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An overview of the progress in the use of compressed natural gas in Nigeria

Analiza osiągnięć w wykorzystaniu sprężonego gazu ziemnego w Nigerii

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ABSTRACT: The world is shifting away from petrol and oil-based energy sources, which have been linked to environmental degradation and global warming. To address these environmental issues and reduce greenhouse gas emissions in the transportation sector, the transition from conventional gasoline-powered vehicles to natural gas (CNG) vehicles has recently gained traction. This paper presents an overview of the progress made in the use of compressed natural gas as viable and environmentally friendly alternative fuel in Nigeria. The efforts made thus far by the Nigerian government in embracing the use of CNG and the projects executed to ensure a smooth transition from the use of conventional fuels to natural gas fuels are discussed. In addition to the existing CNG stations across the country, twelve new stations were installed in two major cities, and the government officially launched hundreds of CNG intra- and inter-state buses in July 2024. It has also established centres for the conversion of existing petrol and diesel vehicles to CNG vehicles, with the goal of alleviating the hardships faced by Nigerians as a consequence of the removal of petrol subsidies. It is suggested that the hazards associated with CNG storage, such as in vessels, tanks, and cylinders, should be critically assessed because their explosions are almost always unexpected and disastrous. Also, possible activities that could potentially lead to explosions should be identified for proper protection.

Key words: alternative fuel, CNG, natural gas, petroleum, safety.

STRESZCZENIE: Na całym świecie obserwuje się odchodzenie od źródeł energii opartych na benzynie i ropie naftowej, które przyczyniają się do degradacji środowiska i globalnego ocieplenia. W celu przeciwdziałania tym negatywnym zjawiskom i ograniczenia emisji gazów cieplarnianych w sektorze transportu, coraz częściej rezygnuje się z konwencjonalnych pojazdów napędzanych benzyną na rzecz pojazdów zasilanych gazem ziemnym. W niniejszym artykule przedstawiono analizę postępów w zakresie wykorzystania sprężonego gazu ziemnego (CNG) jako realnego i ekologicznego paliwa alternatywnego w Nigerii. Omówiono działania podjęte przez rząd nigeryjski na rzecz rozwoju infrastruktury CNG oraz projekty realizowane w celu zapewnienia płynnego przejścia z paliw konwencjonalnych na paliwa gazowe. Oprócz funkcjonujących już na terenie kraju stacji CNG, uruchomiono dwanaście nowych obiektów w dwóch głównych miastach, a w lipcu 2024 roku rząd oficjalnie wprowadził do użytku setki międzymiastowych i miejskich autobusów zasilanych CNG. Ponadto, utworzono centra konwersji pojazdów benzynowych i wysokoprężnych na jednostki zasilane gazem ziemnym, aby złagodzić trudności ekonomiczne mieszkańców Nigerii wynikające z likwidacji subsydiów na benzynę. Zwrócono również uwagę na konieczność przeprowadzania dokładnej oceny zagrożeń związanych z magazynowaniem CNG w zbiornikach, zasobnikach i cylindrach, ponieważ ich eksplozje są niemal zawsze nieprzewidywalne i mogą mieć katastrofalne skutki. Podkreślono także potrzebę identyfikacji działań mogących prowadzić do takich zdarzeń w celu zapewnienia odpowiedniego poziomu bezpieczeństwa.

Słowa kluczowe: paliwo alternatywne, CNG, gaz ziemny, ropa naftowa, bezpieczeństwo.

Introduction

Compressed natural gas (CNG) is essentially a natural gas that is mostly composed of methane and has been compressed to a high pressure while still in its gaseous state for easy transportation or storage purposes prior to being used as fuel for vehicles (Okoro et al., 2024). CNG is a hydrocarbon-based fossil fuel. It originates from crude oil extraction and is a by-product of coal mining. Currently, hydrocarbons account for the vast majority of global energy use, with crude oil serving as the primary fuel source. CNG, among a variety of alternative energy sources, is anticipated to assume a leading role in meeting the world's energy demands (Aba et al., 2023; Shaarawi et al., 2024). The growing pattern in its consumption compared to other fossil fuels is due to increasing requirements for energy from a developing global economy and ecological demands

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to adopt a fossil fuel that is not environmentally destructive. One of the most significant disadvantages is the increasing consumption of fossil fuels, which are finite and susceptible to being exhausted over time due to growing demand. The usage of fossil fuels, especially petroleum, has increased significantly over time, owing to challenges such as population growth and changing users' lifestyles (Wang and Azam, 2024).

