Nuclear decommissioning in Brazil and China:
Regulatory development, incompleteness and future synergy

Introduction

Nuclear facilities at the end of their lives cannot simply be shut down and left unattended. A decommissioning process is necessary for the partial or complete removal of radioactive waste, using decontamination and dismantling techniques.

Brazil and China represent, respectively, 2.9% and 3.6% of the nuclear share of electricity generation worldwide[1], and nuclear generation expansion is part of both countries' long-term energy plans. Sooner or later, Brazil and China will need to deal with the decommissioning of power reactors reaching the final stage of their lifecycle and the new installations' decommissioning plans, pressuring the prompt assessment of local regulations and practices.

Over the last decades, the law and regulation of nuclear power plant decommissioning is developing worldwide at a fast pace. Influenced by the International Atomic Energy Agency's (IAEA) decommissioning safety standards, advanced jurisdictions such as the UK, US and Japan have made substantial progress in the elaboration of their national frameworks[2].

Conversely, the emerging economies of Brazil and China have only recently started to discuss their own nuclear facilities' decommissioning framework. Looking at the current stage of these latecomers' framework through the legal prism of the

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[1] IAEA, 'Power Reactor Information System – PRIS', 2016 <https://www.iaea.org/pris/> accessed 2 December 2017.

[2] Kirsten Jenkins, DarrenMcCauley, Raphael Heffron, HannesStephan, and Robert Rehner, 'Energy Justice: A Conceptual Review' (2016) *11 Energy Research & Social Science*, 174-182.

advanced jurisdictions governments' regulations and strategies allows envisaging the paths to follow.

This paper aims at assessing the Brazilian and Chinese efforts, achievements and challenges in the establishment of national decommissioning legal regimes using the analytical lenses developed by probing into the strengths exhibited by selected advanced jurisdictions' decommissioning regulations and experiences, in namely the UK, US and Japan.

The first part examines the decommissioning regulations and experiences of the UK, US and Japan, extracting the four elements of: solid legal frameworks, including institutional competencies; nuclear waste management and the environment; public engagement; and technological innovation. These four elements form a structural perspective that can be applied to earlier stages nuclear decommissioning frameworks to pinpoint their level of effectiveness.

The second and third parts present the case studies of Brazil and China's nuclear decommissioning regulations, respectively. The forth part encloses the discussion as posited within the above framework consisting of four elements, which will capture the key drivers for the regulatory development in the emerging economies of Brazil and China.

1. Advanced nuclear decommissioning frameworks and experiences

1.1. International

Under the auspices of the IAEA, States operating nuclear energy power plants have adopted the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management[3] establishing obligations to ensure the waste management safety resulting from the closure (Article 17) and decommissioning (Article 26).

Moreover, for the last 30 years the IAEA[4] has played a significant role in the development of international decommissioning safety standards for regulators, operators and stakeholder[5]. The 2016 'Governmental, Legal and Regulatory Framework for Safety General Safety Requirements' recognizes as essential elements of the governmental policy the creation of provisions facilitating 'the decommissioning of facilities and the safe management and disposal of radioactive waste' (Requirement 10). Although non-legally binding instruments, the IAEA safety standards possess persuasive esteem, overtly influencing many national regulators in designing their own frameworks.

According to the IAEA, decommissioning is a process that aims at placing the closed facility in such a condition that it poses no unacceptable risk to the public, the workers, and the environment[6]. The IAEA offers a divisional definition and tripartite categorization of alternative decommissioning strategies[7], in order of preference[8]: (i) immediate dismantling, in which the radioactive material can be removed shortly after

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[3] Entered into force in 2001.

[4] Others international organizations, such as the OECD Nuclear Energy Agency, the Western European Nuclear Regulator's Association and the WANO - World Association of Nuclear Operators are also involved with the technological research and regulatory aspects of the decommissioning of nuclear power plants within their scope of works.

[5] The IAEA Safety Guides collection about decommissioning of nuclear power plants includes: (i) 2017 Safety of Nuclear Fuel Cycle Facilities – Specific Safety Requirements No. SSR-4; (ii) 2014 Decommissioning of Facilities Series No. GSR Part 6, Decommissioning of Nuclear Power Plants and Research Reactors Safety Guide No. WS-G-2.1; and (ii) 1999 Decommissioning of facilities using radioactive Material No. WS-R-5.

[6] IAEA, *Safety Reports Series No. 50 – Decommissioning Strategies for facilities using radioactive material* (IAEA, 2007), para. 2.1.

[7] ibid para. 2.2-2.4.

[8] Michele Laraia, *Advances and Innovations in Nuclear Decommissioning* (Woodhead Publishing, 2017) 28.

the end of operations; (ii) deferred dismantling, in which the facility is placed in a safety area for a period before dismantling, to allow the reduction of the radioactive elements to acceptable levels; and (iii) entombment, in which the radioactive material is encased in a long-lasting structure, equivalent to a waste disposal site, recommended for exceptional circumstances such as after a severe accident[9].

The IAEA safety standards recognize the Environmental Impact Assessment ('EIA') as a procedure that permits public participation and the assessment of measures to reduce the radiation exposure to humans and the environment within the radius or risk[10]. According to the IAEA Decommissioning and Environmental Remediation Programme, technological innovations can play a significant part to safely clean-up nuclear sites, such as the use of robotics to control remotely the decontamination process and to handle the plants components[11].

The IAEA promotes assistance for the States' plans and implementations of the decommissioning safety guides and encourages co-operation amongst them for the exchange of technical information, knowledge and experiences, including a network for the interactions of decommissioning activities professionals[12].

1.2. US

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[9] ibid 28.

[10] IAEA, *Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes* (IAEA, 2014).

11 IAEA, Decommissioning and Environmental Remediation, *IAEA Bulletin* (April 2016) 22-23.

[12] IAEA International Decommissioning Network – IDN <https://nucleus.iaea.org/sites/connect/IDNpublic/Pages/default.aspx> accessed 22 December 2017.

The US Nuclear Regulatory Commission (NRC) is an independent regulator tasked with protecting public health and safety regarding nuclear energy[13]. The NRC sets out the fundamental requirements for nuclear power plant decommissioning in a range of regulations[14], revised in August 1996 to reflect the experience obtained during actual decommissioning activities.

In the 1990s, several nuclear power plants completed decommissioning without a viable option for disposing of their spent nuclear fuel, because of the lack of a geologic repository's definition by the federal government.

The NRC requires early notification of planned decommissioning activities and forbid major decommissioning activities prior to the provision of certain information to the NRC and the public.

In the US, the public has several opportunities to participate in the decommissioning process: (i) after the submittal of a post-shutdown decommissioning activities report to the NRC; (ii) when NRC receives the license termination plan; and (iii) prior to the issuance of a license amendment approving the plan. In addition, when NRC holds a meeting with the licensee, members of the public may observe the meeting, except when confidential information is involved[15].

The long-standing trend of the US leadership on nuclear R&D has been declining lately[16], culminating with the 2017 bankruptcy filling of the local company Westinghouse, for many decades the world's leading supplier of safe and innovative nuclear technology, which included nuclear decommissioning services.

