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RISK ASSOCIATED TO HYDROGEN STORAGE AND ITS TRANSPORTATION IN THE CONTEXT OF CONAKRY, REPUBLIC OF GUINEA.

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DECLARATION

I hereby declare that the thesis submitted is my original work and that no other sources or learning aids, other than those listed, have been used.

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SAKOUVOGUI MASSA GOUO

DEDICATION

I address this memorial to my family and all the people of Guinea.

To my family of the First Love Church International.

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ABSTRACT

The energy demand is a major challenge given the defective roads and the population explosion in the city of Conakry. Faced with this difficulty, petrol stations are the services of the energy source for the consumer. Thus, the risks associated with these installations including fire and explosion attract more attention. However, hydrogen grafting at these petrol stations could be an alternative to this situation, hence the topic "**Risks related to the storage and transport of hydrogen in the context of Conakry, Republic of Guinea**". The aim of this research is to identify the risk associated to hydrogen storage and its distribution based on the risk associated to petroleum to identify the potential risk in case of hydrogen use in the same station in Conakry. Specifically, it involves (i) the study of hydrogen storage and transportation standards, (ii) an inventory of the storage and transport of petrol and gas, (iii) proposing a scenario of the risks associated with the storage and transport of hydrogen referring on hydrocarbons, and (iv) finally, to propose measures and solutions to minimize the risks of storage and transport of hydrogen in Conakry. The approaches used are based on documentary exploitation, survey and mapping and direct field observation. Google Earth Pro, Arc QGIS 3.16 were used to complete satellite image processing and map development. The associated risk assessment was carried out by selecting several scenarios using the SWOT analysis. The results show that there are more than 100 existing gas stations in the city of Conakry. However, these service stations are mostly located in the area not suitable for hydrogen integration. Only a service station located in the appropriate area is favourable to accommodate hydrogen technologies in the city of Conakry. Taking into account the considerations developed by the respondents in this survey and on the basis of standard documents, it is clear that accidents may occur either by failure of equipment and means of protection or by act of malice by the recklessness of users and employees. Some of these accidents involve flammable cloud fire and explosion phenomena. The accident scenarios to be retained could therefore consist in considering leaks accidental or intentional fuel occurring on distribution areas, attacks coming from the outside. To ensure the safety of the plant operator, customers and people around the refuelling station, additional mitigation plans were proposed. Future in-depth studies to validate the distances between the equipment of the energy station by modelling in case of accidental leaks, fire and explosion are necessary as well as the specification of the classification of hazardous areas in which any potential ignition source can be adequately controlled.

Keywords

Petrol and gas stations, Hydrogen, storage, transport and Conakry, energy station.

RESUMÉ

La demande en énergie est un défi majeur compte tenu des routes défectueuses et de l'explosion de la population dans la ville de Conakry. Face à cette difficulté, les stations-services sont les sources d'énergie pour le consommateur. Ainsi, les risques associés à ces installations, y compris les incendies et les explosions, attirent davantage l'attention de la population. Cependant, la greffe d'hydrogène dans ces stations-services pourrait être une alternative à cette situation, d'où le thème "Risques liés au stockage et au transport d'hydrogène dans le contexte de Conakry, République de Guinée". L'objectif de cette recherche est d'identifier le risque associé au stockage d'hydrogène et sa distribution en se référant du risque associé au pétrole pour identifier le risque potentiel en cas d'utilisation d'hydrogène dans la même station à Conakry. Il s'agit notamment (i) de l'étude des normes de stockage et de transport de l'hydrogène, (ii) d'un inventaire du stockage et du transport de l'essence et du gaz, (iii) de la proposition d'un scénario des risques liés au stockage et au transport de l'hydrogène se référant aux hydrocarbures, et (iv) enfin, proposer des mesures et des solutions pour minimiser les risques de stockage et de transport d'hydrogène à Conakry. Les approches utilisées sont basées sur l'exploitation documentaire, le relevé et la cartographie et l'observation directe sur le terrain. Google Earth Pro, Arc QGIS 3.16 ont été utilisés pour compléter le traitement d'image satellite et le développement de cartes. L'évaluation des risques associés a été réalisée en sélectionnant plusieurs scénarios à l'aide de l'analyse SWOT. Les résultats montrent qu'il existe plus de 100 stations-services dans la ville de Conakry. Cependant, ces stations-services sont pour la plupart situées dans la zone non adaptée à l'intégration de l'hydrogène. Seule une station-service située dans la zone appropriée est favorable pour accueillir les technologies de l'hydrogène dans la ville de Conakry. Compte tenu des considérations développées par les répondants dans cette enquête et sur la base de documents standards, il est clair que des accidents peuvent survenir soit par défaillance de l'équipement et des moyens de protection, soit par acte de malveillance de la part des utilisateurs et des employés. Certains de ces accidents impliquent des incendies de nuages inflammables et des phénomènes d'explosion. Les scénarios d'accident à retenir pourraient donc consister à considérer des fuites accidentelles ou intentionnelles de carburant survenant sur des zones de distribution, des attaques venant de l'extérieur. Pour assurer la sécurité de l'exploitant de la centrale, des clients et des personnes autour de la station de ravitaillement, des plans d'atténuation supplémentaires ont été proposés. Des futures études approfondies pour valider les distances entre les équipements de la station énergétique par modélisation en cas de fuites accidentelles, le feu et l'explosion sont nécessaires ainsi que la spécification de la classification des zones dangereuses dans lesquelles toute source d'inflammation potentielle peut être contrôlée de manière adéquate.

Mots clés

Stations-service, Hydrogène stockage et transport.

ACRONYMS AND ABREVIATIONS

AFID	Alternative Fuels Infrastructure
AFREC	African Energy Commission
APEA	Association for Petroleum and Explosives Administration
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
CGA	Compressed Gas Association
CNG	Compress Natural Gas
CNT	National Transition Council
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EI	Energy Institute
EIGA	European Industrial Gas Association
FMEA	Failures Methods Events Analysis
GIS	Geographical Information System
HAZOP	Hazard and Operability
H_2	Hydrogen
HYPROVAL	Hydrogen Approval
HRSs	Hydrogen Refuelling Service station
ICC	International Code Council
ISO	International Organization for Standardization
LPG	Liquified Petroleum Gas. Either pure propane or pure butane
M	Meter
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organizations
NFPA	National Fire Protection Association
PFS	Petrol Filling Station
PHA	Process Hazard Analysis
PUWER	Provision and Use of Work Equipment Regulations
QRA	Quantitative Risk Assessment
QRA	Qualitative Risk Assessment
SAE	Society of Automotive Engineers
SONAP	National Petroleum Corporation
THC	Total hydrocarbon Content
UL	Underwriters Laboratories
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use

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INTRODUCTION

Background

The primary sources of energy in Guinea, specifically in Conakry, consist of biomass and oil according to African Energy Commission's (AFREC), (2020) energy balance. The majority of electricity generation comes from hydropower and fossil thermal sources. Biomass, primarily in the form of charcoal, accounts for the largest portion, contributing to 77% of the primary energy consumption. Over 84% of households have access to biomass as an energy source *(*AFREC, 2020). Guinea relies entirely on imported petroleum products, and there are limited quantities of stored Liquid Petroleum Gas (LPG), which is only affordable for wealthier consumers due to its relatively high price.

In Conakry, the storage and transport of hydrocarbons is a major challenge due to the lack of infrastructure and resources. The city has a limited number of service stations that store hydrocarbons. Most of these service stations are located in the city centre, where all the socio-professional and administrative activities take place. The majority of these service stations are privately owned and operated. This results in dependence on foreign companies to provide storage and transport services, which can be costly and inefficient.

A report analysis of the data collected by Berger, (2019) revealed constraints at institutional level. These include the failure to implement a procedures manual, the absence of a permanent framework for collaboration between the main players in the sector, and the absence of a clear policy on energy alternatives to polluting conventional energy sources.

In addition, according to the same author, the lack of infrastructure has led to a reliance on road transport, which is slow and can be dangerous due to poor road conditions. Traffic is congested and the public transport system is unreliable. Lack of investment in infrastructure has led to a lack of safety for drivers and pedestrians. Today, the government is working to improve the storage and distribution of hydrocarbons, but progress is still slow. The storage of hydrocarbons is a strategic challenge that requires the use of reliable and proven technologies.

Surveys conducted by ONU-Habitat, (2020) on road traffic modelling revealed the problems inherent in transport in Conakry. Traffic levels are higher in the city centre. Thus, internal movements in the municipalities are more important characterizing the impact of the absence of secondary networks on the saturation of the main axes of the city.

Survey conducted by World bank, (2017) reported that about 60% of the main network in the city of Conakry were in poor condition. In addition, the city is invaded by many strains that create natural segmentations. These routes are used as a means of transportation to resolve radial congestion and connectivity issues between neighbourhoods. The following figure 1 shows the different lines and the traffic of the vehicles.

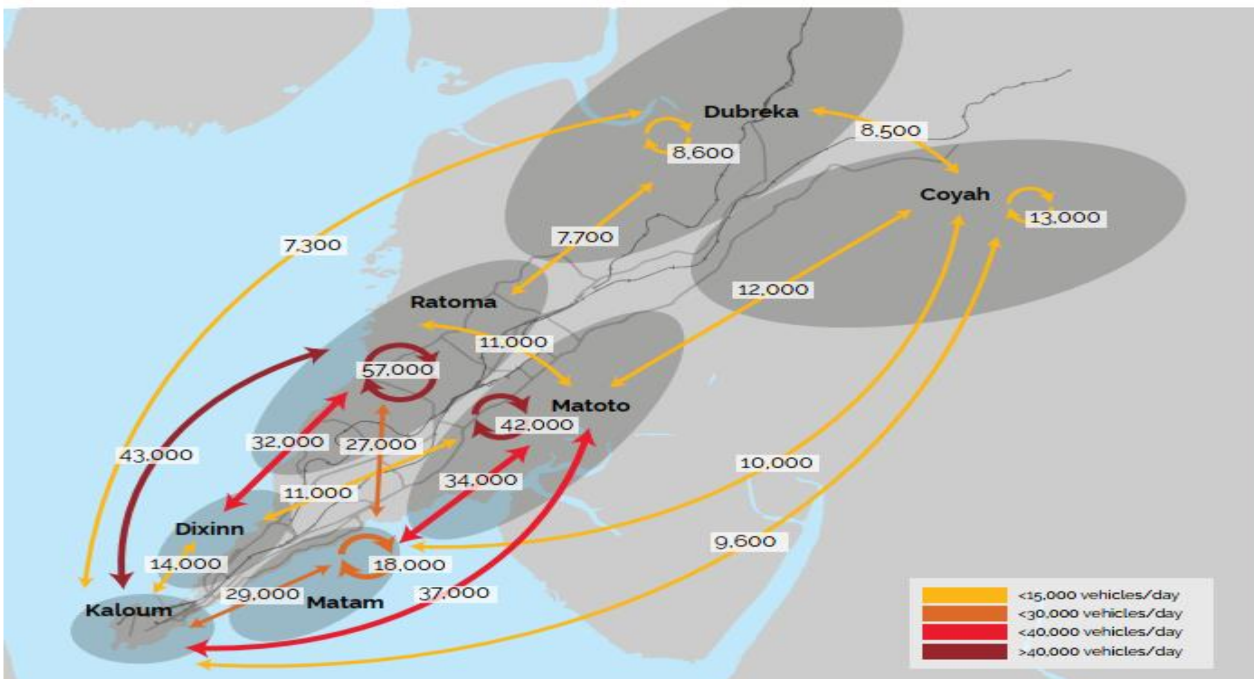

Figure 1 : Vehicle flows in Conakry (Berger,2019)

Moreover, the lack of management of the major hubs, the anarchic parking and the untimely stops of craft carriers are all additional factors of congestion and road insecurity. The anarchic traffic and parking of trucks in relation to the Port is a major problem of road safety and congestion on all types of roads. No sidewalk or public space is spared by the lawless parking of vehicles. However, public transport is largely informal and cannot meet the demand for mobility under current conditions. These factors reflect a high level of fuel consumption at Conakry gas stations (World bank, 2019).

For fuel delivery to the customer, the gas station is the main source of supply. A gas station is defined as land used to sell motor vehicle fuel and lubricants. It may include the sale of accessories or parts for motor vehicles, food, beverages and other convenience items, the maintenance or washing of motor vehicles and the installation of accessories or parts for motor vehicles.

According to Bah, (2013) there are now more than 46 Total Energies in Conakry. This company provides these customers with gasoline, petroleum, diesel, lubricant, gas, insecticide, car maintenance and bitumen products. Some service stations provide washing and emptying services for these customers' vehicles. In addition to other companies exist such as Energy VIVO, which distributes and markets Shell products and services in Guinea; STAR, SONAP, Guinean Petroleum Company (SGP), Petrol and Mining Environment, SODIGAZ Guinea, etc.

In recent years, competition between these various companies has led to the construction of several service stations in the suburbs. This allows young people opportunities to integrate hydrocarbons into the system. However, young people who are looking for the jobs are exposed to certain service stations without prior training.

Furthermore, hydrocarbons are highly flammable and are typically stored in underground tanks where they are sold at retail through metered gasoline pumps. Service station nozzles can cause unintentional leakage near gas pumps. These leaks can result in fuel losses during refuelling as they release gasoline vapours from the vehicle tank due to elevated fluid levels in the tanks. The location of retail outlets deserves planning direction and adherence to existing guidelines because of their importance to the health and safety of the public. Due to the nature of the handling of these flammable and hazardous materials, they can present fire and explosion hazards if ignited (Hilpert *et al.*, 2019; Chaiklieng *et al.*, 2020).

Likewise, hazardous chemical typically stored in petrol station are unleaded petrol, premium unleaded petrol, petroleum liquefied (LPG), diesel and compress natural gas (CNG). Studies of harmful exhaust emissions from diesel and CNG transit buses under real-world operating conditions have shown that CNG buses can reduce CO2 by 6% and NOx by 90%. However, compressed natural gases (CNG) are characterized by higher CO emissions of 45% and total hydrocarbons (THC) emissions of 156% (Warguła *et al*., 2020).

Effective planning initiatives reduce and eliminate potential impacts of major hazards. Therefore, it is necessary to know the normal operation of the service station and the risks at each step of the work. For example, technical practices have been put in place by Total and Shell with respect to regulatory provisions in order to minimize risks at Conakry stations. It is always recommended that the driver get off the bike or car while refuelling, and that the engine be turned off.

Among the major hazards identified from the operational of petrol station are fire, explosion and toxic release which comes from the tank filling process by road tanker, hazards when storing and handling and finally while fuel dispensing and transferring process.

In 2015 in Accra, Ghana, a major accident due to the release of fuel from the underground tank caused the explosion and fire during a flood. 250 people were killed while hiding at the gas station (BBC News, 2015). Similar incidents occurred in Germany on the outskirts of a gas station northeast of Frankfurt on 17 January 2022 resulting in the death of two people (Newspaper, 2022). In Guinea-Conakry, ethnic violence in the south had led to the throwing of stones and shots at gas stations. Violence had set gas stations on fire, resulting in the loss of life (Moshiri, 2013).

Beyond these risks, the heavy reliance on fossil fuel resources, which cause global problems, must be reduced in order to improve the environment and consequently its impact on human health. To do this, the energy transition is an important step that must be taken to safeguard the planet. So, after the signing of the Paris Agreement in 2015, many countries around the world focused on the hydrogen economy, aiming for green and renewable energy by moving away from the existing carbon economy, which has been the main source of global warming. Hydrogen is the most common element on earth. However, this light substance can spread rapidly, but it also poses a low risk of explosion.

However, sufficient hydrogen storage for future use at Conakry gas stations would help to mitigate climate change by reducing greenhouse gas emissions. Hydrogen is widely considered a clean source of energy from the viewpoint of reduction in carbon dioxide emissions. Thereby hydrogen refuelling stations are essential to fuel cell vehicle operations.

According to Gye *et al.* (2019) hydrogen filling stations are operated by using by-product hydrogen generated in the petroleum refining process and filling the tube trailers with by-product hydrogen, which is then sent to compressors. It is then compressed under high pressure and sent to priority panels, moving from the priority panels to the storage tank and dispenser. With respect to the development of hydrogen stations, many countries have difficulty expanding hydrogen infrastructure due to the high risk of hydrogen. The planning process for hydrogen refueling stations (HRS) involves making decisions about the specific technology, quantity, locations, and capacities of the stations. This plan aims to address the expected hydrogen demand for an increasing number of fuel cell vehicles in a particular region, considering factors such as population growth (Greene *et al.*, 2020).