Global well-being and economic growth have an inherent connection with energy expansion. Satisfying the increasing demand for energy with a secure and ecologically friendly approach is a significant problem. The demand for consistent and inexpensive energy is becoming increasingly basic. Sustainable energy helps to grow industry, modernise agriculture, promote trade, and improve transportation (Scheffran et al., 2020; Li and Chen, 2021). Petroleum has traditionally been the primary and widely used energy source with regard to worldwide yearly energy usage. Petroleum products have been utilised to power automobiles, cook, and generate energy. The petrochemical industry uses petroleum as a raw material to produce solvents, polyurethane, plastics, and a wide range of other intermediate and consumer products (Ukpaukure et al., 2023).

Natural gas was not common before the 18th century, probably because of the usage of produced gas, particularly "coal gas" (Wang et al., 2023). The vast majority of industrialised nations began to use natural gas in the late 19th century. During this time, large-scale distribution and transmission pipelines were built to transport gas to the required locations. Natural gas usage increased steadily from the 1960s until the mid-1970s, when a scarcity of crude oil led most industrialised countries to seek other forms of energy. Since then, natural gas has evolved into one of the primary sources of energy derived from fossil fuels. Despite being highly flammable, natural gas has quickly gained popularity as a fuel due to its colourlessness and high energy value. As natural gas started to gain prominence as a substitute for conventional fuels, it allowed for fast technical improvement as well as the acquisition of expertise and knowledge in numerous natural gas-related areas. During the past few decades, there has been steady progress in scientific and technological advancements related to the production of natural gas, its transmission, distribution, utilisation, management, and safety in both upstream and downstream operations (Yang et al., 2021). This paper presents an overview of the progress made in the use of compressed natural gas as a viable and environmentally friendly alternative fuel in Nigeria.

Characteristics of compressed natural gas

Compressed natural gas is a fuel gas that has been compressed to a volume of less than one percent of its volume at normal atmospheric pressure. The primary component of CNG is methane (CH_4). CNG is often stored in spherical or cylindrical rigid containers at a pressure of 20 to 25 MN/m^2. The quality of CNG varies according to its origin, location, storage capacity, and mode of shipment. The chemical composition of CNG is subject to change, which can have an impact on engine efficiency, the quality of the fuel, and even the longevity of the engine (Fan et al., 2021). The natural gas that is to be compressed must be free of liquid or solid impurities. In this setting, the gas may contain considerable amounts of dust, water, and other hydrocarbons. Water in particular must be monitored carefully, as it can be turned into ice or form hydrocarbon hydrates. The water content and hydrocarbon dew points of the supply gas also need to be determined. Apart from viscosity and compressibility, compressor performance is also influenced by the relative density of the gas. It likewise becomes vital to design these machines with a certain intake temperature and pressure range (Zakirova et al., 2023; Okoro et al., 2024).

CNG is utilised in converted conventional petrol-powered internal combustion engine automobiles, as well as in vehicles designed particularly for CNG use: either as a standalone (dedicated), with a separate liquid fuel system to enhance range (dual fuel), or in combination with an alternative fuel. It can be used as a substitute for liquefied petroleum gas (LPG), petrol, and diesel fuel. Compared to these fuels, the combustion of CNG creates fewer unwanted gases. Table 1 presents the burning characteristics of CNG. Since CNG is lighter than air and disperses more quickly when released, it is less dangerous than other fuels in the case of a leak. Rails, autorickshaws, pickup trucks, school buses, and commuter vehicles have the potential to incorporate CNG as a response to rising fuel costs and environmental concerns (Gerutu et al., 2023).

