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Review of NuPEAs "Strategic Environmental and Social Assessment Report (SESA) for the Kenya's Nuclear Power Programme"

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Study on behalf of

CJGEA ACTION
Center for Justice Governance and Environmental Action

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1 Introduction and Scope

The Center for Justice Governance & Environmental Action (CJGEA) performs an analysis of Kenya's energy policies and the potential role of nuclear power therein. In this context, the CJGEA has asked the Öko-Institute to perform a review of the Strategic Environmental and Social Assessment report (SESA). The aim is to provide a science-based study for input into the technical debate on nuclear power and energy alternatives for Kenya.

The last draft version of the Strategic Environmental and Social Assessment report (SESA) dates to 2023 (NuPEA 2023), by May 2024 no final version of the SESA was available. The SESA is written by SGS Kenya Limited for Nuclear Power and Energy Agency (NuPEA). The aim of the NuPEA is to promote and implement nuclear power in Kenya, therefore, the NuPEA cannot be seen as a neutral organisation with respect to a balanced assessment of nuclear power. For example, the NuPEA starts its "Brief description of nuclear energy" in Chapter 2.1 by stating (NuPEA 2023, p. 46)

> *"Nuclear power is sustainable, environmentally friendly, economically competitive, and safe, in comparison to other power sources."*

As will be discussed in following, these claims are not indisputable facts, as nuclear power faces the specific safety risk of catastrophic nuclear accidents, produces high-level radioactive wastes and cannot per se be seen as an economically competitive source of electricity. Therefore, a balanced assessment would have to clearly identify the actual advantages and possible disadvantages with respect to an introduction of nuclear power in Kenya.

With respect to the scope and aim of the SESA, NuPEA claims that such a balanced discussion of possible positive and negative impacts has been undertaken (NuPEA 2023, p. 170):

> *"The impacts that are expected to arise from the NPP execution could either be termed as positive, negative, direct, indirect, short-term, long-term, temporary, and permanent depending on their area of cover and their stay in the environment. This section also gives details about the potential cumulative impacts from the programme which is one of the objectives of undertaking the SESA. …*
>
> *Prediction and evaluation of impacts, including cumulative effects have been clearly documented including trade-offs. The positive and negative impacts likely to originate from the execution of the NPP are described based on social and biophysical environment and the economic aspects."*

Indeed, according to (NuPEA 2023, p. 107), the function of a SESA is to identify the most environmentally friendly and cost effective solution for the future electricity supply in Kenya:

> *"According to Part VI of the Act, section 42 (1), the lead agencies in consultation with the Authority are mandated to subject all proposals for public policy, plans and programmes to a Strategic Environmental Assessment to determine which ones are the most environmentally friendly and cost effective when implemented individually or in combination."*

It must be noted in principle, that (NuPEA 2023) is still designated as a draft report. This may be the reason for the relatively poor scientific quality of the report with respect to formal aspects. The report cites numerous sources without correctly reproducing them in the bibliography (for example "Stattersfield et al., 1998" cited at (NuPEA 2023, p. 66) or "Rashad, 1998" cited at (NuPEA 2023, p. 208) which are completely missing or "Benjamin K., 2008" cited at (NuPEA 2023, p. 197) which must correctly be referred to as "Sovacool, Benjamin K., 2008"). This limits the reproducibility of the arguments put forward and thus the transparency of the argumentation of the SESA. Furthermore, the report often quotes old and possibly outdated documents (like Giambattista Guidi, F. G. 2010 cited at (NuPEA 2023, p. 208)), so that the current validity of the arguments put forward must be questioned, for example with respect to the economic competitiveness of nuclear power today. Also, outdated data with respect to electricity production in Kenya is cited as "current" values, see for example (NuPEA 2023, p. 190). Finally, the report refers to several Annexes which are not included in the document, again hindering an assessment of the arguments put forward in the main report.

Indeed, NuPEA itself identifies missing scientific capacity to adequately perform state of the art Environmental and Social Impact Assessment (ESIA) reports as a problem in Kenya (NuPEA 2023, p. 215)

> *"Kenya's activities in the nuclear sector have been limited to academic and health sectors and therefore at a very small-scale level. Therefore, the capacity to adequately develop ESIA reports to meet required international standards as well as meeting local guidelines is wanting. It would need the registered EIA Experts who develop these reports to have requisite knowledge on nuclear operations in order to develop a report that is satisfactory to guide informed decisions by NEMA and relevant lead agencies. Currently, general reports on various mega-infrastructural development lack consistency and uniformity in the quality."*

The SESA further recognises, that missing information on the part of the public stakeholders about their role in the decision-making on the future electricity policy in Kenya is a major obstacle for an adequate participation of the public and thus a successful public participation process:

> *"The EIA experts are not guided by law or regulation on what details adequate public and stakeholder consultation and therefore many are left to their own discretion of the same.*
>
> *…*
>
> *During the study, it was discovered that communities lack information on their role and involvement in the EIA process hence making public consultation inadequate." (NuPEA 2023, p. 216)*

Therefore, a thorough analysis of the SESA with respect to missing or inadequately discussed positive or negative impacts of an introduction of nuclear power in Kenya and a communication of these aspects to the general public as planned by CJGEA must be recognised as an urgently needed task.

The introduction of nuclear energy to the electricity system in Kenya will have social and environmental impacts, which will be discussed in Chapter 2, with a focus on economic aspects, safety and nuclear waste. Further aspects like security issues or the site selection process will also be addressed briefly. Besides these social and environmental aspects, more general questions on the rationale of an introduction of nuclear power in Kenya will be addressed in Chapter 3. These cover questions related to the future electricity demand, the importance of grid stability and a reliable electricity supply as well as an adequate consideration of possible alternatives to nuclear power for electricity production. Chapter 4 repeates and summarises the conclusions of the preceding discussion.

2 Social and Environmental Impacts

In its Chapter 1 "Introduction", the SESA confirms that (NuPEA 2023, pp. 29–30):

> *"…, nuclear power has unique characteristics that affect the environment such as accidental radiological releases; risk of radioactive waste and spent fuel leakage; thermal and chemical releases; complexity in the amount of land and time required for construction; the distance of cooling water intake; the international interest and quality assurance requirements; and decommissioning challenges. These issues should be analysed comprehensively in the context of Kenya's environment."*

In its Chapter 4 on "Policy, Legislative and Institutional Frameworks and analysis of the policies, plans, and programmes" the SESA furthermore confirms, that one major aspect with respect to the social impact of its energy policy is the economic production of electricity (NuPEA 2023, p. 100):

> *"The overall objective of the policy is to ensure affordable, competitive, sustainable and reliable supply of energy to meet national and county development needs at the lowest cost, while protecting and conserving the environment."*

In its Chapter 10 "Conclusions" the SESA ascertains (NuPEA 2023, p. 270)

> *"The anticipated environmental, social and economic issues have been adequately identified and assessed …"*

Thus, the major aspects with respect to social and environmental impacts of a nuclear power programme, which are also recognised internationally as major problems of nuclear power, are related to

- its economics,
- the risk of severe accidents,
- the generation of highly radioactive wastes and
- security issues related to nuclear proliferation.

In the following Chapters, we will analyse the SESA with respect to these aspects and discuss whether the anticipated environmental, social and economic issues have been adequately identified and assessed.

2.1 Economics

The economics of producing electricity is one important factor with respect to the social impacts of electricity production.

This is recognised several times in the SESA, for example (NuPEA 2023, p. 44):

> ***"****The justification to plan and implement a NPP in the Country are anchored upon the following benefits:*
>
> *● **Competitive price of Nuclear Power:** Nuclear energy is considered cost competitive compared to fossil fuel-based generation.*
>
> ***…****"*

2.1.1 Claims made by the SESA

The SESA acknowledges that high energy prices have negative consequences for Kenyan development (NuPEA 2023, p. 43):

> *"Despite the growing energy consumption patterns, the Kenyan economy has experienced rapid and persistent rise in energy prices that have had far reaching consequences. Poor households bear the greatest brunt of energy price increase. Not only are they forced to pay higher prices, but also find modern energy out of their reach, thus opting for 'unclean' and health-risk traditional energy forms such as charcoal, firewood and kerosene.*
>
> *Higher power prices also wear away Kenya's manufacturing sector competitiveness regionally and globally, thereby denying the domestic industries revenue. … Higher energy costs are also prohibitive to prospective investors and erodes Kenya's image as a destination hub for investments. All these greatly hamper Kenya's quest to expand her manufacturing sector and further increases poverty as job opportunities shrink."*

With respect to the cost of nuclear power in Kenya, the SESA claims in its Chapter 1 "Introduction" to have performed an economic analysis (NuPEA 2023, p. 39):

> *"Undertook the study on costs of developing the major elements of nuclear power plant infrastructure in order to inform the Government of future budgetary requirements."*

With respect to the cost structure of nuclear power, (NuPEA 2023, p. 190) states that:

> *"From the financing point of view, nuclear plants have some special features that should be considered. The principal ones are:*
>
> *● Large investment.*
>
> *● Long lead and construction times.*
>
> *● Complex technology.*
>
> *● Regulatory risk; and*
>
> *Nuclear plants are capital-intensive compared with alternative energy sources."*

Furthermore, (NuPEA 2023, p. 190) recognises that:

"A long period of time is required for practically all stages of nuclear power project planning and implementation. Relatively long construction times have a major impact on overall capital requirements, which must be financed before the plant produces electricity and before there are revenues. There are also risks of delays and cost-overruns, usually perceived as greater for nuclear projects then for fossil-fuelled alternatives."

Despite this analysis, (NuPEA 2023, p. 46) states that

"Nuclear power plants are expensive to build but relatively inexpensive to operate because of less usage of fuel per unit output."

and based on this the conclusion is drawn that:

"This results in an economically competitive source with predictable electricity generation costs …."

Also, already in its "Brief Description of Nuclear Energy" in Chapter 2.3.1, (NuPEA 2023, p. 46) claims that the economics of nuclear energy are advantageous:

"Advantages of Nuclear Energy

…

Stable and reliable power supply

Affordable electricity

…"

In Chapter 6 "Impact identification and analysis", (NuPEA 2023, p. 170) concludes without giving any reference:

"Nuclear power plants are cheaper to run than their coal or gas rivals. It has been estimated that even factoring in costs such as managing radioactive fuel and disposal nuclear plants cost between 33 to 50% of a coal plant and 20 to 25% of a gas combined-cycle plant. The amount of energy produced is also superior to most other forms. The US Department of Energy (DOE) estimates that to replace a 1GW nuclear power plant would require 2GW of coal or 3GW to 4GW from renewable sources to generate the same amount of electricity."

Furthermore, in Chapter 10 "Conclusions" (NuPEA 2023, p. 270) claims:

"The NPP as envisioned would create an economic turn-around in Kenya with accessible, cheap and reliable electricity for the residents."

2.1.2 Discussion

The cost of producing electricity with nuclear power has been analysed by several large studies from independent organisations, for example (MIT 2003; University of Chicago 2004; MIT 2018).

It is quite clear, that the cost of electricity from nuclear is dominated by the necessary investments needed to build a nuclear power plant. A typical cost distribution is that 65% of the cost of electricity is due to the cost of building the plant, 23% stem from operation, maintenance and dismantling and only 12% are due to the cost of the fuel (Neles and Pistner 2012). More recent distributions allocate 80% to the capital cost, 15% to operation and maintenance and only 5% to fuel cost (MIT 2018). Thus, the cost of building a nuclear power plant is the major cost factor.

Cost data from countries with a heavily state-regulated energy market are not comparable with those from liberalised electricity markets (University of Chicago 2004). Therefore, an analysis of the cost of nuclear power must focus on available information from countries with liberalised electricity markets to assess the full costs of nuclear power.

A recent article summarises the cost of nuclear new build in western countries (Green 2024): In the U.S. there is currently only a single reactor construction project for an AP1000 reactor of 1117 MW net electric capacity under way at the Vogtle site in Georgia. In 2006 Westinghouse estimated they could build an AP1000 reactor for about US$ 1.4 billion. The latest cost estimate for two AP1000 reactors is now US$ 34 billion, about 12 times the original estimate. Another construction project in the U.S. was abandoned in 2017 after about US$ 9 billion were spent, see Figure 2-1.

Figure 2-1: Picture of the abandoned reactor construction project Summers in the U.S.

Source: Photo Courtesy of High Flyer © 2017

There have been several other nuclear reactor projects being cancelled after the first concrete for the reactor base slab was poured, showing that there is a considerable risk for large investments to be lost even after construction start, compare Figure 2-2.

In the UK, two EPR reactors of 1600 MW net electric capacity are being built at the Hinkley Point site. Original estimates in the late 2000s for a single EPR plant were £2 billion (US$ 2.52 billion) (Green 2024). The building of Hinkley Point C will be further delayed, startup of the facility is now estimated to take place somewhere between 2029 and 2031. The plants will be even more costly. EDF states that

> *"The costs of completing the project are now estimated at between £31 billion and £34 billion in 2015 values."*[1]

[1] https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-update-1, last accessed 16.02.2024.

This is about eight times the original estimate. Another EPR project takes place in France. The original cost estimate had been 3.3 billion Euros (US$ 3.58 billion), the project is now estimated to cost 19.1 billion Euros (about six times the original estimate) (Green 2024).

Figure 2-2: Cancelled or Suspended Reactor Constructions

Source: (Mycle Schneider Consulting 2023)

The only EPR already in operation in western countries is in Finland. The project was started in 2005 with an estimated startup date of 2012. In December 2022 the overnight cost for building the plant cited by EDF was 13.2 billion Euros (US$ 14.6 billion). The plant became commercially operational in May 2023 after 18 years of construction (Mycle Schneider Consulting 2023).