This integration study of hydrogen and petroleum storage facilities will allow us to establish a site or station where hydrogen and petroleum products can be efficiently stored and distributed, as well as potential synergies between the two carriers' energy. All studies around the world show that hydrogen offers possible solutions to reduce greenhouse gas emissions and mitigate the effects of climate change. However, there are serious concerns about the risks associated with storing and transporting hydrogen. Special arrangements must be made to address the risks associated with hydrogen to ensure its safe integration into Conakry's existing energy infrastructure.

Furthermore, risk assessment has been used rigorously worldwide in estimating of risk chemical storage regards to flammable and toxicity. Thus, risk assessment should also be adopted and used for the downstream in answering the incidents that had happened in the past to avoid similar occurrence in future. The importance of addressing this issue has brought attention to some researchers.

Problem statement

As the city continue to grow economically and in terms of human population, so are the number of vehicles and the rate of fuel consumption. In the light of this, the daily fuel consumption expectedly increases thereby creating opportunity for potential investors to establish fuel stations in order to fill the supply gap and more importantly to make money. Marketing petroleum products is a very lucrative business that guarantees quick returns; hence, there is a daily upsurge in the establishment of fuel stations in every nook and crannies of the city.

However, the government's dependence on fuel imports in insufficient quantities limits consumer satisfaction in all areas of city development. This crisis often leads to overflows in the city causing injuries and riots. Today, the replacement of fossil fuels with renewable energies such as hydrogen is a new solution that draws more attention to reducing greenhouse gas emissions. Hydrogen is considered a major energy vector for the future.

Yet, hydrogen storage and transport appear to be critical considerations. Therefore, the integration of hydrogen into service stations is necessary given the existing hydrocarbon infrastructure. An essential prerequisite for achieving a hydrogen economy is the development of a quality infrastructure that, by definition, includes the system needed to produce, store and transport hydrogen to its users. Given the particular issue of hydrogen storage, all systems must be analysed in a comprehensive manner. Unlike gasoline or diesel, which easily handle liquids under ambient conditions, hydrogen is a light gas and has the lowest volumetric energy density of any fuel at normal temperature and pressure. Therefore, the most important problem for hydrogen is to store sufficient quantities of hydrogen.

According to Saufi, (2018), there are many researchers who have conducted research in the area of process safety, including risk assessment at major facilities, such as chemical plants, nuclear power plants, transportation facilities and facilities that pose a major hazard, but less so on facilities that do not pose a major risk, such as a gas station. However, there is no specific methodology that was used and introduced into the service station as the chemicals in the station are below the threshold limit as the requirement.

Therefore, an effective risk assessment framework should be developed to highlight the risk so that the operation of the service station is inherently safer. Ultimately, the holistic approach can be implemented that integrates all the elements of site selection, commercial consideration, safety of people and finally the integration of hydrogen into service stations. Today, no specific study has been done for the storage and transport of hydrogen in the city of Conakry. Therefore, the main objective of the present study is to assess the risks associated with hydrogen storage and transport in Conakry.

Research objectives

The specific objectives of this study are:

1. To study hydrogen storage and transportation standards;
2. To inventory the storage and transport of LPG gas and petroleum hydrocarbons stations in Conakry;
3. To propose a scenario for the storage and transport of hydrogen based on LPG gas and petroleum hydrocarbons stations in Conakry;
4. To analyse the risks associated and propose the measure as solutions to overcome of storing and transporting hydrogen in hydrocarbons stations in Conakry.

Research Questions

How to study the storage and transportation standard?

How to inventory the storage and transport of gas and petroleum hydrocarbons in Conakry?

How to propose a scenario of the risks related to the storage and its transport of hydrogen in Conakry?

How to minimize the risks of storing and transporting hydrogen in Conakry?

Scope

The aim of this study is to make the analogy between the encounters in the service stations by hydrocarbons and the risks related to the integration of hydrogen in these service stations.

Structure of the study

The first chapter introduces the work and discusses the problem statement, scope of the study, research questions and research objectives. The second chapter is dedicated to the synthesis of the relevant literature on the different forms of hydrogen storage and the risks associated with their installation. The third chapter presents the results and the discussions on the results obtained. A conclusion and recommendations will end this study.

CHAPTER ONE: LITERATURE REVIEW

1.1 Overview of hydrogen storage techniques and its transportation

Hydrogen has emerged as a promising alternative energy carrier due to its high energy content, versatility, and environmental benefits. However, one of the key challenges in utilizing hydrogen as a widespread energy source is its efficient storage and transportation. Hydrogen is a light, odorless, and highly flammable gas, which poses unique challenges in terms of storage and distribution. Over the years, significant research and development efforts have been directed towards developing safe, efficient, and cost-effective hydrogen storage techniques and transportation methods (Moradi and Groth, 2019).

Sdanghi *et al.* (2019) reported that for hydrogen to be used as an energy carrier requires safe and efficient storage comparable to gasoline. In addition, simple handling and low costs are also important factors to consider. These requirements are essential for widespread adoption and integration of hydrogen as a viable energy source. By addressing these aspects, hydrogen can become a practical and competitive alternative to conventional fuels.

Hydrogen demonstrates the highest gravimetric energy density among non-nuclear fuels and can be readily transformed into thermal, mechanical, and electrical energy (Farias *et al.*, 2022). Its application of this technology in both stationary and automotive contexts, such as fuel cells, offers a promising pathway to harness electrical and thermal energies in an environmentally-friendly manner. This paves the way for a new opportunity to globally embrace sustainable energy on a large scale (Rivard *et al.*, 2019).

In spite of the benefits it offers, there are two primary obstacles hindering the widespread adoption of hydrogen as a viable fuel and impeding the transition towards a sustainable, non-fossil energy solution. The first issue pertains to the fact that hydrogen is an energy carrier, necessitating its production prior to utilization. Consequently, energy is required for the synthesis of hydrogen. The second, hydrogen exhibits the lowest volumetric energy density among the commonly used fuels, 0.01079 MJ/L at standard temperature and pressure (12), much lower than that of gasoline, 34 MJ/L (Preuster *et al.*, 2017).

In order to increase this value, several methods have been developed: (i) compression in gas cylinders; (ii) liquefaction in cryogenic tanks; (iii) storage in metal hydride alloys; (iv) adsorption onto large specific surface area-materials and (v) chemical storage. Among them, compression of hydrogen is the most widespread method to store hydrogen, even if it is not the cheapest one.

1.1.1 Compressed Gas storage

This method involves compressing hydrogen gas to high pressures and storing it in high-strength cylinders or tanks. Compressed hydrogen gas storage offers a relatively simple and mature technology, but it requires heavy and bulky containers, making it suitable for stationary applications rather than transportation. It refers to storing hydrogen at high pressure, typically 350 and 700 bar (~5,000 and ~10,000 psi), in a pressure capable vessel (Preuster *et al.*, 2017;Paul-Boncour and Percheron-Guégan, 2018,).

Bezrukovs *et al.* (2022) reported that to enable widespread adoption of hydrogen in vehicles, appropriate infrastructure and a network of hydrogen refuelling stations are needed. The central component of such a refuelling station is an additional compressor that can guarantee the high hydrogen pressure, up to 100 MPa, needed for refuelling.

1.1.2 Hydrogen storage in liquid form

The storage of hydrogen in liquid form offers double capacity comparing to the high-pressure hydrogen storage (Demirocak, 2017)**.** Its volumetric storage capacity of hydrogen in liquid form is higher than that of gaseous hydrogen, but it is still relatively low compared to other fuels like gasoline or diesel (Preuster *et al.*, 2017).

This is because hydrogen has a very low density, even in liquid form, and therefore requires larger tanks or containers to store a significant amount of energy (Ustolin *et al*., 2020). As an alternative, liquid hydrogen can be transported using trucks or other vehicles as an option. Compared to compressed gas containers, liquid hydrogen trailers can carry a larger amount of hydrogen due to the higher density of liquid hydrogen compared to its gaseous form (Adolf, 2017).

Higher energy per volume levels can be achieved by liquifying hydrogen. However, challenges in hydrogen liquid storage and transportation ultimately pose restrictions on its wider adaption along horizontal and vertical vectors (Otto *et al*., 2022).

1.1.3 Solid-state hydrogen storage

The storage of hydrogen in solid-state form using metal hydrides is a promising technology for efficient and safe hydrogen storage (Faye *et al.*, 2022). Metal hydrides are compounds formed by the reaction of hydrogen with metals or intermetallic compounds, and they can reversibly store and release hydrogen gas through a process called hydrogen absorption/desorption (von Colbe *et al.*, 2019). The host hydrogen storage materials may consist of a solid solution alloy. These are characterized by varying composition and disordered substitution of one element for another on crystal lattice sites (Gross and Carrington, 2008).

The development of efficient hydrogen storage techniques and transportation methods is vital for harnessing hydrogen's potential as a clean and sustainable energy source. Ongoing research and advancements in these areas aim to overcome the challenges associated with hydrogen storage and distribution, paving the way for a hydrogen-powered future.

1.2 Hazard identification and Risks assessment

The chemical process industries frequently handle dangerous chemicals and processes that carry a significant risk of major accidents. Despite notable progress in process safety science and technology, these industries still experience significant accidents due to the increasing quantities of chemicals being managed worldwide.

Rademaeker *et al.* (2013) reported that, the expansion of chemical process industries, along with the introduction of new processes operating at extreme temperatures and pressures, presents additional challenges and risks. Processes involving very high or low temperatures and pressures can be more complex and require stringent safety measures to prevent accidents. The potential consequences of major accidents in the chemical process industries can be severe, including human casualties, environmental damage, and economic losses.

Similarly, Abbasi *et al.* (2017) notes that accidents in the chemical process industry result in significant damage to human health, loss of life, loss of property and environmental pollution. An accident occurs when there is no control over the release of hazardous substances, resulting in fires, explosions or the spread of toxic materials. The severity of an accident is determined by the magnitude of the event and the characteristics of the affected environment.

Hemmatian *et al*. (2015) reported that major accidents usually start with a breach in the containment. Unintentional release of a substance from a confined device such as a tank, distillation column or pipe, resulting from factors such as a hole, crack or open valve. The underlying causes may range from corrosion and mechanical impact to human error. It's important to note that the loss of containment itself can be considered an accident, such as when a pressurized tank explode.

Khalid *et al.* (2017) clarified that once the breach occurs, the subsequent progression of the incident hinges upon various factors, including the state of the material (gas, liquid, or a combination thereof), its characteristics, prevailing weather conditions, and the measures implemented to mitigate the leakage**.**

Therefore, a need of qualitative research to carry out to justify the perception of risk not just to the workers but also to give a general information of risk precautions to the people living vicinity of the service station. Figure 2 shows a precautionary risk measure at hydrogen refuelling stations.

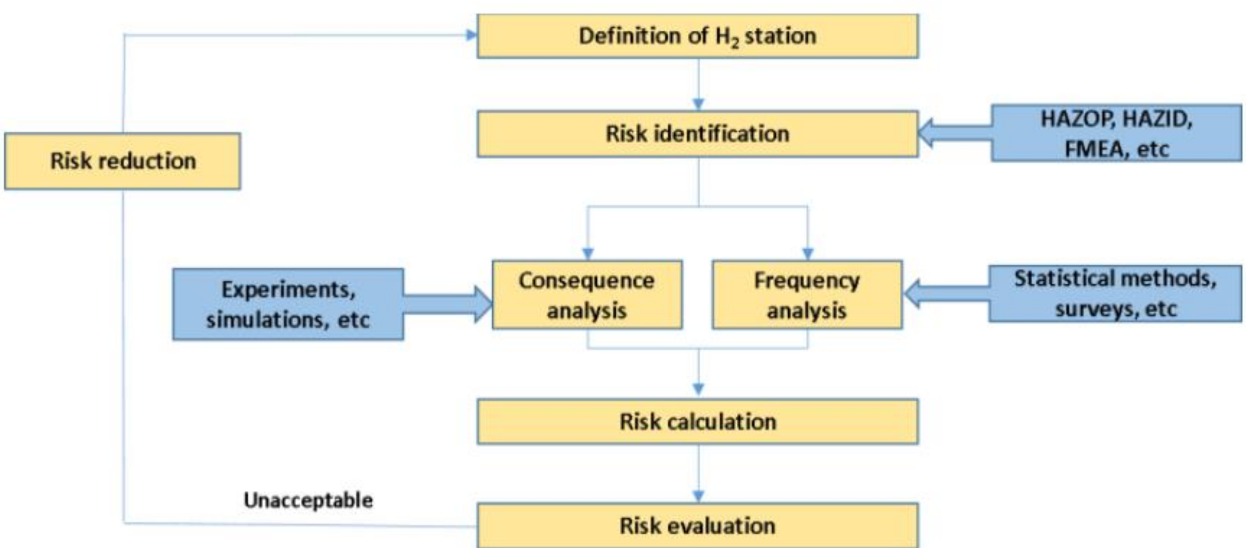

Figure 2 : Risk assessment scheme for hydrogen fuelling station (Veres Jan et al., 2022)

1.3 Risks assessment states of knowledge

Risk assessment is the act of collecting information and analysing it to gain insight into the potential risks associated with a specific setting. It entails a methodical approach to identifying and evaluating possible hazards, aiming primarily to prevent and decrease accidents in potentially dangerous facilities. It is completed by ranking hazards to locate the highest-risk activities. This can be done qualitatively by combining the impact and probability for each hazard into an overall risk level.

Therefore, before moving forward with the construction, the proponent may desire to assess the risks involved and allocate resources to reduce the likelihood of accidents. Similarly, the local authorities responsible for approving the project would be interested in understanding whether the installation poses an acceptable level of risk to the nearby development and the human population

Shamsuri *et al.* (2017) reported that risk assessment has been used since the 1940s during the Second World War to assess the danger associated with storing explosives away from army barracks). Subsequently, in the 1960s, the field of probabilistic reactor analysis (EPR) emerged, with particular emphasis on the safety of nuclear reactors rather than on the broader concept of risk itself. However, it was in the 1970s that the Quantitative Risk Assessment (QRA) was established as a framework to address three key questions:

a) What can go wrong?

b) How likely is it?

c) What are the consequences?

Han and Weng, (2011) mentioned that, the importance of risk assessment has increased in the recent year in estimating the risk related to various hazardous activities. It could be either quantitative or qualitative after considering the objectives of the analysis. Qualitative risk assessment is an initial exercise to assess the risk pose by a proposed installation and it gives the risk ranking of the identified hazards by using risk ranking or risk matrices whereas quantitative risk assessment is an estimation of the risk level in absolute terms.

1.4 Risks assessment techniques

Various risk assessment techniques are commonly used in industries across the globe. These techniques differ in their approach and prerequisites, which means they demand varying levels of expertise from the users. Table 1, presented below, offers recommendations on which techniques are appropriate for process hazard analysis and their specific objectives. However, the specific methodology employed for each technique can vary significantly, so the information provided in the table is intended solely as a guiding reference.

Table 1 : Risk assessment techniques methodology

Method	Qualitative/quantitative	When to be used
PHA	Qualitative	Early in the design process when little detail about design is available.
HAZOP	Qualitative	During detailed design, verify a safe and reliable process design. Focused on the identification of hazards related to the operation of components of a system.
FMEA	Semi-quantitative	Detailed design review with focus on safe design. An effort to rank the risk contributors in included. Identifies equipment failure modes and resulting consequences or hazards. Also identifies single point failures and requirements for redundancy or safety systems

1.5 Risks assessment methods

1.5.1 Qualitative risks assessment

Risk assessment can be categorized as either qualitative or quantitative, encompassing the identification of incidents and the analysis of their consequences. Initially, a qualitative assessment is conducted as a preliminary study to obtain a general understanding of the risk level before proceeding to a quantitative assessment. It can be conducted using both qualitative screening tools and detailed quantitative risk analysis tools.

The process of risk assessment is illustrated in figure 3 and involves an iterative approach. A commonly used method for identifying hazards is the Hazard and Operability (HAZOP) study. Once the HAZOP study is completed, the identified hazards can be recorded to establish accident sequences. The likelihood of each accident sequence can be estimated using a combination of fault trees and event trees.

