Ensuring the growth of the electricity grid of LDCs with SMRs

Transition and technology policy - Strategic paper

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Executive summary

Small and Micro Modular Reactors (SMR & MMR) have the potential to provide a reliable and low-carbon source of energy in Least Developed Countries (LDC). A roadmap is presented here for the enhancement of SMRs and MMRs in LDCs, with the use of an innovation prize as a pull mechanism, as well as the creation of a monetary fund as a push mechanism. Other measures are also suggested to improve social acceptance, such as informing and integrating the population early in the process. While this presents a challenging solution, it is worth pursuing it in order to have a cleaner energy source in LDCs.

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1 UN Grand challenge: Clean and affordable energy

Access to clean and affordable energy is a key factor to achieve many of the United Nations' Sustainable Development Goals (SDGs). Energy is an important driver of economic growth and development, and is necessary for operate homes and industries. However, traditional sources of energy, such as fossil fuels, have negative impacts on the environment and contribute to climate change. Ensuring that all people can access to clean and affordable energy is therefore a crucial element of sustainable development. This is particularly the case for developing countries, such as in Africa.
Many developing countries in Africa have trouble accessing a reliable source of energy. This is due to several factors :

- Lack of infrastructure: Many African countries lack infrastructure such as transmission lines and distribution networks, to deliver electricity to homes and businesses. This can make it difficult to expand access to energy, especially in rural areas.
- High costs: The cost of electricity can be prohibitively high in many African countries, making it difficult for households and businesses to afford. This is due to a variety of factors, including the cost of fuel and the lack of competition in the energy sector.
- Poor governance: In some cases, corruption and poor governance can hinder the development of the energy sector in African countries. This can induce inefficient use of resources and make it more difficult to attract investment in the energy sector.

Overall, the lack of access to energy is a major barrier to economic development and poverty reduction in many African countries. Increasing access to energy is therefore a key priority for these countries.

Nuclear energy potentially plays a significant role in achieving the United Nations' Sustainable Development Goal on clean and affordable energy for all. While nuclear energy has faced controversy in the past, it has the advantage of being a low-carbon energy source that can provide reliable electricity. Among the reasons why nuclear energy may be a good option for developing countries looking to increase access to clean and affordable energy, the most important ones are:

- Low-carbon energy: Nuclear energy does not produce greenhouse gases during operation, making it a low-carbon energy source. This is particularly important for countries looking to reduce their carbon emissions in order to mitigate the impacts of climate change.
- Reliability: Nuclear power plants can operate continuously for long periods of time, providing a reliable source of electricity. This can be especially useful in developing countries where the electricity grid may be unreliable or subject to frequent outages.
- Low cost: Generating electricity from nuclear energy cost less and less recently, making it more economically competitive with other forms of energy. This can help to make electricity more affordable for consumers in developing countries.

For these reasons, the nuclear energy could represent be a good solution for developing countries to have access to affordable energy.
This is especially the case for small modular reactors (SMRs) or micro modular reactors (MMRs), which may be an ideal solution to the lack of access to energy source in developping countries for several reasons :

- Their scalabilility : SMRs/MMRS are smaller and more flexible than traditional nuclear power plants, which makes them easier to scale up or down to meet changing energy needs.
- Their small cost : The smaller size of SMRs or MMRs can potentially make them more economically competitive with other forms of energy, especially in smaller markets.
- Their safety : SMRs/MMRS are designed to be safer and more secure than traditional nuclear power plants, they have passive safety systems that do not require operator intervention in the event of an emergency, and they are more resistant to natural disasters and acts of sabotage.

It is important to note that the adoption SMRs or MMRs, like any form of nuclear energy, comes with its own set of challenges, including the management of nuclear waste and the risk of accidents. These issues must be carefully considered when evaluating the suitability of nuclear energy for any particular country.

2 Small and Micro Modular reactors (SMR & MMR)

2.1 Description of the technology

Nuclear reactors are power-producing machines designed to utilize a steady-state chain reaction in nuclear fuel. Small modular reactors (SMRs) and micro modular reactors (MMRs) are nuclear reactors classified based on their power output, which is approximately 300 MW and 30 MW, respectively. In comparison to traditional power reactors, which have a power output of around 1 GW, SMRs and MMRs have several advantages that make them particularly relevant for small grids, such as those in developing countries. These advantages include ease of operation, reduced risk of catastrophic accidents, lower cost and faster deployment, and the ability to be scaled down to lower power levels.

2.1.1 Electronuclear processes

The exloitation of nuclear energy involves some crucial steps that can be summarised by:

Mining: Uranium, the primary fuel for nuclear power plants, is mined from the earth and extracted from ore deposits.