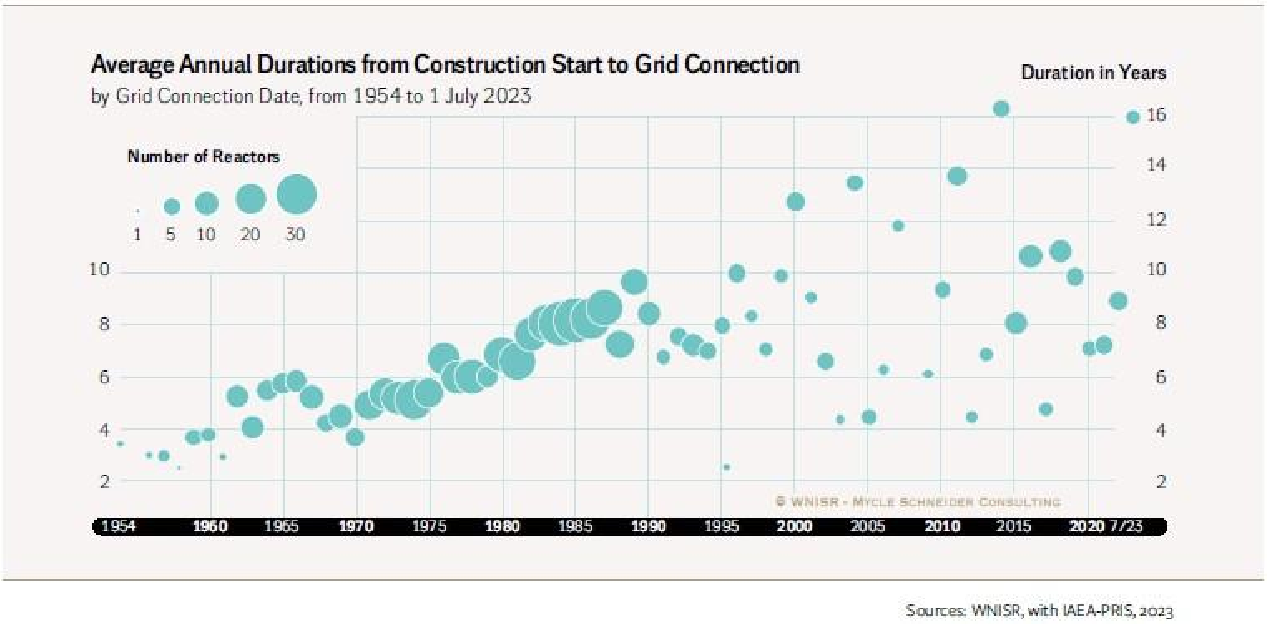
No other nuclear power plant is under construction in western countries.

Besides the construction cost of nuclear power plants, the time to complete construction is of major importance, as financing of the investment costs during construction time can be a major cost driver.

An assessment of past and present construction times is undertaken by (Mycle Schneider Consulting 2023), compare Figure 2-3. It is evident that the average construction time has increased over time with a large spread in recent years:

> *"The longer-term perspective confirms that short construction times remain the exceptions. Ten countries completed 66 reactors over the decade 2013–2022 — of which 39 in China alone — with an average construction time of 9.4 years …, slightly higher than the 9.2 years of mean construction time in the decade 2012–2021."*

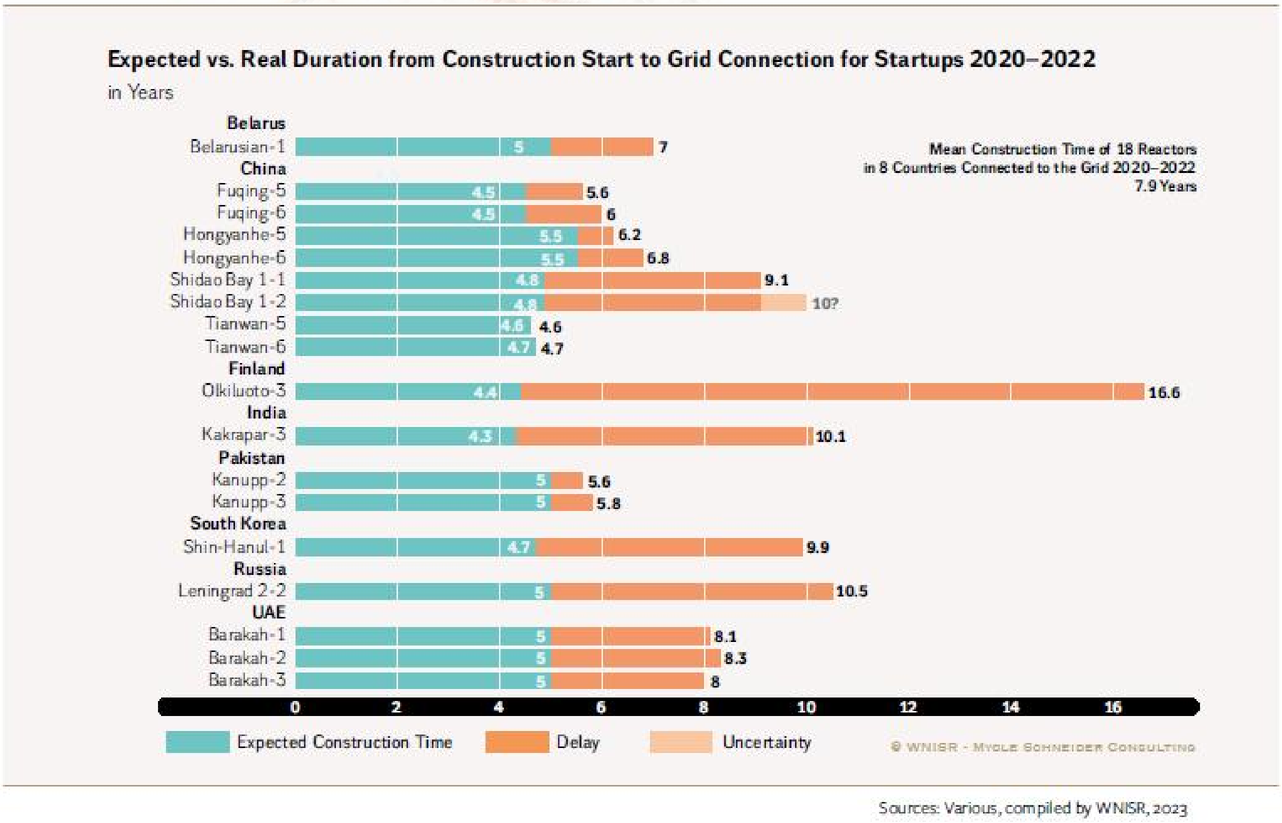
Figure 2-3: Average Annual Construction Times in the World



Source: (Mycle Schneider Consulting 2023), Figure 13

While initial estimates for construction times are typically around five years, real construction times can be much higher, compare Figure 2-4.

Figure 2-4: Construction delays for reactor units started up 2020-2022



Source: (Mycle Schneider Consulting 2023), Figure 14

Cost is best expressed by the levelized cost of energy (LCOE), which considers all cost factors (like investments, operational costs, fuel cost and potential further costs like those for CO_2-emissions). An up-to-date analysis of the LCOE of nuclear power in comparison to other technologies to produce electricity is given by (Lazard 2023). For nuclear new build, they estimate unsubsidised LCOE to be between

- US$ 131-221 per megawatt-hour (MWh).

This must be compared with the cost of coal of

- US$ 68-166 per MWh

or that of renewables like solar photovoltaics (utility scale) of

- US$ 24-96 per MWh (or US$ 46-102 per MWh if storage cost is included)

or of onshore wind of

- US$ 25-75 per MWh (or US$ 42-114 per MWh if storage is included).

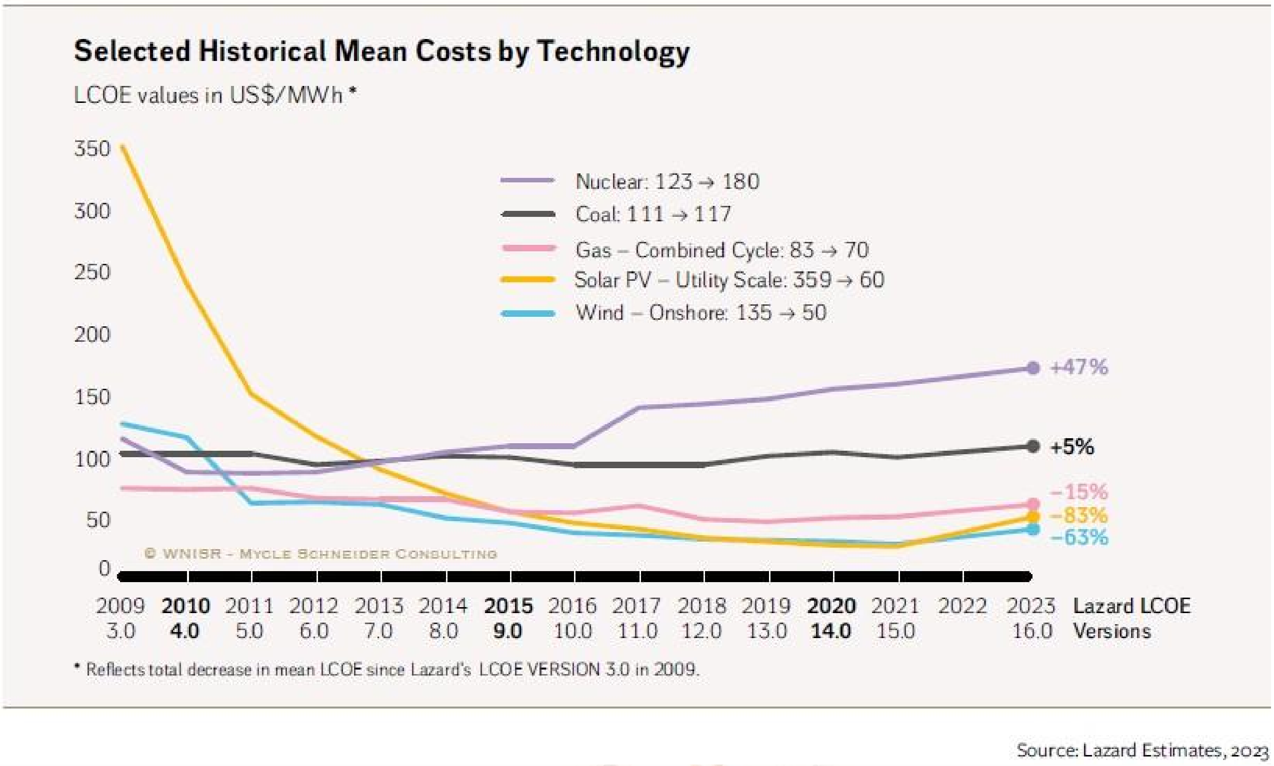
These numbers clearly show that nuclear power is the most expensive way to produce electricity today, more than the use of coal and far more that the use of renewables, even if storage cost is included.

Most other studies show comparable LCOE values for nuclear power (Mycle Schneider Consulting 2023):

> *“Analysis of IEA’s Electricity Survey estimates mean LCOEs range from US$51/MWh in non-OECD countries to US$62/MWh at a 5 percent discount rate. This is far below the mean nuclear LCOE of U$100/MWh in an independent meta-analysis (including the IEA datasets) of 88 planned and completed nuclear projects (WIP/DIW). IEA’s Net Zero assessments indicate a range from US$102/MWh in the U.S. to US$145/MWh in the E.U. at 8 percent discount, with the World Energy Outlook indicating a range from US$87/MWh in the U.S. to US$129/MWh in the E.U. at the same discount rate.”*

Today’s values have also to be considered in a historic perspective, compare Figure 2-5. Over the period of 2009 to 2023, the cost of nuclear power has increased by about 47%. Contrary to that, cost of renewable energy production has decreased considerably in the same time frame. LCOE for solar PV (at a utility scale size) dropped by about 83%, that of onshore wind by about 63%. Thus, while 20 years ago the cost of nuclear and coal still were roughly comparable and wind and solar PV were clearly more expensive, this picture has completely changed since then with nuclear being the most expensive production technology for electricity today, while renewables are much less expensive than even conventional technologies (coal or gas).

Figure 2-5: Historic development of LCOE for different electricity production technologies



Source: (Mycle Schneider Consulting 2023), Figure 64

Sometimes small modular reactors are claimed to become commercially attractive compared to today's large light water reactors. Actual figures paint a different picture. Russia has so far constructed a single floating twin-reactor plant of small capacity, which is estimated to produce electricity for about US$ 200 per MWh. China has constructed a demonstration twin-reactor high-temperature gas-cooled reactor; its construction cost was estimated to be around US$ 6000 per kilowatt installed capacity. The Carem reactor still under construction in Argentina is estimated to cost US$ 750 million (for an installed capacity of just 32 MW, roughly US$ 23.500 per kilowatt of installed capacity). The most prominent project to build a small modular reactor in the U.S. was the NuScale project planned for a site in Idaho. The project was recently abandoned after the cost estimate for a 462 MW plant had risen to US$ 9.3 billion (US$ 20.100 per kilowatt of installed capacity, and an assumed LCOE of US$ 129 per MWh) (Green 2024).

