching Switchgear to enhance safety in the scenario of electrical fault (Goebels *et al.*, 2022). Electrical arcs can safely react and decrease the probability of equipment getting damaged or fired which leads towards improved reliability for this newly launched product. This organisation also developed sustainable alternatives to switchgear by replacing SF₆ in high-voltage and medium-voltage switchgear. The organisation has used air or nitrogen as an insulator in switchgear. The organisation revealed that it can use a combination of solid insulation and atmospheric air with electrical field control to pressurise it. Thus, it can be identified that Eaton Corporation successfully made technical innovations in finding alternatives to SF₆. There are other innovations apart from solid insulation including vacuum technology and composite enclosures. Vacuum technology uses vacuum instead of SF₆ for reducing carbon and greenhouse emissions to the environment which is beneficial for reducing the negative impacts on the environment (Węgierek *et al.*, 2023). It is also immune to extreme weather conditions. Therefore, it also helps to deal with the pollution that occurs due to the deterioration of switchgear. Composite enclosures use composite materials including fibreglass-reinforced polymers. It is lightweight and uses durable material that has better resistance towards chemical UV radiation and corrosion (Hari and Mohana Rao, 2021). Therefore, it has the effective capability to protect against natural disasters and it is used for environmental resistance and long-term durability. Thus, it can be explained that technological innovation in switchgear took place to contribute towards a greener future while increasing safety, reliability and cost-efficiency.

Further, technological innovation in switchgear emphasised safety and performance efficiency. The integration of communication devices and intelligent protection relays with switchgear helps to provide advanced alarms and diagnostics that can warn organisations regarding abnormal circumstances. In India, innovative switchgear includes hybrid and GIS. India is focusing on power infrastructure by considering renewable energy sources (Sidhu *et al.*, 2020). High voltage switchgear covering disconnected circuit breakers and instrument transformers are crucial for including renewables in the power grid that can decrease energy losses and increase capacity. Therefore, high-voltage switchgear is crucial for the power industry to protect the power system and prevent damage to equipment. Thus, innovation related to switchgear is more focused on performance efficiency in terms of energy saving and dependability. In the Indian power industry air insulated switchgear has been more popular as it is expensive compared to GIS. However, GIS switchgear started to gain popularity in the Indian market because it has low maintenance costs and occupies 35% less space (Papadiotis *et al.*, 2022). However, the innovation in the Indian market includes hybrid switchgear which combines the components of SF₆ GIS technology and AIS. The modular and compact design is beneficial for areas where space is limited and expensive. It combines a different range of functions in one switch gear model but it costs near about 20% more than AIS (Chennakeshava *et al.*, 2021). Busbars in this switchgear are air-insulated and other equipment's including disconnectors, connecting elements, bushings, circuit breakers, busbars, sensors and current transformers are gas-insulated. Therefore, the Indian market must focus on technological innovation that can reduce greenhouse emissions to the environment by utilising the alternative option of SF₆ insulated GIS.

Challenges in the switchgear industry for reducing carbon emission

Major developing countries are taking action to reduce carbon emissions related to the Switchgear industry. However Indian Switchgear market can face different challenges in adopting and implementing carbon reduction strategies. The senior consultant Vishal Patil of WIKA India which is a part of German company WIKA Alexander Wiegand SE & Co. KG explain that in India it will take the next 15 to 20 years to adopt an alternative insulating medium of SF₆-based GIS (Sathiyar et al., 2022). Developing countries like Germany can become SF₆-free by 2030 but India lacks the infrastructure facility to adopt sf₆-free switchgear. If the Indian power industry uses GIS without SF₆ then it needs to make complete changes in its infrastructure which can enhance the cost of installation. A few companies in India are focusing on SF₆-free GIS including Elektrolites Power, Havells India and Schneider Electric India (Prasetya *et al.*, 2021). Global switchgear manufacturers started to produce sustainable switchgear in the Indian market but the power industry needs to improve its overall infrastructure to effectively utilise the technically advanced switchgear.