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[13] US Nuclear Regulatory Commission, About NRC <https://www.nrc.gov/about-nrc.html> accessed 22 December 2017.
[14] Title 10 of the Code of Federal Regulations, Part 20 Subpart E, and Parts 50.75, 50.82, 51.53, and 51.95.
[15] Luther J. Carter, Nuclear imperatives and public trust: Dealing with radioactive waste (Routledge, 2015).

1.3. UK

The first nuclear reactor in the UK was built in the 1950s. A growing number of nuclear power plants have therefore reached the end of their life cycles.

In 2005, the UK government established an independent authority – the Nuclear Decommissioning Authority (NDA) – to implement clean up and decommissioning processes of nuclear reactors[17]. According to the 2004 Energy Act, the NDA will not perform the decommissioning and remediation tasks itself but it has the rights to outsource the work by contracts and oversees the British Energy's planning and budgets for decommissioning.

Accordingly, the UK's four major principles of decommissioning are: (i) to ensure the continuous safety of the citizens, workers and the environment; (ii) to minimize the negative environmental impacts; (iii) to release and regenerate land for future proper other use; and (iv) to minimize the financial costs[18]. Aligned with these principles, the 1999 Nuclear Reactors (Environmental Impact Assessment of Decommissioning) Regulations, as amended, require the assessment of the potential environmental impact of projects to decommission nuclear facilities before consent is given.

To deal with the complex case of the Sellafield site, the NDA has been encouraging technological inovations in the nuclear decommissioning sector, such as lasers[19] and robots[20] to reduce risks for workers. Opened in 1947 as a pioneer

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[17] The Institution of Engineering and Technology, *Legal framework for the nuclear industry in Great Britain* (the IET, 2017).

[18] The Institution of Engineering and Technology, *Nuclear Decommissioning* (the IET, 2008).

[19] Laraia (n 10) 238.

commercial nuclear power station, Sellafield is the largest nuclear site in Europe, with over 1,000 nuclear facilities that have accumulated tonnes of radioactive waste.

One of the distinguishing features of the UK's whole framework is that it highly values public engagement for the decommissioning processes and the wider nuclear sector[21]. In 2013, the policy statement 'The UK's Nuclear Future' highlighted the importance of t public engagement and awareness, which was later reaffirmed "In the Public Eye" report, containing recommendations of related actions. In fact, the UK nuclear sector has made significant progress in engaging with the public. This trend has been described as motion "from the control by an elite group of technical experts to a more deliberative and transparent approach". For example, the nuclear waste management institutions have become aware that mere technical expertise is not sufficient to justify their solutions to the wider public and to implement the plans successfully[22].

Also, the UK has a strong framework, industries and technologies for nuclear waste management, as demonstrated by the 2014 "Implementing Geological Disposal" and by the 2015 follow-up public consultation of UK's National Programme for the Responsible and Safe Management of Spent Fuel and Radioactive Waste. Once more,

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[20] 'UK funding for innovative solutions', <https://search.proquest.com/docview/1859865292?accountid=9851> accessed 17 January 2018.

[21] International Atomic Energy Agency, *An overview of stakeholder involvement in decommissioning* (IEA 2016). See also National Nuclear Laboratory, 'Public Engagement in the Nuclear Sector: A UK and EU perspective' (2016) EU08051/06/10/01 Issue 3.

[22] This approach is also evidenced by recent amendments to the UK planning and infrastructure law, in which the Secretary of State has more power for decision-making when considering the public engagement.

the public plays a critical role in planning and formulating the long-term solutions for UK's radioactive waste[23].

1.4. Japan

Japan has very few natural energy resources hence, nuclear power is considered fundamental for its energy security. The first commercial nuclear power plant was established in 1966. At present, there are 51 nuclear power units with a total installed capacity of 44,917 MW, ranking Japan within the top three nations in the world in terms of installed capacity whilst generating around 30% of Japan's electricity supply[24].

The Japanese legal frameworks for regulating nuclear power sectors comprise three major pieces of legislation, namely the Atomic Energy Basic Law of 1955, the Law for Regulation of Nuclear Source Material, Nuclear Fuel and Reactors of 1957, and the Law Concerning Prevention from Radiation Hazards due to Radioisotopes etc. of 1957. There are also other regulations and administrative directives derived from the Atomic Energy Basic Law[25].

Democracy, independence, and public disclosure form the three fundamental pillars and principles clearly addressed by the Japanese Atomic Energy Basic Law (Article 2). Article 4 of the Basic Law sets up the basic institutional architecture for regulating nuclear power in Japan. Under this design, the Atomic Energy Commission

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[23] Raphael Heffron, Nuclear Waste Management, *the Yearbook of International Environmental Law* (OUP 2016) 212-214.

[24] Reference documents for IRRS Japan 2016.

[25] Yoshio Baba, 'The Problems Facing Nuclear Power in Japan – Emphasizing Law and Regulations' (2016) 69 *Nuclear Law Bulletin* <https://www.oecd-nea.org/law/nlb/nlb-69/nlb69-baba.pdf> accessed 17 January 2018.

(AEC) and the Nuclear Safety Commission (NSC) in the Cabinet Office jointly ensure a democratic approach to the peaceful use of nuclear energy in Japan.

With regards the nuclear decommissioning license and related processes, the Reactor Regulation Act details all the requirements and items that should be included in a decommissioning plan. The frameworks place strong emphasis on technical control and constraint over nuclear material and equipment, restricting the transportation of nuclear fuel material and waste. Japan clearly refers to the IAEA's safeguard mechanisms in these matters.

The Japanese Environmental Impact Assessment Law sets procedures governing environmental impact assessment on decommissioning projects, although it lacks guidance about the final disposal facilities[26].

The main feature of the Japanese institutional design is its independence and efficiency. More recently, a new Nuclear Regulation Authority (NRA) was established as an independent regulatory authority, which can operate without external influences from the Ministry of Environment and other governmental agencies. The main tasks of NRA cover review and integration of the domestic nuclear regulations and the development of human resources in the nuclear energy sectors[27].

Also, Japan has a comprehensive framework for nuclear damage compensation[28]. Though Japan is not a party to the 1963 Vienna Convention on Civil

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[26] ibid.

[27] Jun Fukasawa and Momoko Okusaki, 'Reform of the Nuclear Safety Regulatory Bodies in Japan' (2012) International Nuclear Law Association 2012 Congress, 8-11 October 2012, Manchester, England.

[28] C-S. Chen, 'Establishment of an East Asian Nuclear Safety and Liability Regime' (2014), International Nuclear Law Association 2014 Congress.

Liability for Nuclear Damage, the original 1961 Nuclear Damage Compensation Law has been revised and updated in recent years, referring to the relevant international standards. After the Fukushima Daiichi nuclear disaster, Japan has adopted the unlimited liability of the operator, and the decision that the operator cannot benefit of an exemption from liability for accidents caused by a grave natural disaster[29].

Regarding the application of technological advances in the nuclear decommissioning pratices, Japan has developed advanced robotic techniques to tackle remaining radioactive areas of the Fukushima Daiichi nuclear disaster[30].

