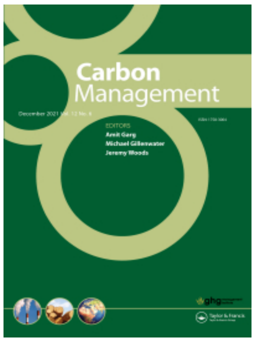

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Carbon reduction and nuclear energy policy U-turn: the necessity for an international treaty on small modular reactors (SMR) new nuclear technology

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ABSTRACT

Pressure to reduce carbon emission and meet Net-zero targets is forcing countries to re-introduce nuclear energy in their energy-mix. As a result, many countries have re-classified nuclear energy as a green energy to encourage investments and developments in this sector. Further, advances in nuclear energy technology have led to the development of Small Modular Reactors (SMR), which has continued to stimulate increasing interests from both developed and developing countries. Hence, it is expected that in the coming years, there would be increased deployment of SMR across the globe. This renewed interest in nuclear energy and expected global deployment of the novel SMR, would encounter some legal issues. Therefore, this paper analysed the nuclear energy international legal and regulatory frameworks (relevant nuclear energy conventions and treaties) currently used for the conventional large nuclear power plants (NPPs) to understand how adequate they are for SMR deployment. Various critical gaps were found in the extant laws that could make them not to fully cater for all the peculiarities of the new SMR nuclear technology. This may affect the effective regulation and smooth deployment of SMRs across countries. Therefore, this paper argues that a single specific international treaty on SMR that will cover the regulation of all aspects of SMR deployment, and their peculiarities is highly needed to support countries to justly transition into a Net-zero era.

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Small modular reactors (SMR); new nuclear technologies; nuclear energy; carbon emission; international treaty; green energy; Net-Zero

Introduction

There is an ongoing global race to reduce carbon emission and to mitigate climate change impact. This is stimulating a renewed interest in the deployment of nuclear energy for power generation across many countries [1]. The past decades witnessed an ebb in the deployment of nuclear energy in the energy mix of many countries, with many countries decommissioning their nuclear power plants, due to safety concerns raised by devasting impacts of accidents that occurred at nuclear power plants [2]. However, interest in nuclear power is making an increased comeback into the energy mix of many countries; this renewed interest has mainly been triggered by many factors such as reduction of carbon emission and global geopolitics [3]. Efforts geared towards the reduction of greenhouse emission has put a squeeze on fossil energy usage across countries. Countries are now facing increasing pressure to transition away from fossil-based energy to meet their climate change obligations. Nuclear energy is a viable energy source that can cushion the effects of the push for countries to transition away from fossil fuels. It is a low carbon energy source, hence, contributes minimally to global CO2 emissions. Its carbon footprint of around 15–50 grams of CO2 per kilowatt hour (gCO2/KWh) is quite minimal compared to those from fossil-based technologies such as gas-powered plants with average footprint of around 450 gCO2/KWh and coal (1,050 gCO2/KWh) [4].

Furthermore, compared to other low carbon energy generation technologies, nuclear energy is the only proven low-carbon generation technology that can provide reliable baseload power. Base load powers of others such as wind and solar are variable, depending on external factors such as weather condition. Hence, nuclear can help in balancing the variability of wind and other renewables [5]. In addition, nuclear energy technologies provide additional economic and environmental

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benefits. New designs of reactor (SMR) can match the cost per unit of power of offshore wind turbines. This cost is inclusive of waste management and eventual decommissioning, unlike other technologies, which do not take these additional costs into consideration in the quoted cost, hence, additional investments would be required for waste management and decommissioning of other low carbon technologies. The enhanced efficiency of SMR has promising prospects for nuclear energy technologies, by increasing their competitiveness in the low-carbon energy market.

In addition, the energy crises caused by the ongoing Russian-Ukraine War, which exposed the heavy reliance of countries on fossil-based fuel, and threat to their energy security, forced countries to scramble for alternative energy sources to improve their energy security [6]. Hence, nuclear energy is progressively becoming the favourite energy choice, especially in temperate regions where energy from renewable sources such as solar, and wind have been deemed unreliable [7].

The renewed interest in nuclear has also been driven by advances in nuclear energy technology, which have led to the development of small modular nuclear reactors (SMRs) with promising prospects. These reactors promise simplicity and ease of installation and operation, and as such can be deployment on a largescale anywhere in the world. Hence, the SMR is generating a lot of interests from various stakeholders and promises to become the main power source for the future, for many countries [8].

This renewed interest in nuclear energy, has made many countries to reverse some of their previously held anti-nuclear energy stance and policies to re-accommodate nuclear energy deployments in their clime [9]. As part of this policy U-turns, nuclear energy has been reclassified as a green energy by many countries, hence opening the door for government support and grant of incentives for nuclear power plants [10]. There is an expectation that deployment of nuclear energy would dramatically increase in the coming years. Based on the current figures from the International Atomic Energy Agency, there are about 416 operable nuclear reactors for electricity generation and 59 under construction around the world [11]. To bring energy-related CO2 emissions to net zero by 2050, the International Energy Agency (IEA), estimates that global nuclear capacity would need to almost double from current levels to reach 812 gigawatts (GW) in 2050 [12].

The nuclear energy sector is primarily regulated by international conventions and agreements mainly organized by the International Atomic Energy Agency (IAEA). Other international conventions such as that of the maritime sector are also applicable to it, especially for the transportation of nuclear energy materials through the sea. SMR is a nascent technology that has not fully been tested, its deployment under existing nuclear energy legal frameworks may lead to issues and disputes between the manufacturers and host states. Therefore, this paper aims to analyse the existing legal framework to ascertain their adequacy, suitability, and applicability to SMR. While few available literatures on SMR usually discuss the general applicability of these legal frameworks to SMR [13–16]; this paper highlights the serious possible implication of the gaps and omissions in these frameworks on faster development and deployment of SMRs. It also provides additional analyses on the challenges of the applicability of the current IAEA safety standards to SMRs [17]. And the possible effect of current issues threatening the Energy Charter Treaty (the only legally binding international treaty for the energy sector) on SMR.

The article proceeds as follows: firstly, it explores the historical view of the nuclear energy re-integration in Nuclear Energy Re-Integration – Historical Perspectives section. Secondly it gives a background to SMR in Background to Small Modular Reactors (SMR) section. Current Body of Knowledge Assessing the Applicability of Existing Nuclear Legal Framework to SMR section provides a review of the available literature on the applicability of existing international legal framework on SMR. Issues in Regulating the Peculiarities of SMR section analyses the design and structural differences of SMR compared to the conventional NPPs and bringing to fore the necessity for a separate global legal framework for SMR. Limitations of International Nuclear Energy Conventions section brings in the main highlight of this article demonstrating the insufficiencies, gaps and worries in the current nuclear legal frameworks. The Need for International Treaty on SMR section further emphasizes on why there is need for an international treaty on SMR if its development and deployment is going to be faster to help countries achieve their net-zero targets. Finally, Conclusion and Recommendations section gives a summary of the findings and the recommendations.

Nuclear energy re-integration – historical perspectives

Interest in nuclear energy generation commenced in the late 40s following the discovery of massive energy released from the splitting of an atom in the early 1930s [18]. Although initial interest in nuclear energy technology focused on development of nuclear weapons, soon after World War II, interest in harnessing the massive energy from nuclear materials for electricity generation piqued. By 1951, electricity was generated in the United States by an experimental nuclear reactor, the small Experimental Breeder reactor – EBR-1 [18]. The success of this led to increasing civil nuclear energy developments in the United States and other parts of the world.

By 1954, the world's first nuclear powered electricity generator began operation in Obninsk, in the then Soviet Union [18]. By 1956 the world's first full-scale commercial nuclear power station (Calder Hall I) commenced operation at Sellafield Cumbria, in the UK [19]. Following this was the commencement of fully commercial nuclear energy generation in 1960 from the Yankee Rowe nuclear power station in Massachusetts US [18].