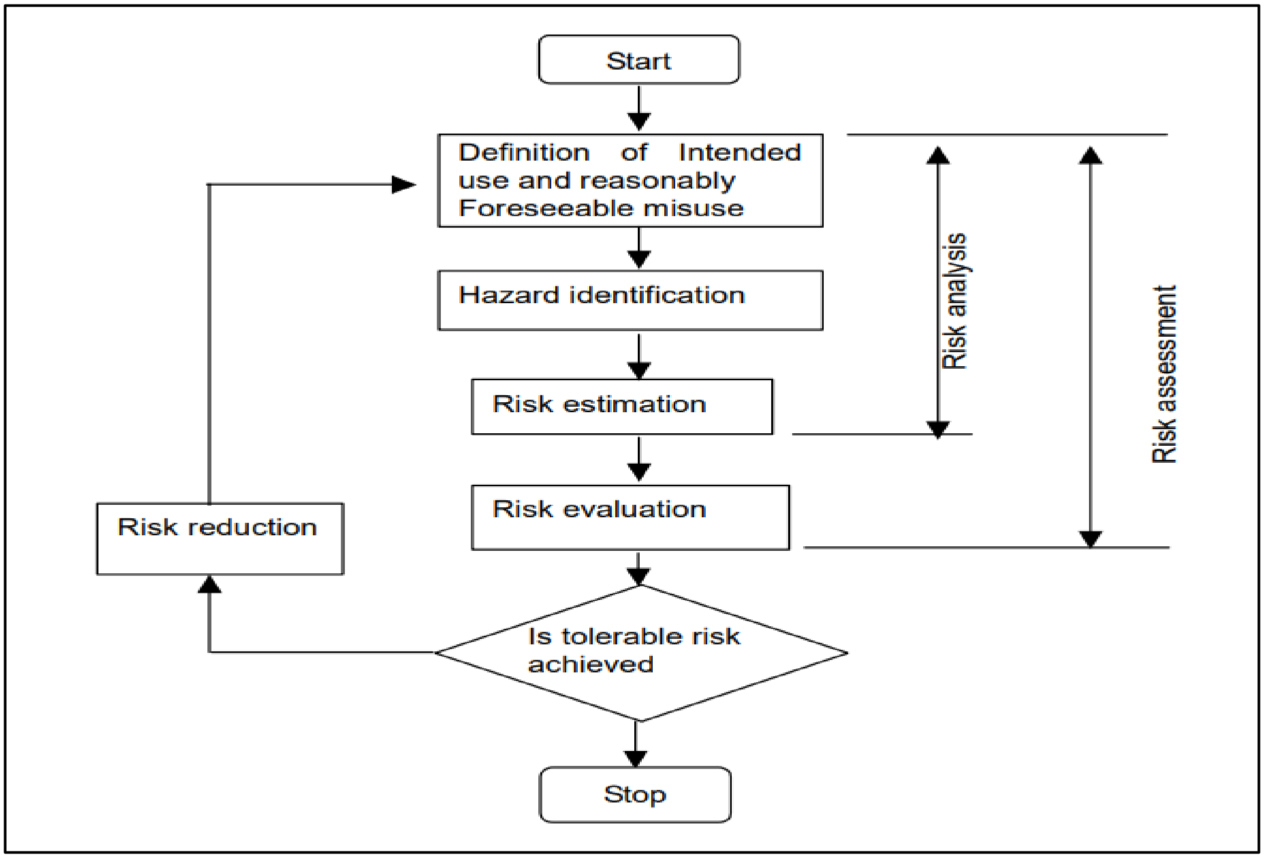

Figure 3 : Interactive process of risk assessment and risk reduction

Initially, a preliminary evaluation is carried out to obtain a general understanding of the risk level before proceeding with a quantitative assessment. The results of this qualitative risk assessment include risk ranking and risk index. Qualitative risk assessment methods are employed to prioritize various activities, including additional analysis, based on their importance (Xuchao Zhang *et al.*, 2022).

Table 2 shows an example of simplified or basic technique to categorise risk based on expert individual or team judgement while Table 3 is example of general risk matrix evaluation which is more in details.

Table 2 Basic qualitative risk assessment matrix for risk ranking (Haland and Borre, 2008)

Likelihood or Frequency	**Consequence severity**		
	High	**Medium**	**Low**
High	High	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low

Table 3 Risk matrix (Håland and Borre, 2008)

Severity / Probability	**Catastrophic (1)**	**Critical (2)**	**Marginal (3)**	**Negligible (4)**
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low

1.5.2 Quantitative risks assessment

Quantitative risk assessment entails using numerical data to calculate the probability and potential consequences of a given situation. By accurately quantifying risk, it provides the opportunity to adopt a more objective and analytical approach compared to the qualitative method. In essence, quantifying risk involves assigning a numerical value that represents the likelihood of a specific outcome, such as a fatality. There are many benefits on implementing QRA as outlined in Table 4 below.

Table 4 : Strength of quantitative risk assessment (Saufi, 2018)

No	Quantitative advantage	Present method compliance
1.	Results are substantially based on independently objective processes and metrics	All components are based on mathematical computation
2.	Great efforts put into asset value determination and risk mitigation	Employs rich knowledge database for risk mitigation and includes a mechanism for valuing asset impact
3.	It includes a cost/benefit assessment	Provides a range of measures for users to select to mitigate risk
4.	Results can be expressed in management-specific language	Can produce reports based on statistical computation of degree of control implementation

1.6 An overview of risk assessments for HRSs in the world

The hydrogen fuelling station can be described as a sophisticated technological system, comprising multiple interconnected devices that both interact internally and are influenced by external environmental factors (Veres Jan *et al.*, 2022). Therefore, the use of hydrogen in transport is a priority area and search for alternative fuel for road transport is absolutely necessary and unavoidable in the future. Filling stations will be given strategic importance, as their development must go hand in hand with the development of hydrogen mobility (Kim *et al.,* 2013).

Sakamoto *et al.* (2019) commented that hydrogen is dangerous because of its property of low ignition temperature, low ignition energy, wide explosion limit and fast burning speed. In a confined space, hydrogen is dangerous, like any other flammable gas. (Nakayama *et al*., 2016) analysed accidents and incidents at HRSs in Japan and the USA to identify the safety issues. Most types of accidents and incidents are small leakages of hydrogen, but some have led to serious consequences, such as fire and explosion. Recently, there was a serious incident in Norway at Kjørbo, where a strong explosion was observed (Mikalsen *et al.,* 2021).

Due to its properties, several studies have conducted a risk assessment. For example, risk assessments have been carried out with quantitative methods (Russo et al., 2018) , qualitative techniques (Sakamoto *et al*., 2016; Sun *et al*., 2014; Kasai *et al*., 2016), integrated methods (Al-shanini *et al.*, 2014), and the safety distance of hydrogen refueling station have been analysed (Lowesmith *et al*., 2014 ; LaChance *et al.,* 2012). The applicability of these methods is governed by regulations and standards in each country. These different evaluation methods ensure the proper functioning of the station including the safety of staff and their customers.

CHAPTER TWO: MATERIALS AND METHODS

2.1 Study of hydrogen storage and transportation standards

2.1.1 Documentary exploitation

Documentary exploitation, according to McCulloch, (2004), allows "to extract and process documents for further research, a search for information according to a specific need". This comprehensive analysis of the use of documents includes the data collection such as satellite data, location of PFS, collection of materials, international guidance for establishment, planning policy, legislation, published reports from the regulatory reforms and association and literatures from various developed and developing countries on storage and transport of hydrocarbons and hydrogen. These data were used to identify risks, critically analyse existing standards in a few countries with hydrogen facilities.

2.1.2 Risk assessment regulations/methodologies

Different regulations and laws around the world impose specific criteria for hydrogen refuelling stations. In Europe, for instance, there are directives in place to address these requirements. Directive 2014/94 (AFID - Alternative Fuels Infrastructure Directive) outlines the technical standards that must be met (Pique *et al.*, 2017). According to the same author, Directive 2012/18/EU (SEVESO) includes provisions for hydrogen refuelling stations, with storage facilities over 5 tonnes needing to adhere to lower-level requirements, while storage points exceeding 50 tonnes must comply with upper-tier requirements.

Table 8 in Chapter 4.1 corresponding to these requirements shows its various directives.

2.1.3 Safety distances

With increasing demand for FCEV, HRS are required to be upscaled and co-located alongside conventional fuels in commercial and residential areas. Co-location of hydrogen with different fuels may, however, require specific safety measures. However, with the storage and transport of hydrogen, the risks at the station are expected to increase. The safety distances refer to the smallest suggested gaps that should be maintained between different systems. For instance, in the context of conventional petrol stations, these distances are determined by the regulations and studies. These regulations establish the minimum separations required between the underground tank filling area, gas vapor ventilation systems, and the dispensers.

Matthijsen and E. S. Kooi, (2006) reported that safety distances between service stations and living and working areas appear similar for compressed hydrogen, petrol/diesel and compressed natural gas. Safety distances for LPG are greater. A filling unit for hydrogen can be placed in diesel/petrol stations without increasing safety distances.

Further, there is often additional discrepancy in how safety distances may be specified. For instance, in some cases, the safety distance values may be constant whilst in other cases they could be a function of the hydrogen storage pressure. The latter is much more realistic and a blanket specification of safety distances should be avoided (Middha and Macfarlane, 2021).

Table 5 Safety distances for multifuel station (Grasso et al., 2019)

Type of exposition	Safety distances for multifuel stations [m]	
	Dangerous elements of hydrogen refuelling station	Hydrogen dispensers
Gasoline and diesel oil tanks	10	
LPG tanks	20	10
Dangerous elements of natural gas refuelling station	15	8
Dispensers		8

Some regulations agree in the distances. This is for example; the storage of H_2 compared to petrol tanker delivery, underground storage of gasoline, gasoline dispensers and nearby buildings. On the other hand, other locations differ in distances. According to the guidelines, Table 6 shows the minimum safety distances between each equipment of the service station.

Table 6 Minimum safety distances between each equipment at the energy station

Location	**US**	**UK**

Dispenser to occupied buildings, footpaths highway and potential ignition sources	1.5 m	-
Potential release point from storage or compression equipment to buildings (Shop Service)	10.7 m	8m
H2 storage or compression equipment to dispensing	-	-
H2 storage or compression equipment to H2 vents	8m	8m
H2 storage or compression equipment to above ground fuel storage tank or Petrol Tanker Delivery	15m	8m
H2 storage to gasoline storage	15m	8m
Gasoline to H2 dispensing	3m	-

2.1.4 Guidelines

In addition to utilizing scientific literature, this thesis has also discovered the subsequent regulations and technical aspects related to the design, location, storage, refueling, and others measures concerning the utilization of hydrogen, petrol, and liquid petroleum gas (LPG). The documents consulted for this purpose are as follows:

2.1.4.1 The regulations found to analyse the storage and transport of petrol

The documents consulted for the analysis of hydrocarbon storage requirements are as follows: The guidance issued by the Health and Safety Executive (HSE, United States): *Guidance to the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)*, 2020); *Petrol Filling Stations: Guidance on Managing the Risk of Fire and Explosion* (The Energy Institute (EI), 2018). Design, construction, modification, maintenance and decommissioning of filling stations (*The Blue Book created by the Association for Petroleum and Explosives Administration* (APEA) and Energy Institute (EI)): *Hazardous Area Classification and Planning and Design* (APEA/EI, 2018).

2.1.4.2 The guidelines found to analyse the storage and transport of hydrogen

The following documents were used to study the requirements of hydrogen storage and transport such as: *ISO/IEC 60079-10-1:2020 Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres*, (2020); Rivkin *et al*., (2016): *Guide to Permitting Hydrogen Motor Fuel Dispensing Facilities*; *Guidance* on *hydrogen delivery systems* for *refuelling* of *motor vehicles*, *co-located* with *petrol fuelling stations* (published by Energy Institute, London); Petroleum and Gas Inspectorate, (2022): *Hydrogen Safety Code of Practice*; ISO/TS 19880-1:2016, Gaseous H2 - Fuelling Stations. Part 1: General requirements. *Risk reducing measure;* NASA, (2005), *Safety standard for hydrogen and hydrogen systems.*

2.1.4.3 The regulations consulted to analyse Liquid Petroleum Gas (LPG)

The relevant legislation for the safe use of LPG includes in the following documents: *Storage of Flammable Liquids in Containers HSG51*, (2015); *Health and Safety at Work Etc Act 1974,* (1974); *Provision and Use of Work Equipment Regulations, 1998 (PUWER); Pressure Systems Safety Regulations,* 2000; *Dangerous Substances and Explosive Atmospheres Regulations, 2002* ***(DSEAR*****).**

2.1.5 Comparison of guidelines

Comparative research conducted by Pique *et al*. (2017), reviewed regulations, codes and standards for hydrogen refuelling stations designed specifically for light land vehicles in several countries, including the United States (especially California), the United Kingdom, Italy. The study identified various technical components required for a hydrogen refuelling station. These components include hydrogen storage systems (either cryogenic or compressed gases) and a buffer, compressor stations, high-pressure buffer, hydrogen cooling systems, distribution equipment, and distribution area. However, due to a lack of consensus among countries, there is currently no comprehensive list of international standards available. Likewise, ISO / TS 19880-1: 2016*,* examples of safety distances are collected according to the country where they are applied.

Different guidelines have been used to describe the layout of the station:

- US (United States): NFPA 2 Code 2 (Gaseous hydrogen systems of a pressure between 51.5 MPa to 100 MPa), and also NFPA55 (Compressed gases and cryogenic fluids code)
- UK (United Kingdom): (British compressed gases association, 2018);

-The design, construction, maintenance and operation of filling stations dispensing gaseous fuels;

- Hydrogen filling site safety separation distances, consideration guidance in BCGA CoP CP 41.

2.2 Inventory of the storage and transport of LPG gas and petroleum hydrocarbons stations in Conakry.

2.2.1 Site selection

The study was carried out at petrol stations in Greater Conakry. The greater Conakry is subdivided in 7 communes: Kaloum, Dixin, Matam, Ratoma, Matoto, Coyah and Dubreka. Conakry has an estimated population of 2.7 million. The climate of the city is tropical, and is characterized by temperatures ranging from a maximum of 37°.5 in April to a minimum of 24°.6 in August. The average annual rainfall is estimated at 4300.7 mm of rain with a maximum in July-August. The rains extend over about 100 to 115 days mainly from May to October.The relatively high humidity is between 70 and 85% (Bangoura, 2017). The geographical information system (GIS) made it possible to find the possible for the installation of petroleum stations and LPG combines with hydrogen.

2.2.2 Geographical information system (GIS)

According to By and Huisman, (2009) GIS is a tool that has been successfully used for site selection of any proposed project and has proven to be very useful in solving spatial problems Guler and Yomralioglu, (2017).

To make full use of GIS in the evaluation of the PFS location in Conakry, a good database and appropriate requirements have been developed. This is the process of declaring the features to be included in the database, taking into account the entities, the attributes, their relationships and, of course, the representation of these entities in the database. This is a general assessment of the adequacy of the adopted study area. The weighted overlay process was applied taking into account oil service stations, topography, roads and existing land uses in areas around the petroleum and LPG gas service station.

2.1.1 Survey

First, oil company executives, gas station managers, non-governmental organizations (NGOs), the National Transitional Council (NTC) and officials from the various ministries were contacted by email and telephone. Then, the presence of 2 field guides made it possible to identify and locate the different stations. Immediately, the number of respondents and the telephone numbers of the stations were mentioned.

A total of 105 services stations over 200 were chosen for this purpose. The choice of the station was based on the age of the station, the location, the aging of the equipment and the topographical position. The choice of this criterion is justified by the fact of identifying the failures and causes related to the various incidents (fire, explosion, site and environmental pollution) of the service stations in Conakry.

2.1.2 Data collection

For field data collection, taking into account the objectives assigned to the present work and the nature of the information to be collected, a quantitative approach was used. The survey method was used. The choice of this method is justified by the fact that it is an organized and methodical collection of data on features of interest to some or all of the units of a population using well-defined concepts, methods and procedures.