Enrichment: Natural Uranium is not suitable for use in a reactor as it is, as it contains only a small percentage of the isotope ^{235}U. Therefore, it musts undergo a process called enrichment to increase the concentration of ^{235}U.

Fuel fabrication: After enrichment, the uranium is formed into fuel rods or pellets, which are then encased in a metal casing called a fuel assembly. These fuel assemblies are placed in the reactor to generate electricity.

Reactor operation: In the reactor, the ^{235}U atoms are split (fission) when struck by neutrons, releasing energy in the form of heat. The heat is used to produce steam, which drives a turbine to generate electricity.

Spent fuel management: After the fuel has been used in the reactor for a period of time, it becomes "spent" and is no longer suitable for use in the reactor. The spent fuel is stored temporarily in a spent fuel pool near the reactor, before being transported to a facility for long-term storage, disposal or recycling.

Disposal: There are several options for the disposal of spent nuclear fuel, including deep geological disposal, in which the fuel is placed in a deep underground repository, and reprocessing, in which the fuel is chemically treated to extract usable materials. The most appropriate method for disposal depends on the specific characteristics of the fuel and the national regulations in place.

2.1.2 Notes on nuclear energy

Note on the technologies There are various ways to use nuclear reactions to generate power, including molten salt, high temperature, pressurised water, or gas-cooled reactors. However, it is beyond the scope of this paper to provide a detailed description of these methods.

Note on the fuel Uranium is the most commonly used fuel in nuclear reactors. Its associated costs represent a relatively small portion of the operational expenses of nuclear power plants, and there is a sufficient global supply of uranium to meet current demand. Australia, Canada, and Kazakhstan are the main suppliers with the remaining reserves being scattered across dozens of country. According to the World Nuclear Association [2], global reserves of uranium are estimated to be 6.1 million tons, which is enough to meet current world's demand for approximately 90 years. Additionally, other technologies are being developed or already exist that can use alternative fuel sources, which could extend the supply of nuclear fuel for centuries. Given these considerations, the topic of nuclear fuel will not be covered in this paper.

Note on a suitable design for developing countries To be of any use to developing countries and be able to compete with cheap fossil based power plants, an SMR design must be ***affordable***, ***reliable*** and ***easy to build and operate***. What matters in infrastructure projects of this nature is both the CAPEX and TOTEX which can be summarised in terms of $/MWh, the cost of the electricity produced by the plant. Because those countries have often never had access to nuclear energy in the past, this design needs to be able to be deployed in countries with no prior nuclear experience and thus require low-resource and knowledge-based maintenance or operation.

2.2 Problem-Solution analysis of the technology.

In order to establish an adequate policy to address the global energy problem and more particularly in developing countries, it is necessary to situate the

problem in the problem-solution space. The pathway of the mission is mostly a solution-led pathway as the SMR are the solution we want to implement. We will have to work also on the social acceptance, world policies and on the technical accessibility of the SMR. It is also partly hybrid as the problem still needs to be better apprehended by local population. The table 1 details the different points of the contestation, complexity and uncertainty on the problem side as well as on the solution side.

	Problem side	Solution side
Contestation	- Small contestation about climate change but no unanimity about the priority to implement green energy sources in developing countries	- Availability of other resources (easily accessible or not) in a given territory - Not adapted to the actual world policies on nuclear energy
Complexity	- Energy issue closely related to the political, economical and geographical situation of a country.: developed countries wants a clean energy production system while developing countries are looking for something cheap, reliable and fast	- New nuclear technologies and difficulties to experiment - Skilled labour or manpower needed
Uncertainty	- Increasing needs of quickly available and stable sources of energy for all countries but no clear view on which energy mix to choose	- Social acceptance of a nuclear solution - Different solutions are possible

Table 1: problem-solution space of the mission "Ensuring the growth of the electricity grid of developing countries with SMRs"

3 Recommendations

In this part, a roadmap will be provided for ensuring the growth of the electricity grid of LDCs (Least Developed Countries) with small modular reactors (SMRs). The goal of this roadmap is to ensure the successful development of this mission.

3.1 Development and adoption of the technology

3.1.1 Development of a design

Innovation prize As some designs of small modular reactors (SMRs) are already very advanced, establishing a prize, as a pull mechanism, could help to steer the development of a commercially viable design that meets the standards, or the ex ante specifications, outlined in section 2.1.2, and is suitable for operation in developing countries. This prize could incentivize the development of an SMR design that is specifically tailored to the needs of these countries and can be safely and reliably operated in their grids.

To win the prize, companies must build a demonstrator as a partnership with a developing country. In this way, the development is ensured and first reactors can be tested and improved.