However, after a few nuclear accidents at various power stations with devastating consequences, public interest in nuclear energy generation waned. The world has experienced various nuclear power plant accidents. Prominent among these are the 1986 Chernobyl nuclear accident in the then Soviet Union; the 1979 Three Mile Island accident that occurred in Pennsylvania US, and the 2011 Fukushima nuclear disaster at the Daiichi Nuclear Power Plant in Japan. The lack of continued public support for nuclear energy in different countries limited maximum deployment of nuclear energy as many countries opted for investment in safer energy options.

Austria was the first country to officially ban nuclear energy usage [20]. In 1978, The Austrian government voted to ban nuclear fission for Austria's energy supply. And in 1997, the Austrian Parliament collectively passed legislation to remain an anti-nuclear country. Italy had closed its last reactors in 1990. And a referendum in 2011 planning to revive nuclear energy generation by 2030 was rejected due to the Fukushima disaster [21]. Australia has always had an absolute prohibition policy regarding nuclear energy [22]. In 1998, the Australian parliament enacted the Australian Radiation Protection and Nuclear Safety Act 1998. A legislation that prohibits the construction and operation of nuclear power stations. New Zealand is another developed country not using nuclear energy for its electricity generation. Denmark as well prohibited nuclear power plants development since 1985 [23].

The Fukushima nuclear disaster further pushed many countries across the world away from nuclear energy use as the impact of natural disasters on nuclear accidents once again came to the fore. As a result, many countries especially in Europe, began to decommission some of their existing nuclear power plants and blocking future nuclear investments, while others took drastic steps to commence phasing out of nuclear energy plants from their territories. For example, in Germany, the Federal Government decided to terminate the use of nuclear energy for commercial electricity generation. Many of its nuclear power reactors started undergoing decommissioning and the remaining three nuclear power reactors in operation were finally shut down in 2023 [24].

However, the energy crisis triggered by the Russian-Ukraine War, which limited natural gas supply to many European countries and the resurging push for the exploitation of non-fossil energy to cull greenhouse gas emission, is making countries to reconsider the deployment of nuclear energy as an alternative energy source. As part of the efforts to combat climate change, many countries signed the Paris Agreement, a legally binding international treaty on climate change at the UN Climate Change Conference (COP21) held in Paris, France in 2015 [25]. The intent of the Paris Agreement is to hold "the increase in the global average temperature to well below 2 °C" while pursuing efforts "to limit the temperature increase to only 1.5 °C above pre-industrial levels."

Currently, nuclear energy is an appealing alternative to fossil fuel as it is perceived as a low-carbon and cleaner energy resource with commensurate capacity to combat carbon emission. Hence, a re-consideration of deployment of nuclear energy and its re-introduction into the energy-mix of many countries has been brought to the table. This has gained the support of critical stakeholders in the sector (including governments, regional blocs, and nuclear agencies), calling for further investments and development of nuclear power generation and re-integration into the energy mix. This call was re-echoed during the 28th annual United Nations Climate Change Conference (COP28) 2023, where countries launched a joint declaration to triple nuclear energy capacity by 2050 [26].

In line with this new trend, the European Commission in 2023 proposed the Net-Zero Industry Act (NZIA), which aims to improve the investment environment for the union's manufacturing capacity of technologies needed to meet its climate neutrality goals and decarbonisation of their energy system. Under its definition of "advanced technologies," it partially allowed for production of energy from nuclear small modular reactors as one of the acceptable technologies [27]. This tentative step has now been overridden by the European Parliament, which subsequently voted to wholly include nuclear fission and fusion among a list of other technologies into the Net-Zero Industry Act [28].

In the UK, the government's Ten Point Plan for a Green Industrial Revolution (2020), the Net Zero Strategy (2021) and the Mobilising Green Investment- Green Finance Strategy (2023) highlight the role of nuclear energy as a significant part in assisting it to attain its pledge to reach net-zero carbon emissions by 2050 [29]. In March 2023, the UK government announced the commencement of the "Great British Nuclear," a body responsible for developing robust new nuclear build projects. It also announced that nuclear energy will be subjected to consultation, and to be classed as environmentally sustainable in the green taxonomy, to equate it to the same level of investment incentives as was granted to renewable energy [30].

The United States through its various climate and clean energy innovation funds promotes the procurement and demonstration of advanced nuclear technologies, including nuclear small modular reactors (SMRs), which it sees as a game-changer for climate change efforts [31]. In Asia, to curtail high air pollution from coal-fired plants, China is spearheading the building of new nuclear power plants including SMRs, while Japan despite the setback from the Fukushima accident, is committed to reprocessing its used fuel to recover uranium for re-use in electricity production (although the fresh earthquake that occurred this January 2024 now casts doubt on their ability to revive nuclear power plants) [32,33]. India and South-Korea are also major players in the recent consideration and use of nuclear energy.

In other regions, the drive to maintain energy security and achieve the UN sustainable development goals has also led to various newcomer countries that are at various stages of the deployment of nuclear energy, as a key part of their energy mix. In Africa, nuclear energy is gaining momentum as a possible option to boosting energy supply. Apart from South Africa, which is the only country in African owning NPPs, other countries such as Egypt, Nigeria, Ghana, Kenya, Ethiopia, Rwanda, Senegal, Uganda, Tanzania, Zambia, and Namibia, are at various stages of building new nuclear power plants and are likely markets for SMR power plants [34]. Nuclear energy is also considered critical to Africa's agenda for sustainable development [35]. Nuclear power is not a common source of energy in Latin America. Currently, there are five operable nuclear power reactors and one under construction in the whole of Latin America region [11]. However, Chile has been listed among the newcomer countries considering nuclear energy generation [36].

International nuclear agencies and socioeconomic organisations have also voiced out their support for the reintegration of nuclear energy. They argue that the re-deployment of nuclear energy into the energy-mix is urgently needed to achieve net-zero climate targets on decarbonization [37,38]. The International Atomic Energy Agency (IAEA) stressed in its special report that nuclear power will play a key role in achieving the aspirations of the Paris Agreement and the Sustainable Development Agenda 2030 [38]. The IAEA has also stated that nuclear power is now regarded safer than it was before Fukushima Daiichi [39], and that nuclear power has proved its vital role as an adaptable, reliable supplier of electricity during the COVID-19 pandemic [40].

Also, weighing into this is the Organisation for Economic Co-operation and Development (OECD). In its Nuclear Energy Agency (NEA) analysis of over 90 pathways to net-zero emissions considered by the United Nations Intergovernmental Panel on Climate Change shows that to limit global warming to no more than 1.5 °C, installed nuclear energy capacity must triple to 1,160 gigawatts by 2050 [26]. The Nuclear Energy Agency at the 27th Conference of the Parties of the UNFCCC (COP27) in Egypt was also of the view that nuclear energy produced through new innovative technologies such as SMR can play a key role in helping to alleviate the impacts of climate change [41].

Background to small modular reactors (SMR)

Small modular reactors (SMRs) are new nuclear reactors that have the capacity to generate electric power of up to 300 MWe or less [42]. SMRs are also generally classed as low carbon power source as they can produce a large amount of low-carbon electricity. Besides using nuclear fission reactions to produce energy, the reactors of these new nuclear power plants are characterised by two main features (small and modular), which distinguishes them from traditional large power reactors [43]. They are classed as small because they are physically a fraction of the conventional nuclear power reactor in size. In terms of modularity, SMR systems and components are designed to be factory-assembled and transported as a unit to a location for installation. Currently, there are only two operational SMRs – the Russian Akademik Lomonosov floating nuclear power plant that is producing energy from two 35 MW(e) SMRs, and the HTR-PM demonstration SMR in China [44]. Over 80 commercial SMR designs are being developed around the world based on different types of reactor coolant such as the Light Water-cooled SMRs (LWRs), high temperature gas-cooled SMRs (HTGRs), Liquid Metal-cooled Fast Neutron Spectrum SMRs (LMFRs), Molten Salt Reactor SMRs (MSRs) and Microreactors (MRs) [45].