A recent study has shown that the cost structure of small modular reactors is and will be unfavourable. Most probable cost estimates show that the median LCOEs for SMR start at US$ 116 per MWh for high temperature reactors and at US$ 218 per MWh for PWRs (Steigerwald et al. 2023). The authors conclude:

> *"None of the tested concepts is able to compete economically with existing renewable technologies, not even when taking their variability and necessary system integration costs into account."*

Besides the actual cost of producing electricity, the SESA regards nuclear power as a reliable source of energy. While it is correct, that nuclear power plants are generally used as a source of baseload power that operate continuously for time spans of typically 12-18 months, for various reasons nuclear power plants may face unforeseen unavailability of considerable length (e.g. due to limitations in the availability of cooling water or unforeseen safety problems). The average load factor of nuclear reactors has been in a range between 76.7% and 82.4% over the years from 2003 to 2022, compare Chapter 3.3 for a more detailed discussion. Thus, it is clear that nuclear power plants may face unplanned downtimes of considerable lengths, not being a fully reliable source of electricity production.

Another relevant cost factor with respect to nuclear power are severe nuclear accidents, see Chapter 2.2.

2.1.3 Conclusion

The SESA does not give any robust assessment of the economics of nuclear power in Kenya. While the SESA correctly lists major factors impacting the economics of nuclear power (like large investment needs, long lead and construction times, complexities, and risks) without further justification, the SESA claims nuclear power to be cost competitive to conventional technologies like coal or gas and does not even give any reasonable comparison to renewable energies at all.

International analysis clearly shows that nuclear new build is one of the most expensive electricity production technologies today, more expensive than the use of coal and far more than the use of renewables, even if storage cost is included.

The SESA furthermore claims that nuclear power is a reliable energy source. While this is certainly true with respect to its independence from intermittent energy provision like solar or wind, nuclear power might also face relevant unplanned downtimes due to different reasons like cooling water shortages or safety issues.

Therefore, the SESA falls short of adequately identifying and assessing the economic consequences of introducing nuclear power in Kenya.

2.2 Safety

Safety is one of the most important factors in determining the possible environmental impacts of nuclear power.

This is also recognized by the SESA (NuPEA 2023, p. 52):

> *“Safety is the central principle when designing a new nuclear installation to be constructed.”*

And it is also stated in the executive summary (NuPEA 2023, p. 5):

> *“The nuclear safety management is key, as nuclear is seen to require significant containment in the event of unnatural or natural risks.”*

2.2.1 Claims made by the SESA

With respect to reactor safety, the importance of an external electricity supply is highlighted (NuPEA 2023, p. 63):

> *“Hence, the reactor cooling systems must continue to operate for several days after a reactor shuts down, to prevent overheating and damage to the reactor core. Therefore, reliable cooling arrangements must be provided, and this requires robust and diverse sources of reliable electrical supply. … Because of this reliance on electrical power, nuclear plants are normally required by their operating license to have multiple sources of electricity, including a minimum of two independent offsite power sources (i.e., two connections from the transmission system to the NPP), and onsite power sources (typically a combination of batteries and diesels or small gas turbines).”*

Due to this, the SESA acknowledges the need for major improvements of the national grid (NuPEA 2023, p. 59):

> *“All the identified potential regions are all connected to the national grid but still face grid reliability challenges. Some of the counties within the regions, especially northern Kenya at times rely on thermal generators for their power such as Samburu, Turkana and Marsabit. The existing grid infrastructure consist of 132kV and 220kV lines, with on-going upgrades to new higher capacity transmission lines like the 400kV Ethiopia-Suswa line. The electric grid needs for nuclear installations vary, with a nuclear power plant requiring connection to a 400kV HVDC line for output and a 220kV line for station uses, while a research reactor can use the standard 132 line stepped down to 66kV for station uses.”*

In its Chapter 6 on “Impact identification and analysis”, the subchapters “6.3.4 Impacts of Nuclear Power Programmes on Water Resources” and “6.3.5 Nuclear Power activities' potential for groundwater contamination” focus only on consequences of “normal operation” and “contaminations”, while the potential consequences of severe accidents are not taken into account.

In its Chapter 6 on “Impact identification and analysis” the SESA ascertains the possible impacts of accidents in nuclear power plants in Chapter 6.5 “Negative Occupational Safety and Health in Nuclear Power Sector” (NuPEA 2023, p. 192):

> *“**Radiological and non-radiological health risks associated with nuclear accidents and with the misuse or unauthorized use of nuclear materials and facilities**: As demonstrated in 1986 at Chernobyl, nuclear plant accidents can result in the release and dispersion of large quantities of radioactive materials hazardous to human health into the*

environment. High levels of radiation exposure to workers and members of the public can ensue, causing acute radiation effects and death. Beyond the health effects arising from radiation exposure, physical injury to workers can result from an accident, and an accident may create panic in populations and lead to physical injuries and even loss of lives. …

***Psychological health impacts**: these relate to mental health. Normal operations and accidents pose psychological risks to workers and members of the public. Psychological impacts from nuclear energy risks may arise because:*

- *Radiation is invisible, tasteless, odourless and generally intangible and*

- *It is not uncommon for the potential consequences of nuclear energy accidents to be equated with the effects of nuclear weapons."*

This is again repeated with respect to Chapter 6.5.1.3 "Accidental radioactive emissions" (NuPEA 2023, p. 193):

"First, the impact of nuclear accidents has been a topic of debate since the first nuclear reactors were constructed in 1954, and has been a key factor in public concern about nuclear facilities. Technical measures to reduce the risk of accidents or to minimize the amount of radioactivity released to the environment have been adopted, however human error remains, and 'there have been many accidents with varying impacts as well near misses and incidents'. As of 2014, there have been more than 100 serious nuclear accidents and incidents from the use of nuclear power. Fifty-seven accidents have occurred since the Chernobyl disaster, and about 60% of all nuclear-related accidents have occurred in the USA. Serious nuclear power plant accidents include the Fukushima Daiichi nuclear disaster (2011), Chernobyl disaster (1986), Three Mile Island accident (1979), and the SL-1 accident (1961). Nuclear power accidents can involve loss of life and large monetary costs for remediation work."

Despite this discussion, the SESA continues by summarising the "consequences" of nuclear accidents and incidents in its Table 6-4 "A summary of nuclear accidents and incidents that have occurred in the world" (NuPEA 2023, p. 195)

In this Table, only direct casualties with respect to the major accidents of Chernobyl (1986, 30 direct casualties) and Fukushima (2011, 2 casualties) are listed. Costs of the accident at Chernobyl are claimed to be US$ 6.700 million, those of Fukushima to be US$ 1.100-1.900 million. No further consequences of these accidents are evaluated. Based on this, the SESA concludes (NuPEA 2023, p. 207):

"While the devastating earthquake and tsunami in 2011 in Japan caused 20,000 casualties, none were related to the release of radioactive material in the accident at the Fukushima Daiichi nuclear power plant. The levels of radiation exposure from the accident were similar to the global average background levels of radiation and no radiation related health effects are expected among exposed members of the public and their descendants."

Still, the SESA acknowledges that (NuPEA 2023, p. 202):

"Generally, disaster preparedness and management in the country is quite low. The energy sector has an inherent risk to the community due to high voltage, thermal release, radiation etc. The energy sector needs to develop specific stand-alone emergency response plans on the national level for each sub-sector …"

The SESA requires (NuPEA 2023, p. 247):

> *"Safe distances should be provided with reference to risk assessment, ensuring 100% safety of persons/organisms who do not directly interact within the NPP development."*

The SESA furthermore acknowledges, that (NuPEA 2023, p. 90):

> *"The assumption here is that a conventional large (1000MWe) NPP requires an EPZ at least 30KM in radius.""*

While it makes clear, that an emergency protection zone (EPZ) of at least 30 km in radius is needed, it relativises this statement in Chapter 6.4.5 "Local Livelihood and Community Development", where it concludes (NuPEA 2023, p. 184):

> *"For development of buffer zones, IAEA recommends that through their guidance, countries need to develop the safety distance guidelines. Such large buffer zones will inevitably adversely affect access to these vital resources necessary for the survival of the communities if they draw their livelihood thereof.""*

The SESA draws some key policy recommendations with respect to safety, including but not limited to (NuPEA 2023, p. 9):

- *"Development radiation protection standards*
- *…*
- *Establishing Emergency response facilities/ Emergency response organization*
- *Develop mechanism for emergency notification of nuclear incidents*
- *There should be a clear set of guidelines and regulations provided with regards to safe distances/buffer zones for developing NPP facilities.*
- *…*
- *Formulation and implementation of the national nuclear sector disaster risk reduction and emergency response management plan."*

Despite all of this, in its Chapter 10 "Conclusion" the notion "safety" is not mentioned at all.

2.2.2 Discussion

The introduction of a safety-intensive technology such as nuclear energy requires that the decision-makers in the country are aware of the risks and that this leads to a high degree of responsible behaviour in dealing with the technology. Extensive knowledge of the potential hazards and the corresponding hazard assumptions to be determined is required when selecting and designing reactors for specific sites (Oeko-Institut e.V. 2011).

The potential hazards and their impacts can be derived on the one hand from the accident analyses of existing plants and on the other hand from knowledge of accidents and incidents that have already occurred and operating experience. Based on such information, it is examined below whether the risks of nuclear energy are adequately presented in the SESA and whether the potential risks are consciously included in the decisions. Only in this way will it be possible for operators to take responsibility for their own actions, for supervisory authorities to carry out appropriate checks and monitoring and for neighbouring countries to avoid potential hazards (Oeko-Institut e.V. 2011).

Severe accidents

The following discussion on the consequences of severe accidents and the appropriate risk metrics is taken from (Oeko-Institut e.V. 2021). Severe nuclear accidents can lead to significant off-site consequences due to the release of large amounts of radioactivity. The release of radioactivity will impact human health by inhalation of airborne radionuclides, ingestion of radionuclides by food or water or by direct radiation due to radionuclides deposited on land. To minimise the consequences to human health, different countermeasures will be taken after a nuclear accident. These countermeasures include sheltering, evacuation, short- or long-term relocation of humans as well as restrictions on land use or drinking water supplies (BfS 2015). While these countermeasures can drastically reduce the impact on human health (and thus the number of fatalities and corresponding fatality rates), they will result in significant consequences concerning other indicators of severe accidents like land loss or costs.

The SESA focusses on direct casualties related to severe accidents. A discussion of severe accidents based only on fatality rates without considering the consequences of countermeasures taken to limit these is clearly insufficient.

Indeed, the question of an appropriate risk metric is not new. Already in discussions about the risk of nuclear power taking place in Germany in the 1980s, extensive literature discussed the possible impacts of different electricity production technologies on aspects of sustainability. A critical review of this was performed for example in (Oeko-Institut e.V. 1989) and it is recognised already at that time:

> *“In the common debate, 'risk' is usually defined as 'extent of damage' times 'probability of occurrence'. This definition is based on insurance considerations. A dimension often used to compare risk is 'deaths per year of operation of a plant'. The extent of damage here refers to the type of damage 'fatalities'.*
>
> *…*
>
> *However, the results of such comparisons are problematic because the actual effects of each accident always consist of different types of damage, e.g. health damage, financial damage, ecological damage. Each of these types of damage has its own extent of damage in the concrete case, which is different from that of the other types of damage.*
>
> *…*
>
> *The multidimensionality of the extent of damage also becomes clear when comparing 'Bhopal' and 'Chernobyl'. Although there were significantly more deaths and direct damage to health in 'Bhopal' than in the reactor accident, the extremely far-reaching contamination, the rendering unusable of entire areas of land and housing estates, the other effects on agriculture and the cost consequences for several national economies made 'Chernobyl' at least as serious an accident.“* [2]

Other important factors, as mentioned by the SESA but not taken up in the further analysis, are related to

- consequences for life and health of humans including direct and indirect deaths, acute and chronic illnesses, genetic damage, psychological damage, fear of further accidents;

[2] Translation by the authors.

- consequences for infrastructure including consequences for drinking water supplies, land contamination, removable and non-removable surface contamination, land loss, loss of neighbouring facilities, loss of further infrastructure;
- consequences for other lifeforms including loss of livestock, loss of wildlife, loss of rare species, loss of biotopes;
- economic costs including cost for civil protection, remediation activities, evacuations, loss of production, damage to image of companies or industries;
- social and political consequences including changes in behaviour of individuals or groups, changes of social or political standards, consequences for international relations and finally
- ecological consequences including impacts on biosphere, ecological resources and natural condition.

With respect to the maximum number of casualties for a catastrophic nuclear accident, (Burgherr and Hirschberg 2014) give a number of 6,596 for a Swiss Generation II PWR and a number of 46,990 for a Generation III EPR (with the higher number due to a much larger radioactive inventory of the EPR compared to the Generation II PWR analysed).

(Hirschberg et al. 2016) conclude with respect to the maximum consequences:

> *“Nuclear and hydro accidents may, however, have very large consequences. … The experience-based maximum consequences of accidents with new renewables are small.”*

(Ashley et al. 2017) analyse a potential severe accident in a hypothetic U.K. nuclear power plant. The radiologic release of this accident is assumed to be about one order of magnitude lower than the release at Fukushima and two orders of magnitude lower than at Chernobyl (Ashley et al. 2017, Table 9). Based on these assumptions, they estimate a mean number of 44,000 evacuees and a maximum number of 390,000. With respect to the need for permanent relocation, they estimate a maximum number of 41,000 people.

Hirschberg et al. give an estimate on land contamination in (PSI 2003). They distinguish between interdicted area, which can successfully be decontaminated within 20 years and then resettled, and condemned area, which cannot be decontaminated within 20 years. They estimate possible maximum consequences in terms of lost land at 3,500-4,500 km^2 (about twice the size of the state of Luxembourg).