First reactors The first reactor of each proposal submitted for the innovation prize must be built in a developing country, as previously mentioned. This requirement serves two purposes: it allows the feasibility of the design to be tested in real-world conditions and it involves the intended clients in the decision-making process. Companies will need to consider the non-technical aspects of their design and how they can be implemented in practice. Similarly, countries interested in adopting small modular reactors (SMRs) will need to consider the practicalities of integrating these devices into their energy systems, including any necessary regulatory changes at the benefit of potential cost savings.

3.1.2 Development of a regulatory framework through international institutions

Safety agency Safety agencies are crucial for evaluating and overseeing the safety of nuclear power plants (NPPs). However, establishing such agencies can take time and requires specialised knowledge and expertise. To ensure that reactors in developing countries receive adequate oversight, there are several approaches that can be taken:

- Existing safety agencies can support the development of foreign national agencies through exchanges of personnel, such as training for-

eign staff in-house or sending their own agents to assist on-site.

- An international agency, such as the United Nations' International Atomic Energy Agency (IAEA), could be established or expanded with a mandate to inspect reactors of signatory countries and issue recommendations or even the authority to shut down reactors.

Both of these approaches present challenges, as ensuring safety may require the agency to have the power to affect the operation of a reactor, while at the same time, countries must retain the ability to make sovereign decisions. Finding a balance between these conflicting goals will be crucial for the success of any agency tasked with overseeing the safety of NPPs.

Cost competitiveness The cost of small modular reactors (SMRs) and micro modular reactors (MMRs) is currently uncertain due to the newness of the technology. However, it is worth noting that traditional nuclear energy has become increasingly expensive in recent years as reported in [4]. The levelized cost of electricity (LCOE) is a useful metric for comparing the costs of baseload power sources such as nuclear, coal, gas, and hydro, and it shows that nuclear energy has become less competitive compared to fossil fuels. This is partly due to increased regulatory pressures, but this is outside the scope of this paper. Another factor that contributes to the cost disparity is that the market does not typically account for the carbon emissions of fossil fuel plants. To make nuclear energy more competitive compared to cheaper but polluting options, one solution is to introduce a form of carbon pricing to internalise externalities from fossil energy, such as a direct tax or a cap-and-trade system like the European Union Emissions Trading System (EU ETS) . However, this would require international collaboration, as such a measure would have short-term economic impacts and could create a situation where countries that take this positive step on their own are penalised.

3.1.3 Fostering new power plant builds

Early adoption Developed industrial countries, particularly those without a current nuclear energy infrastructure, can play a key role in the development and refinement of new nuclear technologies. By serving as early adopters, these countries can provide a supportive environment for addressing any issues that may arise during the testing and implementation of new designs. As more reactors are built, their designs are going to be refined while their costs are likely to decrease, making it more feasible for adoption by developing countries.

Monetary fund A monetary fund could be established as a push mechanism to accelerate the adoption of SMRs in low developing countries by providing access to financing and technical assistance. This fund could be financed through a combination of government grants, support from international organizations such as the United Nations, and private investment.The repayment terms of the found would be based of the economic output of the plant.

To ensure that access to the fund is not provided to potentially harmful projects, it is necessary to establish clear guidelines (regulations and rules) and principles for eligibility. These principles should cover areas such as safety, integration into the local communities, and competence in project management and execution. This would insure that environmental regulation are respected an. Detailed information on these safety principles, settled up by IAEA, can be found in section 3.1.2. The guidelines could also include to communicate early with the local community, to hire local worker and in general offer to the community and always be transparent. More information about the social acceptance can be found in section 3.2. By requiring adherence to these principles, we can ensure that projects receiving funding are aligned with our values and goals. This fund could also help providing technical assistance to the borrowers to facilitate the construction and adoption of an SMR.

3.1.4 Handling of nuclear waste

Nuclear waste comes in many forms, each of which requires a specialized treatment protocol. The waste can be classified based on its lifetime and activity level. There are two main solutions that are being considered to handle nuclear waste. **Nuclear waste repositories** are designed to isolate nuclear waste from the environment for a duration that is determined by the lifetime of the radioisotope. Some elements can be stored in concrete and monitored for a few decades, while the most radiotoxic elements require long-term storage for a duration that spans tens of thousands of years. On the other hand, a **waste burner** is a type of nuclear reactor designed to operate using nuclear waste from other reactors and "burn" it to produce energy. The fuel in these reactors is transformed into stable isotopes, which can then be recycled or disposed of without requiring special measures.