SMRs are increasingly becoming popular due to its many benefits stemming from the nature of their design (small and modular) [44]. For example, due to their smaller footprint, SMRs can be sited on locations not suitable for larger nuclear power plants (NPP). The modular nature entails that they can be prefabricated by the manufacturers and subsequently shipped and installed on site elsewhere. This means that they are more portable and affordable to build than conventional large power reactors. Unlike the large NPPs that could lead to construction delays and extra cost, SMRs promises to offer a cheaper option, and due to their modular nature, they can be deployed incrementally to match increasing energy demand. In addition, they can be installed into an existing grid or off-grid in remote areas with insufficient grid coverage and be easily integrated into existing alternative energy sources (fossils, and renewables) [5].

Furthermore, they are built with additional safety measures such as the passive systems and inherent safety measures with the ability to safely self-shutdown in an emergency [42]. Most SMRs are also more economical to maintain than conventional reactors as some of them such as those with breeder capability have reduced fuel requirements [42]. Thus, SMR power plants will generally require less frequent refuelling (3 to 7 years), in comparison to large plants that require refuelling between 1 and 2 years. As a result of the various benefits of SMR, many countries including the UK, US, China, Russia, Canada, and Argentina are at various stages of the development and incorporation of SMR into their energy mix. The UK, EU, Canada, and US have earmarked huge sums of funding support to stimulate SMR development and deployment. In the UK, six SMR design companies namely Rolls Royce SMR, EDF, GE-Hitachi Nuclear Energy International LLC, Holtec Britain Limited, NuScale Power and Westinghouse Electric Company UK have been chosen to compete for advanced SMR technology [46].

Current body of knowledge assessing the applicability of existing nuclear legal framework to SMR

Being a new technology, SMR is provoking a lot of interest among researchers. Studies have focused on various aspects of SMR ranging from technology and innovative aspect of it to its regulation. There have been a number of legal research that have explored the applicability, suitability, and adequacy of existing nuclear international legal frameworks to SMR. With regards to applicability, authors like Kalleveen, Roland, Karcz among others have examined the applicability of the existing nuclear conventions to SMR [13–16]. They found that there are certain gaps in them that may affect smooth deployment of SMR. For instance, a study by the JRC of the European Commission done by Kalleveen found that the international nuclear legal framework does not address SMRs in a consistent fashion but does not intentionally exclude SMRs from its scope [13]. It can in some instances apply to all types of SMRs, in others, to certain types only. The study also found that the international nuclear legal framework does not make a distinction based on technology but rather a distinction based on the location of the SMR (land-based vs floating) or based on the purpose of its use (military vs civilian use, or transportation use). As a result, regulation of SMRs compared to conventional reactors is currently inadequate in existing legal framework [13].

The study suggests that the current international legal framework would need adjustment or interpretation to cover all SMRs. And that inadequacy of the current international legal framework towards SMRs is an opportunity to harmonize the legal framework at the multilateral level [13].

Also, Roland [15] analysed the applicability of existing nuclear legal framework to Land-based SMR (Type 1) and Marine-based SMRs (Type 2). He stated that "it can be directly concluded that all

SMRs used for the propulsion of a means of transport or to produce energy for any purpose related to their transport are excluded by both the Paris and the Vienna Conventions," although the exclusion was not intended by the convention's drafters [15]. He also pointed out that the conventions did not provide for floating SMRs, that is those not anchored to the seabed or the shore. Such floating reactors are considered not fixable and hence fall outside the scope of the conventions [15]. And that although, the Convention on the Liability of Operators of Nuclear Ships, adopted in Brussels on 25 May 1962, provided for nuclear ships, this convention never came into force. Hence, he argues that this convention could serve as a good basis for harmonising the nuclear liability framework concerning marine based SMRs of type 2 as well as SMRs used for the propulsion of ships or vessel [15].

He further stated that "the fact that … the current international liability framework resembles a patchwork is thus challenging for SMRs, especially with regard to type 2, whereby factory-fuelled reactors are shipped around the globe. Indeed, with the transfer of liability from one operator to another which might be party to different conventions, the possibility arises of damages being inadequately covered and reciprocally managed by the state involved. This is not only a problem for victims in the case of an accident but could also have a significant impact on the effective deployment of SMRs" [15]. To him there are two challenges that create uncertainty and unforeseeable risks, which may reduce the attractiveness of SMR projects, these are the absence of a harmonised international liability framework; and secondly, the fact that damages remain uncovered in some areas and situations due to the geographic scope of the conventions.

Similarly, Karcz [16], who assessed the adequacy of existing international legal frameworks for response to incidents involving Floating Nuclear Power Plants (FNPP), found that the existing response requirements and mechanisms for a nuclear accident or nuclear security event concerning FNPP are either limited, vague or non-existent within the Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment (ACPPNM), the International Ship and Port Facility Security (ISPS) Code, the International Maritime Dangerous Goods (IMDG) Code, and other international instruments within nuclear and maritime law [16]. A floating nuclear power plant simply means a floating power station that derives its energy from a nuclear reactor such as SMR.

Fialkoff [16, 47], found major gaps within the existing international nuclear and maritime frameworks that classify an FNPP. In his article he concluded that even though he believes that existing frameworks may be sufficient for the security of FNPPs regardless of classification, he observed that the adequacy of the frameworks for FNPPs is still doubtful due to their silence on the requirements specific to nuclear operations in the maritime domain [16, 47]. Also regarding FNPPs, Lysenko highlighted that they are non-self-propelled vessels and that "Trans-ocean and long-distance transportation of FNPPs would require different technical options and different legal regulations" since they are non-self-propelled vessels not covered by the existing maritime conventions [48].

However, surprisingly, despite all the gaps and omissions identified they concluded that these conventions can still be applicable to SMR. Roland, despite acknowledging the gaps in the existing conventions, argued that these issues are not critical to impair the development of SMRs and thus, necessitate a revision of the conventions, as the conventions already sufficiently secure the liability chains that SMR deployment implies [15]. This is problematic, because if the conventions have gaps, they cannot be said to be fully applicable to SMR, hence, the gaps demonstrate a need for a new legal framework that can adequately address the gaps. This paper notes that their analyses did not fully take into considerations the peculiarities of the design features of SMR (see Issues in Regulating the Peculiarities of SMR section), while arriving at the conclusion that the existing conventions in their current state should still be applicable to SMR.

In particular, this paper brings into discussion additional SMR challenges such as those arising from the design of SMRs, limitations in dispute resolution provisions in existing conventions/treaties, lack of legal framework for increased SMR fuel enrichment, and the possible implication of the current withdrawal of countries from the Energy Charter Treaty on SMR foreign investments and contractual arrangements which all supports the call for a new international nuclear treaty that would specifically and fully address the regulation of SMRs instead of amending all the various existing conventions.

This position is supported by findings from other related works. Popov [49], who examined the problems and prospects of the international legal framework in the context of SMR and transportable nuclear power units, argued that the deployment of SMRs requires a transparent and balanced legal framework that will define the specifics and boundaries of shared responsibility between the host and supplier country, especially in the case of innovative floating SMR projects [49].

The IAEA has also discussed that the diversity of SMR technology and potential deployment scenarios, raises questions regarding the applicability of the existing international legal frameworks for the safe and secure uses of nuclear technology, as well as the legislative and regulatory frameworks giving effect to these instruments at the national level [50].

A recently published position paper by the European Chemical Industry Council, recommended for the review of the existing liability framework for nuclear assets specifically in anticipation of SMR deployment on industrial sites, to provide clarity in responsibility between SMR technology providers and industrial off takers to minimise system costs [51].

In the same vein, Sam, and others [52–54], observed that the lack of a harmonised nuclear regulatory framework across the globe, poses a considerable impediment to the deployment of SMRs. Several other studies [55–59] suggest that a harmonised regulatory approach would also favour the deployment of SMRs in the overseas market as the SMR designs should be licensable not only in their home country, but also in other countries to break into the global market.