Table 1. The burning characteristics of natural gases (Chala et al., 2018; Leonardo and Semin, 2022)

Tabela 1. Charakterystyka spalania gazów ziemnych (Chala i in., 2018; Leonardo i Semin, 2022)

Characteristic	CNG	LPG
Auto-ignition temperature [°C]	540.15	374
Adiabatic flame temperature [°C]	1947	1980
Density [kg/m^3]	0.75–0.83	510–560
Lower calorific value [MJ/kg]	47.1	49.5
Lower flammability limit [% vol of fuel in air]	5.3	1.9
Higher flammability limit [% vol of fuel in air]	15.0	8.5
Laminar flame velocity [m/s]	0.38	0.43
Boiling point at atmospheric pressure [MPa]	–162	–42
Colour	No	No
Odour	No	No

As shown in Table 2, the primary constituent of compressed natural gas is methane (CH_4), which makes up 87%–96% of the fuel. It is extracted from natural gas fields and associated petroleum gas during the extraction process and compressed at high pressure (200–250 bar) before being delivered to the place of utilisation in specialised tanks (Rotaru et al., 2024).

Table 2. Composition of compressed natural gas (Rotaru et al., 2024)
Tabela 2. Skład sprężonego gazu ziemnego (Rotaru i in., 2024)

Component	Content [vol %]
Methane	87.0–96.0
Ethane	1.8–5.1
Propane	0.2–2.5
Isobutane	0.01–0.3
n-Butane	0.01–0.3
Isopentane	0.01–0.14
n-Pentane	0.01–0.14
Hexane	0.01–0.06
Nitrogen	1.3–5.6
Carbon dioxide	0.1–1.1
Oxygen	0.01–01
Hydrogen	0.02

CNG as a viable and environmentally friendly alternative fuel

The world is undergoing an energy shortage as a result of the depletion of finite fossil fuel resources. The use of fossil fuels, particularly liquid fuels, is deemed unsustainable owing to resource decline and pollution build-up. Different kinds of alternative fuels are being investigated worldwide to address the negative consequences of fossil fuels while meeting rising industrial and consumer demands. Natural gas has emerged as a possible alternative fuel due to its global abundance, low emissions, and comparable engine performance to traditional liquid petroleum products, especially diesel and petrol. Some alternative fuel sources have been identified to possess considerable potential for delivering lower total pollution emissions than petrol and diesel fuel. CNG, a primarily methane-based fossil fuel, represents one of the purest combustion alternative fuels (Ibeneme and Ighalo, 2020; Kanakana-Katumba et al., 2023).

Natural gas is compressed to less than one percent of its original volume to create CNG, which is then stored at elevated pressure in sturdy cylinders. In addition to costing 41% less for a 10-kilometre trip, CNG-powered cars release over 70% less greenhouse gas (GHG) than petrol or diesel cars, make less noise. CNG provides a more reliable energy source than traditional crude oil fuels, which may be extremely volatile and unpredictable. CNG is an environmentally friendly fuel that meets the highest requirements of many countries seeking to transition to alternative fuels. Because of its inherent clean burning, this fuel is regarded as one of the greatest choices for fossil fuel substitution (Gerutu et al., 2023).

CNG production is an innovative process that transforms natural gas, which is often used in homes, plants, industries, and several other applications, into a vehicle fuel. This is accomplished by compressing the gas and retaining it in a pressurised container, making it usable as an ecological and highly effective fuel alternative for automobiles (Ali et al., 2024). Moreover, a recent estimate indicated that CNG utilisation will continue to rise with regard to exportation and commercial usage, implying broader applications and utilisation. In a comparable manner, CNG's widespread use may be attributed to the fact that an increasing number of countries are now adopting natural gas-powered vehicles. The rate of compressed natural gas usage in automobiles has surged by 25% across the globe, with the majority of the contributions emanating from Latin-American and Asian regions, including countries such as Uzbekistan, Argentina, India, Brazil, Pakistan, China, Iran, and others, demonstrating the growing need for CNG (Ibeneme and Ighalo, 2020; Shaarawi et al., 2024).

CNG resources in Nigeria

Compressed natural gas, a fossil fuel-derived yet ecologically benign fuel, has emerged as one of the most popular alternative forms of power generation worldwide. Furthermore, because CNG is readily available in enormous quantities in Nigeria, it is currently recognised as a leading alternative fuel for transportation applications. It may be used as a replacement fuel in standard diesel and petrol engines, since it reduces air pollution emissions, and is less expensive than petrol or diesel. Nigeria has adopted the usage of compressed natural gas, with the government implementing various initiatives. The most notable of these is the introduction of compressed natural gas automobiles as a result of the elimination of gasoline subsidies to alleviate the economic hardship faced by Nigerians. The reasoning behind this is to equip Nigerians with a less expensive and ecologically sustainable mode of transportation (Gerutu et al., 2023; Oluwakoya, 2024).