(IRSN 2013) estimates the possible sizes of contaminated land for major accidents in a French 900 MW nuclear power plant. Areas of up to 18,800 km^2 may be contaminated in the case of a major accident. 1,300 km^2 of those may be contaminated to a degree that people would have to be relocated from that area.

The consequences of a severe accident in German nuclear power plants have been analysed in (BfS 2015). With respect to a high land contamination (of more than 40,000 kBq/m^2) the authors conclude that areas in a distance of up to 65 km and a total area of approx. 312 km^2 could be affected. Permanent relocation of adults results for distances up to 82 km.

The impact of severe accidents on water bodies could be very significant. (Aliyu et al. 2015) discuss the impact of the Fukushima nuclear accident on marine ecosystems and conclude that the impact is still largely unknown. Based on the lessons learned from Fukushima, an analysis of the possible consequences of a severe accident in a Swiss nuclear power plant shows a strong impact on drinking water supplies not only in Switzerland but also in Germany, as the lakes under consideration and the flowing waters of the Aare and Rhine would be at high risk in the event of an accident (Oeko-Institut e.V. 2014).

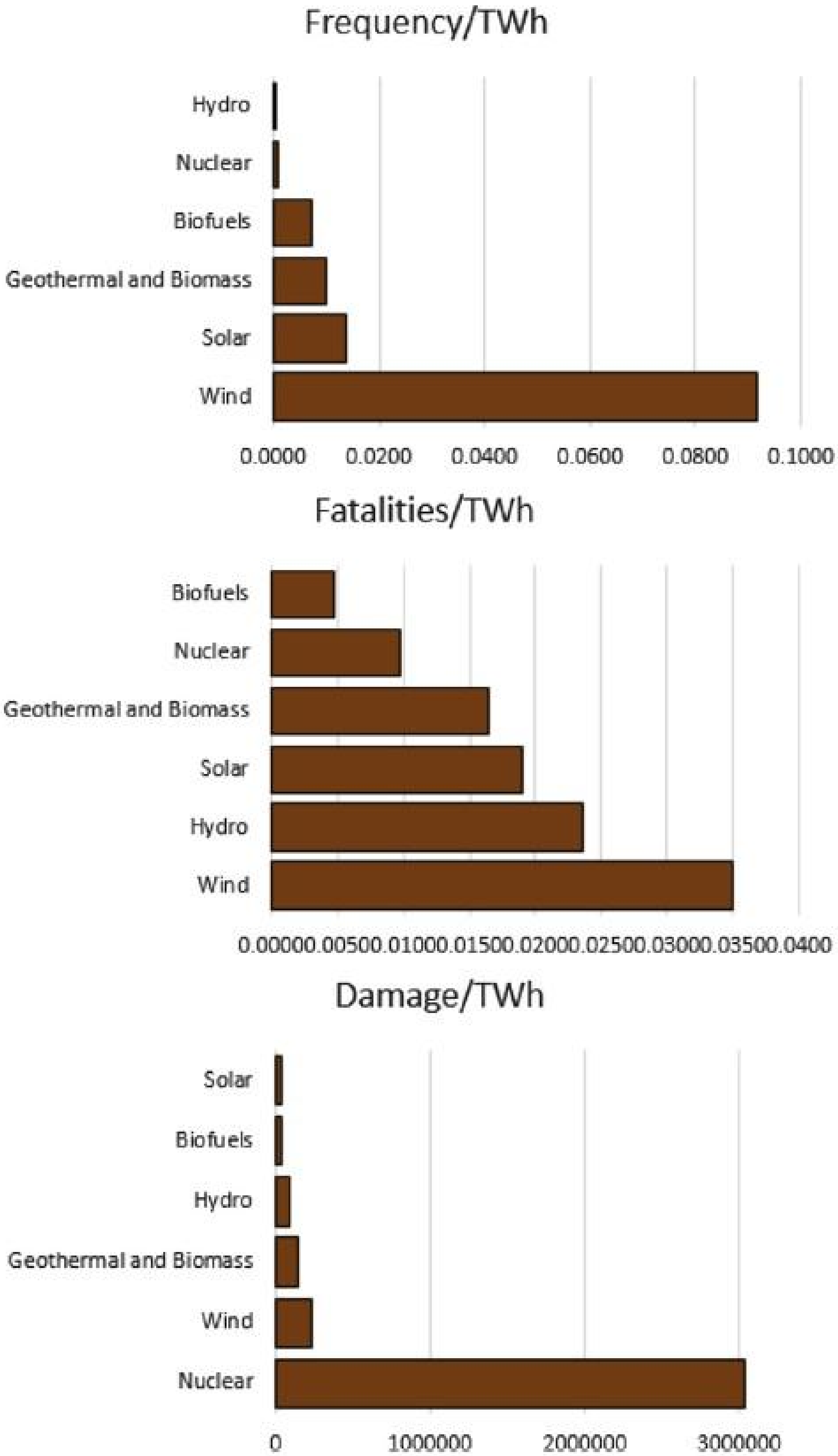
To estimate the actual cost of a nuclear accident is by far not straightforward. (OECD; NEA 2000) already discussed relevant methodological aspects and a comparison of different approaches was given in (OECD; NEA 2018). Several authors have performed cost estimates for historic events as well as for different classes of hypothetical accidents.

An analysis for an accident in a 900 MW power plant in France is performed by (IRSN 2013). They estimate the total cost and distinguish grave and major accidents. For grave accidents, they estimate an average value of 120 billion Euros with an error margin of 50 to 250 billion Euros. For major accidents, they estimate an average value of 450 billion Euros with an error margin of 200 to 1,000 billion Euros.

(Sovacool et al. 2016) assess the risks of energy accidents based on a database of 686 actual accidents over the period 1950-2014. They analyse the frequency, fatality, and scope. By scope they estimate the property damage inflicted by the accidents. An average accident in their database inflicts a mean of US$ 388 million in damage and has 267.2 fatalities, compare Figure 2-6.

For accidents in nuclear energy, they evaluate a mean value of US$ 1.4 billion in property damage, approx. twice the value for hydro and more than fifty times the value for other renewables (wind, solar, hydrogen, biofuels, biomass, geothermal). Even the normalised risk in terms of damage per TWh amounts to US$ 3 million for nuclear, compared to between US$ 35,500-235,400 for the other technologies. Thus, the authors conclude that nuclear accidents are the most expensive, inflicting a total of US$ 265.1 billion (or 90.8 percent of the total damage of energy accidents). For the Fukushima accident, they assume property damage of US$ 162.7 billion, the Chernobyl accident is listed with a total property damage of only US$ 7.7 billion and the Three Miles Island accident accounts for US$ 2.7 billion.

Figure 2-6: Low-carbon energy accident frequency, fatalities, and damage normalised to TWh, 1990–2013



Source: (Sovacool et al. 2016)

The accident in Fukushima Dai-ichi

On 11 March 2011, a severe earthquake shook the east coast of Japan. The resulting tsunami flooded large coastal regions and caused serious incidents at several Japanese nuclear power plant sites, including the catastrophic accident at the Fukushima Dai-ichi plant, compare Figure 2-7.

The immediate trigger for the accident at Fukushima Dai-ichi was the earthquake off the east coast of Japan. The magnitude of the earthquake at the site was greater than the seismic strength on which the design of the plant was based. The earthquake caused a complete loss of the external power supply in all six units at the Fukushima Dai-ichi site. The damage caused by the tsunami at the plant was central to the entire course of the accident. The inadequate protection of the plant against tsunamis is now largely attributed to a failure on the part of the supervisory authorities in conjunction with a lack of safety awareness on the part of the operator. Due to close links between politicians, supervisory authorities and operators, the authorities did not provide independent and effective supervision of the safety of nuclear power plants. Instead, the operator was able to assert its interest in avoiding high costs for retrofitting and a public debate about the safety of its plants. As a result, more recent findings on site hazards and international recommendations on necessary safety improvements were not translated into binding requirements for the plant (Pistner 2013).

Since the serious accidents in Fukushima, the causes and consequences of the meltdowns in three reactors and the massive problems in four spent fuel pools, compare Figure 2-8, have been the subject of intense international scrutiny. In the European countries, the safety standards had to be scrutinised and adapted on the basis of a large number of new findings. The SESA falls short of analysing the accident in any comprehensive way, taking into account possible lessons learned from this event.

Figure 2-7: Tsunami flooding the Fukushima Dai-ichi site in March 2011

Source: TEPCO/MEXT

Figure 2-8: Destroyed reactor buildings after hydrogen explosions at the Fukushima Dai-ichi site in March 2011

Source: TEPCO

(Aliyu et al. 2015) discuss different estimates for human health effects of the Fukushima nuclear accident and estimate the maximum mortality due to all causes at 10,000.

Following the Fukushima Dai-ichi nuclear accident, a total of 160,000 people have been evacuated from the vicinity of the plant. (Ashley et al. 2017) estimate that about 48,000 people who lived in the restricted area have moved outside of the Fukushima prefecture. For the Fukushima nuclear accident, they cite an amount of US$ 38.9 billion in compensations paid by TEPCO up to 2015 and an estimate for further costs for decontamination and renovation of US$ 65.9 billion.

As of 1 May 2023, according to the Fukushima Prefecture, 27,020 people were still away from home. In order to deal with the consequences of the accident, large decontamination work took place in the Fukushima Prefecture. This resulted in huge amounts of contaminated soil shipped to interim storage sites. As of March 2023, a total of 11,55 million m^3 of contaminated soil is stored in interim storage facilities. As of June 2023, the total compensation amount paid out by TEPCO is 10,817 billion yen (US$ 77.5 billion) (Mycle Schneider Consulting 2023, pp. 258–269).

(JCER 2019) estimates the clean-up costs after the Fukushima accident to 35-80 trillion yen (around 270-617 billion Euros).

(Wheatley et al. 2016) estimate, that the average cost of nuclear energy events per year worldwide is around the cost of the construction of a new plant. They estimate the cost of the Fukushima accident at US$ 166 billion (about a factor of 100 compared to the SESA estimate).

In view of this, Naoto Kan, Japanese Prime Minister at the time of the earthquake, stated in the journal Foreign Affairs on 8 March 2012:

> *"I have thought very hard about the types of safety measures necessary to prevent any such disaster from happening again. However, when one weighs these measures against the tremendous risks, it is clear that no amount of precautions will make a country completely safe from nuclear energy. I have reached the conclusion, therefore, that the only option is to promote a society free of nuclear power."*

The Chernobyl accident

On 26 April 1986, Unit 4 of the Chernobyl nuclear power plant in Ukraine suffered the worst accident in the history of civilian nuclear technology. A massive increase in nuclear power release destroyed the reactor and the subsequent fires in the graphite used in the reactor released a large proportion of the reactor's radioactive inventory into the environment. The accident occurred during a safety test carried out during the shutdown of the reactor. This serious reactivity accident was caused by mistakes made by personnel in conjunction with deficiencies in the planning of the test and errors in the safety design of the reactor (Oeko-Institut e.V. 2006).

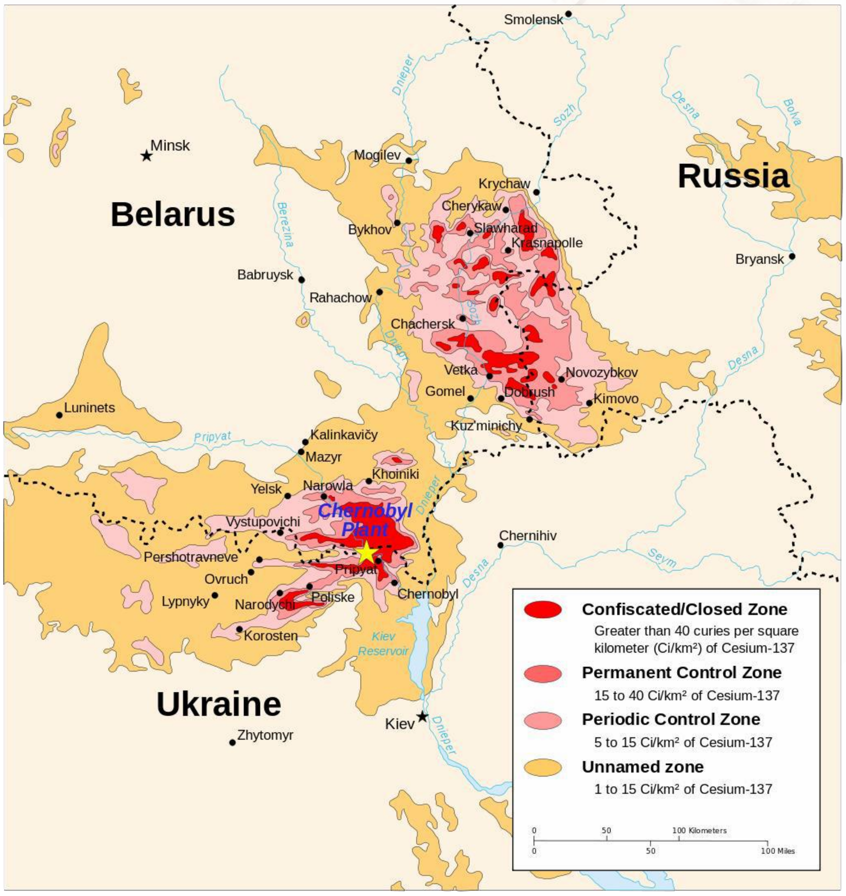
The reactor accident in Chernobyl and its serious consequences for the population and the area surrounding the nuclear power plant, the Ukraine, neighbouring countries, and even non-neighbouring countries in Europe, which still persist today after nearly 40 years, compare Figure 2-9, are not considered in depth in the SESA.