Issues in regulating the peculiarities of SMR

Existing nuclear legal framework were made based on the design, and operation of large nuclear power plants, hence, it is expected that they will not fully cover for the innovative designs of the SMR technology as SMRs are remarkably different from conventional nuclear power plants, in terms of design, deployment, and operations. Key limitations in the existing framework to adequately regulate the SMR emanate from the design of SMRs, SMR licencing, SMR deployments and gaps in certain nuclear energy conventions. These are addressed below.

SMR design and regulatory challenges

The design of the SMR varies from those of conventional nuclear power plants. These differences add some level of complexity in existing nuclear safety conventions and regulations, that was not considered before. As noted by the SMR Regulatory Forum, SMRs have different designs, which are likely to be compact and complex, compared to existing nuclear power plants (NPPs) [60]. Hence, new approaches need to be developed as a result of the differences [60]. SMRs are multimodule NPPs, an SMR power plant may include several modules at a single site unlike large NPPs which are generally a single reactor unit on a site as defined in existing IAEA safety standards [17]. With this new type of design, construction, and commissioning of a new SMR power plant will include several modules at a single site and there may be some shared systems, interactions or other dependencies between the modules that may affect safety [17].

Requirement 8 in the Safety of Nuclear Power Plants: Design, Specific Safety Requirements. SSR-2/1 (Rev. 1) specifies that:

> Interfaces of safety with security and safeguards safety measures, nuclear security measures, and arrangements for the State system of accounting for, and control of, nuclear material for a nuclear power plant shall be designed and implemented *in an integrated manner so that they do not compromise one another* [61].

Due to the possibility of interdependence of multiple SMRs in a site, the safety of one SMR may be affected by issues in another SMR on the same site. Where this is the case, safety requirements will need to be framed so that any sharing, do not compromise the safety systems' ability to perform their functions [17]. Already, the Forum is considering a new approach that will incorporate a holistic approach to assessing risks to safety, security, and safeguards (known as 3S) [60]. According to them, the new approach termed "3S-by-design" will involve an assessment that will be done from the earliest stages of the design development [60]. In particular, the forum has noted that it will be inadequate to use existing approach whereby installation of the final security and safeguards arrangements are done as part of last construction activities, for new SMRs. Rather, new SMR features are expected to be incorporated in the early design stages. [e SMR Regulatory Forum has further advised for international collaboration for a review of higher-level guidance to regulation of the 3S assessment principles [60].

Regarding safety, SMRs are designed to have various inherent and passive safety features, which may replace the active safety components used in existing reactors. They include the following: having a low nuclear material inventory (which may lead to reduced source of radioactivity release); having low core power capacity (which reduces overall cooling requirements and allows for a wide selection of sites); having larger surface to volume ratio (which facilitates easier decay heat removal) and compact design that reduces the risk originating from certain external hazards such as earthquakes, missile strikes [60].

Regarding security, there are concerns that SMRs have new security design features, that may pose a new risk different from those posed by large NPPs and thereby need a changed approach to nuclear security regulation [60] Even though some IAEA guidance on security may apply to some SMRs [61–65], however, the SMR Regulatory Forum has recommended one that will address SMR design possibilities of integrated physical security and information security, including cyber security, into one robust nuclear security system [60]. Other security risks that will be created due to the nature, design, and operations of SMR include increased dependency on off-site response personnel forces instead of stationary personnel forces. Also, SMR use of new types of fuels, different insider risks due to autonomous operation and remote site and monitoring, and temporary units may increase nuclear security risk and may delay timely off-site responses. And there might be increased supply chain risks due to insider threat paths [60].

In addition, to the safety and security issues, SMRs designs also pose a different kind of safeguards problems. IAEA safeguards are a set of measures applied to independently check that nuclear technologies are free from misuse and misapplication for non-peaceful purposes [66]. Unlike the existing safeguards for the large NPPs which may occur separately, SMR's involves a combinations of different challenges in a single design [67]. According to the SMR Regulatory Forum, SMR has new design features that may affect compliance with existing safeguards [60]. Some of these include the following [60]: Firstly, it may become difficult to continue to use satellite or other forms of remote sensing to verify operation due to its low thermal signature. With their small and modular nature, the radiation from SMRs is relatively smaller than those from large NPPs, which are usually detectable from many spaceborne satellite sensors. Secondly, the conventional method of optical viewing of the fuel in the core or in the spent fuel storage will become difficult for some SMR that use non-water coolants such as sodium. Thirdly, current safeguards inspection activities will be challenged due to SMR Spent-fuel storage geometry such as changing the positioning of smaller fuel storage elements vertically for cooling purposes. Finally, as IAEA's safeguards agreements are usually signed by different countries, it will become problematic for SMR due to its new modular feature whereby its manufacturing and fuelling for operation may occur in different countries. This will obviously change existing safeguards implementation measures.

SMR double licensing feature

SMR deployment is still nascent, hence, there is limited international experience in regulating it. Only few countries have issued a construction or an operating licence for SMRs, and each are adopting different approaches to its regulation [68]. There are also significant uncertainties surrounding the deployment and operation of SMRs due to variability of novel features of the reactors. As SMRs technologies will have innovative features, concepts, technology, and deployment models, it would be challenging for extant regulatory frameworks of many countries made available for conventional large NPPs to keep pace with the developments. Hence, it becomes imperative for a specific one to be made for SMR [68]. Here we will be discussing a new and different SMR feature – double licensing and its varying approaches across different regions.

Licensing is a key determinant in the timing of SMR development and commercialisation. Therefore, there is need to reform existing regulatory processes due to SMR peculiarities. Calls have also been made for the harmonization of the licensing procedures due to the different SMR designs [69].

Firstly, due to the fact that SMR will be factory built in one country and transported to another country/place for installation, it immediately brings up the issue of double licencing. The manufacturing company will have to obtain licence in its country before building it, likewise, the installation country will also have to obtain licence to install SMR in their country. What this means is that there will be protracted timing and delays from both ends. The licensing process of SMRs may also require additional considerations due to its other peculiar and different deployment cycle such as offsite commissioning and transportation, onsite commissioning, and offsite decommissioning.

Knowing that nuclear energy investments are already capital-intensive, SMR developers and buyers will detest any licence quagmire. In the nuclear energy industry, licensing disputes range from challenges to the grant of licences and to sudden licence withdrawals. For instance, in the Federal Court ruling on partial licence for works at Angra III -*Public Prosecutor v. National Nuclear Energy Commission* [70], the Brazilian public prosecutor sued the National Nuclear Energy Commission (Comissão Nacional de Energia Nuclear – CNEN) for granting partial construction licence to Eletrobràs Termonuclear S.A (Eletronuclear) for preliminary works carried out at the Angra III NPP.

Meanwhile, the issue of double licensing may also give rise to increased inter-governmental and political issues. Because nuclear NPP licensing generally touches on national security issues, there are usually some national resentments in granting certain licences to some foreign developers. A good example is seen in the American Nuclear Infrastructure Act of 2021, Sec. 102 (Denials of certain domestic licenses for national security purposes) and Sec. 303. (Investment by allies) [71]. Proper international regulation of SMR could avert this resentment by pre-stating in advance specific requirements or guidelines that will help to filter genuine foreign investments to note if they pose national security risk or not than generally outlawing them. For example, by assessing the degree of independence from the state control, transparency, and disclosure etc [72]. Doing this will help to boost SMR commercialization around the world without unnecessary regulatory licensing hiccups.

Likewise, some countries have also started devising various approaches to work through this novel SMR feature so as to curb likely delays from the manufacturer's licensing side. They are becoming pro-active in their pre-licensing approaches by having flexible and predictable regulatory schemes for SMR. They include Canada's pre-licensing Vendor Design Review (VDR), Argentina's Ad hoc licensing process/scheme, and the UK's Generic Design Assessment (GDA) methodology [68].

In the UK, Rolls-Royce SMR has also developed a new internal holistic approach to licensing called an integrated E3S (Environment, Safety, Security and Safeguards) case [73]. It has been presented to the UK regulators for assessment throughout the GDA. The main aim of E3S Case is to increase licensing flexibility when exporting Rolls-Royce SMRs outside of the UK. It is hoped to be elevated to a digital platform to aid with flexible licensing approach.