1.5. Correlations in the advanced nuclear decommissioning approaches

The selected jurisdictions of US, UK and Japan bear common policy goals for decommissioning practices. The regulation standards of these jurisdictions draw up supported by the IAEA and its efforts to promote nuclear safety.

In a related parallel form, the US, UK and Japan decommissioning legal regimes focus on (i) maintaining safety throughout the entire decommissioning process, and (ii) minimizing environmental impacts, including the radioactive waste management and the requirement of the EIA. As common traits, they all have solid independent regulatory systems and involve civil society at the most critical stages of the decommissioning processes. Moreover, apart from the current circumstances

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[29] Stephen G. Burns, 'The Fukushima Daiichi Accident: The International Community Responds' (2012) 11 *Washington University Global Studies Law Review*, 739-773.

[30] Michal, V, 'Remote operation and robotics technologies in nuclear decommissioning projects', *Nuclear Decommissioning Planning, Execution and International Experience* (Woodhead Publishing Series in Energy, 2012).

excepting the US, the UK and the Japan are making sustained investments in the applications of nuclear technology in favor of the safety standards.

The continuous development of nuclear technologies enables the reduction of the financial costs of decommissioning, the achievement of environmental sustainability, and the maintenance of nuclear safety. These are crucial factors for their successful experiences[31].

Based on the successful decommissioning practices above, it would be useful to distill the following analytical elements: (i) solid legal frameworks, including institutional competencies; (ii) nuclear waste management and the environment; (iii) public engagement; and (iv) technological innovation. Such elements form a structural perspective that enables the assessment of the effectiveness of the decommissioning framework of jurisdictions at an earlier stage.

In the following chapters Brazil and China's regulatory developments will be described and accessed based on this four-element analytical framework. Rather than a mere comparison of the experiences of Brazil and China with those of US, UK and Japan, the extensive nuclear decommission experiences of the advanced jurisdictions will be used as means to measure their progress.

2. The decommissioning of nuclear power plants in Brazil

2.1. Overview of nuclear energy in Brazil

[31] Although there are relevant local differences in the means and the level of the variables adopted by the US, UK and Japan, such analysis is outside of the scope of this work.

Nuclear power has been produced in Brazil since the 1980s. Located at a coastal area of the Rio de Janeiro State, the power plant complex Central Nuclear Almirante Álvaro Alberto - CNAAA consists of two reactors producing energy contributing to the national power grid, Angra 1 and 2, and a third under construction, Angra 3. Angra 1 began commercial operation in 1985, with a generating capacity of 640 MW, whilst Angra 2 has been under commercial operation since 2001, possessing a generating capacity of 1,350 MW. Both Angra 1 and 2 are the by-product of international co-operations: Angra 1 was purchased from a US company and Angra 2 was built with German technology as part of a comprehensive nuclear agreement between Brazil and West Germany, signed in 1975[32]. Angra 3's construction works started in the 1980s, but they were interrupted several times due to financial and political issues. Its completion currently depends on partnerships with foreign investors for financial support. Angra 3 is expected to add 1,405 MW of power to the national power grid by 2026, when the reactor is projected to begin operating[33].

Nuclear power plants provide approximately 3% of Brazil's electricity Nuclear energy is a component of the thermal complementary source of energy to the Brazilian energy matrix, which is largely based on hydroelectricity (<65%)[34].

According to the National Ten-year Plan 2026 (2017)[35], Brazil's energy demand is expected to grow at 1.9% per year from 2016 to 2026[36]. Synchronously,

[32] Luiz Pinguelli Rosa, 'Specific case of large energy system impact in Brazil risk assessment and management of nuclear energy' (1984) 10 Environmental International 437.

[33] Brazil, Empresa de Pesquisa Energética – EPE, 'Plano Decenal de Energia - PDE 2026' (2017) 58. <http://www.epe.gov.br/pde/Paginas/default.aspx> accessed 19 November 2017.

[34] The Brazilian energy matrix subsumes further thermal sources of energy including gas (10%), biomass (7.4%), coal (2.4%) and oil (2.2%); and non-hydro renewable such as wind (9.2%), and solar (0.1%) energy. All the data of the electric power sector refers to August/2017 <http://www.mme.gov.br/web/guest/secretarias/energia-eletrica/publicacoes/boletim-de-monitoramento-do-sistema-eletrico/boletins-2017> accessed 17 December 2017 (in Portuguese):.

the correspondent expansion of the energy supply in its consolidatory form encapsulates non-fossil fueled sources, including nuclear energy. The Plan relies largely on Angra 3 as part of the expansion of the nuclear energy sector by 2026, referring vaguely to the installation of further power plants after 2026, at shorter intervals of 5-7 years[37]. Published ten years earlier, the National Energy Plan 2030 provided a more ambitious project of four new nuclear power stations operating at a generating capacity of 1,000 MW each in addition to Angra 3, and the expansion of nuclear fuel production[38].

It is arguable that Brazil can benefit from the expansion of nuclear energy as a complementary source of the energy matrix[39]. Recent episodes of water scarcity in São Paulo[40] demonstrate that Brazil's hydropower overdependence on water makes it vulnerable to climate and rainfall change patterns, often resulting in electric power shortages[41]. Nuclear power plants could alleviate the pressures on water resources, without contributing to greenhouse gas emissions[42]. Also, in comparison to non-hydro renewable sources, nuclear power plants' continuous generation of energy provide energy security and higher reliability to the national system against the intermittent

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[35] The National Ten Year Plan is an annual study conducted by the Energy Research Company from the Brazilian Ministry of Mines and Energy.

[36] EPE (n 42) 48.

[37] ibid 53.

[38] EPE is currently developing a National Energy Plan 2050.

[39] Guimarães, L S. 'News and Views: Nuclear Power in Brazil' (2011) 41 Braz J Phys, 107-108; Joaquim F. de Carvalho and Ildo L. Sauer, 'Does Brazil need new nuclear power plants?' (2009) 37 Energy Policy 37 1580.

[40] Herton Escobar, 'Water security. Drought triggers alarms in Brazil's biggest metropolis' (2015) 347 (6224) *Science*, 812.

[41] Erik Eduardo Rego, Celma de Oliveira Ribeiro, Oswaldo Luiz do Valle Costa, Linda Lee Ho, 'Thermoelectric dispatch: From utopian planning to reality' (2017) 106 *Energy Policy*, 266-277.

[42] R. L. P. dos Santos et al., 'The Importance of nuclear energy for the expansion of Brazil's electricity grid' (2013), 60 *Energy Policy*, 288.

contributions of solar and wind[43]. The advantages include the fact that the country could potentially reach self-sufficiency in its nuclear energy production since it has one of the largest reserves of uranium in the world and the technological competencies in the nuclear fuel cycle, from mineral prospecting to uranium enrichment and fuel fabrication[44].

2.2. Nuclear energy sector legal framework

The 1988 Brazilian Constitution establishes the national legal regime for nuclear activities. Accordingly, the Federal Union has control over the operation of nuclear facilities, including nuclear power plants, and possesses monopoly command over surveying, milling, mining, exploiting and exploring over nuclear minerals and materials and the related activities of industrialization and commerce (Articles 21, XIII and 177, V).