The questionnaire technique is adapted to collect accurate and easily quantifiable with a large number of participants. This is consistent with the various incidents produced in the stations which are in general quantitative or quantifiable data. The questionnaire was divided into two main sections. The first section A was aimed at the 10 heads of the Ministries of Energy, Environment, Habitat and Planning, the National Transition Council and non-governmental organisations. Section B was directed to the 4 persons in charge of the industrial oil companies and the 16 services stations managers. Questions were directed to the contacts. The questionnaire was administered to the respondents by the 2 field guides. The duration of the interview was a maximum of 30min. The aim was to gather information which could be used to assess the risks of storage and transport of LPG gas and oil from hydrocarbon stations in Conakry.

2.1.3 Data analysis

For the analysis of field collected results, the data were entered, coded and analysed using Microsoft Excel 2019.

2.2 Proposal a scenario for the storage and transport of hydrogen based on LPG gas and petroleum hydrocarbons stations in Conakry.

In Conakry, hydrocarbons are imported and stored in a central repository. However, the storage and handling of hydrocarbons are typically regulated by the government and may involve various private and public entities. Considering the results of the investigation 3.2 and the standards and regulations applied in this methodology, these results suggest that there could be accidents leading to incidents such as fire and explosion (Red Guide). These accidents were identified from the central depot to the gas station. The scenarios were described according to the various accidents and incidents that occurred during the operations processes of the activities.

2.3.1 Factors affected when combine the petrol and LPG service station with hydrogen in Conakry.

2.3.1.1 Before starting the combined hydrogen gas station

Impacts on local people and their property: A strategic environmental assessment must be conducted to characterize potential impacts (as directed by the Ministry of the Environment).
Roads: Roads from the time of deposit to the relevant service station must be repaired to avoid additional risks.

2.3.1.2 During operation of the gas station combined with hydrogen

Ignition sources: The number of ignition sources is not expected to increase significantly.
it can be ignited by smaller ignition sources than other types of fuel, since hydrogen ignites much easier. As a result, the gas cloud is more likely to find a source of ignition than compressed gas.
Increased maintenance (risk of installation errors): As for hydrogen in gaseous form, the facility will be relatively complex and must be maintained and inspected by qualified professionals.

Fire department's extinguishing effort: Lack of appropriate equipment in place will be a major concern. In the event of a fire, it will be important for the fire service to ensure that storage tanks are not exposed to excessive heat from the fire without reducing the pressure through the safety valves. There may also be a risk when using water on the tank to cool it that the safety valve will be sealed by ice formation.

External fire – possibility of escalation: Heat exposure to insulated tanks with hydrogen can as a worst-case lead to BLEVE (Boiling Liquid Expanding Vapor Explosion). However, the fact that these tanks are insulated, protects against a BLEVE. This is unlike, for example, LPG, which is stored on uninsulated tanks.

Complexity of the facility (joints, couplings etc.): Liquid hydrogen is stored at relatively low pressure in insulated tank. The design of the facility is relatively simple, but it require the right safety equipment and staff. Evaporation from storage tanks must be regularly ventilated to avoid pressure build-up. The need for ventilation depends on the consumption and temperature of the gas supplied.

Size of safety distances: Size of safety distances will be staying in different zones will require facility-specific considerations. In some cases, greater safety distances may be required for facilities with hydrogen and LPG than facilities with gasoline and diesel.

Unique scenarios for the energy carrier: Liquid hydrogen is stored at very low temperature. Severe cooling in the event of a spill is unique to this type of fuel. This can cause frost damages for people exposed to the leak or for construction materials, such as steel, that become brittle and crack.

Quantity of flammable substance: The calorific value of the amount of hydrogen in gaseous form needed to drive a car a given distance measured in MJ/100km is similar to that of a petrol or diesel car. It is assumed that the consumption of a car running on liquid hydrogen is equivalent to the consumption of a car that runs on hydrogen in gaseous form.

Customer attendance on the distribution lead: This will be a factor for safety measures in the distribution area. Thus, the safety principles must be applied in accordance with the standard recommendation.

Fuel purchase hours for heavy trucks: The hours of fuel intake for heavy vehicles must be regulated only in the late night to avoid congestion.

Awareness of the surrounding population and visitors: It must be a key element for the success of the activities.

Other (not fire related, economy, health etc.) that is affected: Establishment and maintenance may affect the facility's economy.

2.3 Analysis of associated risks and proposed measures as a solution to overcome hydrogen storage and transport in Conakry.

An analysis of the various regulations and standards and the results of the survey revealed the risks associated with the storage and transport of hydrogen in the city of Conakry.

This summary focused on the factors affected by the station's implementation as well as the possible scenarios during the operations of the service station's activities.

CHAPTER THREE: RESULTS AND DISCUSSIONS

This chapter is devoted to the results of the critical analysis of the various study manuals on the storage and transport of hydrogen in service stations around the world. In addition, the synthesis of the inventory of the various concerns in the study area will make it possible to propose the different scenarios, analyse them and propose measures as a solution to overcome the storage and transport of hydrogen in the Conakry hydrocarbon stations.

3.1 Study of hydrogen storage and transportation standards

Analysis of the below 6 tables shows that there are various standards and code development organizations, such as the National Fire Protection Association (NFPA), the American Society of Mechanical Engineers (ASME), the Compressed Gas Association (CGA), Underwriters Laboratories (UL), the European Industrial Gas Association (EIGA), the Society of Automotive Engineers (SAE), the International Organization for Standardization (ISO) and the International Code Council (ICC), based on hydrogen facilities, including refuelling stations.

So more, these organizations are working to establish a set of rules that ensure safety. However, there are several barriers to the harmonization of these codes and standards around the world. Thus, each state or government works on its own initiatives to find acceptable standards and standards. Generally, each project initiator is responsible for their action.

Table 7 Risk control measures and safety distances

		Technical barriers	Humans' barriers	Preventives Measures	Protectives Measures	Safety Distances	Inspections by Industrialists	Monitoring by authorities	Thresholds	Risks analysis	Operating license
International Application											
Technical Committee ISO Standard / Technical Specifications	FD ISO/TR 15916	X	X	X	X						
	ISO 17268	X	X	X	X						
	ISO/TS 20100	X	X	X	X	X					
European application											
Commission European	HYAPPROVAL WP2	X	X	X	X		X	X	X	X	X
EGIA	IGC Doc 15/06/E	X	X	X	X	X					
American application											
United States	NFPA 55					X					
United States	International fire code: section 2309	X	X	X	X						
SAE	SAE J 2601	X	X	X	X						
National application											
Germany	Compresses gases 514	X	X	X	X	X					
Canada	CAN/BNQ-1784-000	X	X	X	X	X	X		X		X
Italy					X						
	FPTCGHRS	X	X	X		X					

3.2 Inventory of the storage and transport of liquefied gases (LPG) and petroleum hydrocarbons in Conakry

3.2.1 Geographical information system (GIS)

The results show that there are more than 100 existing gas stations in the city of Conakry. However, these service stations are mostly located in the area not suitable for hydrogen integration. Only a gas station located in the appropriate area is suitable to host hydrogen technologies in the city of Conakry. The figure 4 shows the suitable place for the implementation of the energy station.

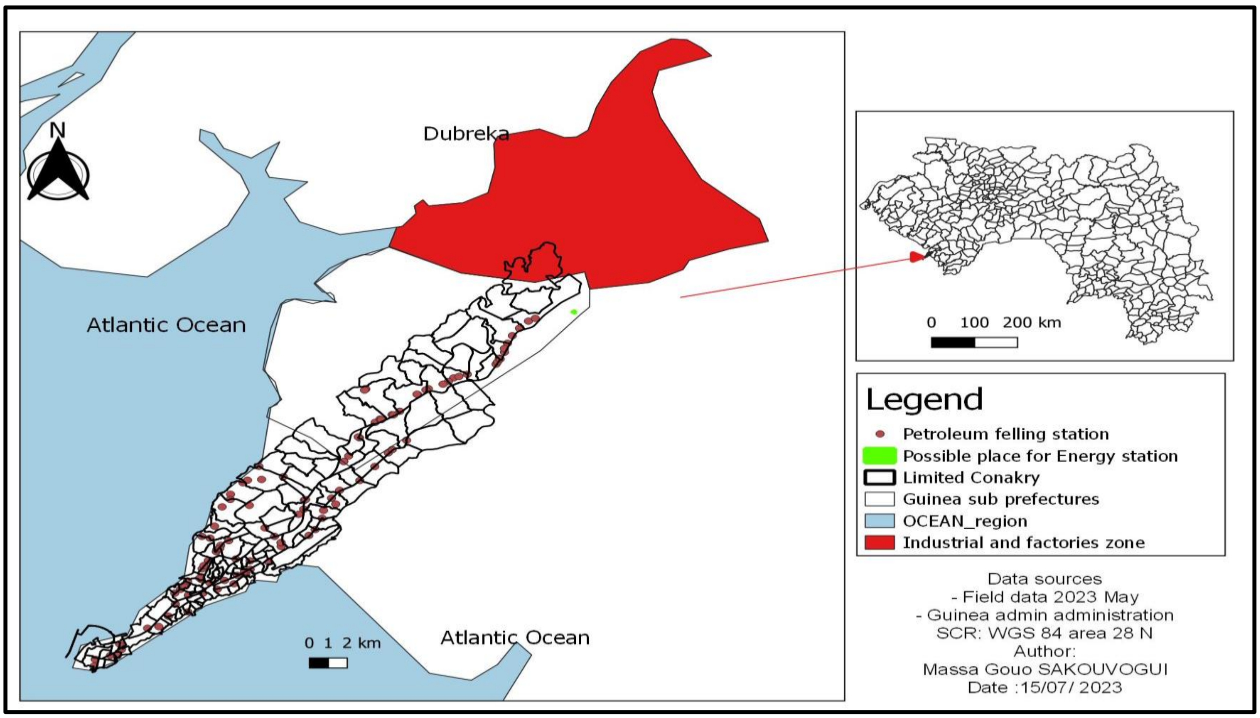

Figure 4 : Location of the suitable place for hydrogen in the city of Conakry

It was observed that these sufficient numbers of existing service stations are located in the populated areas of Conakry. It highlights the performance and control of the Ministry of Habitat and Ministry of Environment. These existing service stations, located in an unsatisfactory area, have the potential to cause damage to resources. Therefore, this should be avoided in this study for planning and development in the city of Conakry as vision by (Berger, 2019) for 2040. The figure 5 shows the population density and jobs in the city of Conakry.

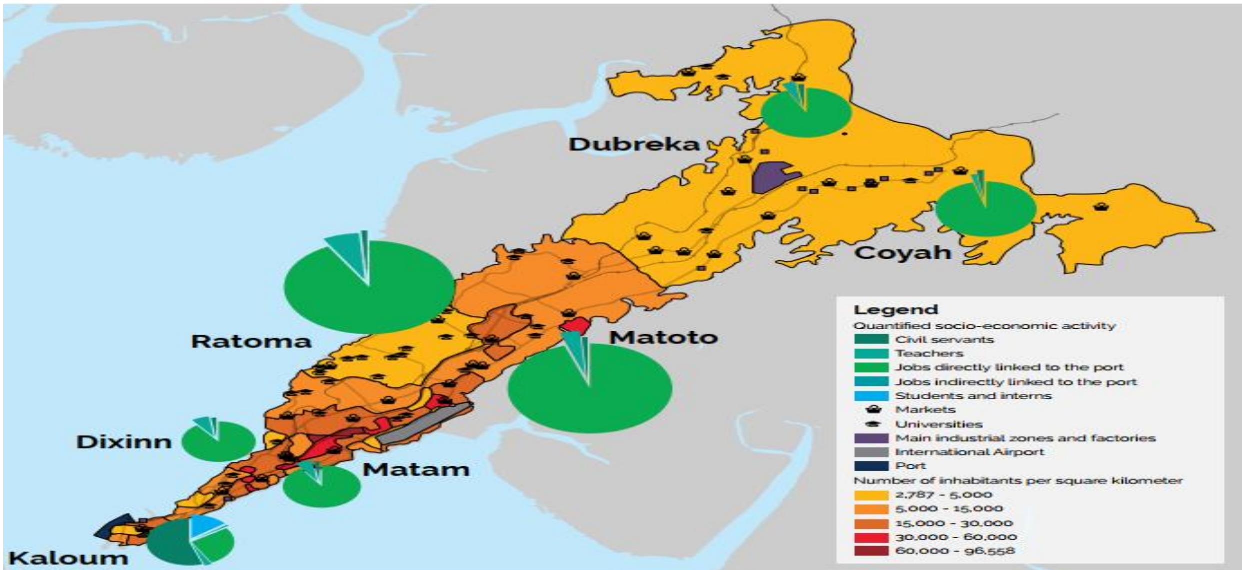

Figure 5 : Population densities and employment in the City of Conakry urban area (Berger, 2019)

3.2.2 Survey

3.2.2.1 Level of compliance of oil and gas services station with the standards established in Conakry.

The figure 6 presents the level of compliance of texts and regulations in service stations in Conakry.

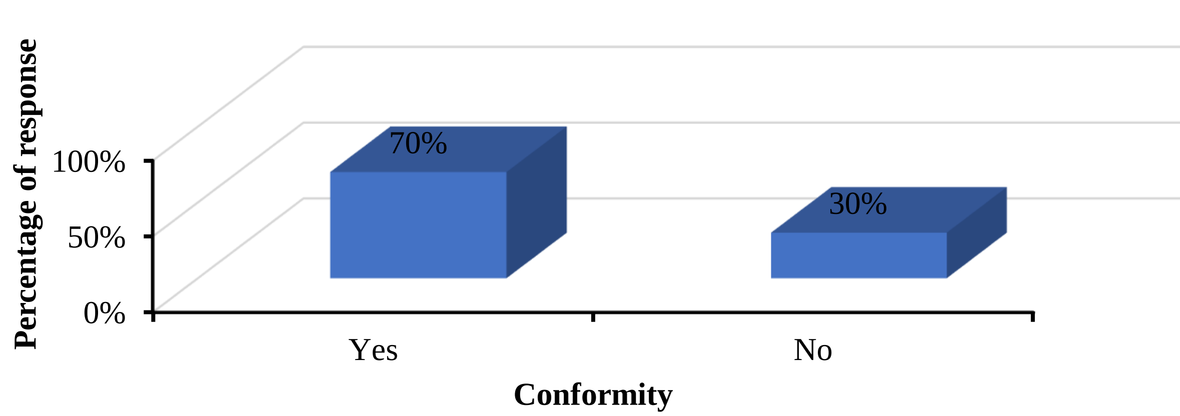

Figure 6 : Level of compliance of texts and regulations in service stations in Conakry

The analysis of the figure 6 above highlights the level of compliance of oil and gas stations with the standards established in Conakry. The survey reveals that 70% of those surveyed point to the application of standards at gas stations. However, 30% of respondents do not meet the standards established.

3.2.2.2 **Primary energy sources in services stations in Conakry**

The figure 7 presents the primary energy sources in service station.

In the city of Conakry, the following energy sources provide electrical power at gas stations. The results of the survey show that 75% of the respondents say that the gas stations are served by the Guinean electric company and their own generator. While 10% of the respondents respectively each reveal Guinea's electrical companies and others. However, 5% of the respondents mentioned that the service stations are served by their own generator.