Although, these licensing approaches are innovative, however, lack of uniformity across board could still lead to delays in deploying SMR on a global commercial level. The IAEA has also mentioned the need for a harmonized global licensing approach for SMR [74].

SMR and TNPP deployment practice

A key feature of SMR is that they are factory fabricated. They could be built in one country and transported to a buyer country elsewhere. The fact of off-site manufacturing and construction could disrupt the regulatory approval procedures in the buyer country as there may be discrepancies in the buyer country's design and manufacturing regulatory provisions. The problem with this is brought to the fore when different transportable nuclear power plant (TNPP) such as SMR deployment practices are assessed.

The first and usual practice is where TNPPs are moved to the installation site/country without any fuel in the reactor. Loading of the fuel only takes place on-site. This practice does not really pose a problem as it is already covered by existing regulatory standards.

The second practice is where TNPP are moved to the installation site with fresh nuclear fuel loaded in the reactor. This practice is a new one that will pose novel problems for transport because this practice is not specifically covered in existing national safety standards or specific safety provisions for the transport of radioactive material [17]. Hence, both the manufacturing and the buyer countries will not have specific regulatory approval procedures for it as the fuel here will be fresh one and not spent fuel.

The classification of SMR new nuclear technologies as "green"

There is an ongoing debate on whether nuclear energy in general and SMR new technology in particular can be classified as a "green" energy [75]. This is notwithstanding that nuclear energy is a known low carbon source of energy. With nuclear energy re-integration being re-considered by many regions (see Nuclear Energy Re-Integration – Historical Perspectives section above), countries are reclassifying it as a green energy e.g. UK and some EU member countries [76]. However, critics have accused governments of "greenwashing" nuclear energy to improve its acceptability. Greenwashing is the act of deceptively presenting or marketing certain products or processes as having environmental benefits [77].

In Europe, a group of five countries (Austria, Germany, Denmark, Luxembourg, and Portugal) have objected to the new classification of nuclear energy as green/sustainable. In a joint declaration, the group stated that nuclear power is incompatible with the EU Taxonomy Regulation's principle (the "do no significant harm" principle) [78]. Hence, they argue that the consideration to include nuclear into the taxonomy is a "greenwashing" effort, which could threaten EU's target of becoming climate-neutral by 2050. Part of their concern is that nuclear energy is not yet sustainable in all its life cycle (referring to the radioactive waste cycle as nuclear power plants do not yet have permanent disposal facilities built) [79]. They have also warned that the classification could rather result to exhausting EU funds rather meant for renewable energy developments/investments.

Already this has resulted in legal disputes, especially in the European Union. Expectedly, environmental organizations are the major critics of the inclusion of nuclear energy in the taxonomy [80]. In 2022 Austria sued the EU Commission [81], and in 2023, two more separate legal disputes have been lodged at the European Union's general court in Luxembourg by Greenpeace and by a coalition of the Client Earth and WWF for including nuclear in the EU guide to "green" investments [75, 82].

More potential legal disputes may arise from this controversial classification of nuclear energy, as certain incentives made available to investors in nuclear energy technologies such as SMR, based on their classification of new as green may be revoked, if governments are forced or decide to reclassify them as non-green energy resource in the future.

This article is of the view that this problem could be addressed and expressly defined in finality if there is an international treaty on SMR. There might be need to differentiate new nuclear technologies such as SMR from the conventional large NPPs (in worst case scenario), as SMR due to its smaller size will produce lower and manageable radioactive waste, and thereby, will not necessarily pose a significant threat to the environment even in the likelihood of nuclear accident. Hence, SMR new technology will be suitably regarded as green energy with low carbon emission and lower produced nuclear wastes.

Limitations of international nuclear energy conventions

Due to the sensitivity of nuclear energy, countries rely on international nuclear laws in establishing regulatory frameworks for their nuclear energy deployments. Currently, the nuclear energy sector is regulated by various international conventions/treaties agreed mainly under the auspices of the International Atomic Energy Agency (IAEA), and the Organization for Economic Co-operation and Development (OECD)'s Nuclear Energy Agency (NEA) [83]. They include mainly the following international nuclear conventions: Convention on Nuclear Safety (CNS) of 1994, Vienna Convention on Civil Liability for Nuclear Damage of 1963, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management of 1997, Convention on the Physical Protection of Nuclear Material (CPPNM) of 1980 and the Amendment to the Convention on the Physical Protection of Nuclear Material (CPPNME), Convention on Early Notification of a Nuclear Accident of 1986, Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency of 1986.

In addition to these conventions, the IAEA also provide regulatory Safety Standards Series for use by member states in their national regulations. They comprise of the following three categories: the Safety Fundamentals, (this presents the fundamental objective and principles of protection and safety), the Safety Requirements (which establish the requirements that need to be met to ensure sustainable protection of people and the environment), and the Safety Guides (which provide recommendations and guidance on how to comply with the requirements) [84].

There are some significant limitations in existing nuclear energy legal framework to fully address the peculiarities of new nuclear technologies. These limitations which pertain to their applicability, adequacy, and suitability will hamper the effective regulation of SMR deployments and operations. For instance, there new innovative safety features that have been introduced in the SMR, that were not in the large reactors. The IAEA SMR Regulatory Forum has evaluated some of its safety standards such as the Safety of Nuclear Power Plants: Design [61], and the Governmental, Legal and Regulatory Framework for Safety, etc [85] with regards to their applicability to SMRs and has identified certain novel evolutionary and innovative designs peculiar to SMR nuclear technologies that may warrant a more comprehensive framework [60].

With regards to the conventions, some gaps and inadequacies have been found in certain provisions contained in the Convention on Nuclear Safety (CNS), the Conventions on Nuclear Liability, the conventions on nuclear liability etc. These are discussed in the following section.

Convention on nuclear safety (CNS) of 1994

The Convention on Nuclear Safety (CNS) is the main legally binding international treaty to achieve and maintain a high level of nuclear safety worldwide [86]. It's main aim is to ensure safety in all nuclear installations and avoiding radiological hazards in the environment [86]. It therefore advocates for enhancement of national measures and international co-operation on nuclear installation safety.

The key gap/omission here is that the CNS did not cover a certain type of SMR, the water based SMRs. The lack of clear definition for water based SMRs in existing CNS is a critical gap/omission for SMR regulation as many deployments of SMR will be marine based.

Generally, SMR designs can be categorised into about six types based on the basic nuclear technology design. These include Light Water-cooled Reactor, High temperature gas-cooled SMRs, Liquid metal-cooled fast neutron spectrum SMRs, Molten Salt Reactor SMRs, and Microreactors.

Currently, the scope of application of the CNS covers only land-based nuclear installations. Article 2(i) of the CNS defines "nuclear installations" as follows:

> Nuclear installation means for each Contracting Party *any land-based civil nuclear power plant* under its jurisdiction, including storage, handling, and treatment facilities for radioactive material as are on the same site and are directly related to the operation of the nuclear power plant …

The issue here is that SMR power plants can be deployed on land and at sea such as marine based SMRs, SMR Floating Power Unit (FPU) or transportable nuclear power plants (TNPPs). Marine-based SMRs constitute a proportion of SMRs. There are about eight marine based water-cooled SMRs [45]. They include the following: KLT-40S (JSC "Afrikantov OKBM," Russian Federation), BANDI-60 (KEPCO E&C, Republic of Korea), ABV-6E (JSC "Afrikantov OKBM," Russian Federation), RITM-200M (JSC "Afrikantov OKBM," Russian Federation), VBER-300 (JSC "Afrikantov OKBM," Russian Federation), SHELF-M (NIKIET, Russian Federation), ACPR50S (CGNPC, China), ACP100S (CNNC, China)

Some of them have been deployed in nuclear icebreaker ship. The KLT-40S is deployed in the Akademik Lomonosov floating nuclear power plant which started commercial operation in Pevek of Russian Federation in May 2020, is from this subcategory and is the first SMR design connected to the grid. The KLT-40S marine-based SMR in particular has unique safety features that would require careful consideration in their regulations [45]. They have safety systems installed on FNPPs that are distinctive from those applied to land-based installations concerning the security of the water areas surrounding the FNPP, anti-flooding features, anti-collision protection, etc [45].