The National Policy on Nuclear Energy Act was enacted in 1962 (Law N. 4.118 of as 27 August 1962, as amended by Law N. 6.189, of 16 December 1974, and Law N. 7.781 of 27 June 1989), creating the National Nuclear Energy Commission (Comissão Nacional de Energia Nuclear, CNEN) as the national nuclear regulator. The CNEN reports to the Ministry of Science and Technology (MTC) and its functions vary from assisting the formulation of the national nuclear policy and licensing nuclear power plants to establishing the standards and guidelines of nuclear activities, including radiological protection and nuclear safety, inspections, safeguards of nuclear materials, waste transport, disposal and safety, research and development, training and human resources development.

[43] Guimarães (n 48) 107-108.

[44] R. L. P. dos Santos et al. (n 40), 288.

Over the years, the Brazilian nuclear regulatory system has been criticized for the potential conflicts of interest amongst the CNEN's attributions. The CNEN is responsible for formulating regulations and issuing licenses. At the same time, it is responsible for enforcing the law and its own regulations as an inspector of nuclear operations. In this context, the CNC's independence could be questioned for being an inspector of activities approved by its own act. Also, according to the international standards of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Art, 20(2))[45], regulatory functions must be independent from other organizational measures related to spent fuel or radioactive waste management[46].

No nuclear power station shall be installed in Brazil without an operation license.[47] In addition to nuclear licensing, a separate environmental license is required to prevent or mitigate impacts to the environment during the installation, operation or decommissioning of the nuclear power plant. The National Environmental Agency[48] is responsible for the licensing and EIA[49].

Although public participation is a requirement for the elaboration of rules by CNEN and for the EIA[50], in practice there are limitations to public participation, which can be weak or nonexistent, predominantly because scientific language is not

[45] The Convention was signed and ratified by Brazil according to the National Decree N. 5935, of 19 December 2006.

[46] The issue was the subject-matter of the Committee on Environment and Sustainable Development of the Chamber of Deputies Report (2006) and a Class Action filed by the Brazilian Federal Prosecutors (2007).

[47] According to the Regulations CNEN-NE-1.04, of 14 December 1984 and the CNEN 15/02, of 12 December 2002.

[48] Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, IBAMA.

[49] Resolution CONAMA (from the National Counsel of the Environment) N. 237, from 19 December 1997.

[50] Resolution CONAMA N. 001, of 23 January 1986 and Resolution CONAMA N. 237, of December 19th, 1997; and Law N. 9,784, providing the General Regulation in Administration, of 29 January 1999 (Srticles 31 to 34).

accessible to the public and there is no requirement for a nontechnical summary [51] and, occasionally the public lack influence on actual decision making.

Eletrobras Eletronuclear is responsible for the planning, construction and operation of the power plants. It is a subsidiary of the Brazilian state-owned electrical power company Eletrobras reporting to the Ministry of Mines and Energy.

2.3. Brazilian Decommissioning Framework

In April 2012, the CNEN opened for public consultation the draft regulation on the decommissioning of nuclear power plants, from 4 April to 2 June 2012[52]. The participants' contributions were limited to the semantic aspects of the text[53], whilst lacking in a substantive commentary of the decommissioning process, impacts and costs.

Some months later, the CNEN published the Normative Order N. 133, which took effect on 8 November 2012 (also known as the CNEN Norm NN 9.01, thereinafter referred as "CNEN Decommissioning Rules"), covering the following topics: scope of application, responsibilities, decommissioning phases and strategies guidance, funding and management, expressly referencing health, safety, security and environmental requirements throughout.

According to the CNEN Decommissioning Rules, the operator of the nuclear power plant is responsible for the planning and implementation of decommissioning,

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[51] Glasson, John and Salvador, Nemesio Neves B. 'EIA in Brazil: a procedures-practice gap. A comparative study with reference to the European Union, and specially the UK' (2000) 20 Environmental Impact Assessment Review.

[52] Consulta Pública - Projeto de Norma - NN 9.01 - Descomissionamento de Usinas Nucleoelétricas <http://appasp.cnen.gov.br/seguranca/normas/cp-conspub.asp?ano=2012&numero=09> accessed 17 December 2017 (in Portuguese).

[53] Consulta Pública - Projeto de Norma - NN 9.01 - Descomissionamento de Usinas Nucleoelétricas <http://appasp.cnen.gov.br/seguranca/normas/cp-analise.asp?ni=102> accessed 17 December 2017 (in Portuguese).

including security and protection against radiological risks (Article 4). It is possible for the operator to delegate specific tasks of the decommissioning process to third parties, but will remain responsible for the security of the plant (Article 4, paragraph 1). The operator is also responsible for funding decommissioning and managing resulting radioactive waste (Article 5), and is required to carry out the environmental impact assessment (Article 6, V).

The CNEN Decommissioning Rules reflect the IAEA's menu of decommissioning strategies, to be elected at the operator's discretion. As previously discussed, the strategies comprise immediate dismantling, deferred dismantling and entombment, with each option varying in the timescale required for decontamination or removal of contaminated assets. When opting for one of these strategies, the operator should consider international experiences and other relevant policies particular to radioactive waste management as well as the management and the storage of the waste resulting from the decommissioning.

In Brazil, the waste management process is subject to specific legal requirements. The Brazilian Law N. 10.308 of 20 November 2001 contains the general rules on radioactive waste, regarding the selection of the location, construction, licensing, operation, monitoring, costs and civil responsibility. The criteria to consider for the selection of location are located in Article 5 and the apportionment of duties and responsibility between CNEN and the operator are also contained in the said legislation. This Law must be read and interpreted in conjunction with the CNEN specific regulation concerning waste management[54], which addresses the technicalities of activities relating to waste such waste classification according to

[54] CNEN Rules: NE-6.05, of 17 December 1985; NE-6.06, of 24 January 1990 and NN-6.09, of 23, September 2002.

the degree of contamination, and the three types of deposit for radioactive waste alternating in accordance with initial, intermediary or final phase.

To date, no solution has been devised for the infallible, definite and indefinite disposal of radioactive waste. This is a particularly sensitive issue for Brazil due to the 1987 nuclear accident known as Cesium 137, when citizens came into direct contact with high levels of radiation stemming from an old abandoned hospital[55]. 6,000 tons of radioactive waste are stored in a deposit located in the accident region. As for the spent nuclear fuels from the nuclear power plant in operation, they are temporarily deposited inside the CNAAA complex. To counter this threat, during the environmental licensing for Angra 3 the national environmental agency IBAMA required as a prerequisite to licensing the creation of a geological deposit coated in concrete and steel, for the storage of radioactive waste, enduring one hundred years.

Moreover, in the aftermath of the 2011 Fukushima Daiichi accident, when many countries decided to re-examine their nuclear safety regulations[56], Brazilian nuclear safety legislation was not particularly revised. This fact however renewed calls for the creation of an independent agency for nuclear power in Brazil[57] and it has affected the public opinion in Brazil concerns about nuclear safety and waste disposal[58].