Further, the lack of initiative from the Indian government to develop sustainable switchgear is another challenge for reducing carbon emissions related to it. The Indian government does not make it compulsory to manufacture SF₆-free switchgear (Münch and Marian, 2022). It also does not take action to remove SF₆ from medium voltage switchgear. There is a lack of regulation in India that can monitor emissions of SF₆. There are international regulations on SF₆ emissions for example the US Environmental Protection Agency made it compulsory for large organisations to report SF₆ emissions since 2009 (Hu *et al.*, 2023). California also developed regulations to eliminate the purchase of SF₆-based products by 2033. The European Union also developed F-gas regulation in 2014 based on the accessibility of alternative technology. The Indian government banned emitting harmful greenhouse gases like Hydrochlorofluorocarbons (HCFCs) but it does not take similar action for SF₆ (Billenet *et al.*, 2020). Therefore, manufacturers of switchgear in India do not track SF₆ emissions and it does not have a compulsory reporting system which prevents organisations from becoming accountable and transparent regarding SF₆ and carbon emissions. Government policies play a crucial role in influencing industries to use sustainable switchgear and the government can also motivate industries by applying sustainable switchgear for Government projects (Sovacool *et al.*, 2021). The lack of government initiation and effective monitoring of SF₆ and carbon emissions from switchgear in India reflects the challenges for the industry to reduce carbon emissions from it. It can also be determined that the SF₆ monitoring in India is dependent on international institutes which creates challenges for developing sustainable switchgear.

Further, developing alternatives to SF₆ or sustainable switchgear is a long-term process. It takes decades for organisations like Siemens Energy to find an alternative technology that can eliminate SF₆ gases from GIS (Dong *et al.*, 2023). Developing sustainable technology in switchgear requires intense research and development. Therefore, it is important to understand the necessity of preventing greenhouse gas emissions from switchgear to invest in research on development for finding substitutes. Creating new technology and implementing it is a time-consuming process and the Indian power industry also needs to be focused on using sustainable infrastructure and switchgear. In addition, Switchgear has a lifespan of a minimum of 25 years. The long lifespan of the product enhances the challenges related to its safety, maintenance, efficiency, productivity and sustainability. Outdated switchgear not only hampers the environment but also reduces the efficiency of the power systems (Islam *et al.*, 2021). Therefore, sustainable practices need to be introduced at each phase of the life cycle of switchgear which requires advancement in technology along with regular upgradation in electrical systems. Thus, adapting sustainable practices becomes difficult because they need to be adopted for different phases of the product.

Furthermore, one-third of organisations across the globe lack funds for sustainable innovation. Manufacturing organisations allocate 12.2% of their budget and energy, and oil and gas organisations allocate 11.9% of their budget to sustainability (Consultancy.eu, 2023). Therefore, sustainability not only includes sustainable innovation but also includes all the actions taken by the organization to

enhance overall economic, social and environmental sustainability. It has been difficult for organisations across the globe to increase budgets for sustainability in the past few years due to economic vulnerability. The Indian Switchgear market is not an exception because it also lacks funding for investing in research and development of sustainable switchgear (Syed *et al.*,2020). Therefore, lack of sufficient funding is another challenge for sustainable Switchgear manufacturing to reduce carbon emission.