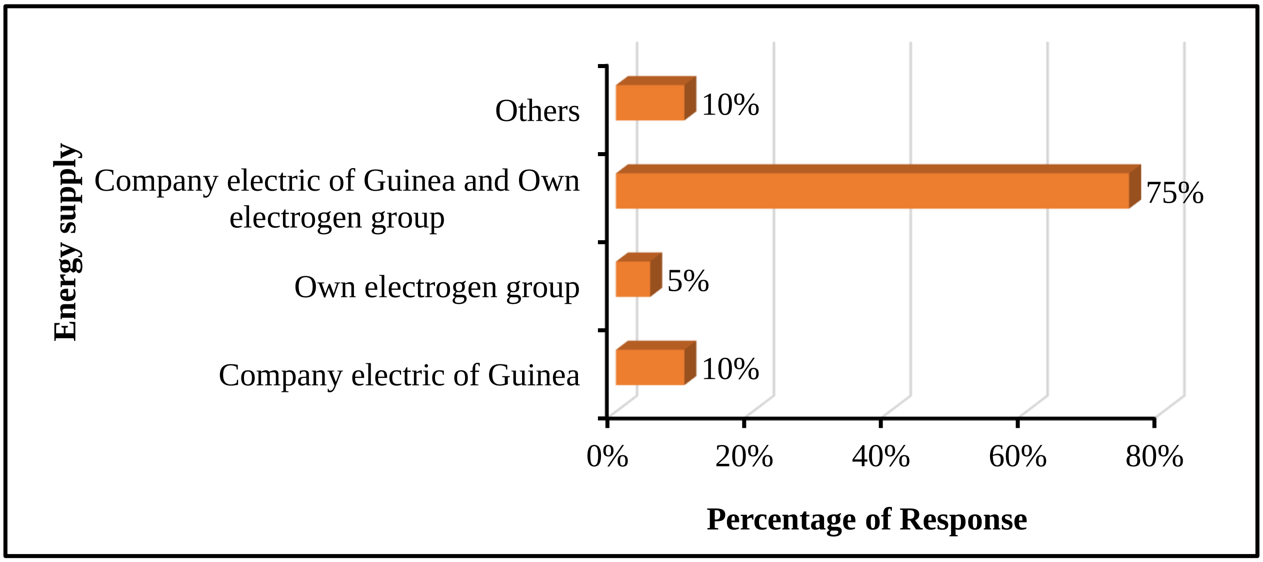

Figure 7 Primary energy sources in service station in Conakry

3.2.2.3 The minimum distance between buildings and service stations

The figure 8 presents the distance between gas station to buildings.

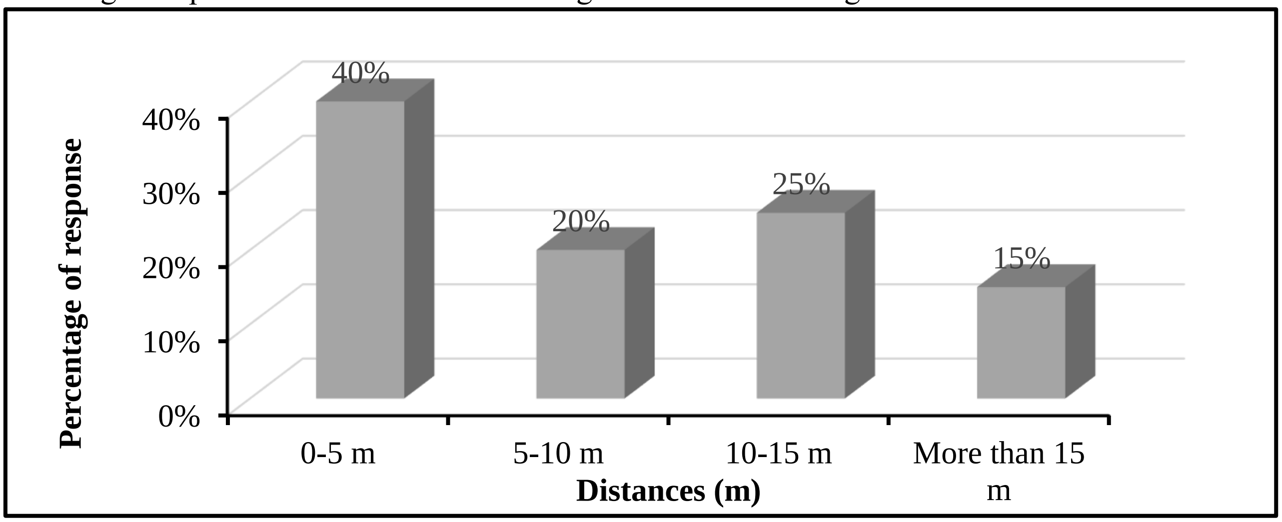

Figure 8 : Distances between gas stations to buildings in Conakry.

The figure 8 shows the distances between gas stations and homes. According to the survey analysis, 40% of the respondents reveal that the distances between the stations and the dwellings are 0 to 5 meters. 25% of respondents place these distances from 10 to 15 meters, 20% of respondents also place these distances from 5 to 10 meters and finally 15% of respondents indicate these distances to 15 meters and more.

***3.2.2.4* The minimum distance between two gas stations**

The figure 9 presents the distance between two gas stations.

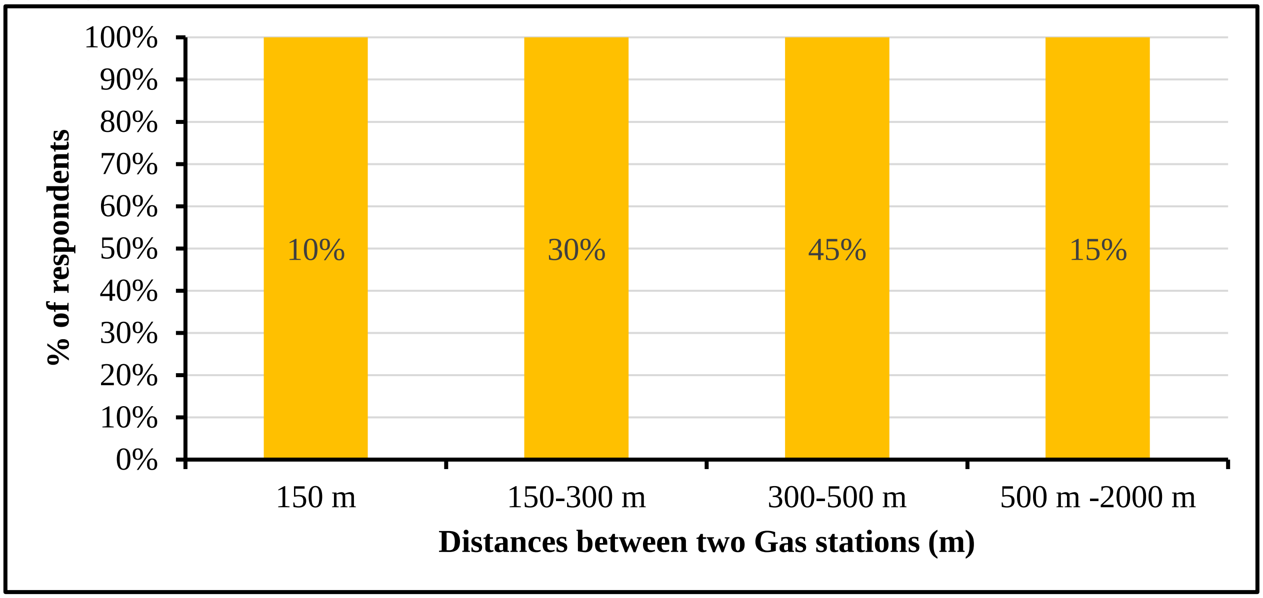

Figure 9 Distances between two gas stations in Conakry

The survey reveals that 45% of respondents indicate the minimum distances between two service stations from 300 to 500 meters. 30% of respondents mention these minimum distances of 150 to 300 meters, 15% of respondents direct these distances from 500 to 2000 meters and finally 10% of respondents indicate these distances to 150 meters.

3.2. 2.5 The minimum distance between the dispensers and the road

The figure 10 presents the proportion of services stations with the distance between the dispenser to road. In terms of distances between distributors and roads, the survey reveals that 35% of the services stations are located three metres from the road. While 25% of gas stations have distributors placed two meters and five meters from the road respectively, and finally 15% of the service stations are place the distributors from one metre from the road.

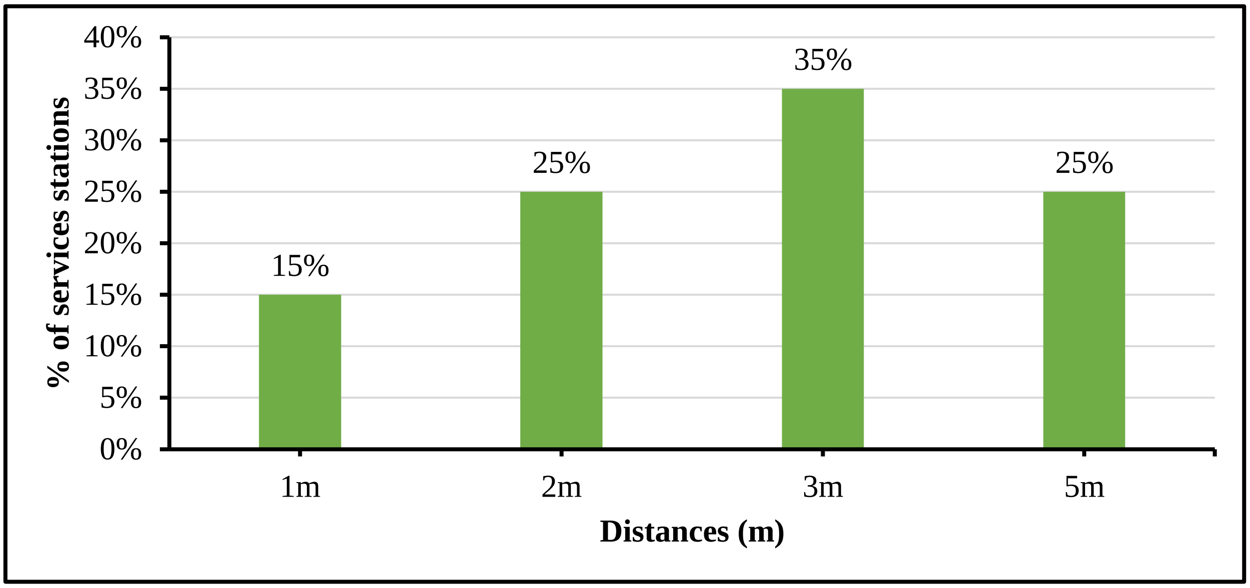

Figure 10 : Proportion of services stations with the distance between the dispenser to road

3.2.2.6 Types of accidents regularly recorded at gas stations in Conakry.

The figure 11 presents the numbers of accidents recorded at the gas stations.

Accidents always happen at service stations. With regard to the incidents regularly recorded at Conakry gas stations, 50% of the respondents report that they never have accidents at their gas station. However, 25% of the respondents say they have at least twice recorded accidents at their gas station. 20% of the respondents say they have at least one accident at their gas station and 5% of the respondents also report having more than two accidents at their gas station.

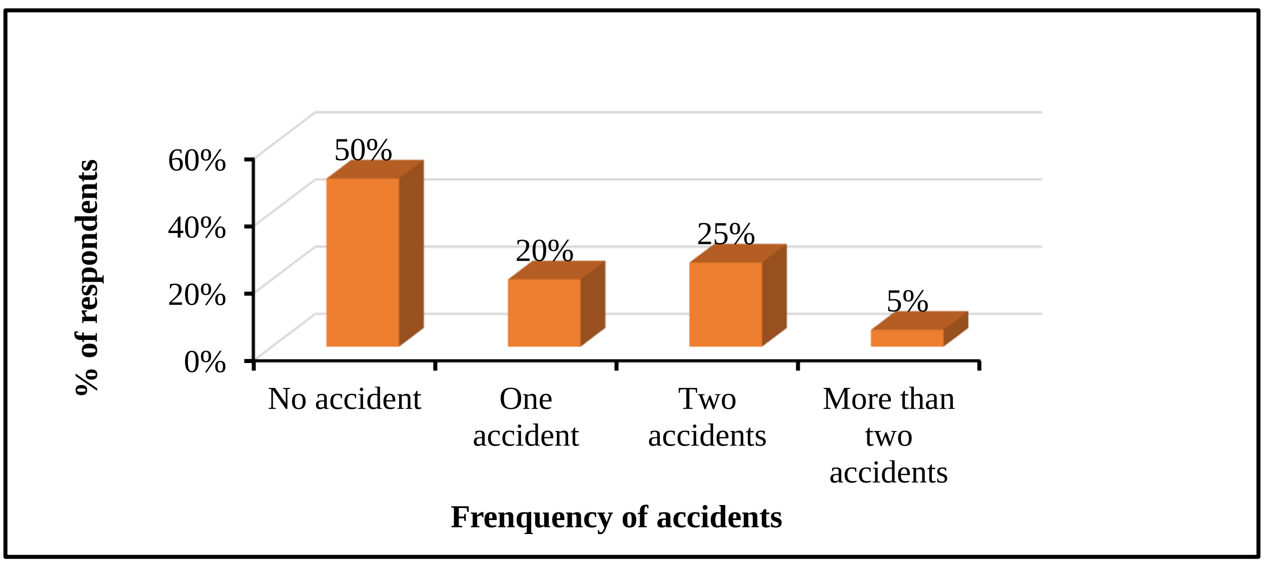

Figure 11 Number of accidents recorded at the gas station in Conakry

3.2.2.7 Combination of hydrogen, liquefied petroleum gas (LPG) and petroleum hydrocarbons in Conakry.

The figure 12 presents hydrogen integration at gas station in Conakry.

Regarding the combination of hydrogen in petrol and liquefied gas stations, 20% of the respondents believe that this new energy would solve the energy crises in Conakry; 10% of the respondents believe in the creation of our jobs against 70% of the respondents who are not pronounced on these concerns.

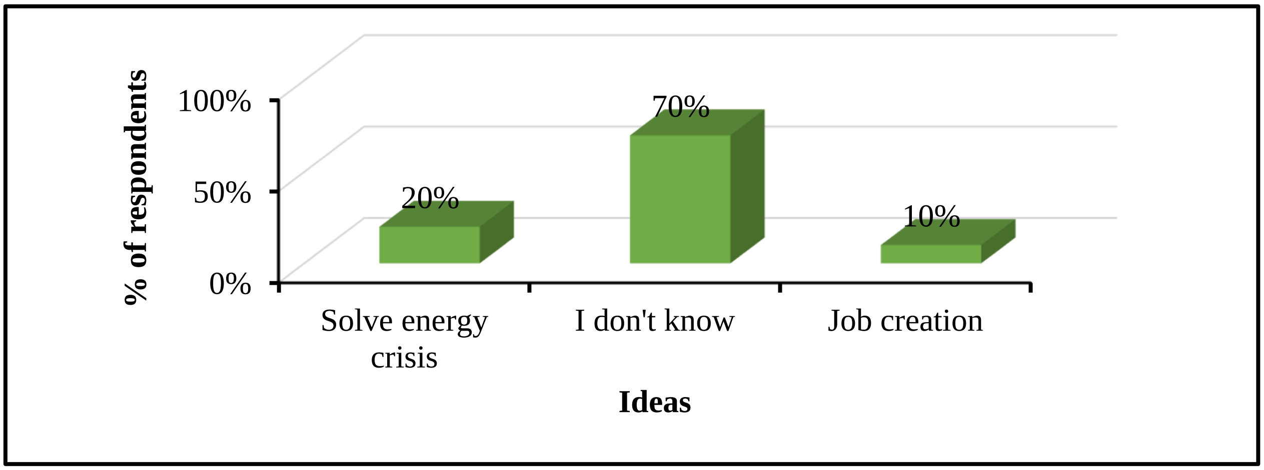

Figure 12 Hydrogen integration at gas station in Conakry.

3.2. 2.8 The emergency situations at the service stations in Conakry.

The figure 13 presents the emergency situations at gas stations

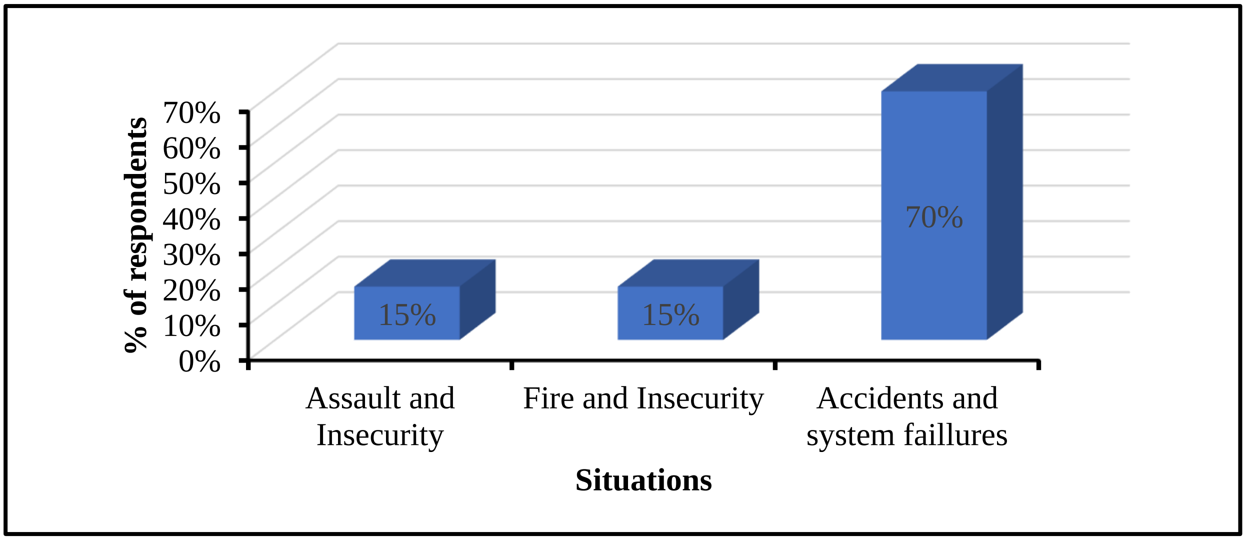

Figure 13 Emergency stituations at gas stations in Conakry.