The CNEN Decommissioning Rules also deal with the decommissioning planning phases. During the nuclear licensing phase of the power plant, prior to its installation, the operator must present to CNEN the Preliminary Decommissioning Plan (Article 11) proposing the decommissioning strategy and including amongst

[55] Robert Gale, 'Radiation accident grips Goiania' (1987) 238 (4830) *Science*, 1028-1031.

[56] News staff, 'Nuclear Power's Global Fallout' (2011) 331 (6024) *Science*, 1502-1503.

[57] José Goldemberg, 'News and Views: Perspectives for Nuclear Energy in Brazil after Fukushima', (2011), 41 *Braz J Phys*, 105.

[58] R. L. P. dos Santos et al. (n 40), 288.

other requirements, the budget and financial guarantees. Regarding the Final Decommissioning Plan (Article 12), it should be presented two years before the end of the commercial operation of the power plant, as part of the nuclear licensing process. The Final Decommissioning Plan should be implemented in less than 60 years after the cessation of commercial operation and once approved, it replaces the Preliminary Decommissioning Plan.

Alongside the Final Decommissioning Plan, the operator must submit to CNEN a specific Security Analysis comprising all the planned activities and the abnormal events that could occur during the decommissioning. The Security Analysis must contain, as one of the foundations of the Final Decommissioning Plan, an evaluation of the potential leakage of radioactive substances, which might adversely affect the public and environment. The CNEN Decommissioning Rules include a provision addressing the financial resources required to support decommissioning costs, which should be available even in the event that decommissioning occurs before the agreed date, due to accidents or the operator's decision (Articles 15 and 16).

To support the decommissioning costs of nuclear power plants in Brazil, Eletrobras created funds which amounted to approximately R$335Mi (US dollars) in 2014. Resources are transferred to the funds on a yearly basis and correspond to 1.5% of the gross billing from selling energy as produced by Angra 1 and 2. CNEN has established provisions for the management of financial resources for the decommissioning activities, following the CNEN Order N. 9.02 (Resolution CNEN 204/16, of 26 October 2016).

Once the decommissioning procedure is over, the operator must submit to CNEN the Decommissioning Final Report, demonstrating the implementation of the Decommissioning Final Plan and that the final stage of the nuclear power plant was achieved (Article 24). Following the approval of the Decommissioning Final Report, CNEN issues the Liberation of Regulatory Control (Article 28).

For the power plants under construction or in operation, which is the case for Angra 1, 2 and 3, the CNEN Decommissioning Rules has established a 2 year time-frame for the preparation of the Decommissioning Preliminary Plan.

In practice, Brazil has never experienced the decommissioning of its nuclear power plants. Angra 1 and Angra 2, both possess an estimated operating life of 40 years. Nevertheless, Angra 1 is approaching the end of its operating life and will be subject to closure and decommissioning in the near future. Unless an extension period is requested, Angra 1 will complete 40 years of commercial operation in 2025.

As per Angra 2, it will reach the end of its operating life in 2040. Although the CNEN Decommissioning Rules from 2012 requires the preliminary decommissioning plan before the installation of the nuclear power plant, for obvious reasons these rules could not be applied to past events such as the installation of Angra 1 in 1985 and of Angra 2 in 2000. Eletrobras Eletronuclear is currently developing the preliminary decommissioning plan for Angra 1 and 2.

3. The nuclear decommissioning framework in China

3.1. China's growing role in global nuclear industry

China's nuclear power industry has seen faster growth in the past five years[59]. At present, the number of nuclear power plants in operation in China has reached 36

[59] Huang Ge, 'China see nuclear advances' (2017) *Global Times*, < http://www.globaltimes.cn/content/1070579.shtml> accessed 19 January 2018.

facilities. China's total installed capacity of nuclear power is 56.9 million kilowatts, ranking it the third largest nation in the world in terms of generating capacity. Nuclear power reached a record high of 3.9 percent of China's total power generation in the first half of 2017[60].

In the 2012-17 period, nuclear power projects built in China accounted for more than 90 percent of the world's new project construction in the nuclear sector[61]. The country aims to add more than 60 nuclear power plants to its collection in China by the end of 2020. According to BP's statistics, China's nuclear electricity generation will increase by 11% every year at least until 2035, and account for over 75% of global growth in nuclear electricity generation[62]. Bloomberg energy finance also reported that China will overtake the US as the largest nuclear generator in the world by 2026[63]. This speed of progression roughly equates to the building of a new nuclear reactor in China, every three months for the next two decades.

The rapid growth of the nuclear industry will transform the power generation model in China as well as help the Chinese market reduce its dependence on coal. In fact, the reduction of overcapacity in the coal power sector and technological progress have been major driving forces in the recent and projected development of China's nuclear industry. China is also strengthening efforts to develop independent technology through innovation, while also improving safety standards. Currently, 20 nuclear power plants are under construction and 10 of them have adopted China-

[60] 'China Focus: Domestic steam Generator headed for nuclear power plant' (2017) *Xinhua News*, <http://www.xinhuanet.com/english/2017-10/17/c_136686751.htm> accessed 17 January 2018.

[61] ibid.

[62] 'Russia completes world's first Gen III + reactor; China to start up five reactors in 2017' (2017) *Nuclear Energy Insider* <https://analysis.nuclearenergyinsider.com/russia-completes-worlds-first-gen-iii-reactor-china-start-five-reactors-2017> accessed 17 January 2018.

[63] ibid.

designed third-generation nuclear power technology, namely the “third-generation” reactor design Hualong One steam generator[64].

Even after the Fukushima Daiichi disaster, China’s energy policy for developing nuclear power did not change significantly[65]. But a weak and opaque governance framework has long been viewed as an obstacle. The existing legal framework does not adequately address the role of government, state-owned nuclear enterprises and the military force when it comes to the issues of waste management, safety and nuclear material use.

Domestically, the first nuclear facility was built in the 1950s. Several reactors, including research reactor, civil and military reactor, have achieved their decommissioning stage[66]. Moreover, China has already contracted to construct nuclear power units overseas for Argentina, England, Egypt, Kenya and Romania. Nuclear safety has therefore become an important issue both in China’s domestic nuclear sector and its international operations. Plans to build dozens of new nuclear power plants and export China’s nuclear technologies to the rest of the world, have brought with them strong pressures for the Chinese government to improve its legal and governance regimes pertaining to the sector[67].

3.2. A new regulatory reform – China’s Nuclear Safety Law of 2018

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[64] ‘Safe nuclear generation another hallmark of Chinese ingenuity’ (2017) *China Plus*, < http://chinaplus.cri.cn/opinion/opedblog/23/20170925/31400.html> accessed 17 January 2018.

[65] M. V., Ramana, Amy King, ‘A new normal? The changing future of nuclear energy in China’, *Learning from Fukushima: Nuclear power in East Asia*, (National Australian University Press, 2017), 103.

[66] Yidong Zhou, ‘Decommissioning Status at CIAE and Proposes for IDN’ China Institute of Atomic Energy CIEA, Beijing <https://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN_2007/China.pdf > accessed 17 January 2018.