Therefore, if these category of SMRs are not recognized under Article 2 above, the implication is that their safety is not covered by the CNS, which is the main legally binding international treaty to achieve and maintain a high level of nuclear safety worldwide. Generally, in contrast to the land-based conditions, marine-based SMRs need to adapt to the effects of ocean waves and external hazards including natural and man-made hazards, such as tsunami, aircraft crash, and underwater earthquake, need to be taken into consideration for the safety of marine-based SMRs [87]. Hence, the need for a separate international legal framework for SMR where the safety of both land-based and sea-based nuclear installations will be specifically covered together with the peculiarities of their operations.

In addition to this, there have been expressed dissatisfaction with various existing provisions in the nuclear safety regulatory frameworks to cater for the nuclear energy sector [60, 88]. The implementation of the Convention on Nuclear Safety (CNS) is left to the national regulators-Article 4 [86]. However, national nuclear regulations are limited in their implementation. This limitation was brought to fore by the Fukushima Daiichi NPP accident. Even though Japan had the technological and human capacity, the accident still occurred. Hence, there is call for the re-examination of the nuclear safety implementation regime that could also meet expectations of current realities such as disasters that might be exacerbated by climate change, and the incapabilities of nuclear energy newcomers to adequately develop and support a strong nuclear safety mechanism [88].

Conventions on nuclear liability

There are various international conventions/treaties on civil liability for nuclear damage, with their own peculiar provisions. These include: The Paris Convention on Third-Party Liability in the Field of Nuclear Energy of 1960 ("the Paris Convention"), the Vienna Convention on Civil Liability for Nuclear Damage 1963 (Vienna Convention), and the Joint Protocol 1988 [89]. Their overall aim is to establish some minimum standards for providing financial protection against damages resulting from certain peaceful use of nuclear energy,

The Paris Convention on Third-Party Liability in the Field of Nuclear Energy of 1960 ("the Paris Convention") is a treaty made under the auspices of the Organisation for Economic Co-Operation and Development (OECD). This was followed by the Convention Supplementary to the Paris Convention (Brussels Supplementary Convention) of 1963. It is noted that these are only applicable within the European region.

Similarly, the Vienna Convention on Civil Liability for Nuclear Damage (Vienna Convention) was adopted under the auspices of the IAEA in 1963. It was updated by the 1997 Protocol to Amend the Vienna Convention.

After the Chernobyl accident, there was need for a more cooperative international nuclear liability regime [90]. This led to the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention (Joint Protocol), adopted in 1988, under the joint auspices of both the OECD and the IAEA. In 1997, apart from the Protocol to Amend the Vienna Convention, the Convention on Supplementary Compensation for Nuclear Damage (CSC) was also adopted under the auspices of the IAEA. And in 2004, the Protocols revising the Paris Convention and the Brussels Supplementary Convention were adopted under the auspices of the OECD.

An essential part of the legal frameworks for nuclear energy generation is the provision for civil liability for nuclear damage. This is mainly contained in international nuclear conventions and some domestic nuclear laws. Currently, there is not yet a global nuclear liability legal regime, rather there are different treaties and conventions catering for this. The regulation of nuclear liability with numerous conventions is problematic, because the conventions are peculiar and have varied provisions catering for different aspects of liabilities, Furthermore, not every country are party to all the conventions. Hence, this poses issues around transboundary liability issues where nuclear harms may affect countries that are parties to different conventions. The modularity of SMRs aggravates this issue as SMR deployment is expected to involve many countries during transportation as well as the other cycles of its deployment. Therefore, before the expected boom in new nuclear technologies happens, there is urgent need to establish a global nuclear liability framework for possible damages that may arise.

Furthermore, there are peculiarities in the principles applicable to nuclear liability regime that may be problematic for SMR and other new nuclear technologies. Firstly, there is inconsistencies in the conventions (OECD or the IAEA) with respect to the minimum liability amount the operator is expected to pay as damages. For example, under the OECD's Paris Convention of 1960, the lower liability limit was fixed at 5 million SDR (SDRs-a unity of currency of the International Monetary Fund). And in 2004, the Protocols revising the Paris Convention and the Brussels Supplementary Convention combined provides for a liability minimum limit of EUR 1.5 billion [91]. However, under the IAEA's 1963 Vienna Convention, the lower limit was fixed at USD 5 million. But this was later increased in the 1997 Vienna Convention to a lower limit 300 million SDR [92].

The problem with all these is that while not all countries are parties to any of these conventions e.g. China and South Africa (as they have theirs in their domestic nuclear laws and appear to want unlimited liability instead), others are mostly parties to either that of OECD or that of the IAEA. Hence, as there is expectation that demand for SMR installations will increase in the near future across many countries, there will be conflicting minimum liability limits applicable in different regions. And this might lead to operators engaging in "treaty shopping" which might affect the marketability of SMR by operators at the long run.

To improve consistent application of the liability principles, there is urgent need to have a specific international nuclear civil liability legal framework, that would cater for the peculiarities of SMR new nuclear energy technologies. For instance, there would be need to make reasonable consideration of the features of SMR such as its smaller size nature, which could mean relatively lower minimum liability limit for SMR manufacturers/operators (compared to that of large NPPs). This may also entail shared responsibility and joint liability (as SMR will most likely be manufactured and operated in different countries) to ensure that adequate measures are taken.

Dispute resolution clause

SMR is expected to be deployed at a commercial scale around the globe and due to its novel features and the fact that some of the existing conventions did not fully address some of these features, this paper is of the view that the trans-boundary nature of SMRs is prone to lead to various commercial legal disputes. For example, looking at its dual licensing and fragmented civil nuclear liability divergences as discussed in SMR Double Licensing Feature and Conventions on Nuclear Liability sections).

This paper observes (as will be seen below) that apart from the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention, which has no dispute resolution clause, the other conventions did provide for same [89]. [[1]] However, for those that provided for it, the question is, are they adequate and encompassing for SMR deployment and commercialization or are there some limitations in those clauses? This paper has found three areas of the limitations in them.

They include the following:

- Non-State or Companies as contracting parties
- Contractual disputes
- Limited dispute Settlement Methods

Firstly, it is observed that all the conventions (apart from the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention which made no such provision) considered only inter-state disputes resolutions. None, provided for non-state/corporate and a host state dispute settlement. As some of the SMR manufacturers are companies e.g. Rolls-Royce SMR UK that means any dispute arising between such foreign companies and the host state buyer are not covered under the available treaties. This is significant as some host states may be reluctant to buy or engage for installation, SMRs from government-controlled companies manufacturing the SMR due to national security concerns, see Section 102 of the of the American Nuclear Infrastructure Act of 2021 [71].

Secondly, the nature of the disputes covered in the conventions pertain only to interpretation or application of the Conventions. Again, as SMR is envisaged to be commercial in nature, contractual issues are likely to be part of possible disputes between SMR manufacturers and the host states. Significantly, due to the nature SMRs, it is expected that the contractual relationship will mainly be between individual companies and host states or agents of host states. Under this condition, disputes that may arise out of these are currently not covered by the existing nuclear laws. This also buttresses the necessity for a new SMR treaty to cover these potential omissions. Although, it can be argued that such disputes might fall under other existing frameworks such as international investment and international commercial dispute resolution mechanisms, however, the crux of the matter here is that there is no reference in the existing nuclear conventions/treaties, that such disputes could be resolve *via* such dispute resolution settlement mechanism. Hence, the existing conventions are currently inadequate to cater for SMR commercial disputes. See Articles 8 and 9 of Model BIT UK 2008 [93].