Many emergency situations occur at gas stations unexpectedly. For this case study, 70% of the respondents say that accidents and system failures are the most common situations. However, 15% of the respondents each point to aggression and insecurity on the one hand and on the other hand to accidents and system failures.

3.2. 2.9 Knowledge about the hydrogen as a fuel in Conakry

The figure 14 presents the hydrogen as fuel in Conakry

With regard to hydrogen as a fuel in Conakry, 70% of the respondents say they have no knowledge about hydrogen compared to 30% who nevertheless have some information through the media, activity reports and advertising spots.

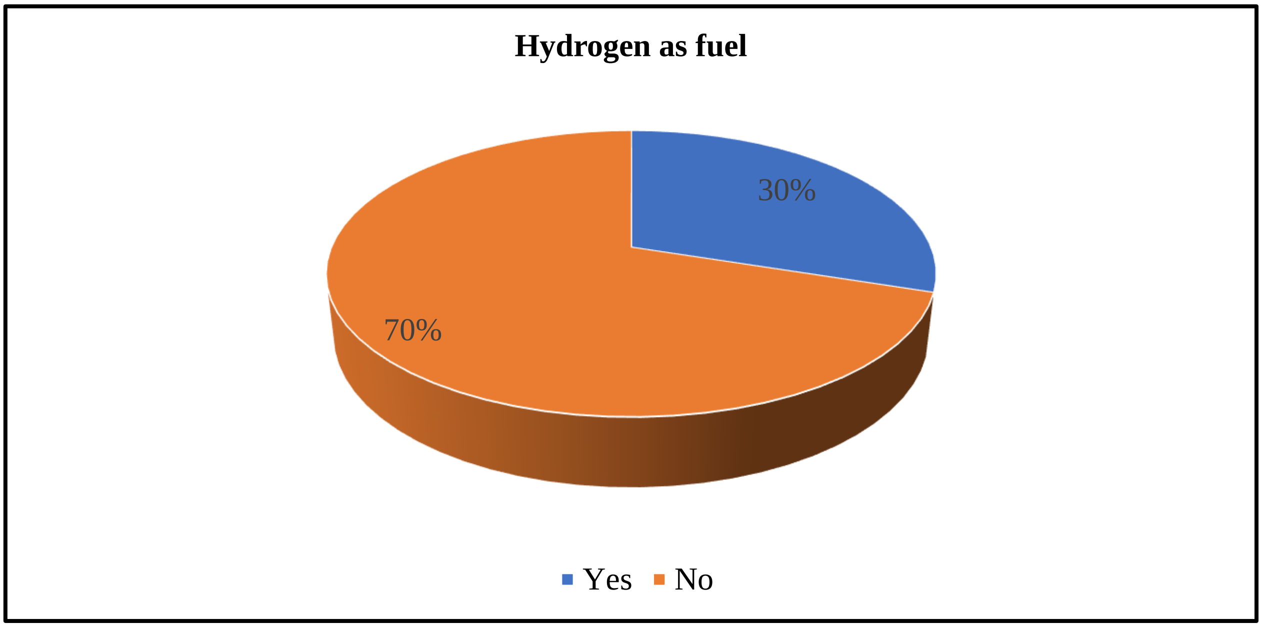

Figure 14 : Hydrogen as fuel in Conakry

3.2.2.10 Different causes of accidents at petrol station in Conakry

The figure 15 presents the causes of accidents at petrol station in Conakry.

The survey reveals that 35% of the respondents suggest operational errors at service stations. 20% each of the respondents indicate breaks or leaks in piping and static electricity. 10% each of the respondents report on instrument failures and pipe failures. 5% of the respondents also mention ruptures or cracks in the tank.

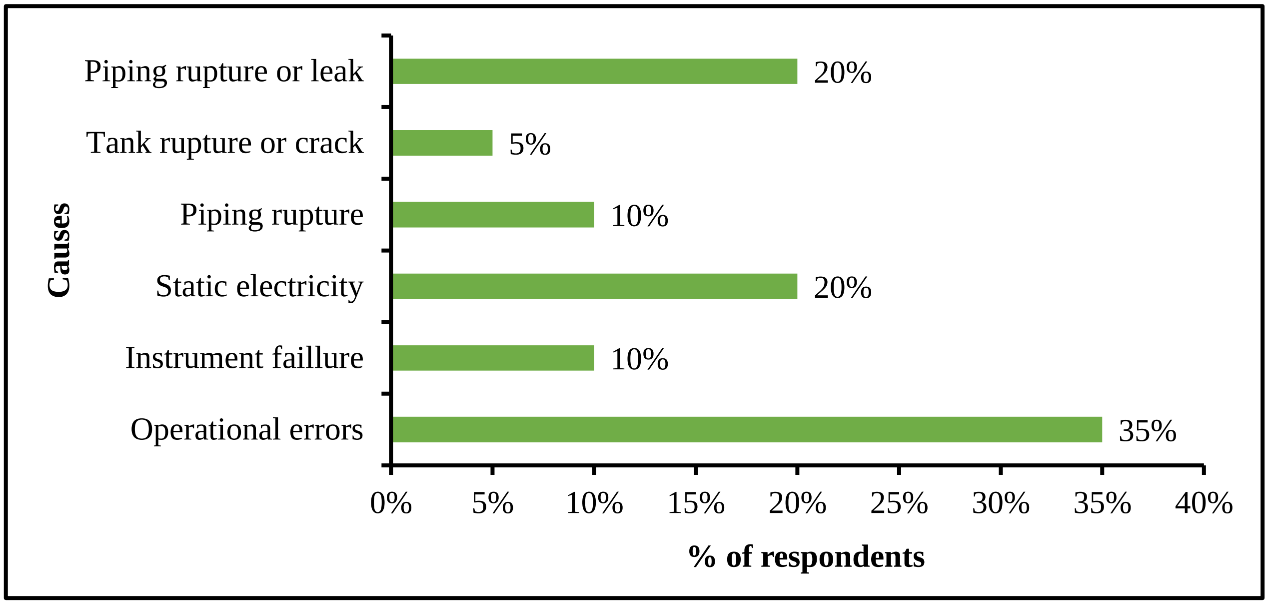

Figure 15 : Causes of accidents at petrol station in Conakry

3.2.2.11 Fires during the unloading of a tanker truck in petrol station service in Conakry

The figure 16 presents an unloading a tanker at gas station.

The observation in the figure 16 shows that 100% of the respondents say that there have never been fires during the unloading of a tanker truck at the gas stations in Conakry.

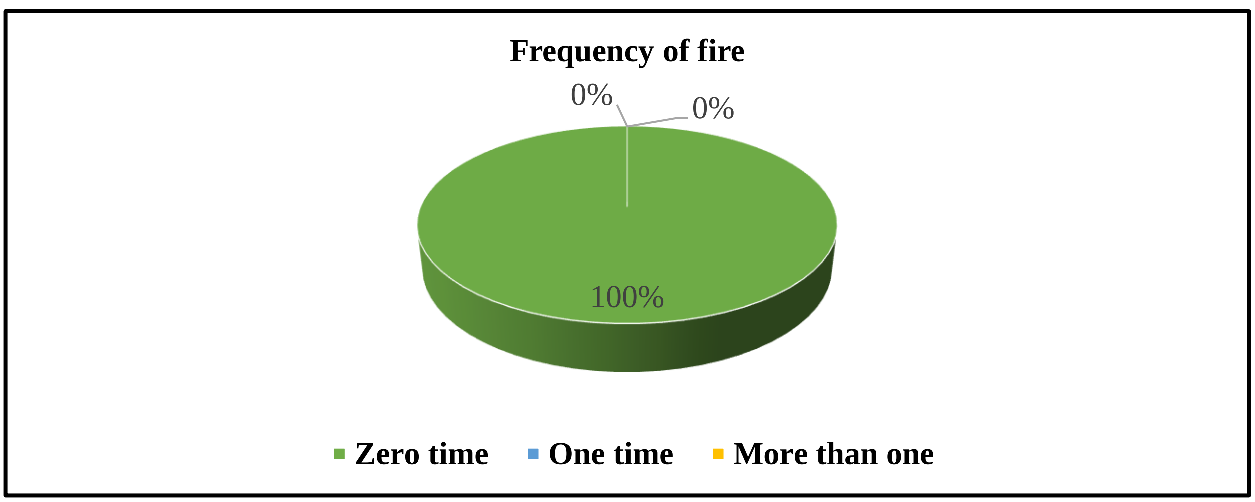

Figure 16 Unloading a tanker at gas station

3.2.2.12 Types of incidents at petrol station in Conakry

The figure 17 presents the various incidents at gas station in Conakry.

At Conakry gas stations, there are several types of incidents. The survey reveals that 95% of the respondents consider the pollution of the fuel distribution tracks as the main source of incidents at Conakry gas stations. On the other hand, 5% of the respondents denounce the fires.

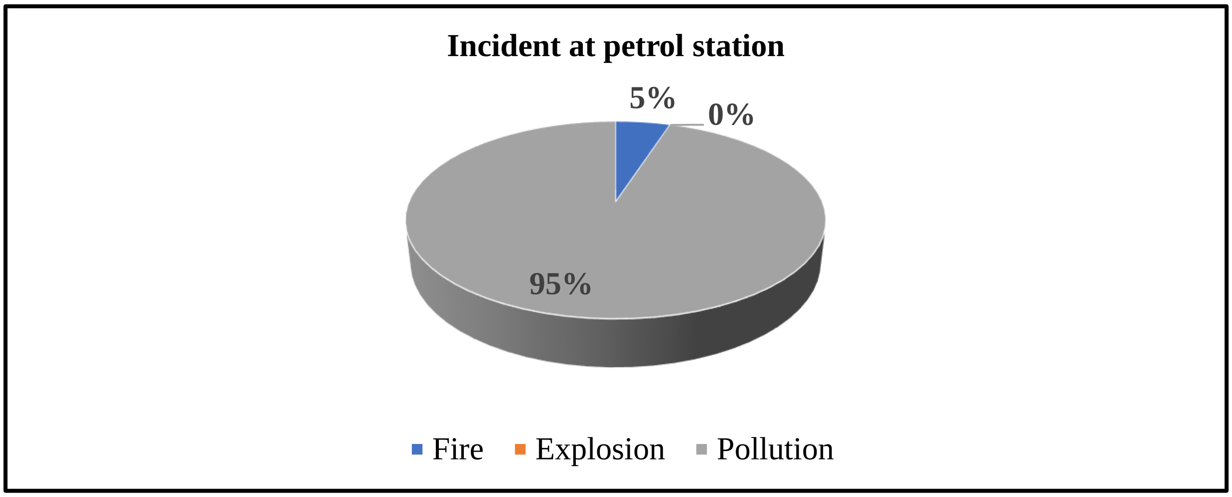

Figure 17 : Various incidents at gas stations in Conakry

3.2.2.13 **Traffic accidents while transporting fuel in Conakry**

The figure 18 presents the numbers of traffic accidents while transporting fuel.

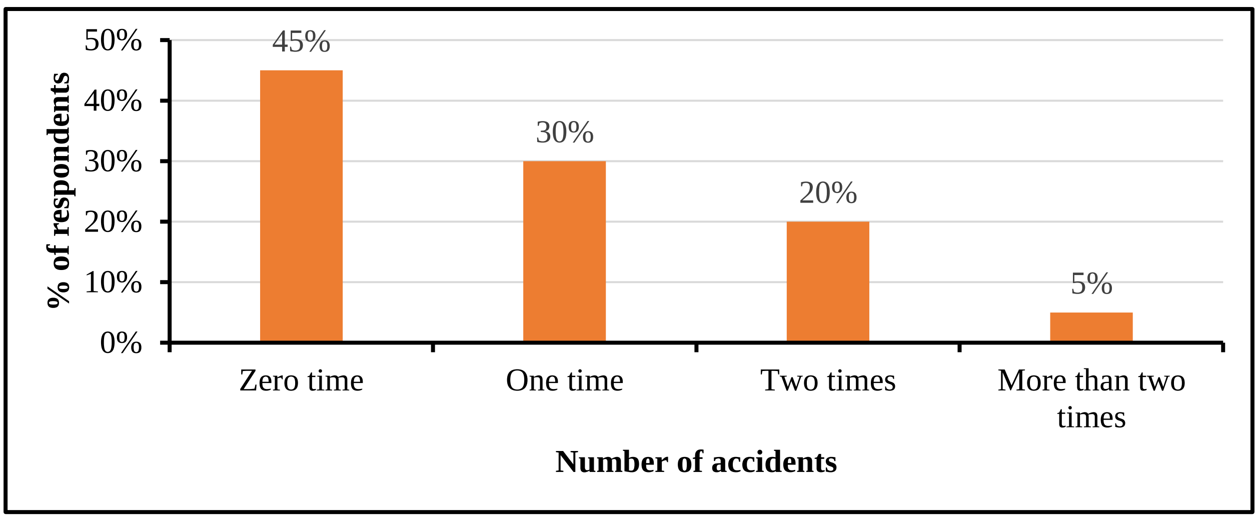

Figure 18 : Number of traffic accidents while transporting fuel

The illustration in the following figure 18 shows that 45% of the respondents never recorded traffic accidents when transporting fuel to service stations in the city of Conakry. 30% of the respondents recorded traffic accidents at their service station at least once. Yet 20% of the respondents recorded traffic accidents during the transport of fuel twice. As for 5% of those surveyed, they recorded more than twice these traffic accidents.

3.2.2.14 **The requirement for a permit to deposit and transport hydrocarbons in Conakry**

The figure 19 present the permit requirements to deposit and transport hydrocarbons in Conakry. Hydrocarbons are stored and transported at gas stations in the city of Conakry. Thus, 50% of respondents express that the storage and transport of hydrocarbons are governed by environmental regulations. 30% of the respondents say that the storage and transportation of fuel is done by respecting the national price of fuel, safety and security and also 20% of the respondents rely on the requirement of the use of new equipment for the transportation.

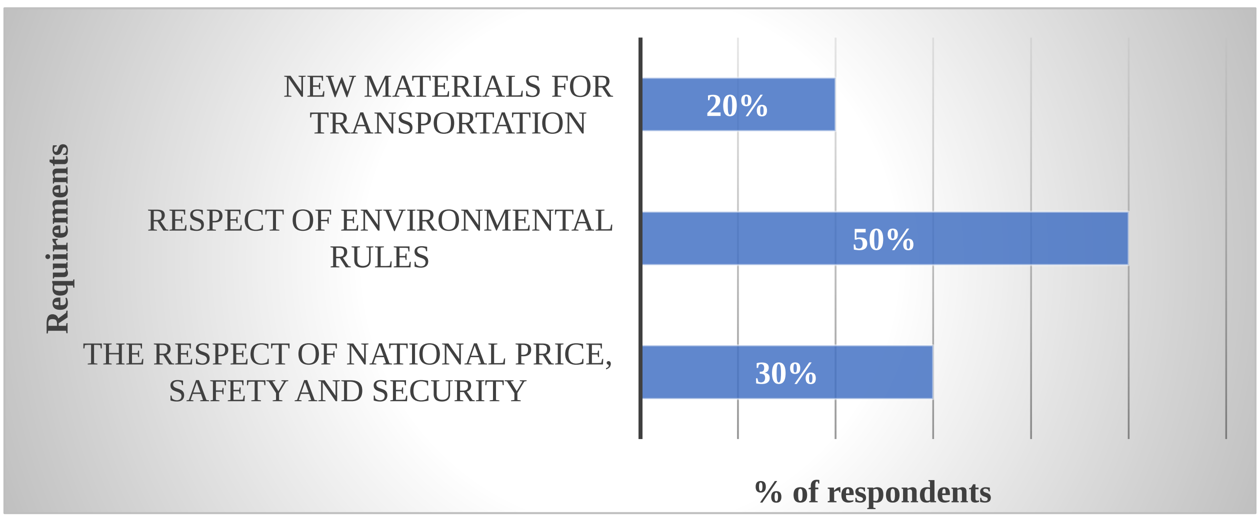

Figure 19 : Permit requirements to deposit and transport of hydrocarbons

3.2.2.15 The safety principles in the gas station of Conakry

The figure 20 shows the safety principles at gas stations in Conakry.