[67] H.Yang, J. L., Clarke, & J. R. Thompson, ‘Nuclear energy: Improve collaboration’ (2016) 353(6304) Science, 1107-1107.

In September 2017, China's National People's Congress passed a new Nuclear Safety Law[68]. The new law will take effect in January 2018 and aim to enhance the safe use of nuclear energy, liability in the form of compensation for nuclear damage, public participation and international cooperation[69].

The new Nuclear Safety Law is a milestone in China's nuclear development history. Before that, China only promulgated the Prevention and Control of Radioactive Pollution Law and other administrative regulations, which focused rather narrowly on the prevention and control of radioactive pollution[70].

The new law lays out a comprehensive framework for nuclear safety and in totality include 8 sections[71] and 94 provisions. This newly-published law is expected to have significant impacts on decommissioning practices and the nuclear sector at large

3.2.1. Regulatory body reform

The Nuclear Safety Law in principle maintains the administration system established by the Prevention and Control of Radioactive Pollution Law and the other administrative standards[72]. It systematically consolidates requirements which were previously scattered across administrative regulations and ministerial decrees into a

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68 Y. Wu, 'Public acceptance of constructing coastal/inland nuclear power plants in post-Fukushima China' (2017) 101 *Energy Policy*, 484-491.

69 F. Yuan, 'Discussion About Public Participation in Environmental Impact Assessment in China's Nuclear Power Plant Project' (2017) 25th International Conference on Nuclear Engineering (V008T12A012-V008T12A012). American Society of Mechanical Engineers.

70 R. Mu, J. Zuo, & X. Yuan, 'China's approach to nuclear safety—From the perspective of policy and institutional system' (2015) 76 Energy Policy, 161-172.

71 1) General principles; 2) Safety of nuclear materials and waste; 3) Nuclear accident emergency response; 4) Public participation and information disclosure; 5) Administrative supervision and safety inspection; 6) Legal liabilities of nuclear damages, 7) Administrative liabilities of nuclear safety, and 8) Miscellaneous

72 Z. Ming, L.Yingxin, , O.Shaojie, S.Hui, & L. Chunxue, 'Nuclear energy in the Post-Fukushima Era: Research on the developments of the Chinese and worldwide nuclear power industries' (2016) 58 *Renewable and Sustainable Energy Reviews*, 147-156.

law, and supplements and improves the current nuclear safety system (See Article 6). Furthermore, the new legislation will grant further powers to China's National Nuclear Safety Administration (NNSA). Also, Article 54 requires that the State shall set up a coordination committee to respond to nuclear emergency accidents.

3.2.2. Decommissioning plan and procedures

The regulatory authority, NNSA and the State Council list the specific documents which should be submitted by the decommissioning operator[73]. These documents must prove that the whole decommissioning process will operate safely[74].

Upon the decommissioning of a nuclear facility, the governmental environmental protection department of the province, autonomous region or municipality where the nuclear facility is located shall organize the monitoring of the type and concentration of radionuclide at the site of the nuclear facility and in the environment surrounding it.

3.2.3. Nuclear safety and radioactive waste management

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[73] Article 30 of China's Nuclear Safety Law: "Before a nuclear facility is decommissioned, the nuclear facility operating entity shall apply for decommissioning to the nuclear safety supervision and administration department of the State Council and submit the following documents:

(1) An application for the decommissioning of the nuclear facility.

(2) A safety analysis report.

(3) An environmental impact assessment report.

(4) Quality assurance documents.

(5) Other documents required by the laws and administrative regulations."

[74] Article 29 of China's Nuclear Safety Law: "When a nuclear facility ceases to operate, the nuclear facility operating entity shall manage the shutdown by safe means to ensure safety during the shutdown and guarantee the basic functions, technical personnel and documents required by decommissioning."

Chinese governmental officials have repeatedly claimed that China's nuclear sector has not experienced a single major accident or serious radiation incident in the 25 years since it connected its first reactor to the grid, making it far safer than coal[75]. Despite this, The International Atomic Energy Agency released a report on China's nuclear safety last year claiming that China's nuclear safety record had been strong but needed "further work" in areas such as waste management and handling ageing plants[76].

The Nuclear Safety Law mainly regulates the possession of nuclear material, processing, storage and disposal of radioactive waste, safety management of spent fuel, and transportation of nuclear material and radioactive waste[77]. Of these, the new additions are the license for processing radioactive waste and the safety management of spent fuel[78].

It is the first time that the Chinese legislator explicitly makes provision for safety management liability and disposal costs of spent fuel in the nuclear power sector[79]. Article 90 of the Nuclear Safety Law clearly lists both nuclear operators' and suppliers' liabilities to compensate for damages caused in the event of nuclear accidents.

3.2.4. Public participation and information disclosure

To the nuclear industry, information disclosure and public participation are pivotal for ensuring that the industry develops in a healthy manner and acts to de facto

[75] S. Zhou, & X. Zhang, 'Nuclear energy development in China: a study of opportunities and challenges' (2010) 35(11) *Energy*, 4282-4288.

[76] IAEA PRIS, PRC China <https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CN>

[77] Article 39 of China's Nuclear Safety Law.

[78] Article 43 of China's Nuclear Safety Law.

[79] W. Geng, Z. Ming, P. Lilin, L. Ximei, , L. Bo, , & D. Jinhui, 'China' s new energy development: Status, constraints and reforms' (2016) 53 *Renewable and Sustainable Energy Reviews*, 885-896.

strengthen a culture of nuclear safety. The new law clarifies the roles of central government, local governments and nuclear operators, and requires them to jointly improve information disclosure and public participation.

Under the Nuclear Safety Law, all the relevant governmental departments shall disclose readily available information regarding nuclear safety, supervision reports, radioactive environmental quality, and nuclear accidents[80]. Nuclear operators should publish their annual nuclear safety reports, including information on their nuclear safety management system, radiation monitoring data and environmental assessments[81].

All such information shall be disclosed in a timely manner through official statements, online publications or any other means available to facilitate citizens' access to information. In addition, citizens, enterprises or any other organizations, such as NGOs and international organizations, may apply to the relevant governmental agencies for access to the information stated above[82].

Regarding public participation, nuclear operators and the local governments of the nuclear unit locale shall solicit stakeholders' opinions on main nuclear safety issues and shall facilitate public interest through public hearings, discussion forums, or any other effective means which permits for the meaningful deliverance and integration of feedback[83]. This new system is expected to encourage Chinese citizens to participate in nuclear industry development. A focus on information disclosure and public participation, allows for knowledge of and contribution to nuclear procedure and substance, thereby enabling transparency which may eventually enhance public

[80] Article 55 of China's Nuclear Safety Law.

[81] Article 56 of China's Nuclear Safety Law.

[82] Article 57 of China's Nuclear Safety Law.

[83] Article 58 of China's Nuclear Safety Law.

acceptance of nuclear energy in China. This important step highlights China's newly invigorated determination to develop the nuclear sector, albeit in a sustainable way[84]. In addition, information disclosure and public participation measures can equally apply to decommissioning procedures as well.