Thirdly, this paper observed that not all the conventions gave a varied option of dispute settlement methods to use. The CNS's provision is the poorest here as it merely provides for one method-"a meeting" as stated in Article 29 [86]. The Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management provides for a "meeting, mediation, conciliation, and arbitration" methods in Article 38 [94]. The Convention on Early Notification of a Nuclear Accident (Article 11) and others however provided for varied methods such as negotiation, consultation, arbitration, or International Court of Justice for decision. [[2]]

However, while the Vienna Convention 1963 did not contain any clause on disputes, the Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage in Article 17 contains similar clause such as that of Article 11 of the Convention on Early Notification of a Nuclear Accident. The Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention 1988 made no provision at all about this.

Regulatory issues for SMR floating nuclear power plants

There is rising pressure on the shipping sector to decarbonise as it has been shown that shipping accounts for nearly 3% of global CO2 emissions [95]. The sector can look to a low carbon energy resource such as nuclear energy to power the ships. This could be in the form of either nuclear-powered ships using small nuclear reactors such as SMR or using nuclear to produce alternative fuels.

However, shipping experts have voice out the need for a "clear, consistent and predictable set of rules and regulations" that will cater for the integration of new nuclear energy technologies in the sector [96]. Review of existing nuclear ship regulations is a vital precursor to deployment of nuclear-propelled ships based on new technologies. This is very evident even from the Preamble No.4 of the Code of Safety for Nuclear Merchant Ships 1981 [97] which provides that:

> While development of the Code has been based upon established and accepted shipbuilding, marine and nuclear engineering principles, *it is recognized that review will be necessary as technology progresses.*

Initial application of the Code is also restricted to only conventional types of ships propelled by nuclear propulsion plants with pressurized light water type reactors. This is further adumbrated in its Section 1.6 on Review of the Code, where it provides for review for new types of ship and for technical progress in the design of the ships.

There is also increasing interest from countries to ponder on the use of floating nuclear power plants (FNPPs). The idea is to use FNPPs in the future to replace fossil-fuelled floating power plants. A floating nuclear power plant is a floating power station that derives its energy from a nuclear reactor such as SMR; Instead of a stationary complex on land, they consist of a floating vessel such as a barge [98]. While the Russian Federation started commercial operation of an FNPP in 2020, others such as China, Denmark and Republic of Korea are developing FNPP, and others are considering deploying them.

However, FNPP regulation have been done only at the national level [99]. The possibilities of international deployment of FNPPs have been discussed by the IAEA. And a major concern has been noted regarding its international legal and regulatory challenges and implications such as its licensing and regulation process for transportation across international waters [99]. In Particular it does not have a specific international convention applicable to its nature. These could be addressed in detail for SMR FNPP if a treaty on SMR is made.

A key area of concern is that the 1982 UN Convention on the Law of the Sea (UNCLOS) does not contain specific rules for non-self-propelled vessels with nuclear power units such as floating SMRs e.g. a barge especially where it is involved in a long distant transportation. Its provision in Article 22 (2) is rather reflective of the usual self-propelled nuclear-powered ships.

> In particular, tankers, nuclear-powered ships and ships carrying nuclear, or other inherently dangerous or noxious substances or materials may be required to confine their passage to such sea lanes [100]. See also Article 23.

Similar problem is seen in the International Convention for the Safety of Life at Sea (SOLAS) of 1974, which is one of the leading international agreements on the law of the sea regulating the safety of merchant ships. In Regulation 2 of its Chapter 1, a nuclear ship is defined as a ship provided with a nuclear power plant. And its Regulation 3 provides for the exceptions which expressly states that it is inapplicable to "Ships not propelled by mechanical means." Moreover, its Chapter VIII provides against radiation hazards for only nuclear-powered ships. The main thing here is that FNPP is not really regarded as a ship. It is an autonomous power facility, manufactured as a non-self-propelled "vessel" towed by two tugboats. So, it does not apply to SMR FNPPs.

Issues emanating from the withdrawal of countries from the Energy Charter Treaty (ECT) 1994

Although the Energy Charter Treaty (ECT) 1994 is not a nuclear international legal framework under the auspices of the IAEA, it is however, the only multilateral legally binding framework for the energy sector in general. It made important provisions that cover any energy transactions such as commerce and trade (Part II) and Investment Promotion and Protections (Part III) [101],. And in its Annex 1, it specifically provides for nuclear energy materials including nuclear reactors. However, its application is limited mainly to the European region. It is therefore not applicable internationally. See the Preamble to the ECT [101].

SMR designs when fully developed, is expected to be deployed at large commercial quantities globally. The intricacies of their commercial transactions will be better managed *via* a multilateral legal framework just as the ECT. However, the ECT currently is even now no longer a viable multilateral legal framework to be applicable to new nuclear technologies such as SMR, because it is presently in chaos. Many of the countries that are signatories to the ECT are now withdrawing from it because according to them, it is not compatible with the EU's enhanced climate ambition under the European Green Deal and the Paris Agreement [102]. In October 2020, the European Parliament took a step further to vote to end fossil fuel protection under the ECT. And in March this year 2024, both the union and its member states formally agreed to make a "coordinated and orderly" simultaneous withdrawal from the ECT [103]. Similarly, this year, the United Kingdom also announced its plans to withdraw from the treaty due to a failure in negotiations to modernise the treaty [104,105].

If many countries withdraw from the ECT, then this may invariable affect SMR investors in the European region from claiming various investment protections afforded to them in the ECT if their countries of origin withdraw. Bearing in mind that it is mostly these ECT members that are into SMR manufacturing e.g. the United Kingdom, France, Denmark, Czech Republic, and Sweden.

Another reason for their withdrawals is that the treaty allows investors to sue governments, which enact new climate policies that could undermine their expected investment financial returns. Multinational companies who have invested in fossil fuel production and nuclear power can sue national governments under the ECT for loss of profit on their investments as a consequence of the transition to only renewable energy (nuclear energy is not a renewable energy). As nuclear energy projects are very expensive, investors generally require long period of operation to recoup expenses. As a result, they are very nervous of national/regional policy changes that could affect their expected revenues. For example, the decision of the German government to ban nuclear energy generation through the enactment of a new law, the 13th amendment of the Nuclear Power Act led to various legal disputes. In *Vattenfall v Federal Republic of Germany*, the Swedish energy company Vattenfall AB challenged the change made by the German government *via* its new legislation that will lead to the phase-out of nuclear energy in Germany. Vattenfall alleged the German legislation violated its rights under the Energy Charter Treaty 1994 as its defined investments made in the energy sector subsequently decreased in value. As a result, it claimed for compensation for lost earnings and investments made following the confiscation of generation rights of its nuclear power plants by the German government [106].

Also, in *RWE AG v. Federal State of Hessen* [107], following the same decision of the German Government to phase-out the use of nuclear energy for electricity generating purposes, the relevant regulatory body of the Land Hesse, without giving RWE Public Limited Company, the operator of NPP, the opportunity to be heard, ordered a three-month suspension of the operation of its Biblis nuclear power plant. This decision was challenged by the operator as unlawful and claimed for compensation as well. However, in 2021, German government agreed to pay Vattenfall, RWE, and other companies affected which have also sued for compensation such as Eon and EnBW, compensation for the forced premature closure of their nuclear power reactors [108].

Nuclear energy investors have also challenged constitutional changes that imposed nuclear taxes on them. In Belgium, nuclear plant operators sued the government on the Constitutionality of the 2008 Programme Act through which nuclear taxes were imposed on them [70]. Although the court ruled that the taxes were lawful. Also, in the case of *Kernkraftwerke LippeEms GmbH v. Hauptzollamt Osnabrück*, where the German nuclear fuel tax was challenged as incompatible with the EU competition law and the EURATOM Treaty. (a judgment of the European Court of Justice on the nuclear fuel tax [109]

Consequently, the coordinated withdrawals will weaken the viability of the ECT. This is worrisome as currently, there is no specific international legal framework created for SMRs to protect SMR foreign investments and contractual arrangements. They may as a result decide to engage in bilateral agreements, but this will not equally promote harmonized regulation of commercialization of SMR with its different design and development cycles as discussed in Issues in Regulating the Peculiarities of SMR section.