The analysis of the figure 20 above shows that 90% of the respondents say that the safety principles are respected at Conakry gas stations against 10% of the respondents point out that the stations-services to individual establishments do not apply safety principles. In these individual stations, no personnel training is provided for workers. The risk of exposure to accidents is very high. This is why staff training is necessary at the station’s service stage.

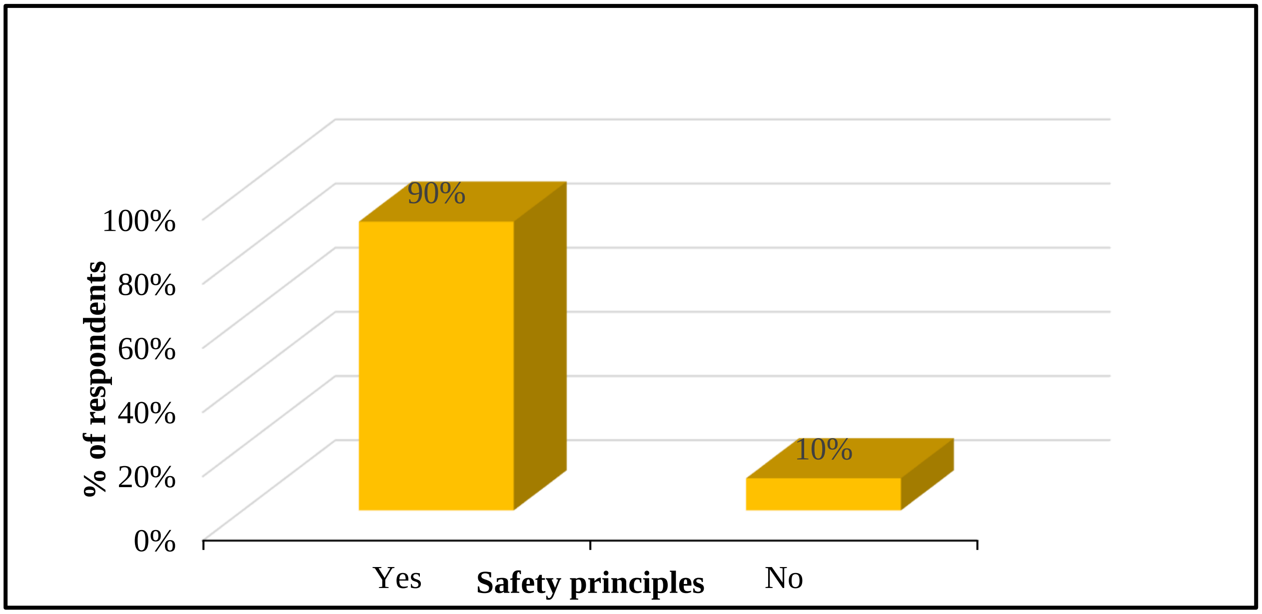

Figure 20 Safety principles at gas stations in Conakry

Discussions

The analysis of the study of standard regulations for the storage and transport of hydrogen shows that several guidelines introduce internal and external safety distances for hydrogen refuelling stations. But there is still a lack of consensus among the different countries on the safety distances to be applied and how to determine them. This lack of consensus prevented the adoption of the ISO/TS 20100 technical specification as a comprehensive standard. The disagreement exists mainly between the United States and Europe. This study must focus on an international ISO/TS 20100 application and a European application (HYAPPROVAL WP2) and all supplemented by national applications. The survey reveals that more than 85% of existing petrol filling stations do not comply with the regulations, thereby constituting danger to the public. Hazards variables observed in relation to distance between petrol station, the residential area and road were: air pollution, fire outbreak, traffic congestion, traffic accidents, and soil pollution. In the light of this synthesis of accidents, it is clear that accidents may occur either as a result of equipment and protective equipment failure or by act of malice either by careless users and employees. Some of these accidents involve fire and flammable cloud explosion. Only a service station is located in an area where population density is low. In addition, this area is surrounded by a field space favourable to the integration of hydrogen as shown in figure 24 in appendix.

3.3 Proposal of the different risk scenarios related to the storage and transport of hydrogen based on hydrocarbons in Conakry.

In this part, the study focused exclusively on the accidents and incidents described by the investigation in the service stations in Conakry. The survey identified the following events:

- ✓ Pollution of the fuel distribution area as the main source of incidents;
- ✓ The aggression and insecurity accidents and system failures;
- ✓ Petrol service attendants are placed at the risk of violence during robbery attacks or public disorder at filling stations. These workers may be killed or maimed for life if they do not cooperate well with the invaders;
- ✓ Traffic congestion due to poor road conditions creates traffic accidents when transporting fuel between the depot and service stations;
- ✓ Breaks or leaks in piping and static electricity;
- ✓ Ruptures or cracks in the tank;
- ✓ Existing recommendations also note explosion and fires.

Based on the hazards identified in these service stations, this study can be divided into three scenarios during the combination of its different energy carriers.

Thus, the first scenario may constitute a traffic accident during the transport of gasoline and liquefied gas (LPG) between the depot and the service station. These accidents can be caused by poor road conditions. Other factors such as the reckless behaviors of some drivers in search of customers and the sense of traffic. In this case, when there is an accident, the fuel can be spilled or dispersed in a significant perimeter of the road and neighborhood. In addition, tankers and public transport vehicles pass through areas where very vulnerable populations live, such as schools, hospitals and markets on road arteries. Therefore, incidents can have far-reaching consequences, as the dangerous cloud can travel long distances of kilometres and pose a danger to human health and the environment. The Figure 21 Scenario1 Accidental related to the transport of oil (B) and LPG (C) at the service stations from the central depot (A). Distances and sizes are only illustrative.

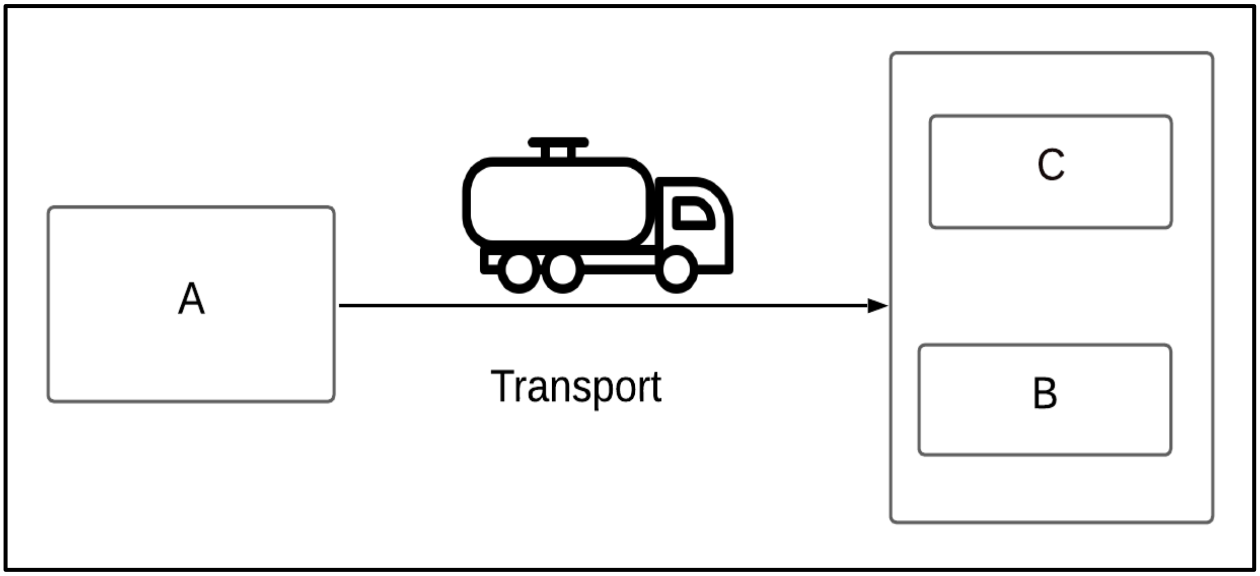

Figure 21 Scenario1 Accidental related to the transport of oil (B) and LPG (C) at the service stations from the central depot (A). Distances and sizes are only illustrative.

The accidental scenario 2 related to the transport of hydrogen is presented in Figure 22 below.

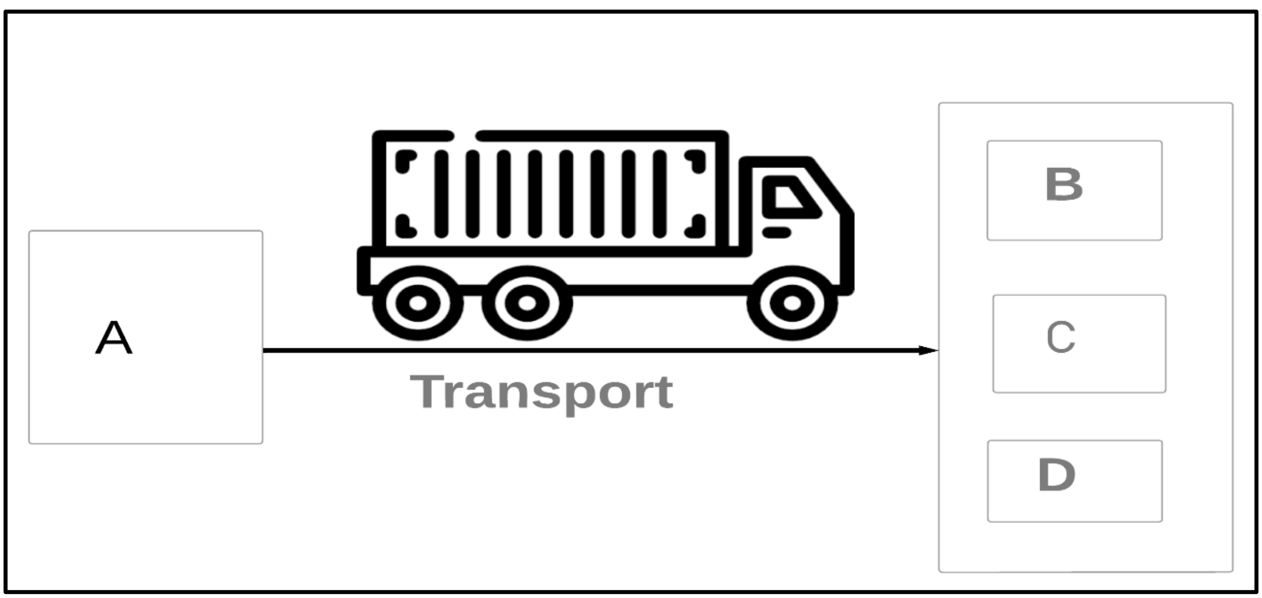

Figure 22 Accidental scenario 2 linked to the transport of hydrogen (D) in the combined service station from the central depot (A). Distances and sizes are only illustrative.

Then, the second scenario above concerns the transport of hydrogen between the depot and the energy service station. Always imagining bad road conditions, accidents can occur during the transport of hydrogen to the energy station. When there is a traffic accident, hydrogen leaks could have serious repercussions on the entire city of Conakry. Hydrogen has hazardous physicochemical properties that include the risk of explosions or fires. Weather conditions, particularly wind speed and direction, which prevail at the time of the accident, can also affect the damage that an accident can cause. A series of accidental events such as jet fire, flash fire, detonation, fireball, confined vapor cloud explosion may be observed.

Finally, the third scenario consists of the interaction between the different energy carriers in the service station. In this case, when an event occurs several energy carriers could be affected. Chain events at the energy station can result in undesirable consequences such as injury or significant property damage. For energy carriers in gaseous or liquid form, loss of containment means gas release or fuel spills to the surrounding area. The possible interactions between the different scenarios are shown in Figure 23.

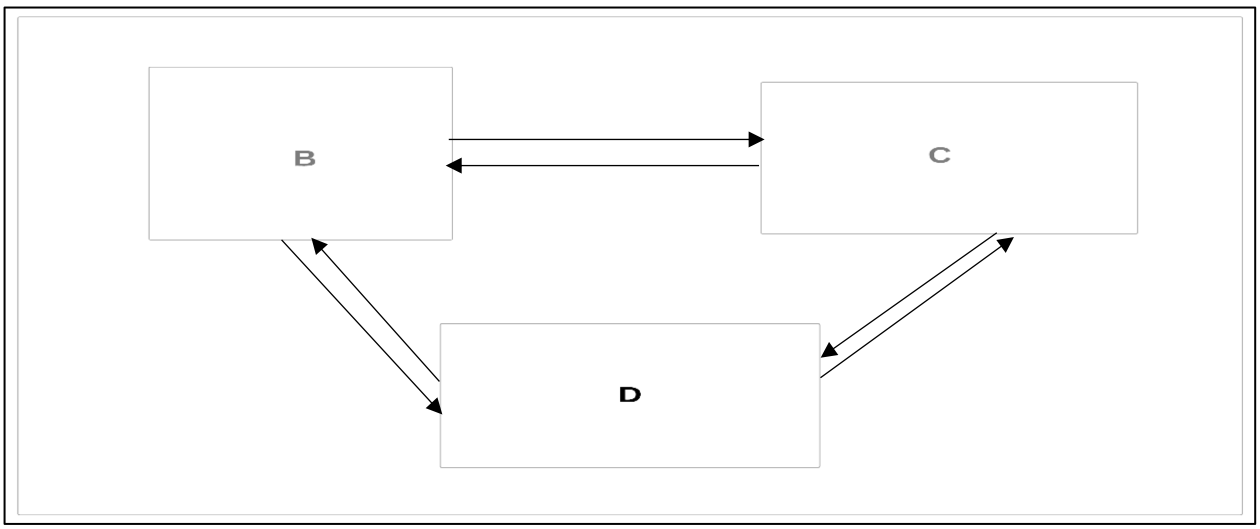

Figure 23 Scenario 3 related to the interactions between oil (B), LPG (C) and Hydrogen (D)in the combined service station. Distances and sizes are only illustrative.

For example, due to an accidental leakage of an energy vector on the distribution area, a fire can occur on this area and spread very quickly to the vehicles that are there. It can then be assumed that the various car tanks give way thus forming a pool fire limiting (to the maximum) to the gutters that surround this area. Therefore, all vehicles parked on the distribution area would certainly find themselves caught in the flames. One could also imagine that the explosion of the flammable cloud would spread to all surfaces of the gas station.

In general, an increase in the total energy content at the same location at an increased risk, whether it be gasoline, hydrogen or LPG energy carriers.

3.4 Risk analysis and proposed measures to overcome hydrogen storage and transport at hydrocarbon and LPG service stations in Conakry.

3.4.1 Assessment of factors that may be affected by the combination of the petrol and LPG service station with hydrogen in Conakry.

The risks associated with the storage and transport of hydrogen in the city of Conakry based on hydrocarbons and petroleum liquified (LPG) have been identified. After risk identification, the most frequent accidents and their main causes were identified. In addition, equipment failure would be the most common cause of accidents for all fuels at a conventional gas station. Other causes such as external aggressions and operating errors are also sources of accidents.

In addition, maintenance and supply operations are the common causes of accidents at the service stations investigated. The analysis of the risks associated with the storage and transportation of hydrocarbons at Conakry gas stations indicates that there is a need for a well-suited fuel management system. Therefore, the storage risk assessment and its transport of hydrogen in the city of Conakry corresponds to the following.

The table 8 assesses the factors affected by the service station installation.