3.3 China may take the lead in international cooperation

The introduction of the Nuclear Safety Law is timely as China has now been developing its nuclear sector for over three decades. This new law has established a more comprehensive governance system for the industry and connected the country more closely with the international nuclear market.

Today the Chinese nuclear industry is also faced with challenges in going global, as nuclear power projects are capital intensive and are often affected by political issues in some overseas markets. Due to China's international obligations under binding treaties, the new law also requires the government to enhance international cooperation mechanisms in nuclear safety affairs and prevent the threat of nuclear terrorism.

East Asia will be the focus of nuclear power in the near future[85]. To strengthen regional cooperation, China, Japan, South Korea and other ASEAN countries have launched a large-scale regional nuclear power development scheme. In 2011, China, Japan, and South Korea signed a "China-Japan-South Korea Nuclear Security Cooperative Initiative". Based on this initiative, all three parties must establish cooperative frameworks and take action for achieving regional nuclear safety.

[84] Chong Liu, 'Pressing global nuclear security problems and China's response'(2017) NAPSNet Special Reports, October 2017 <https://nautilus.org/napsnet/napsnet-special-reports/pressing-global-nuclear-security-problems-and-chinas-response/> accessed 17 January 2018.
[85] ibid.

ASEAN also established a similar multilateral agreement in the region, namely the ASEAN Nuclear Safety Regulatory Cooperation Network (ASEANTOM)[86].

Furthermore, China and Taiwan entered into a bilateral Nuclear Power Safety Agreement in 2011[87]. This cross-strait cooperative mechanism was designed to for the sharing of information, monitoring of nuclear safety, and safeguarding public health and the environment. Besides this agreement with China, Taiwan has been trying to cooperate with Japan and Korea and to join the ASEAN regional initiative especially through the APEC platform[88].

At the individual company level, some UK firms have provided their expertise and experiences to assist Chinese operators with nuclear decommissioning and waste management[89]. The collaboration between Atkin and Taihai as well as the one between James Fisher Nuclear and the China National Nuclear Corporation (CNNC) are both good examples[90]. The CNNC was set up in 1988, succeeding the Chinese Ministry of Nuclear Industry. The main responsibility of the CNNC is to regulate the nuclear generators, manufacturers, civil and military research institutes. In addition to building large nuclear power units, the CNNC also owns and operates almost all the decommissioning facilities and waste management operations in China, including a reprocessing plant and a geological repository for nuclear waste. This provided both

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[86] ibid.

[87] Chen (n. 26).

[88] ibid.

[89] 'UK firm to assist Chinese with nuclear decommissioning'(2016) *Nuclear Matters* <http://nuclearmatters.co.uk/2016/09/uk-firm-to-assist-chinese-with-nuclear-decommissioning/> accessed by 26 December 2017.

[90] Previous MOU and Agreement on Co-operation for Peaceful Uses of Nuclear Energy were signed between China and Brazil in 1984. See also Elaine Li, 'James Fisher Nuclear introduces China in the UK decommissioning market' (2016) *NBN Media* <https://nbn.media/james-fisher-nuclear-introduces-china-uk-decommissioning-market/> accessed by 26 December 2017.

policy and commercial opportunities for the world's leading enterprises in nuclear decommissioning and waste management.

Based on the current East Asian regional structure of co-operation and the rapid growth of China's nuclear sector, China might consider taking the lead in regional and international nuclear cooperation. This will also be beneficial to China's nuclear decommissioning sector and performance.

In 2017, China and Brazil also signed their third Memorandum of Understanding (MOU) regarding nuclear cooperation[91]. This agreement is made between the CNNC and Brazil's Electronuclear. It aims at deepening bilateral cooperation in achieving nuclear safety and highlights the common interests in completing the construction of Brazil's Angra 3 nuclear power plant. Since Brazil and China are not geographically proximate, the geopolitical reasons behind this collaboration are worth exploring[92].

Besides sharing a common nuclear power plant decommissioning regulatory momentum, Brazil's and China's asymmetric capacities can be reciprocally combined: China's policy to 'go global' through exporting nuclear technology including heavy components in the supply chain perfectly accommodates Brazil's needs of an investor for the completion of its third nuclear reactor, currently under construction, and future nuclear power plants projects.

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[91] 'Brazil and China sign new nuclear power cooperation agreement' (2017) Macauhub < https://macauhub.com.mo/2017/08/30/pt-brasil-e-china-assinam-novo-acordo-de-cooperacao-na-energia-nuclear/> accessed 16 December 2017.

[92] Russia is also interest in completing Angra 3 However, China is expected to have an advantage in terms of financial resources. China and Russia are both part of the "nuclear club" and they have been recently competing against each other as exporters of nuclear energy technology to developing countries. See A Abdenur and C Kassier. 'Nuclear Energy and the BRICS' (2014) 15 *Georgetown Journal of International Affairs*, 55-66.

4. Discussion - The evolution of decommissioning regulation

Looking at the regulatory frameworks in the selected advanced jurisdictions of US, UK and Japan, all of them have established detailed guidelines and regulations, paying attention to relevant aspects of nuclear decommissioning. Following these standards operating procedures, decommissioning operators can complete the process step-by-step. Moreover, these advanced jurisdictions usually have independent and efficient regulators for overseeing nuclear decommissioning operations.

For safety purposes, the state-of-the-art technology for decommissioning nuclear reactors adopted worldwide is considered to be adequate. However, there are opportunities for further enhancement, especially with regards to minimizing human intervention, increasing efficiency and improving waste treatment[93], as shown by the current efforts of the advanced jurisdictions of the UK and Japan, and of the US (primarily in the recent past). Although technological innovations are not always seen as a commercial advantage[94], they represent invaluable gains for the safety and governance of nuclear activities,.

Nevertheless, nuclear decommissioning is not only a scientific and technological issue. The process requires well-designed regulations and guidelines to consolidate its implementation. The form and content of decommissioning regulations have important practical implications and play a major role in promoting or, conversely, preventing social change.

In addition, it is noted that nuclear decommissioning processes also encounter an array of social and environment challenges and conflicts, most notably in relation

[93] IAEA, Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities (IAEA, 2008), 2

[94] ibid, 1.

to waste management. The introduction of the waste management aspects of treatment, storage, transportation and disposal during site clean-up in the decommissioning rules, worldwide, is not without reason. Decommissioning is integral to and inseparable from waste management due to the fact that decommissioning entails the ultimate disposal of remaining waste whilst waste management represents an average of 60% of total decommissioning costs[95].

This raises the issue of public acceptance and trust. The public's non-acceptance is rooted in lack of information and knowledge, fear of risks, low level of public participation, and the well-known NIMBY syndrome. The literature also elucidates how this public non-acceptance and the bad personnel transition can do harm to the smooth progression of nuclear decommissioning. Sometimes serious social challenges can eventually cause the abandonment of decommissioning projects[96]. Therefore, effective information disclosure procedures and well-designed public engagement mechanisms are both key factors to democratizing nuclear decommissioning and enhancing the transparency and legitimacy of this process.