(Burgherr and Hirschberg 2014) estimate that for the Chernobyl accident

> *"expected latent fatalities range from about 9000 for Ukraine, Russia and Belarus to about 33,000 for the whole northern hemisphere in the next 70 years."*

According to (Ashley et al. 2017), following the Chernobyl nuclear accident, a total of 335,000 people have been evacuated from highly contaminated area. For the Chernobyl accident, they cite estimates of losses of up to hundreds of billions of US$.

Figure 2-9: Contamined area after the Chernobyl accident of April 1986



Source: Wikipedia

2.2.3 Conclusions

Severe accidents in nuclear power plants can happen and they do have significant consequences for human health and the environment.

The SESA report refers to a very limited amount of scientific literature, which does not provide a comprehensive assessment of different consequences of severe accidents. While admitting different consequences of severe accidents, the SESA only discusses two indicators with respect to severe accidents – the number of fatalities and the cost of accidents (to a very limited degree) –, that are clearly an insufficient risk metric to fully represent the consequences of severe accidents.

The SESA report does not discuss other indicators with respect to severe accidents – like the number of people evacuated or relocated, the area of land contaminated for decades or even centuries nor the economic consequences of a severe accident – although they are relevant and there exists scientific literature making clear that these indicators have to be taken into account.

Therefore, the SESA falls short of adequately identifying and assessing the possible safety consequences of introducing nuclear power in Kenya.

2.3 Security

In its Chapter 6 on "Impact identification and analysis" the SESA ascertains the possible impacts of a misuse of nuclear materials for weapons purposes (NuPEA 2023, p. 192)

> *"**Radiological and non-radiological health risks associated with nuclear accidents and with the misuse or unauthorized use of nuclear materials and facilities**: … Perhaps the greatest possible health impact that could arise from nuclear energy is the clandestine development and use of nuclear weapons by a nation using materials that have been diverted from civilian nuclear energy facilities.*

2.3.1 Claims made by the SESA

In its chapter 6.4.8.1 on "Weapons proliferation and terrorism" the SESA concludes (NuPEA 2023, p. 188)

> *"With any proposed development or expansion of nuclear energy globally, nuclear weapons proliferation is a key concern that must be addressed. Today, there are also fears of the possibility of nuclear weapons reaching the hands of terrorist groups. Proliferation of enrichment or reprocessing capability may make it easier for terrorist groups to obtain highly enriched uranium or plutonium which, in theory, might be used to make small and unsophisticated but nonetheless horrific bombs. Finally, there is the spectre of terrorist groups attacking or attempting to sabotage nuclear power plants. Questions about proliferation are key owing the recent history and terrorism occurrences within Kenya and her neighbours. Coupled with legal gaps within the sector on its safety of operation, cyber security and possible sabotage at the profit of malicious users of nuclear material, proliferation has therefore the capacity to cripple the economy if tested, trusted systemic and human resource firewalls are not put in place."*

The dangers associated with potential military or terrorist attacks on nuclear facilities are presented correctly, when the SESA describes (NuPEA 2023, p. 194)

> *"Soundly, the vulnerability of nuclear plants to deliberate attack is of concern in the area of nuclear safety and security. Nuclear power plants, civilian research reactors, certain naval fuel facilities, uranium enrichment plants, fuel fabrication plants, and even potentially uranium mines are vulnerable to attacks which could lead to widespread radioactive contamination. The attack threat is of several general types: commando-like ground-based attacks on equipment which if disabled could lead to a reactor core meltdown or widespread dispersal of radioactivity; and external attacks such as an aircraft crash into a reactor complex, or cyber-attacks. For example, The United States 9/11 Commission found that nuclear power plants were potential targets originally considered for the September 11, 2001 attacks. If terrorist groups could sufficiently damage safety systems to cause a core meltdown at a nuclear power plant, and/or sufficiently damage spent fuel pools, such an attack could lead to widespread radioactive contamination.*
>
> *Nuclear reactors become preferred targets during military conflict and, over the past three decades, have been repeatedly attacked during military air strikes, occupations, invasions and campaigns."*

With respect to the threat of international terrorism, the SESA ascertains (NuPEA 2023, pp. 58–59):

"Kenya exists within a geo-political environment which harbours a certain level of risk that can compromise national security, energy security, public safety, and the national economy, for example terrorism from militia based in neighbouring countries. All the three basins face the same security risks that may be targeted at a nuclear installation."

This is again repeated in more detail (NuPEA 2023, p. 189):

"The proximity of Kenya to the war-torn Somalia, increases the risk of terrorism attacks due to Al-Shabaab's group alliance with the ISIS that poses a nuclear attack threat in the world. Lamu coastal line has been recipient of attacks by the insurgent group in the recent past, with attacks such as the Mpeketoni attack in June 2014, which would expose the NPP to possible attacks or make it an easy source, in case of sabotage or systemic administrative failure, for nuclear weaponry manufacturing material."

But even within Kenya, the SESA recognises a potential for terrorist attacks (NuPEA 2023, pp. 183–184):

"Members of the local communities in candidate areas and the public in general have often expressed concerns about inadequate information and guidance on the human rights redress mechanisms and procedures in infrastructural development. This situation tends to encourage attempts and threats by communities to attack developments sites and interfere with site operations on the basis of unresolved grievances."

This is further emphasised (NuPEA 2023, p. 187)

"Due to the increased execution of terrorism related incidents and other forms of violent crimes mainly in Nairobi, Rift Valley, Northern, North Eastern, Lamu and Mombasa in the Coast region, the energy industry being a multi-billion sector, has resulted in stakeholders becoming more alert to the need for effective mechanisms that assure Kenya's and the East Africa region's energy security. The security issue is also of importance since a number of insecurity incidents/postelection violence have been recorded in Kenya's prospective candidate basins. It is of importance to note that the nuclear power programme which is a capital-intensive industry attracts foreign investments and large extents expatriates who may become easy target to the terrorism (ransom) activities. In addition, nuclear facilities as vital installations that require adequate security management and intelligence to ensure they are safeguarded. Any attack to such a facility, is a huge threat to public health and the environment."

Despite this, in its Chapter 10 "Conclusion" the notion "security" is not mentioned at all.

To counter the security risks, the SESA recommends (NuPEA 2023, p. 238):

"The GoK should improve the ability of Kenya's Defence Forces, National Intelligence Service, and National Police Service to protect critical infrastructure in the nuclear sector by having institutional units covering security measures and issues that would foster information sharing. The risk of cyber-attacks, terrorist attacks and proliferation associated with nuclear power programmes, necessitates a strong security system encompassing well trained human personnel and strong system firewalls against hacking."

2.3.2 Discussion

As correctly stated by the SESA, nuclear technology can be used for peaceful energy production and for military purposes such as nuclear deterrence and ultimately to wage nuclear war. The following discussion is based on the assessment in (Oeko-Institut e.V. 2021). As also correctly recognised by the SESA, nuclear proliferation is the spread of nuclear weapons, nuclear weapons technology, fissile materials and fissile material production technologies, and of other materials or know-how relevant to the use and fabrication of nuclear weapons.

The unimaginable destructiveness of nuclear weapons was shown by the attacks on Hiroshima and Nagasaki. As discussed in (Oeko-Institut e.V. 2021), any use of a nuclear weapon would have catastrophic impact on human health and the environment. The conferences on humanitarian impact of nuclear weapons in Vienna, Nayarit and Oslo 2013-2014 summarised the evidence of the immediate and longer-term impacts of the use and testing of nuclear weapons. The last conference was attended by 157 states. The humanitarian impact of nuclear weapons is also the background against which the Treaty on the Prohibition of Nuclear Weapons was negotiated and entered into force in January 2021 (UN 2017).

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is the cornerstone treaty to curb proliferation (UN 1970). Nuclear disarmament efforts as enshrined in Article VI did not make much progress. Instead today the world faces renewed interest in nuclear weapons with nuclear weapon states modernising their arsenals and emerging new nuclear weapon states. According to article IV of the NPT, all states have an inalienable right to the peaceful use of all nuclear technologies and parties to the treaty should also facilitate the development and distribution of peaceful technologies.

The risk of nuclear proliferation is acknowledged by the Intergovernmental Panel on Climate Change (IPCC) in its 2018 report (IPCC 2018, p. 461). They argue that increasing the share of nuclear energy to reach the goal of only a 1.5°C global temperature increase,

> *"can increase the risks of proliferation (SDG 16)".*

The IPCC refers to the Sustainable Development Goals (SDG) that the United Nations laid out in its "2030 agenda for sustainable development" (UN 2015). Central for nuclear proliferation in this set of goals is the SDG 16 (peace, justice and strong institutions). But literally all other SDGs would be impacted by nuclear testing, nuclear war, or an inadvertent use of nuclear weapons. Also, the IAEA acknowledges unique challenges of nuclear power – among which is nuclear proliferation – for sustainable development (IAEA 2017, p. 7).

The SESA implicitly argues, that since large institutional arrangements of engineered safeguards designed to reduce the risks of nuclear proliferation are applied, the risks will be mitigated. The assumption is that the current system of control is capable of discovering actors that intend to acquire nuclear weapons early enough and that there are effective means available to stop them.

But as with severe nuclear accidents one has to account for low probability, high risk events. The vast infrastructure of international safeguards and physical protection measures is a certain protection against the risk of nuclear proliferation. Also, the system of international security is set up to disincentivise the acquisition and use of nuclear weapons. But these systems are not failproof. States can have incentives to build nuclear weapons (Sagan 1996) and take advantage of the dual-use characteristic of nuclear technologies, but also terrorists could acquire fissile materials (nuclear terrorism) (Belfer Center 2016).

If the protective systems fail, there could be catastrophic effects. Even a very localised nuclear war would have global climatic effects as (Robock et al. 2007) showed. The consequence of nuclear weapons use is not in any meaningful sense comparable to risks by other technologies in terms of casualties and harm done. Effects would not only affect humanity and the environment today, but future generations as well.

Nuclear power plants, but potentially also other facilities of the nuclear supply chain like reprocessing facilities could be targets of terrorist attacks or could be impacted by consequences of military conflicts (be it intentional or by accident). The use of nuclear energy demands extensive institutional and material infrastructure upon a foundation of stable intrastate conditions and interstate relations. This being the case, inter-, intra- or substate conflicts can result in catastrophic accidents, either deliberately or unintentionally. If there are nuclear facilities located in a crisis region, the risk of a nuclear disaster is markedly heightened. This can be explained not only in terms of the strategic relevance of the energy supply in military conflicts, but also the increased accident risks and hazards arising from collateral damage, as well as the erosion of the safety culture and institutional control in crisis regions with a nuclear infrastructure. Even just the escalation of a political dispute or the persistence of low intensity conflicts can make it generally more difficult and complex to maintain nuclear safety, if intrastate safety mechanisms come under strain or even fail as a result (Oeko-Institut e.V. 2017).

(Hirschberg et al. 2016) estimate the risk of a terrorist attack on energy facilities. In this context, they analyse the possible consequences of an attack on nuclear power plants in the US, Finland, and China. Fig. 8 in (Hirschberg et al. 2016) show frequency-consequence curves for Chinese and Finnish nuclear power plants. From this figure one can draw the conclusion, that for

- the Chinese nuclear power plant, the maximum number of fatalities is approx. one million and
- the Finnish nuclear power plant, the maximum number of fatalities is approx. 30,000.

No numbers are given for the corresponding US facilities. Still Fig. 7 in (Hirschberg et al. 2016) gives the corresponding risk of immediate and delayed fatalities per year, showing that the risk for the nuclear power plant in the US is even higher than for the Chinese plant.

Other literature does also discuss at least qualitatively the risks associated with nuclear facilities in crisis regions (Oeko-Institut e.V. 2017). According to (Burgherr and Hirschberg 2014, p. 48), 0.5% of the accidents in the energy sector analysed are due to conflicts, making clear that this aspect cannot be ignored with respect to severe accidents in nuclear facilities, which is also generally admitted by the SESA report without drawing further conclusions.

2.3.3 Conclusions

The SESA report does not fully assess the risks of nuclear proliferation when assessing the possible impacts of nuclear energy production in Kenya. Any use of nuclear weapons would have catastrophic impacts on human health and the environment. The SESA report evades the complex history and an in-depth discussion of the use of nuclear energy and nuclear proliferation. But the simple fact is that all nuclear technologies have a dual-use characteristic and therefore carry a potential for misuse. Any discussion of nuclear energy not covering nuclear proliferation is thus incomplete.

While the SESA recognises the possibility of terrorist attacks on a nuclear facility, if fails to assess possible consequences of a potentially successful terrorist attack. Thus, it also fails to fully assess the corresponding risk, nor does it compare this risk with possible alternatives to nuclear power.

Therefore, the SESA falls short of adequately identifying and assessing the possible security consequences of introducing nuclear power in Kenya.

2.4 Nuclear Waste Management

Another major factor in determining the possible environmental impacts of nuclear power is the generation of highly radioactive waste, that has to be separated from the environment for a very long time frame.