Necessity for stringent regulation of SMR fuel enrichment

A key aspect of SMRs is their use of relatively higher enriched uranium than required by conventional NPPs, which enhances their energy performance and efficiency. Nuclear fuel enrichment involves increasing the concentration of uranium-235, the isotope responsible for sustaining a nuclear chain reaction [110,111]. Currently, the conventional light water reactor (LWR) which are the most common designs under development, generally use low-enriched uranium (LEU) with uranium-235 concentrations ranging between 3% and 5% ("gold standard" for non-proliferation) which are considered to still be within the acceptable limits.

However, some advanced SMR designs (such as the high-temperature gas-cooled reactors (HTGRs) and the Fast neutron reactors (FNRs)) may require higher enrichment levels (up to 20%) to achieve desired reactor performance [112]. According to the IAEA, any advanced reactor designs, including small modular reactors (SMRs), will require high assay low enriched uranium (HALEU) fuel, which ranges from 5 to 20 per cent of uranium-235, beyond the 5 per cent level that powers most conventional nuclear power plants in operation [113]. The use of highly enriched uranium by SMRs poses serious challenges to global security, as they can be repurposed in the production of nuclear weapons and thereby going against the non-proliferation rule [114]. Fast neutron reactors can also be used for converting abundant U-238 in the fuel to Pu-239, which is also capable of being used for producing weapons-material breeder [114,115]. Thus, there is need to balance the trade-off between reactor performance and proliferation risks.

The use of HALEU fuels will make SMRs more economically competitive [116], however, the use of HALEU fuels for commercial power production will require new laws and regulations [117]. This may also include new safety standards due to higher radiation and proliferation risks for their transportation and packaging regulations too [116].

Currently, the Nuclear Non-Proliferation Treaty (NPT) makes no mention of nuclear fuel enrichment [118,119]. Hence, the need to put adequate legal and regulatory frameworks in place to ensure that such enriched fuel do not fall into wrong hands that could use them to produce weapons-grade materials.

The need for international treaty on SMR

Key arguments supporting the necessity for the development of a single global framework for SMR based on the inadequacies in some of the existing conventions have been highlighted in the preceding sections. The option of amending/revising the existing conventions may be argued. However, it has been found that the amending existing nuclear legal framework come with a lot of difficulties [120].

Unlike national laws, the amendment of international nuclear conventions/treaties in the light of new challenges and gaps/omissions is a herculean task due to certain political and procedural impediments [120], such as was experienced in the attempt to amend the Convention on Nuclear Safety after the Fukushima Daiichi accident in 2011 [121]. Pierre Strohl, while commenting about Convention on Nuclear Safety noted that "The convention ultimately conceived has a universal vocation, […] not easy to change, because it is relatively difficult to revise" [122].

Due to the difficulty encountered in amending existing international conventions, a new international treaty on SMR that addresses all these gaps discussed in this paper might be a better approach than amending the individual conventions catering for different aspects of nuclear energy development and deployment.

The main roadblock to converging towards a harmonised regulatory system is the strong willingness of the nuclearized countries to protect their regulatory independence and the national sovereignty of their regulatory practice; consequently, there is a significant reluctance to adapt their regulatory approaches to accommodate specific reactor design requirements from another country [14, 123–125]. Suffice it to say that such countries will rather stand to benefit from SMRs, which is anticipated to be widely deployed in developing countries and will most likely be a big market for them.

An international treaty on SMR will have various benefits. Firstly, it will help to actualize the various efforts on harmonization of SMR regulations especially concerning, safety and civil liability [126]. Secondly, it will provide an encompassing definition that will accommodate every category of SMR. Thirdly, it will demonstrate institutional zeal to promote faster SMR development and deployment to achieve the joint declaration to triple nuclear energy capacity by 2050 [26]. Fourthly, it will serve as a viable global alternative to the crumbling Energy Charter Treaty with specificity on SMRs and covering both its manufacturing, transportation, trade, and investment aspects. Finally, it will provide for a robust dispute settlement clause as discussed in Dispute Resolution Clause section.

Conclusion and recommendations

Nuclear energy is a viable energy source that can contribute to the decarbonisation of the global energy system. About 30% of global low-carbon electricity is provided by nuclear sources. Thus, the importance of nuclear energy in global carbon management cannot be overstated. The International Energy Agency (IEA) estimates that nuclear energy enables the avoidance of about 1.5 gigatonnes (Gt) of global emissions and 180 billion cubic metres (bcm) of global gas demand yearly. This research explored the adequacies and suitability of certain provisions in international nuclear legal frameworks to cater for the peculiarities of SMR (a new nuclear technology). It also provided a historical perspective of the ongoing nuclear policy U-turns in many countries and their possible implications on SMR deployments and potential disputes. It also discussed significant features and design differences between SMRs and conventional large NPPs, which require careful consideration in regulatory provisions. The research found that there are significant gaps, omissions and inadequacies in the legal and regulatory frameworks that make it unsuitable to fully address the peculiarities of SMRs. Some of the existing nuclear energy treaties have definitions that do not accommodate all types and designs of SMRs. Hence, there are some new design differences that make it difficult for the same legal and regulatory frameworks to be applicable to SMR too. Although SMRs are designed to have inherent and/or passive safety systems and the core damage frequency estimated to be 100 times lesser than for the existing large nuclear reactors [60], there are certain complexities in the SMR that poses a new risk, that needs to be addressed in new legal and regulatory framework specific to SMRs.

In addition, the transboundary nature of SMR and its portability, increases transboundary traffic of nuclear materials. This challenges the provisions available in existing nuclear conventions, where widespread global deployment of nuclear energy was not envisaged. Issues arising from nuclear incidents could affect several countries that have ratified different nuclear conventions with divergent provisions. Hence, there is need for a new law that could unify the provisions of these conventions as well as fully cater for the peculiarities of SMRs.

Similarly, the paper found that some key maritime international conventions are now inadequate to apply to nuclear energy new nuclear technologies such as SMR. The UNCLOS and SOLAS as discussed in Regulatory Issues for SMR Floating Nuclear Power Plants section do not contain specific rules for non-self-propelled vessels with nuclear power units such as SMR FNPPs. These limitations could affect the smooth regulation, and timely development and deployment of SMRs.

The paper also considered the current exit of the Energy Charter Treaty members and how this may impact future deployment and commercialization of SMR on a global scale. It found that the exiting member countries are those involved in the development of SMR such as the Rolls Royce of the UK, and the NUWARD of France etc. The ECT is already a legally binding legal framework that is focused on the energy sector and has covered different significant aspects of the nuclear energy sector. Thus, exiting it at this point may disturb the commercialization of SMR. The parties have tried to modify it to suit the current climate emission demands, but this has been unsuccessful.

Finally, the paper emphasized the need for a legal framework on SMR fuel enrichment and its proliferation implications.

Therefore, this paper argues that a global SMR-focused international treaty that will be more adequate to address virtually all aspects of SMR activities is needed.

Fortunately, the IAEA is organizing an SMR Conference from 21 to 25 October 2024 to provide an international forum to discuss the opportunities, challenges and enabling conditions for the accelerated development and safe and secure deployment of SMRs among all possible SMR stakeholders. This is a good avenue for the points and suggestions raised in this paper to be considered and for a position to be taken for an international treaty on SMR.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Notes

1. Article 29 of Convention for Nuclear Safety, Article 38 of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, Article 11 of Convention on Early Notification of a Nuclear Accident, Article 13 of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Article 17 of the Convention on the Physical Protection of

Nuclear Material, Article 17 of the Amendment to the Convention on the Physical Protection of Nuclear Material, Article XVI of the Convention on Supplementary Compensation for Nuclear Damage-good, Article 17 of the Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage.

2. Article 13 of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Article 17 of the Convention on the Physical Protection of Nuclear Material, Article 17 of the Amendment to the Convention on the Physical Protection of Nuclear Material, Article XVI of the Convention on Supplementary Compensation for Nuclear Damage-good, Article 17 of the Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage.

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