The discussions above can be summarized by three policy components – technology, governance, and democracy – based on the elements distilled from observations on the advanced jurisdictions. Though it is a relatively structural and static perspective, this decommissioning policy approach is still useful in assessing the decommissioning regulations in various countries and their performances in practice.

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[95] C Pescatore and T Eng, 'Safe, Efficient and Cost-effective Decommissioning' (2005) 23 (4) *Nuclear Plant Journal*, 62.

[96] M. Laraia, (Ed.) *Nuclear decommissioning: Planning, execution and international experience*, (Elsevier, 2012). See also D. C. Invernizzi, G.Locatelli & N.J. Brookes, 'Managing social challenges in the nuclear decommissioning industry: a responsible approach towards better performance (2017) 35 (7) *International Journal of Project Management,* 1350-1364.

Brazil recently established a decommissioning nuclear power plant framework with clear and detailed provisions, addressing explicitly the close ties decommissioning holds with waste management, environment, public participation and technological innovation. Although individually the regulation is not sufficient to guarantee the highest safety standards, it is certainly a meaningful first step.

An analysis of the Brazilian decommissioning framework in contextual actuality reveals some governance shortcomings which are not demonstrable through a purely legalistic and formal revision of the relevant texts. For example, the CNEN as regulator operates in a dual capacity, carrying out the functions related to both the establishment of standards *and* the monitoring of nuclear operations and waste management, which could potentially represent a conflicts of interests. Ultimately, if the regulator's monitoring function lacks rigour in following the plan approved by itself, the safety of decommissioning activities could be at risk.

Also, at the implementation level of decommissioning rules, three further shortcomings can be envisaged. Firstly, as mentioned before, the public's participation is part of the CNEN legislation process and of the EIA. However, the local communities in the vicinity of nuclear or waste management facilities are not necessarily aware of the risks, since the technical and scientific language of the documents could prove to be unreachable fora lay audience, thereby rendering it unimpeachable. In addition, public participation could be deemed a mere formality as it is very unlikely that the eventual local population's contributions would actually influence the law-making or decommissioning process, unless is the contributions are backed by economic groups' interests or the pressure of an expressive percentage of the population.

Waste management could also be viewed as an obstacle during the decommissioning of Brazilian nuclear power plants, since Brazil does not have a permanent waste disposal site. The government intends to seek bids from municipalities, a decision-making process which will require the ground work of communication between stakeholders involved such as local inhabitants, political authorities, non-governmental organizations and experts.

A final obstacle for the successful implementation of the decommissioning policy in Brazil is exogenous to domestic policies. As evidenced by the lack of funds to conclude Angra 3, it is possible that Brazil will face similar problems in applying state-of-the art techonology to the decommissioning of national nuclear power plants. As mentioned previously, technological innovations are key drivers for public participation and to the promotion of nuclear energy governance. In this instance, Brazil can benefit from further cooperation on nuclear technologies, such as the one recently discussed with China.

In the case of China, an imbalance subsists in the decommissioning policy approach. Although the Nuclear Safety Act 2018 has been passed, there are still several problems. Many countries have established independent nuclear safety regulatory agencies, which are subject to Congress, the President or the direct leadership of the Cabinet, whilst maintaining sufficient independence and authority. Currently, China still lacks an independent regulatory authority for nuclear decommissioning. The functions of the current relevant authorities overseeing nuclear decommissioning to some extent overlap, whilst the departments themselves do not coordinate in an efficient way. Some additional problems are the following: (i) many provisions in the new Nuclear Safety Law are still too vague and require other administrative regulations to support them. This feature makes the law unclear and the outcomes of its implementation can be inconsistent, especially for foreign investors; (ii) Article 4 of the Nuclear Safety Law states the general principles of decommissioning. However, both public participation and information disclosure have not been officially listed as general principles for guiding nuclear decommissioning projects in China, though other Articles mention and improve the current mechanisms; (iii) China's current decommissioning personnel and budgets are still below the average standard globally[97]; and (iv) the basic law – Atomic Energy Law – for managing the whole nuclear sector and industries is not in force and there is no exact date for the passing of this law[98], a significant piece of legislation which can integrate the current fragmented legal frameworks and enhance the national nuclear damage liability system.

From a dynamic point of view, the evolution of decommissioning law and international governance mechanisms are driven by two major active factors, namely technology and democracy. So far, governments have mainly relied on nuclear technologists to establish those "top-down" models for decommissioning nuclear units. We can call this model the "technology-driven model". For example, in China's nuclear safety law, such a development pattern can still be observed. In the future, civil society groups and the local communities will play a greater role in the emergence of a new generation of nuclear energy law and its enforcement, both at the domestic and international levels. This can be recognized as what we can dub "the

[97] In the US, Japan and France, the average number of staff / per reactor reaches 33.5, and the average budget per reactor for the purposes of decommissioning reaches USD 8,260,000. In China, the average staff number per reactor is only 8.3, and the average budget per reactor is only USD 402,200. These numbers clearly present the capacities and challenges for implementing projects in China.

[98] According to the Chinese Plan for Nuclear Safety and Radioactive Pollution Prevention and Control during the Period of the Thirteenth Five-year Plan and the Vision for 2025, approved by the State Council in February 2017, China is still pushing forward the enactment of the Atomic Energy Law.

society-driven model". This is not only an observation drawn from the experience of the countries in the field of decommissioning but also reflective of the content of international treaties regarding nuclear energy security.

To sum up, both technology and democracy jointly promote the evolution of nuclear decommissioning law and a global governance framework. As the mainstream model evolves from the technology-driven one to a new society-driven model, it will truly place the people and local communities in the center of the decommissioning process. To some extent, this trend echoes the key concept of energy justice, which aims to apply justice principles to all aspects of energy policy, such as energy production, consumption, energy security and environmental protection[99].

5. Conclusion

In order to assess Brazil's and China's further development of their decommissioning frameworks and practices, this work has developed an structural perspective shaped by the experienced advanced jurisdictions such as the UK, US and Japan, and composed by the elements of technological innovation, public participation and governance.

In summary, technological innovations in the nuclear sector can benefit humans and the environment, which could be sufficient in constructing an improved public opinion on nuclear activities. Thinking about (i) technological innovation, (ii) public participation and (iii) nuclear energy governance as three separate engines working in synergy, one can imagine that an increased rate of acceleration for each ultimately leads to the speedier achievement of goals each one of them represents.

[99] Heffron and McCauley (n 1).

If envisaged as a virtuous cycle, technological innovation can act as an engine that will trigger more public participation and engagement whilst encouraging the establishment of the respective legal regime. In turn, the public participation engine will propel nuclear energy governance to move towards a comprehensive, democratic, safe and effective legal regime.

Brazil and China have just started to build their national decommissioning nuclear power plant regimes. Some challenges faced by both countries are common, such as the need to strengthen their institutional regulatory bodies and to engage the population in all stages of the decommissioning processes, starting with the design of their own regulation. As per the technological aspect, Brazil's and China's pathways can cross to create a mutually beneficial relationship, in which China would act as a provider of nuclear energy technology to fulfill Brazil's energy expansion needs.