The SESA recognises in its Key Policy Recommendations the need for Kenya to decide on its waste management (NuPEA 2023, p. 9):

> *"Finalize on the development of policy on spent fuel and radioactive waste management (RWM)"*

2.4.1 Claims made by the SESA

NuPEA has been asked (NuPEA 2023, p. 169):

> *"Is safe long-term Radioactive Waste disposal possible within the Kenya? How are we planning for it?"*

NuPEA answered this question as (NuPEA 2023, p. 169):

> *"Nuclear waste management is a critical policy that manages radioactive waste handling, pretreatment, treatment, conditioning, transport, storage and disposal. We either burry it or the supplier collects it. It can also be re-used"*

With respect to the corresponding time frame one has to face when dealing with highly radioactive waste, the SESA argues (NuPEA 2023, p. 32):

> *"Long-term impacts- occurring beyond the planning horizon up to 2030 and after decommissioning of any associated components. This can last up to over 50 years post decommissioning of plants where radioactive wastes involved are high level."*

Concerning the strategy to deal with highly radioactive wastes, the SESA further clarifies (NuPEA 2023, p. 214):

> *"Some of the strategies for consideration in management of Spent fuel are: Long term storage for disposal; Reprocessing and recycling then disposal; direct disposal; Fuel Leasing/ Fuel take back and Retention of spent fuel as a valuable commodity"*

Concerning the international policies on waste management, the SESA states (NuPEA 2023, p. 173):

> *"Globally, government policies dictate whether certain materials – such as used nuclear fuel and plutonium – are categorised as radioactive waste."*

The SESA continues that (NuPEA 2023, p. 175):

> *"Where countries have adopted a closed cycle and reprocess used fuel, the fission products and minor actinides are separated from uranium and plutonium and treated as HLW. In countries where used fuel is not reprocessed, the used fuel itself is considered a waste and therefore classified as HLW."*

With respect to the option of reprocessing, the SESA claims (NuPEA 2023, p. 52):

> *"During reprocessing, uranium and plutonium are chemically separated from the other fission products and minor actinides which remain in the waste. Reprocessing can*

potentially recover up to 95% of the remaining uranium and plutonium in spent nuclear fuel. As such, it can reduce the radiotoxicity of the remaining waste by over 90%. Qua volume can create a reduction of the HLW up to 50%, but it increases the volume of ILW. Up to now, about one third of spent fuel from commercial power reactors has been reprocessed. Reprocessing requires additional dedicated infrastructures."

In the context of the development of a national fuel cycle policy, the SESA also recognizes, that there are proliferation problems associated with reprocessing (NuPEA 2023, p. 117):

"At this point, it should be noted that, due to the risk of proliferation, uranium enrichment and reprocessing constitute a technical as well as a political problem."

2.4.2 Discussion

High-level waste (HLW) contains large concentrations of long-lived radionuclides. It is also waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process. HLW arises essentially from the irradiation of nuclear fuel, and is managed either as spent nuclear fuel, where this is treated directly as waste, or as the streams of actinide and fission products separated in reprocessing (Heinrich-Böll-Stiftung 2021).

The choice of nuclear fuel cycle and radioactive waste management are two of the 'nuclear infrastructure issues' in the planning and operation (and decommissioning) of nuclear power plants as described in the milestone approach of the IAEA (IAEA 2023).

However, while it is mentioned in the SESA report that Kenya needs to implement a radioactive waste management system and adhere to international standards and treaties regarding radioactive waste, Kenya is yet to ratify the international "Joint Convention on the Safety of Spent Fuel and on the Safety of Radioactive Waste Management" as well as a number of other international treaties on nuclear safety, as stated in the SESA.[3]

High-level radioactive waste resulting from nuclear power plants necessarily entails a very long-term commitment to a nuclear waste strategy, including long term financial planning. While a time scale of possibly 50 years after decommissioning a plant is mentioned in the report, this sounds rather optimistic given the experiences of other countries in the last decades. Considering the long-term processes usually spanning decades only for finding a final disposal site that many countries using nuclear power have been and are going through, not including the time needed to build and fill the repository, it seems questionable to not implement a thorough and detailed system for radioactive waste management before considering the construction of nuclear power plants. In the site-finding process for a repository for high-level waste, not only geological, but also political and societal as well as technological perspectives and arguments must be taken into account (IAEA 2023, 3.17; Brunnengräber et al. 2015).

In Figure 2-10, a summary is given of high-level nuclear waste repository planning world-wide. While many of the countries listed there have had nuclear power plants in operation for decades, no disposal site for high level waste is in service anywhere yet. Finland, where nuclear waste is disposed of instead of being reprocessed, is the only country where a site has been chosen and construction is under way, after a site selection process that took around 40 years (Brunnengräber et al. 2015). Germany, where the search for a final repository started decades ago, restarted the process in 2013 due to technical and political problems. The current estimate for the duration of the site selection

[3] https://www.iaea.org/sites/default/files/22/06/jointconv_status.pdf, last accessed on 14.04.2024

process in Germany is given as a time span between 2046 and 2068 for the entire procedure until the actual siting decision may take place. This will be followed by the licensing and construction phase of a repository (BASE 2022). Only very few countries plan for a commissioning of a final repository for high level waste in the first half of this century, most countries see this date in the second half of this century or even have no clear process in place yet. Even within the EU, most Member States have not even entered the lengthy site selection process, while planned operations are estimated to occur mostly in the second half of this century (Heinrich-Böll-Stiftung 2021).

Figure 2-10: Nuclear Waste Repository Planning and Ownership (by Country)

Country	Share of Global Once Operating Nuclear Capacity*	Disposal Site Location	Status	Commissioning date as of 2023	Repository Ownership as of 2023
United States	23.32%	None selected to replace Yucca Mountain	Project proposed	Suspended	State
France	13.48%	Cigéo	Site selected	2035 (10-year slippage from 2015 estimate)	State
China	10.71%	None selected	Project proposed	2050+	State
Japan	9.83%	None selected	Project proposed	2035	Utility
Russia	6.38%	Krasnoyarsk	Site selected	To be confirmed	State
Germany	5.31%	None selected	Site search	2046–2068+ for site selection (several decades slippage from 2015 estimate)	State
South Korea	5.18%		Under study	Construction of underground facilities from 2043-2060	State
Canada	3.17%	None selected	Project proposed	2040+ (5-year slippage from 2015 estimate)	Mixed; NWMO set up by utilities (some state-owned) and Atomic Energy Canada LTD.); not clear on ownership of the repository site.
United Kingdom	2.75%	None selected	Project proposed	2040 (was no target date in 2015)	State
Sweden	2.21%	Forsmark	Site selected	2030-2032 (2-4-year slippage from 2015 estimate)	Mixed; utility responsibility, though most of the reactors are owned by Vattenfall AB which is wholly owned by the Swedish state.
Spain	1.65%				State
India	1.39%	None selected	Project proposed	To be confirmed	State
Belgium	1.2%				State
Finland	0.88%	Onkalo	Construction underway	2024	Mixed; Posiva owned by Fortum (majority state-owned) and TVO (private, but partially owned by Fortum)
Czech Republic	0.79%	None selected	Project proposed	2065	State
Switzerland	0.67%	Nördlich Lägern	Site selected	2060 (was no target date in 2015)	State
Slovakia	0.65%	None selected	Project proposed	To be confirmed	
Hungary	0.39%	None selected	Project proposed	2030	State

Sources: compiled by WNISR, based on NEA, 2020; WNA, 2023; IAEA/PRIS, 2023; repository owner websites, 2023; Pulse, 2022[663]

Source: (Mycle Schneider Consulting 2023), Table 24

The SESA does not give any overview on international experience with nuclear waste disposal. The only operational experience from a geologic repository for high level wastes stems from the Waste

Isolation Plant Project (WIPP) in the U.S., which is used for transuranic wastes from the U.S. weapons complex. It has been plagued by various accidents, incidents, and mismanagement (Klaus 2019).

According to the SESA, it is unclear yet which nuclear fuel cycle option and thus disposal strategy Kenya is aiming for.

In the 2021 draft of the SESA (NuPEA 2021), the SESA still included an entire subchapter on “Radioactive Waste Management Alternatives”, which included technically flawed discussions about “Transmutation” and misleading discussions of “Space disposal” as emerging options for nuclear waste disposal. While this subchapter has been removed from the current version of the SESA, it strongly questions whether the complex issue of nuclear waste management was fully understood and evaluated by the SESA authors.

The current SESA lists long-term storage as a strategy for waste management. Long-term storage in itself is no waste management strategy but a necessary intermediate step before a final solution for nuclear wastes is implemented (BASE 2024). Furthermore safety, social, organisational and financial aspects speak against the active pursuit of such a strategy, as future generations would be burdened with the monitoring of long-term interim storage and, if necessary, repair measures, subsequent disposal and the associated need to maintain competence.

Additionally, the SESA lists fuel leasing with fuel take back arrangements as a viable disposal option. The IAEA recognises the responsibility of the state to deal with its nuclear wastes (IAEA 2023):

> *“The Joint Convention stipulates that radioactive waste should be disposed of in the country in which it is generated. However, it also allows the possibility of waste being disposed of elsewhere in the interests of safety and efficiency.”*

The option to dispose of the wastes elsewhere should only be taken in the interest of safety and efficiency. Therefore, Kenya would have to thoroughly investigate the option to dispose of the nuclear wastes in Kenya and then compare this option with a solution to dispose of the wastes elsewhere. Clear advantages with respect to safety and efficiency would have to be shown before such an option could responsibly be followed.

Reprocessing is mentioned various times in the report as a means for spent fuel management. During reprocessing, the spent fuel is separated into three different waste streams, plutonium, uranium and the remaining high-level waste consisting of fission products and minor acitnides like americium or curium.

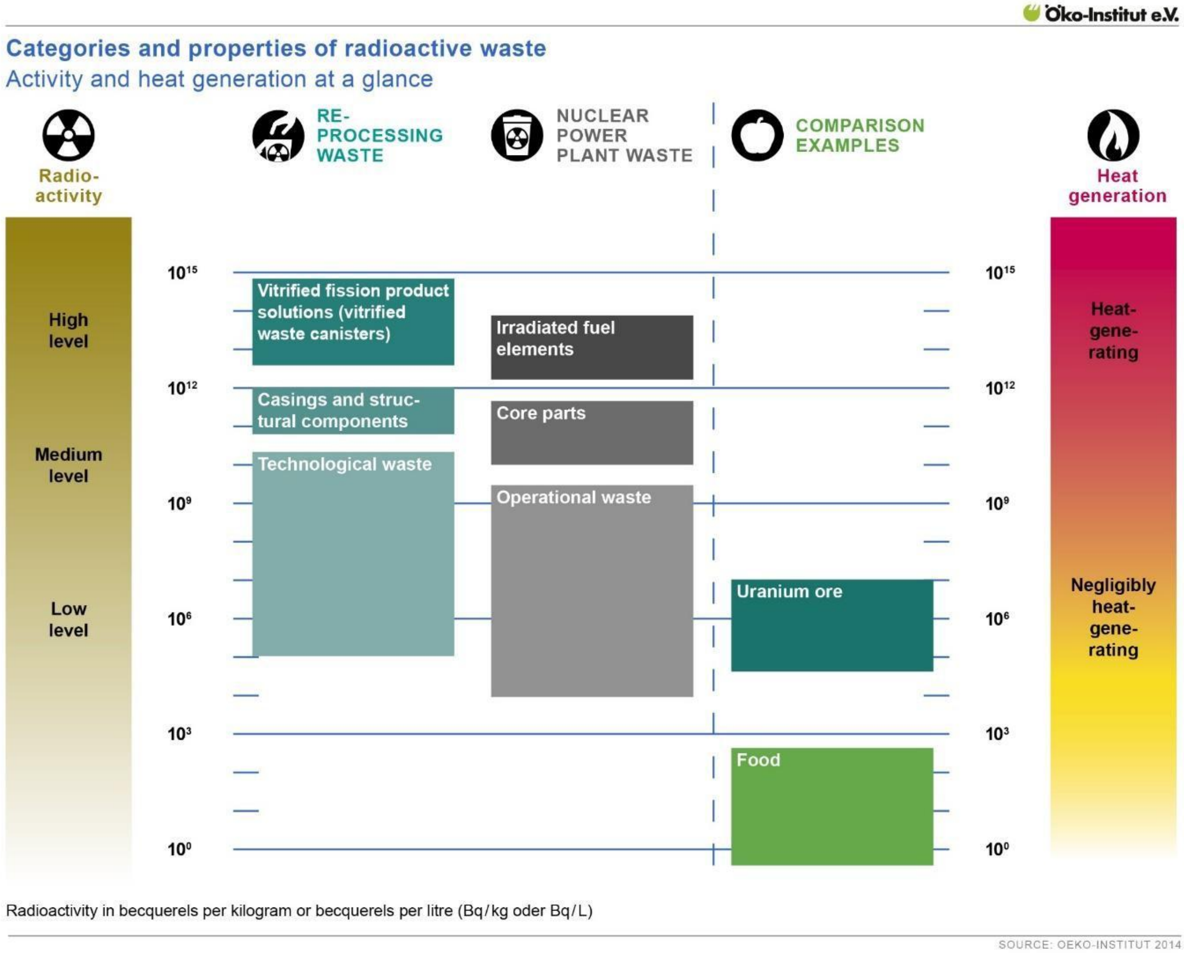
As the fission products and the minor actinides remain in any case after reprocessing of spent fuel, there will still be the need for a final repository for this remaining high-level radioactive waste (IAEA 2022; Oeko-Institut e.V.; WIP; PhB 2024).