Regional agencies One way to share the costs of the chosen nuclear waste management solution (such as a deep-geological repository or waste-burning reactors) is to establish a transnational nuclear waste management agency responsible for the waste produced by member countries. This approach makes sense given the specialized skills and expertise required to safely handle the large volume and variety of nuclear waste. By pooling resources and expertise, it is possible to more efficiently and effectively manage nuclear waste in a way that is safe and cost-effective.

3.2 Social acceptance

3.2.1 Perception of the plants

In order to gain acceptance and support for nuclear power plants, it is important to address two main concerns: the potential risks associated with nuclear energy and the integration of the plant into its area of implementation. On a technical level, measures such as design integrated safeties and operator training can help to mitigate potential risks. However, it is not enough simply to address these concerns technically; it is also essential that the general public is aware of and trusts in the safety measures in place. This requires transparent communication and engagement with the local community to ensure that their concerns are heard and addressed.

The development of new nuclear power plants should not only aim to integrate into the energy system, but also into the communities in which they are located. This can be achieved through initiatives such as hiring local personnel, partnering with local schools, and contributing to the local budget through taxes. However, it is important to recognize that these financial contributions should not be a substitute for genuine human interaction and engagement with the community. To name but one example, the French nuclear power plants have integrated into their surrounding communities and are now integral components of their area. The same is true for the CIGEO nuclear repository which transformed its area from a rural, economically and demographically declining set of villages into a techno-center attracting qualified workers which were in turn followed by services.

To avoid the perception that power plants are only being built for profit with little regard for the communities in which they are located, it is important to promote the idea of power plants as public projects or private-public partnerships. This can help to ensure that the needs and concerns of the local community are taken into consideration and that the benefits of the power plant are shared more widely. By involving some representatives from the community in the planning and decision-making process, it is possible to build a sense of ownership and investment in the project, which can help to foster a more positive relationship between the power plant and the community.

3.2.2 Nuclear waste

One of the major factors that contribute to public opposition to nuclear energy is the perceived risk associated with nuclear waste. However, it's worth noting that there have been no recorded fatalities related to nuclear waste. To address the fear that is often fuelled by ignorance, the Swedish waste agency provides a good example of how to handle the issue. Its approach, which includes transparency and public engagement, has contributed to the high level of approval (over 80%) for the proposed nuclear waste repository in Östhammar, a town located near a nuclear power plant. Similarly, the Swiss company Zwilag, which manages the nuclear waste of the Confederation, has organised open visits to its facilities to allow the public to tour the facility and learn about its operations. These types of initiatives can help to demystify nuclear waste and provide reassurance to the public.

3.2.3 Transparency and information campaigns

Transparency and openness are critical for the successful deployment of any new technology, especially one as potentially controversial as nuclear energy. To build and maintain public trust, it is essential for plants to provide clear and comprehensible reports on key data and for regulatory agencies or safety organisations to publish their reports for all to see. For example, the French regulatory agency, the ASN, makes all of its reports, including accident reports, available to the public. This transparency is crucial for demonstrating a commitment to safety and maintain accountability. In summary, it is not enough simply to prioritise safety; it is also necessary to consistently demonstrate and communicate a commitment to safety in order to maintain the trust of the public.

In order to address these concerns and promote the responsible development of SMRs and MMRs, information campaigns are a powerful tool. It is important for these information campaigns to provide

accurate and comprehensive information about the risks and benefits of this technology. These campaigns should most importantly begin before the start of the implementation of the reactors to ensure that the project will not be perceived as a dangerous black box for the local population. The campaigns should as well continue to be used during the implementation to encourage the community to be involve in the project. This can include information about the safety measures in place to prevent accidents, as well as the steps being taken to ensure the safe and responsible management of nuclear waste.

Overall, information campaigns for SMRs and MMRs are an important tool for educating the public about the potential benefits and drawbacks of this technology. By providing accurate and comprehensive information, these campaigns can help to inform decisions about the use of SMRs and MMRs and contribute to a more informed and receptive public acceptance.

4 Conclusion

In conclusion, the development and deployment of SMRs and MMRs in developing countries holds great potential for addressing the UN's grand challenge on clean and affordable electricity. These technologies offer a number of advantages, including their small size and modular design, which make them more flexible and adaptable to the energy needs of individual countries. They also have the potential to significantly reduce the cost of nuclear energy, making it more accessible and affordable to a wider range of countries.

However, it is important to recognise that the successful development and deployment of SMRs and MMRs in developing countries will require a concerted effort from all stakeholders. Governments, industry, and civil society must all be involved to overcome the technical, financial, and regulatory challenges that will inevitably arise. Through the use of coherent and sensible policies, it is possible to accelerate the development and deployment of these technologies and make a real impact on global energy access and sustainability.

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