Conceptual Framework

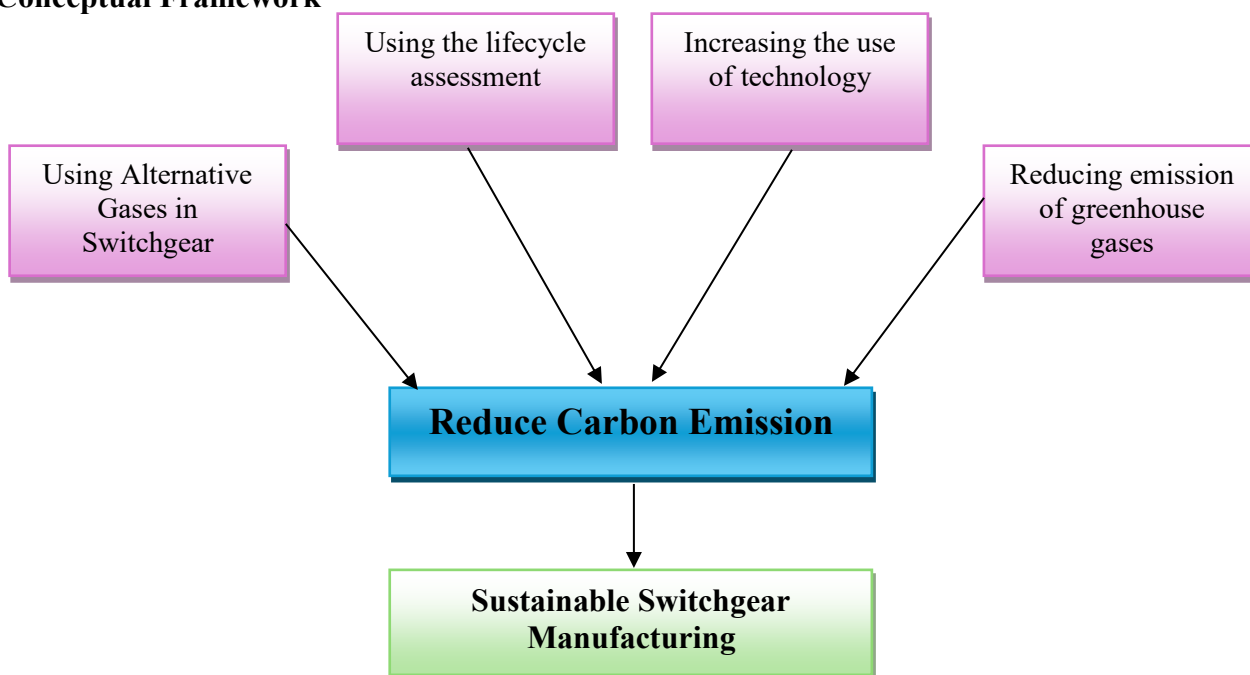


Figure 5: Conceptual Framework
(Source: Self-developed)

The conceptual framework highlights key strategies to mitigate carbon emissions in the switchgear manufacturing process with the ultimate goal of achieving sustainability. Central to this framework is the idea of reducing carbon emissions through multiple pathways, such as using alternative gases in switchgear systems to replace conventional greenhouse gas-intensive options, adopting lifecycle assessment approaches to evaluate and minimize environmental impact across production stages, and increasing the use of advanced technologies to enhance efficiency and reduce waste. These measures, when integrated, provide a structured approach to lower the carbon footprint of the industry. By combining these strategies, switchgear manufacturers can move toward the vision of sustainable switchgear production. The reduction of greenhouse gas emissions, driven by both material innovation and technological advancements, contributes significantly to meeting global climate targets while ensuring the reliability of electrical infrastructure. The framework emphasizes a holistic approach where sustainability is not only a regulatory compliance requirement but also a strategic choice that fosters innovation, efficiency, and long-term environmental stewardship in the switchgear industry.

Research Gap

The literature review has provided an overview of carbon emission reduction strategies in the switchgear industry of different countries. It includes minimum information in the context of the Indian switchgear market. Therefore, the study is developed to identify the strategies which are relevant to the Indian Switchgear manufacturing industry. It has determined that life cycle assessment is important in carbon emission reduction measures and how it is applied by organisations in

measuring product sustainability. However, it has a further scope of examining the impact of the life cycle on carbon emission reduction. Further it has identified technological innovation in switchgear manufacturing by different global organisations for reducing carbon. Thus, the innovation that took place in the Indian manufacturing industry needs to be identified in the future studies.

Conclusion

The literature review has found that the carbon emission strategies in the switchgear manufacturing industry have only been adopted by a few organisations. It has provided examples of Siemens Energy and how the US and Germany have adopted SF6-free GIS in their power supply system. It reflected that major strategies are focused on identifying alternatives to SF6-based switchgear. However, maintenance of Switchgear is also important for reducing carbon emissions because faulty switchgear can also cause carbon emissions. It has been determined that the life cycle assessment is crucial for carbon emission reduction measures because it provides a holistic perspective regarding the environmental impact of the product. The calculation by applying this assessment enables organisations to understand the effectiveness of their sustainable initiative at every phase of the product life cycle. Technology innovation for carbon reduction also includes hybrid switchgear and developing environment-friendly switchgear that uses vacuum, solid insulation or other gases instead of SF6. However, the identified challenges are lack of government initiative, lack of infrastructure facilities and funding in the Indian market.

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