Theoretically, uranium and plutonium extracted during reprocessing could be re-used in the nuclear fuel cycle (IAEA 2007). Reprocessed uranium (RepU) contains different uranium isotopes than fresh uranium, requiring higher precautions from a radiological point of view, making its use more expensive. (WNA 2020) estimates the value of RepU to be half of that of natural uranium. Therefore, re-use of RepU so far has been very limited. (WNA 2020) lists the use of less than 30.000 tonnes of RepU in Europe, Russia and Japan. Given that until 2020 nearly 120.000 tonnes of spent fuel had been reprocessed (WNA 2020), that means that only about 25% of the RepU arising from reprocessing had been re-used, the remainder must still be stored and possibly be disposed of as waste. Concerning the plutonium arising from reprocessing today, it is mostly used to produce mixed-oxide (MOX) fuel for light-water reactors. This MOX-fuel is then used once in light-water reactors and afterwards also stored for direct final disposal. Reprocessing of spent MOX-fuel practically does not take place today. The production of MOX-fuel is also much more expensive and technologically demanding than the use of fuel made of enriched uranium. Therefore, the use of plutonium as MOX-fuel falls short of the plutonium separation by reprocessing. Today, about 420 tonnes of separated plutonium from civilian reprocessing are still stored in separated form (IPFM 2024).

Internationally, most countries have abandoned reprocessing. In Europe, reprocessing is still part of the waste management concept in some countries (France, the Netherlands, Russia), while most countries have suspended or stopped it for mainly economic reasons (Belgium, Bulgaria, Germany, Hungary, Sweden, Switzerland, and most recently the UK). Only France is still reprocessing spent fuel, while two Member States (Czech Republic and Hungary) are considering taking it up. Most countries had to send their spent nuclear fuel abroad for reprocessing to either France, the UK, or Russia (only a few central European countries continue to do so). As of mid-2020, only France (apart from Russia) still operates an industrial reprocessing facility. As the vitrified waste (mostly HLW) is sent back to the country of origin, reprocessing includes transboundary movements of HLW (Heinrich-Böll-Stiftung 2021).

Reprocessing will increase the amount of medium and low-level waste, which then needs to be disposed of. A comparison of the waste streams from reprocessing or directly from a nuclear power plant is given in Figure 2-11. The choice for a closed fuel cycle and thus reprocessing of spent fuel might also increase the proliferation risk (IAEA 2023) and thus greatly increases the responsibilities regarding safeguards. Several countries have renounced reprocessing of spent fuel for non-proliferation reasons.

Figure 2-11: Radioactive waste categories and their properties



Source: Öko-Institut e.V.

The SESA does not estimate cost for final disposal of nuclear wastes and does not explain, how it will be ensured that the necessaryfunds are available when needed. Cost for final disposal of nuclear waste may be significant, (Heinrich-Böll-Stiftung 2021) list the estimated cost for disposing of high level nuclear wastes in the EU-28 at 422-566 billion Euros.

2.4.3 Conclusions

Kenya is yet to join a number of international conventions on nuclear safety and radioactive waste management.

According to the SESA, it is not clear which nuclear fuel cycle and hence which waste management strategy Kenya is aiming for. The former will have an impact on the latter, though, since an open cycle will entail different waste streams than a so-called closed cycle.

All options will necessarily require final disposal of high-level radioactive waste. In the SESA, neither option is discussed in a realistic manner, brushing aside difficulties that have been experienced elsewhere. Various countries have been struggling to find a site for a deep geologic repository for decades, so the SESA answer 'we burry it' is grossly misleading with respect to the technological and political complexity of the process of high-level waste disposal.

Reprocessing, while not fundamentally changing the problems associated with nuclear waste disposal, will bring additional proliferation risks, increase the cost of the nuclear fuel cycle and enhance the amount of low-and intermediate-level waste to be disposed of.

The complexity and long-term obligations of nuclear waste management thus seem to be somewhat disregarded in the SESA, especially the breadth of the task, including geological and technological as well as societal, financial and political aspects.

Therefore, the SESA falls short of adequately identifying and assessing the possible consequences of introducing nuclear power in Kenya with respect to nuclear waste management.

2.5 Uranium production

Environmental impacts of nuclear power production are also related to the uranium needed to produce nuclear fuel.

2.5.1 Claims made by the SESA

The SESA claims (NuPEA 2023, p. 8):

> *"Nuclear power generation uses uranium as a fuel. However, the nuclear fuel for the KNPP will be sourced from the manufacturers to eliminate any emissions that may occur during mining of uranium."*

On the other hand, the SESA recognises (NuPEA 2023, p. 36):

> *"The NPP involves uranium and thorium exploration which has been undertaken through qualitative assessment (aerial survey) and further exploration through quantitative assessment will be carried out in future."*

Based on this, the SESA admits (NuPEA 2023, p. 44):

> *"Kenya has developed a Nuclear Fuel Cycle & Radioactive Waste Policy, in which Kenya shall endeavour to explore her reserves of uranium and thorium."*

2.5.2 Discussion

The extraction and processing of uranium has a considerable impact on the environment. In particular, large quantities of radioactive residues are produced, which may not be adequately secured and stored during uranium ore processing. Air, water and ultimately people may be polluted through carry-over, drift and leaching (Neles and Pistner 2012, Kap. 7).

While this is obviously also admitted by the SESA, no discussion of the environmental impacts of uranium production takes place. The responsibility for these environmental impacts is not acknowledged but attributed to the manufacturer of the fuel. Of course, any environmental impact due to the production of electricity from nuclear power in Kenya will have to be allocated nationally and taken into account in a strategic assessment of the pros and cons of nuclear power production, even if the impacts will have to be borne by other countries.

Even more, the SESA contradicts its own assumption that the uranium used for nuclear fuel will be produced in other countries by stating that a national policy to explore the national uranium reserves exist and that explorations are already under way.

2.5.3 Conclusions

The SESA does not discuss possible environmental impacts of uranium production in Kenya, as it claims nuclear fuel to be purchased from abroad, while at the same time admitting that an exploration of uranium reserves in Kenya is planned for.

Therefore, the SESA falls short of adequately identifying and assessing the possible consequences of introducing nuclear power in Kenya with respect to uranium production for nuclear fuel.

2.6 Site Selection

An important step in the introduction of nuclear power in Kenya is the selection of a suitable site for a nuclear power plant (or other nuclear facilities like interim storage sites of sites for final repositories). While a full assessment of the site selection is beyond the scope of this work, a review of the site selection process as described in the SESA is given in the following.

2.6.1 Claims made by the SESA

The SESA recognises the importance of the site selection process with respect to safety and environmental impacts of the future nuclear facilities in Kenya (NuPEA 2023, p. 53):

> *“Site selection is an important stage in the nuclear power programme. The goal of the siting process is to protect the nuclear power installation against external threats as well as to minimize any social and environmental detriments and threats that might arise from it.”*

The site selection process was performed by a dedicated team based on recommendations of the IAEA (IAEA 2015) for the site selection process (NuPEA 2023, p. 40):

> *“Established a multidisciplinary national Site Selection Team (SST) for nuclear installations and developed the national Criteria for siting of nuclear installations in Kenya based on international safety standards (IAEA SSG-35).”*

In a first step, a screening of different regions and possible sites took place (NuPEA 2023, p. 90):

> *“The twenty-nine (29) NPP potential sites in Kenya were then subjected to a screening (elimination) process, first using exclusionary criteria like capable faults, volcanic hazards and feasibility of implementation of an emergency plan. “*

During this step, several potential sites were removed from the selection process (NuPEA 2023, p. 90):

> *“An example of how capable faults were used as an exclusion criterion in the Lake Victoria region. Any site/s that was located on or within the capable fault 8 km screening distance (e.g., Site 1, Site 2, Site 3, Site 8, Site 9 and Site 12) was screened out and disqualified from ranking. Another example of how capable volcanos was used as an exclusion criterion is for the Lake Victoria region. Any site/s that was located on or within the 5 Km screening radius of a Holocene volcano (e.g., Site 16) was screened out and henceforth disqualified from ranking. Any site/s located within the 15Km discretion radius, and which was vulnerable to volcano-induced events (lahars, pyroclastic density currents, landslide tsunamis) e.g., Site 8 and Site 9 was also screened out and disqualified from ranking.”*

Besides geologic criteria like the flooding potential, the earthquake ground motion or the distance from capable faults and capable volcanos, other important criteria are also mentioned by the SESA (NuPEA 2023, p. 54):

> *“The site should not be located near ecological valuable or vulnerable areas nor densely populated areas.”*

Therefore, the screening process was followed by a ranking of remaining sites (NuPEA 2023, p. 90):

> *“Afterwards, discretionary criteria like access to the national electric grid and transport infrastructure was applied.“*

The ranking of different criteria followed ranking factors shown in Tables 3-5 and 3-6 in the SESA. Of 29 investigated sites, 13 remained after the screening process and the ranking resulted in the following results:

Figure 2-12: Results of the ranking of investigated sites

Coast Region		
SITE	**SCORE**	**POSITION**
Site A	0.138675357	5
Site B	0.192576414	1
Site C	0.143808665	3
Site D	0.184820341	2
Site G	0.199060207	-
Site H	0.141059015	4
Lake Victoria Region		
Site 4	0.256438624	2
Site 6	0.441463377	1
Site 14	0.089189084	4
Site 15	0.212908915	3
Lake Turkana Region		
Site T-1	0.455391176	1
Site T-2	0.257090148	3
Site T-3	0.287518676	2

Source: (NuPEA 2023, p. 7)

This ranking was followed by a sensitivity analysis, during which most of the sites were removed from the site selection process (NuPEA 2023, p. 94):

> *“In both the Lake Victoria and Lake Turkana regions, there are available candidate sites. However, after further analysis, it was determined that these sites are vulnerable to the hazards posed by the Quaternary volcanoes in the region. Given that volcanic hazards (like pyroclastic density currents, ash fall) and volcano triggered hazards (like volcanic tsunamis) can travel for hundreds of kilometres from the volcano vent, these sites can be impacted by volcanic hazards, which may impair the safety of an NPP. Therefore, the SST elected to avoid the Lake Victoria Region and the Lake Turkana region, in view of the aforementioned hazards.”*

Furthermore, the site that was best ranked in the remaining coast region, was also removed from the ranking (NuPEA 2023, p. 94):

> *"In the Coast region, Site G scored highest in the ranking. …*
>
> *However, considering aspects like the topography, geology and flood risk, Site G (in Lamu County) was avoided, because the cost of corrective engineering measures would increase the NPP Construction costs."*

This is also summarised in Chapter 10 "Conclusions" (NuPEA 2023, p. 270)

> *"Three potential candidate sites (Lake Victoria region; Lake Turkana Basin, and the Coast region were sufficiently analysed … and Site G scored highest in the ranking … However, after application of the sensitivity analysis, Site G (in Lamu County) was avoided, because the cost of corrective engineering measures would increase the NPP Construction costs. Thus, Site B is the Preferred Site, followed by Site D."*

2.6.2 Discussion

Generally, the site selection process as described by the SESA, follows the recommendations for a site selection process for example given by the IAEA (IAEA 2015). First, potential sites are screened out due to criteria with a focus on safety reasons, afterwards the remaining sites are ranked with respect to different criteria including socioeconomic ones.

The SESA does not describe in detail the criteria used for screening out potential sites or the exact meaning of the criteria used for ranking of the sites (data used and ranking points achieved due to the underlying data). While it does list the ranking criteria and the corresponding relative importances used to weigh the different criteria, it does also not explain, how these relative importances have been derived. Therefore, the screening as well as the ranking process itself remains largely intransparent and cannot easily be reproduced by the general public. No sensitivity analysis with respect to (small) changes in the points given during the ranking process or the relative importances of the ranking criteria is performed to judge the robustness of the achieved ranking.

After screening and ranking, 13 sites remain as possible candidate sites, of which four are in Lake Victoria region and three in Lake Turkana region. Three of four sites in Lake Victoria region are ranked better than any Coast region site, all three sites in the Lake Turkana region are ranked better than any Coast region site. The best sites in Lake Victoria and Lake Turkana region are ranked more than a factor of two better than the best site in the Coastal region.

Nevertheless, the SESA dismisses all sites in Lake Victoria and Lake Turkana region. As a justification for this, the risks due to volcanic hazards is given. This again is highly intransparent, as the risk due to volcanic hazards is already a screening out criteria as discussed by the SESA and has resulted ina screening out of sites in this step. Furthermore, the volcanic hazard is also included in the ranking criteria as also clearly stated by the SESA. It is therefore by no means comprehensible, why seven sites in the Lake Victoria and Lake Turkana region have not been screened out in the first place and could achieve high rankings in the ranking process, while at the same time being susceptible for volcanic hazards to a degree making it necessary to remove them from the site selection process after ranking.

Finally, even within the remaining potential sites in the coastal region, the site with the best ranking is dismissed due to purely economic considerations. This is again a highly intransparent step, as the site was ranked best due to safety criteria as stated by the SESA (topography, geology and flood risk) and the ranking criteria already included cost of mitigation, costs of remediation and socio-economic impacts.

Therefore, either the development of the screening and ranking criteria of the site selection process were flawed in themselves, or the final site selection process was based on arbitrary decisions taken by the responsible team.

2.6.3 Conclusions

While the site selection process in principle follows international recommendations on how to perform a site selection, several aspects of the site selection process (screening criteria, detailed description of the ranking criteria, derivation of relative importances) are not explained in the SESA to a degree making it possible to reproduce the decisions taken by the responsible site selection team.

Even after execution of the screening and ranking process described in the SESA, large parts of the remaining possible sites, including the ones by far best ranked in the site selection process, are removed from the further process without convincing reasoning.