Table 8 Assessment of the factor affected by the hydrogen integration in service station

Factor	**Scenario 1**	**Scenario 2**	**Scenario 3**
Fire department's extinguishing effort	flame with high radiation and easy to see and very explosive with LPG	Flame with low radiation and not easy to see	Lack of appropriate equipment, high risk

Ignition sources	Small ignition sources can ignite LPG and oil	Small ignition sources can ignite hydrogen	Small ignition sources can ignite all energy carriers
The number of heavy goods vehicles for the purchase of the energy carrier	Limited	Limited	Relevant
Increased maintenance (risk of installation errors)	Maintenance by external: competence important. Some local support in case of connection errors etc.	Maintenance by external: competence important. Some local support in case of connection errors etc.	Maintenance by external: competence important. Some local support in case of connection errors
External fire – possibility of escalation	Several pressure with LPG	Several pressurized pipes, tanks	BLEVE
Complexity of the facility (joints, couplings etc.	Increase	Increase	Increases
Size of safety distances	unchanged	May increase	May increase
Unique scenarios for the energy carrier	High ignition with wide flammability	Low ignition energy, wide flammability range	All the flammability increase

Quantity of flammable substance	Unchanged	Unchanged	Unchanged
Customer attendance on the distribution lead	-	-	Limited
Fuel purchase hours for heavy trucks	Night	Night	Night
Awareness of the surrounding population and visitors	compliance with the principles	compliance with the principles	compliance with the principles
Other (not fire related, economy, health etc.) that is affected	Cost for establishment and maintenance	Cost for establishment and maintenance	Cost for establishment and maintenance

For Scenarios 1 and 2, the transportation of products within the city would be at high risk. The road network is unevenly distributed in the city and suffers from segmentation due to the abundance of rainwater. In addition, the roads are crossed by numerous streams that create natural segmentations. These factors create congestion in all directions of the city. Tankers and public transport cars are running at the same time causing accidents throughout the city.

In scenario 3, the results of the survey indicate two major challenges, namely the interactions between facilities that can contribute to the risk of fire and explosion in two areas:

- The area occupied by the facilities
- And the effects from outside:

Area occupied by the facilities:

Risks for the surroundings should be assessed based on the overall activity at the facility (Ministry of Environment, 2019a). Thus, the cohabitation of several filling systems in this combined service station is likely to have adverse events. In addition, the proximity of several risk objects will affect the risk contours, and therefore the size of areas requiring special attention (or, when dealing with small and medium-sized facilities, the safety distances) will change. One instance of altered risk involves an expansion in the quantity of filling systems catering to various fuel types in a specific region. As a consequence, the cumulative frequency of leaks from each of these systems will be combined, leading to an anticipated rise in the overall leak rate. Unless risk-reducing measures are taken, the total risk from the facility will increase.

Effects from outside: These are silent events that affect the station and then grow. The results of this research have meant external aggressions as the most urgent situations encountered in the stations in Conakry.

This result is similar to that obtained by Mikalsen *et al*., (2021) in Norway where challenges have been identified regarding the interactions between the different energy carriers that can contribute to the risk of fire and explosion in two areas:

- Areal challenges
- Cascading effects

Cascading effects: This is defined as "An event chain that starts as a minor event and grows into a larger event». Some examples of relevant chains of events that have been identified:

- Pool fires that spread outwards, or flow downwards and end up under a gas tank
- Explosion or fire that damages surrounding installations (pressure wave that is spreading, flying fragments, flames, etc.).

- Fire in a small amount of fuel that ignites more fuel which in turn ignites more fuel.

For the implementation of measures as a solution to overcome the risks of hydrogen storage and transport in Conakry, the literature review was adopted. This analysis involves adapting an environmental management approach to the different stages of the hydrogen production, storage and transport processes. Thus, the analysis of the political, institutional, legal and regulatory frameworks was carried out through the National Environment Policy, the Ministry of Hydrocarbons, the Ministry of City and Town Planning under the instruction of Joint Decree

AC/2019/6392/MH/MEEF/MVAT on administrative procedures for the establishment and operation of service stations in the Republic of Guinea.

In addition, relying on the devices of some large oil companies in Guinea such as TOTAL for example where it has an environmental policy and is committed to set up a management system for the management of the company. The Corporate Safety, Environment and Quality Charter is based on ten principles. Article 1 of the Charter states that "Total places the safety of its activities, the health of its respect for the environment and the satisfaction of its customers. The ISO 14001 international standard is used as the standard by Total for all its sites that are committed to setting up the environment.

In Article 5 of the HSEQ Charter which states: the environment, adapted to each activity, are evaluated periodically, indicating the results achieved, setting targets for progress, and implementing action plans and organising the associated control, (…) ". In its Article 4 of the HSEQ Charter announces that "Wherever it carries out its activities, Total shall ensure compliance with applicable laws and regulations". The HSEQ policy allows the company to make organizational and Management to respect health, safety and the environment at work.

This directive will be supplemented by the ISO/Technical Standards Committee Specifications: ISO/TS 20100 on safety distance parameters and that of the European Union Commission HYAPPROVAL WP2 involving the administrative authorities in the effective monitoring of activities (see table 7 above).

CONCLUSION AND RECOMMENDATIONS

The high energy demand in Conakry and the results of the present study indicate the necessity of storing and transporting hydrogen in petrol and LPG filling stations. However, in facilities that handle flammable, pressurized and explosive substances, there is a risk of undesirable incidents. When facilities containing hazardous substances comply with regulations, the risk associated with handling hazardous substances is not considered significant relative to other risks in the city.

The results of this research highlighted the risks associated with storage and transport at a Conakry energy service station. In detail, it enabled to study the regulations and standards for the storage and transport of hydrogen, inventory the various incidents linked to the storage and transport of hydrocarbons, then to imagine a probable scenario for the storage and transport of hydrogen based on hydrocarbons, finally to analyse the associated risks and propose measures as solutions to overcome the storage and transport of hydrogen in hydrocarbon stations in Conakry. The geographic information system (GIS) and the survey used revealed that the hazards came from various categories, namely external aggression, general management of the station, electricity in the workplace, exposure to chemicals, and safety when transporting products. In general, poor management of these categories leads to fire and explosion.

In order to minimize the risk of explosions resulting from hydrogen leaks, it is essential to introduce additional safety measures in hydrogen facilities. These measures include examining safety distances, regulating valve operations, utilizing high-pressure-resistant equipment, establishing a reliable ventilation system, employing leak detectors, assessing fire protection protocols, and controlling potential ignition sources. In conclusion, the hydrogen facilities will be as safe as the petrol and LPG facilities if a complete risk analysis is studied and all the necessary safety measures are implemented. In addition to the existing recommendations cited on regulations and standards, a good organisational, technical and staff training measures are needed. An in-depth study to validate the distances between the combined station equipment by modelling in case of accidental leaks, fire and explosion is recommended. Also, the specification of the classification of hazardous areas in which any ignition source potential can be adequately controlled.

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APPENDIX

Questionnaire on the Risks associated to hydrogen storage and its transportation in the context of Conakry, republic of guinea.

This survey is for academic purposes only. Your confidentiality and privacy are highly assured.

Please answer the questions as objectively as possible.

The objectives of this interview are to inventory the storage and transport of petroleum hydrocarbons in Conakry; to imagine a proposition a scenario of the risks related to the storage and transport of hydrogen and to propose measures and solutions to minimize the risks of storing and transporting hydrogen in Conakry.

It is intended for the Ministries of Energy and Environment, the Energy and Environment Research Centers, the National Council of the Transition (CNT) and representatives of non-governmental organizations (NGO) in the Republic of Guinea and petroleum company.

Fact sheet on the various accidents at the stations-service in Conakry.

I. Name of Ministry, department or Organization

Respondent:____

Occupation: ____

(Ministry / planning-office / consulting / industrial company)

Telephone:____

Signature of interviewer: ………………………………………………………………….

Date……/……/……………...

A. Section 1

II. Questions

1.How do you store hydrocarbons in Conakry?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

2. Petrol station pose hazards to the consumer and nearby residence such as fire, explosion, oil and gas leakage etc.

☐ Yes ☐ No

3. Incidents occur in service stations such as fire, explosion, gas leak etc.

☐ Yes ☐ No

4. Safety measures including holistic risk assessment and engineering control shall be integrate with development planning such as setback or buffer zone for the development of petrol station.

☐ Yes ☐ No

5. Holistic planning includes safety, environment, urban planning, etc. Involve competent technical agencies for the development of service stations.

☐ Yes ☐ No

6. Petrol Station is not listed in the prescribed activity under the environmental quality (Prescribed Activities) (Environmental Impact Assessment)?

☐ Yes ☐ No

7. Before the construction of a service station, the competent authorities are consulted?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

8.What is the role of standards verification services?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

9.Are you sure the standards set by this department are being met?

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……………………………………………………………………………………………………

10.What are the failures of the established measures?

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……………………………………………………………………………………………………

11.What are the requirements for a permit to deposit and transport hydrocarbons?

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12.what are the criteria for installing a gas station in Conakry?

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………………………………………………………………………………………………

13.What is the distance between two service stations

…………………………………………………………………………………………………
…………………………………………………………………………………………………

14.What is the distance between a gas station and the road?

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…………………………………………………………………………………………………

15.What is the distance between a gas station and the houses?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

16. Level of compliance of Petroleum Service Stations with established standards?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

17. How is the transportation of hydrocarbons and lubricants secured in the city of Conakry?

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………

18. What are the roles and responsibilities for considering environmental concerns in gas stations?

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…………………………………………………………………………………………………
…………………………………………………………………………………………………

19. What are the regulations in force for the installation of a gas station in Conakry?

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20. What are the arrangements and guidelines for storing hydrocarbons in the city of Conakry?

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…………………………………………………………………………………………………

…………………………………………………………………………………………………

21. How are hydrocarbon transport regulated?

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22. What do you know about hydrogen as fuel?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

23. What do you think of the combination of petrol stations and hydrogen in the city of Conakry?

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24. What measures are you planning?

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25. How can hydrogen be promising for the future in Conakry?

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Do you have anything else to add?

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……………………………………………………………………………………………………

Thank you for your frank cooperation

See you soon!

Name of the petroleum company and gas station service: ………………………………….

Occupation:

………………………………………………………………………………………..................

(Ministry / planning-office / consulting / industrial company)

Telephone: ………………………………………………………………………………………

Signature of interviewer: ……………………………………………………………….

Date……/……/……………...

1.In what year was your station created?

……………………………………………………………………………………………………

2.Identify your primary energy source?

☐ EDG ☐ Own electrogene group ☐ Other to specify

3. How long has your petroleum station been located at its current location?

☐ < 5 year ☐ < 10 year ☐ <15 year ☐ >15 year

4.What are the emergency situations you may be in faced?

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……………………………………………………………………………………………………

5. How many times have you recorded accidents while unloading fuel?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

6. How many times have you recorded explosions due to the carelessness of the gas station attendants?

……………………………………………………………………………………………………

7. Accidents at your station can be like:

☐ Accidental ☐ Intentional

8. How many times have you recorded fires during the unloading of a tanker truck?

……………………………………………………………………………………………………
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9. How many times have you recorded traffic accidents while transporting fuel?

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10. How many times have you recorded accidents in your station?

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……………………………………………………………………………………………………

11. How many times have you recorded accidents in your station during maintenance?

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……………………………………………………………………………………………………

12. What kind of incidents do you regularly record in your petrol station?

☐ Fire ☐ Explosion ☐ Pollution

13. What are the causes of accidents at your petrol station?

☐ Operational errors	☐ Maintenance errors	☐ Tank rupture or crack
☐ Instrument failure	☐ Static electricity	☐ Piping rupture or leak
☐ Miscellaneous	☐ Others to specify	

14. In case of fire, what measures do you recommend?

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15. What are the difficulties in transporting lubricants and fuel in the city of Conakry?

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16. How far is your gas station from the fire department?

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17. How far is your gas station from the road?

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18. In your opinion, what is the distance between two gas stations?

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19. What is the distance between buildings and gas stations?

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20. What is the level of compliance of oil and gas services stations with the standards established in Guinea?

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21. What are the priority actions in your station or company?

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…………………………………………………………………………………………………

22. How do you anticipate the emergency situations?

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…………………………………………………………………………………………………

23. What training is provided to staff for station protection and the environment?

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…………………………………………………………………………………………………

24. What operational instructions have you established in the distribution process?

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25. Since defining your priority actions, what are the actions corrective and preventive measures that you have implemented?

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26. What are the safety principles at your gas station service?

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27. What are the regulations in force for the installation of a gas station in Conakry?

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28. What do you know about hydrogen as fuel?

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29. What do you think of the combination of petrol stations and hydrogen in the city of Conakry?

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30. What measures are you planning?

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31. How can hydrogen be promising for the future in Conakry?

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Do you have anything else to add?

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Thank you for your frank cooperation

See you soon !

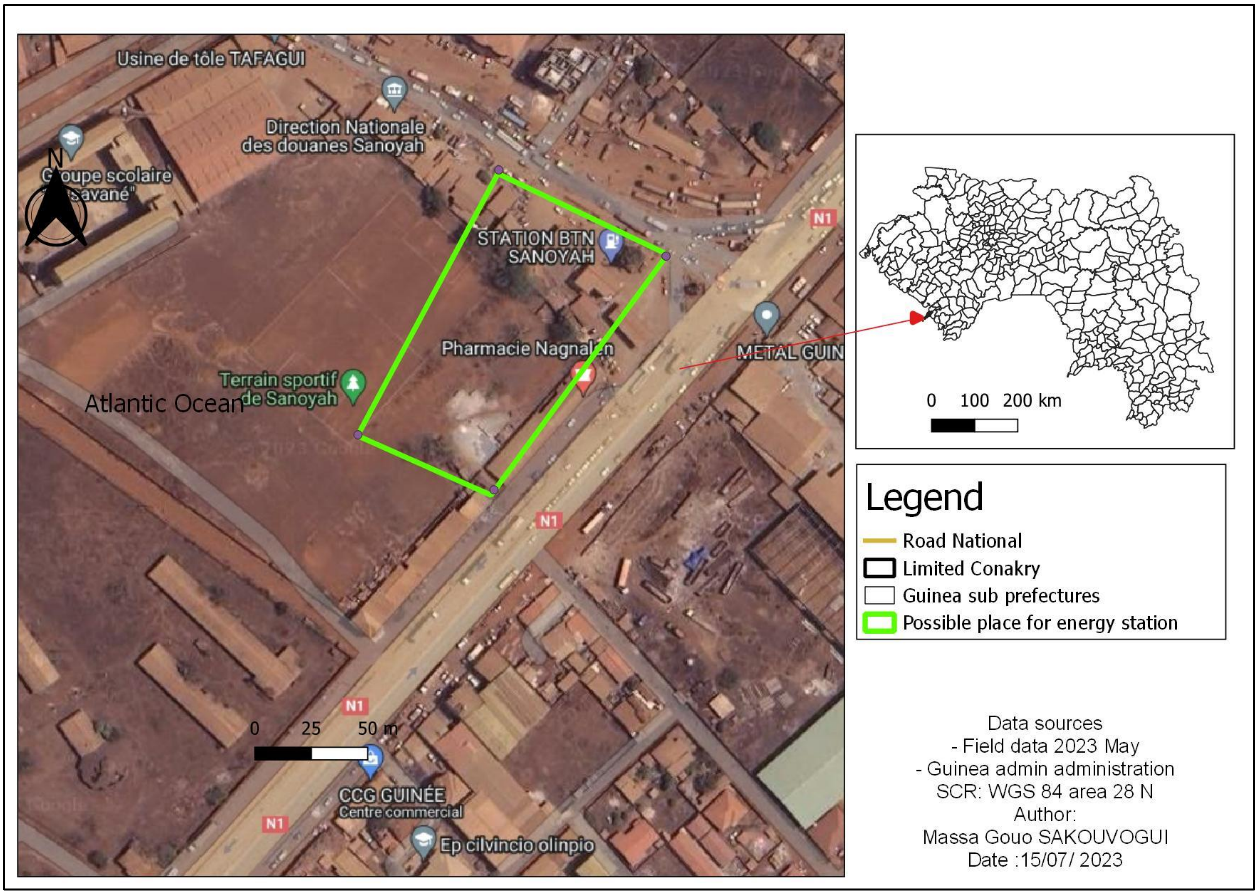

Figure 24 Suitable place for the integration of hydrogen in petrol filling station in Conakry

Source: field survey, 2023**.** This map represents the suitable area for the integration of hydrogen into petroleum service stations in Conakry. In this area, we notice an empty space of land which would favor a lower cost for the eviction of the surrounding populations.