Nigeria is the country with the second-biggest established reserves of oil in Africa and among the ten biggest worldwide, with an estimated 37 billion barrels. With approximately 208 trillion cubic feet of confirmed natural gas reserves, Nigeria is the biggest gas resource holder in Africa and ranks seventh among the countries globally. As part of its efforts to contribute to the global campaign to reduce greenhouse gas emissions, Nigeria has reaffirmed its pledge to support an environmentally

friendly growth of natural gas production and consumption. Utilizing its vast natural gas resources by converting them into compressed natural gas to use as fuel for vehicles is one method the government plans to accomplish this goal (Aba et al., 2023; James et al., 2023).

Since the late 1960s, the Nigerian government has worked to minimize the negative effects of gas production on the ecosystem and economy while also making full use of the nation's natural gas resources. Rules and regulations that forbid gas flaring and venting, the establishment of financial incentives for gas usage projects, the growth of regional and global gas export markets, the encouragement of gas usage for petroleum exploration operations, the application of natural gas as an industrial raw material, and in power generation, the 1997 proposal to use CNG as an automotive fuel are just a few of the important efforts that have taken place (Adeola et al., 2022). These activities have resulted in a variety of concerns, including the violation of regulations to prevent gas flaring and becoming a major exporter of liquefied natural gas and distributor of piped natural gas to some parts of West Africa (Ogunlowo et al., 2018).

Progress in CNG utilisation in Nigeria

According to Ogunlowo et al. (2018), the Nigerian National Petroleum Corporation (NNPC) reported that re-injection of associated gas was almost negligible in 1990; however in 2016, it accounted for approximately twelve percent of the gas found during drilling and extraction activities. As reported by Onolemhemhen et al. (2017), the country's 2008 local gas supply obligation, which requires petroleum and natural gas corporations to sell a percentage of their production to the domestic market, increased the national gas consumption by more than forty percent from 2008 to 2017. Improvements in the use of LNG and the revival of cement and chemical manufacturing are indicatives of the fuel's significance, particularly in the energy and manufacturing industries, where there are currently 23 gas-powered facilities and two more are under construction. Nevertheless, notwithstanding the nation's ongoing energy consumption constraint, the use of CNG as a fuel for vehicles has been slow to gain traction. With over 6 million cars in the nation's automobile fleet, the gas-powered vehicle adoption rate amounts to a mere 0.1% (Ogunlowo et al., 2018; Emeke et al., 2023).

CNG usage for transportation in Nigeria

In 1997, the Nigerian government recommended utilising CNG as fuel for vehicles across the country in the course of attempts to increase indigenous natural gas utilisation. However, this did not happen as intended (Ibeneme and Ighalo, 2020). In June 2017, the authorised National Gas Regulation, which somewhat superseded the Gas Master Plan (GMP), highlighted CNG as an example of the possible option for gas markets and applications, as well as the necessity for the creation of CNG facilities and natural gas-powered vehicles. The National Gas Expansion Programme (NGEP), which was introduced by the federal government by the year 2020 after the gas regulations were approved, aims to encourage the use of sustainable fuels in vehicles and establish CNG as the preferred fuel for transportation (Gerutu et al., 2023).

One of the reasons for initiating the NGEP is to convert a minimum of one billion gasoline-powered vehicles to CNG-powered vehicles by 2021; however, this goal was not achieved. Therefore, using CNG as a transportation fuel offers two ways to help lessen reliance on petroleum imports and ease economic strain, particularly on foreign exchange and subsidy costs. There is currently high demand for compressed natural gas consumption across the nation, but if not properly managed, this might turn into a catastrophic failure and worsen the nation's already poor economic circumstances. The use of CNG must be implemented carefully and purposefully in order to guarantee that citizens benefit from the nation's natural gas resource (Fapetu et al., 2023).

CNG and the Nigerian presidential CNG initiative

A number of projects have led to the creation of certain facilities and capacities related to natural gas extraction, distribution, and marketing. These include building gas extraction facilities and developing outlets, especially for liquefied natural gas export, as well as encouraging gas re-injection. The extraction and utilisation of natural gas derivatives, the use of natural gas as manufacturing raw materials, and the production of electricity from natural gas are among other projects. All of these efforts, nonetheless, had little effect on the domestic market (Ogunode and Aregbesola, 2023). In an attempt to lower transportation expenses for citizens, the present administration has introduced the Presidential Compressed Natural Gas Initiative (PCNGI), a newly introduced CNG fuel for transportation programme, in response to rising fuel prices and the financial consequences of the removal of petrol subsidies. The Presidential CNG Initiative (PCNGI) is a joint venture between the Nigerian National Petroleum Company (NNPC) Limited and the Nigerian Independent Petroleum Company (NIPCO). The administration plans to introduce a million CNG-powereds by 2027 under the PCNGI. In line with the above, the administration pledges to build 56 new CNG fill-

ing facilities around the country by April 2025, as well as to initially launch 11 500 brand-new CNG-powered vehicles in the next few years (with a focus on public transportation buses) and supply 55 000 new CNG switching packages (Olujobi and Irumekhai, 2024).

CNG fuel stations in Nigeria

Recently, Nigeria has been experiencing shortages of both petrol and diesel. Their supply has become increasingly limited and costly for the common Nigerian due to the inactive or sub-functional refineries. Imports have served as the primary source of the refined petrol fuels, which has added pressure on the country's critically needed foreign exchange reserves. On the other hand, the country possesses vast reserves of natural gas, calculated to be six trillion cubic meters. Nigeria produces and exports a significant proportion of its natural gas resources, leaving the domestic market with little left over for use in supporting its growing population and with a negligible effect on the country's development (Abu et al., 2023). Nigeria's CNG development began in 2010 when NIPCO Gas Limited launched a trial project in Benin City, Edo State. NIPCO Gas Limited is a sole subsidiary of NIPCO PLC. By June 2020, Benin City had seven CNG stations constructed and 7,500 CNG-powered vehicles operating there. Major corporations, including Coca-Cola, 7up, and Yongxing Steel, utilise CNG to power their vehicles and forklifts in Benin City. Edo City Transport Ltd. (ECTS) likewise uses CNG to fuel many of its vehicles. In 2019, NIPCO Gas Limited officially opened CNG fuelling outlets in Kwale, Nigeria. Figure 1 shows a CNG fuel station of NIPCO Gas Limited (Edo et al., 2024).

On 4 July 2024, the PCNGI, as part of its autogas project, officially opened 12 retail stations to distribute CNG in the Nigerian cities of Abuja and Lagos. Abuja's stations are located on Airport Road, Kubwa, Gaduwa, Olusegun Obasanjo Way, Zone 1, Dei-Dei, Duste-Bwari Road, and Gwagwalada. In Lagos, the stations are situated at Lateef Jakende, Agidingbi, Mushin, Lekki-Epe Motorway, Mobile Road, and Apapa. These CNG stations include modern reciprocating and hydraulic booster compressors that provide adequate pressure for CNG cars. The cooperation between NNPC and NIPCO Gas Limited, in conjunction with the Presidential CNG initiative, is planned to assist in the establishment of 35 CNG stations across Nigeria, providing CNG to a wide range of CNG vehicles, such as tricycles, sedans, buses, and heavy-duty vehicles. CNG will be delivered to stations in Abuja and Lagos by virtual transportation from mother stations in Ajaokuta (Kogi State), and Ibafo (Ogun State) (Biose, 2019).



Figure 1. A CNG fuelling station of NIPCO Gas Limited in Lagos, Nigeria. Photo taken by the authors

Rysunek 1. Stacja tankowania CNG NIPCO Gas Limited w Lagos, Nigeria. Zdjęcie wykonane przez autorów

CNG fuel safety

Safety is a fundamental concern in many aspects. Compressed natural gas, as a gaseous fuel, is flammable. Fortunately, it mixes quickly and uniformly in the air. It is less susceptible to fire on heated surfaces due to its elevated self-ignition temperature (540°C) and limited flammability range (5–15%). A leak is not necessarily harmful. CNG is less dense than air; thus it dissipates rapidly when released from a tank, and it is usually combustible when the air/fuel mixture contains 5–15% CNG (Rotaru et al., 2024). This narrow flammability range makes it a suitable fuel for use, but strict safety standards are required to ensure that CNG-powered vehicles are as safe as gasoline-powered ones. However, there are obstacles and concerns associated with the widespread use of CNG as fuel. It may pose high risks or lead to accidents due to substandard cylinders, faulty design and installation procedures, and a lack of regulatory controls. In addition, there are potential safety concerns with large buses running on CNG as opposed to diesel. Because of the additional weight of the fuel tank system, CNG-powered vehicles have a longer stopping distance. The main component of CNG is methane (a greenhouse gas), which might contribute to global warming if released (Okoro et al., 2024).

The three primary risks linked with CNG as a vehicle fuel are fire, asphyxia, and elevated pressure. Fuel leakage caused by exceeding the capacity of the fuel tank, impairment to the fuel storage system, and progressive leaking over extended periods are among the most common causes of fires in CNG cars. Excessive CNG exposure can result in natural gas ingestion, which is characterised by exhaustion, persistent headaches, memory issues, loss of focus, vomiting, loss of alertness, and breathing difficulties. CNG acts as an asphyxiant, just like carbon monoxide does. When inhaled, it displaces surrounding

air, preventing the body from receiving the oxygen required for proper breathing. While low concentrations of CNG in the air are typically not hazardous, greater concentrations reduce the amount of available oxygen. As the percentage of CNG rises and the duration of inhalation increases, the side effects will intensify. Moderate exposure over several days or weeks might cause mild physical symptoms while still significantly affecting overall psychological well-being. The long-term effects of accidental CNG ingestion could result in cardiovascular, pulmonary, and neurological issues. Exposure also increases the risk of memory loss, depression, epilepsy, claustrophobia, and cardiac issues. Prolonged oxygen deprivation, as seen with CNG poisoning, can cause lasting damage to the brain and heart (Li et al., 2024).

Recommended safety guidelines for use of CNG fuel in Nigeria

CNG cylinders must be safeguarded against explosion in the case of a fire or over-pressurization. All CNG fuel systems should be equipped with distinctive safety features such as pressure relief devices. It is necessary for the CNG cylinder to have these safety measures to ensure safety. The pressure relief devices will operate at a certain temperature or pressure, releasing the CNG cylinder's pressurised contents if the pressure gets too high. CNG cylinders should also be manufactured in accordance with international standards and made from much sturdier materials than gasoline or diesel fuel storage tanks. According to the standards, all CNG fuel storage cylinders must be manufactured to withstand 2.25 times their fill pressure. This means that the cylinders will have a minimum burst pressure, which will be far above the fuel delivery pressures at the CNG fuel stations. High-pressure CNG fuel system components other than CNG cylinders should be designed to withstand four times their rated pressure, allowing them to endure very high pressure without bursting (Mishra et al., 2024).

The authorities should outline the safety and quality standards to assess the safety provisions of CNG fuel stations across the country. These will be used to determine whether these stations appropriately manage the danger to the safety and public health within their domain in accordance with international standards. They will also help to identify whether the stations need to take additional precautions to reduce risk. It is also recommended that auto-technicians and artisans who will be carrying out daily maintenance and repairs on CNG vehicles should be equipped with the appropriate maintenance and repair practices and safety procedures to ensure the safety of lives and properties in the country.

Conclusion

The world is shifting away from petrol and oil-based energy, which is becoming increasingly expensive and has been linked to environmental degradation, releases of greenhouse gases, and global warming. The Nigerian government's efforts to embrace the usage of CNG, as well as measures carried out to enable a smooth transition from conventional fuels to natural gas fuels, were highlighted. CNG-powered cars and fuel stations have been introduced in an effort to transition to environmentally friendly fuels and ease the hardships of Nigerians as a result of the termination of petrol subsidies. These initiatives will increase local energy utilisation and provide inexpensive and clean energy, which is in harmony with the Sustainable Development Goals (SDGs) (Mishra et al., 2024). The government has established centres for converting existing petrol and diesel vehicles to CNG ones. As with other fuels, CNG is flammable and may catch fire; therefore, it is suggested that the hazards associated with CNG storage, such as vessels, tanks, and cylinders, should be assessed in a comprehensive manner to evaluate, identify, and analyse the risks to enable authorities to develop focused measures to mitigate them.

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