Therefore, the SESA falls short of making the site selection process transparent and comprehensible for the general public.

3 Rationale of a nuclear power programme in Kenya

Besides the immediate social and environmental impacts of introducing nuclear power in Kenya, it is important to check whether nuclear power is the most reasonable option for the future electricity supply in Kenya.

3.1 Electricity demand

In Chapter 4, with respect to the rationale of a nuclear power programme in Kenya, (NuPEA 2023, p. 99) ascertains:

> *"Broadly, the objective of national energy policy in Kenya, is to 'ensure adequate, quality, cost effective and affordable supply of energy that meet development needs, protect and conserve the environment, and use natural energy resources'."*

Thus, a first target with respect to a nuclear power programme in Kenya is an adequate supply of energy that meets development needs.

3.1.1 Claims made by the SESA

With respect to the electricity demand, in Chapter 10 (NuPEA 2023, p. 270) concludes:

> *"The Nuclear Power Programme is a worthy investment towards ensuring that Vision 2030, the Least Cost Power Development Plan reduction of carbon footprint as well is achieved for a sustainable development. The Plan is part of the interventions by the national government through the Ministry of Energy to ensure the 4000 MWe by 2030."*

Besides this aim of 4000 MW installed electric power in 2030, several different and partly contradictory targets with respect to the future installed electric capacity are given. (NuPEA 2023, p. 5) cites an increase for the

> *"estimated peak demand for the period 2022-2041 at an average of 5.34% from 2,036 MW to 5,757 MW in the medium case scenario"*

and based on this concludes

> *"It is projected that as of 2037, nuclear energy shall be contributing a total of 1,000 MW into the national grid."*

(NuPEA 2023, p. 45) gives another year for the first Nuclear Power Plant:

> *"According to NuPEA's Strategic Plan, the first Nuclear Power Plant of 1,000 MW, is to be commissioned by the year 2038."*

In 2021, another draft of the SESA report had estimated (NuPEA 2021, p. 9) that

> *"According to Kenya Nuclear Power Development Plan and NuPEA's View, the first Nuclear Power Plant of 1,000 MW, is expected to be commissioned by the year 2027 and it is expected to grow to 4,000 MW by 2035."*

In its "Executive Summary" the earlier version even claimed still higher targets (NuPEA 2021, p. v)

> *"It is projected that as at 2037, nuclear energy shall be contributing a total of 6.638 MW into the national grid."*

This is confirmed in the current version of the SESA (NuPEA 2023, p. 61):

> *"According to the original Kenya nuclear power development plan, a 1000MWe plant will be connected to the grid by 2026 and 4000MWe in total by 2030."*

(NuPEA 2023, p. 61) again states different targets for the introduction of nuclear power in Kenya:

> *"The current revised nuclear power development plan and roadmap envisions the connection of a 600MWe Small Modular Reactor into the Kenyan Grid by 2038 in order to satisfy the demand projections of the latest LCPDP 2022-2041 Report."*

3.1.2 Discussion

One very important criterion for the future electricity system in Kenya according to the SESA itself is an adequate supply of electricity. Therefore, a clear and transparent picture of the future electricity demand and the role of nuclear power to provide this is required. But the SESA falls short of delivering it.

The draft SESA report of 2021 claimed that until 2027 an installed capacity of 1000 MWe nuclear power would be needed, 4000 MWe until 2035 and 6638 MWe until 2037. Already the installation of a 1000 MWe plant until 2027 starting in the year 2021 would have been impossible given the long times necessary for planning and power plant constructions (compare Chapter 2.1).

Two years later, in the current version of the SESA, a very unclear picture of the future electricity demand, and the corresponding nuclear share is given. In its conclusions, the SESA still refers to 4000 MWe installed capacity by 2030. At another point it refers to a 1000 MWe share in the year 2037 or 2038 respectively (10 years later than in the 2021 report), while at again another point it claims that the latest assessment foresees an installed capacity of only 600 MWe by 2038.

In its discussion about the electricity demand, the SESA on several occasions refers to the projected peak electricity demand. At the same time, the SESA itself makes clear that nuclear power is seen as a baseload source of electricity. The SESA falls short of giving any number on the projected future baseload demand in Kenya.

According to (Republic of Kenya, Ministry of Energy 2021) there is currently sufficient baseload capacity in Kenya. The ministry even sees a need to enhance baseload consumption:

> *"There is need to introduce targeted incentives to attract industrial consumers to enhance base load consumption in the country. This would assist in absorbing vented steam and improve the country load behaviour during offpeak period."*

Based on these figures, there is no clear evidence given with respect to the necessity of building nuclear power plants in Kenya. On the contrary, it is not clear whether an increase in baseload capacity as discussed by the SESA fits to Kenya's future electric system, compare also chapter 3.4. If the installed baseload capacity of a nuclear power plant would not be needed, the plant would have to be shut down, reducing its overall load factor. As the cost of electricity from nuclear is dominated by the investments in the nuclear power plant, while the operational costs of nuclear are limited, this would in turn increase the cost of electricity produced.

3.1.3 Conclusions

In the current version of the SESA, a very unclear picture of the future electricity demand, and the corresponding nuclear share is given. The introduction of a nuclear power programme in a country has to be recognised as a century-long commitment. The necessary infrastructure for a nuclear power programme has to be provided. At least one to two decades will be needed for planning and construction of a first nuclear power plant, operation of such a plant will take several decades, dismantlement and final disposal of the resulting highly radioactive wastes will take further decades. For this whole timespan, the state will have to ensure sufficient expertise and infrastructure. Thus, there should be a clear and unambiguous picture of a future electricity demand justifying the introduction of nuclear power before such a commitment is taken. Given the unclear picture painted by the previous and current SESA concerning the future electricity demand and nuclear's role in Kenya's electricity system, it is highly questionable whether such a decision should be taken on the current state of knowledge.

3.2 Grid stability

(NuPEA 2023, p. 64) recognises that any national electric grid has the need for reserve capacity:

> *"Reserve Capacity is the installation which guarantees that the power system could be in operation with uninterrupted power supply and rated frequency. Generally, reserve capacity includes load reserve, maintenance reserve and emergency reserve."*

3.2.1 Claims made by the SESA

With respect to maintenance, (NuPEA 2023, p. 64) concludes:

> *"The maintenance reserve margin could be set between 8%~15% of system peak load."*

The emergency reserve must cover the unexpected shutdown of the largest plant in the system. Therefore, (NuPEA 2023, p. 60) recognises that:

> *"… Kenya's system capacity is too small to support NPP at this stage and the structure of power supply will also need to improve."*

This is due to the fact that according to (NuPEA 2023, p. 60) the

> *"largest generating unit in a system should not exceed 10% of the grid capacity".*

And therefore (NuPEA 2023, p. 60) concludes:

> *"For a commercial nuclear power plant to be safely operated in the Kenyan grid system, growth must be achieved in both electricity consumption and non-nuclear power production capacity."*

The problems arising with grid stability when a large nuclear power plant is introduced to the national grid is summed up (NuPEA 2023, p. 190):

> *"If the NPP is too large for the grid, the operators will face these challenges:*
>
> *a. Off-peak electricity demand might be too low for a large NPP to be operated in baseload mode, i.e., at constant full power.*
>
> *b. There must be enough reserve generating capacity in the grid to ensure grid stability during the NPP's planned outages for refuelling and maintenance.*
>
> *c. Any unexpected sudden disconnection of the NPP from an otherwise stable electric grid could trigger a severe imbalance between power generation and consumption causing a*

sudden reduction in grid frequency and voltage. This could even cascade into the collapse of the grid if additional power sources are not connected to the grid in time."

Based on electricity demand numbers, (NuPEA 2023, p. 190) concludes:

"The current electricity demand is 1,600 MW and is projected to grow to 2,600-3600 MW by 2020 hence will need to be developed further to accommodate the project nuclear power injection."

With respect to future developments of installed capacities in Kenya, (NuPEA 2023, p. 61) claims:

"In a high scenario, the peak load in 2026 and 2030 will be 10801MW and 19,940 MW respectively. Considering the need of not exceeding the 10% of system capacity, the allowable nuclear power installation capacity is 1000MWe and 2000MWe. Relatively, in reference scenario, the peak load in 2026 and 2030 will be 8,531MW and 14,446MW, which means that the allowable nuclear power capacities are 800MWe and 1400MWe."

Contrary to this claims, (NuPEA 2023, p. 5) cites an increase for the

"estimated peak demand for the period 2022-2041 at an average of 5.34% from 2,036 MW to 5,757 MW in the medium case scenario"

(NuPEA 2023, p. 60) thus recognises:

"Because commercially available nuclear power reactors of proven design offered today have a capacity ranging mainly between 1000 and 1750 MW, the Grid does not support their construction and connection, if not enlarged."

To overcome this restriction, (NuPEA 2023, p. 60) claims that

"An emerging trend in the nuclear industry is the introduction of Small Modular Reactors. … One crucial benefit of SMRs is that they can be deployed incrementally to match increasing energy demand."

3.2.2 Discussion

As correctly stated by the SESA, typical nuclear power plants under construction today have an electrical capacity between 1000 and 1750 MW (IAEA 2024).

As the unplanned shutdown of such a plant would have to be compensated in short time to ensure grid stability, compare also Chapter 3.3, at least the same amount of reserve capacity would have to be available on short notice at any point in time, independent of the actual (peak) electricity demand, leading to possibly high cost for installed reserve capacity (that could not be used to produce electricity as it has to be on standby for an unexpected shutdown of the nuclear plant).

According to the SESA, a single unit should not have a capacity of more than 10% of the peak electricity demand. Therefore, construction of a nuclear power plant of 1000 MWe capacity would only be justified with an overall peak demand of more than 10,000 MW. As discussed in chapter 3.1, the latest demand projection does not see such a demand for the year 2038, even in 2041 the peak demand would only be 5757 MW in the medium case scenario.

To overcome these problems, the SESA refers to "an emerging trend in the nuclear industry" to build smaller reactors, typically claimed to have a unit size of less than 300 MWe.

But actual figures paint a different picture (Oeko-Institut e.V.; WIP; PhB 2021; Mycle Schneider Consulting 2023). Small Modular Reactor (SMR) concepts date back to developments in the 1950s, in particular the attempt to use nuclear power as a propulsion technology for military submarines. While a wide variety of concepts and developments for SMRs exist worldwide, the vast majority of concepts is still at the conceptual level (NEA 2023).

Russia has so far constructed a single floating twin-reactor plant of small capacity, which took 13 years from official start of construction until beginning of commercial operation. China has constructed one demonstration twin-reactor high-temperature gas-cooled reactor, construction of which took 11 years from official start of construction until beginning of commercial operation (IAEA 2024).

There is also no trend visible in reactors currently under construction. As of May 2024, out of 59 reactors under construction only three could formally be allocated to be SMRs. One reactor is being built in Argentina (Carem-25) with a construction start in 2015. The reactor should have been built within two years and started operation in 2017, but even today it is still unclear when the reactor will start operation. Two more reactors are under construction in China (Lingdong-1) and in Russia (Brest-300, an experimental lead cooled fast reactor), construction of which were started in 2021.

The most prominent project to build a small modular reactor in the U.S. was the NuScale project planned for a site in Idaho. The project was recently abandoned after the cost estimate for a 462 MW plant had risen to US$ 9.3 billion (Green 2024). Cost of SMRs so far were extraordinarily high and prospects for cost decreases are low, compare Chapter 2.1.

Prototypes of plants are expected to be built in the first half of the 2030s. Given the current timespans for planning and construction, it is highly unlikely that it would be feasible to plan, buy, license and build commercially competitive SMRs up to 2038.

3.2.3 Conclusions

The current electricity grid in Kenya is not designed to support nuclear power plants with today's typical output of 1000-1750 MW. Substantial grid upgrades would be required before even individual nuclear power plants in Kenya could be connected to the grid. The SESA is discussing the use of SMRs as an alternative. However, despite intensive international discussion of SMR concepts, these are currently not a technologically available and commercially competitive option. According to current knowledge, the cost of SMRs would be significantly higher than that of large nuclear power plants.

3.3 Reliability

Another target for the introduction of nuclear energy in Kenya according to (NuPEA 2023, p. 5) is a reliable energy supply:

> *"… to produce energy that is affordable, reliable, clean and sustainable".*

3.3.1 Claims made by the SESA

Already in its Chapter 1 "Introduction", (NuPEA 2023, p. 29) claims that

> *"Nuclear energy provides such an option as it is most viable for base load operation, is efficient and most importantly, reliable."*

This is again repeated (NuPEA 2023, p. 43):

> *"The government envisions that this can provide relatively safe, secure, and reliable electricity generation at a reasonable and competitive price, while at the same time providing independence from fossil fuel and associated price fluctuations."*

At the same time, nuclear power is clearly introduced as a baseload source of energy (NuPEA 2023, p. 170):

> *"Nuclear power plants can run without any interruptions for a year and more without interruptions except for maintenance, making it a more reliable baseload source of energy. This baseload energy is crucial in sustaining industrial growth."*

There is no further discussion on the actual reliability of nuclear power in the SESA.

3.3.2 Discussion

The SESA claims nuclear power to be a reliable source of energy.

It is correct, that nuclear power plants are generally used as a source of baseload power that operate continuously for time spans of typically 12-18 months before new fuel has to be loaded into the reactor core. Also, nuclear power plants do not depend on fluctuating external input like sunshine and wind.

But for various reasons nuclear power plants may nevertheless face unforeseen unavailabilities of considerable length (for example due to limitations in the availability of cooling water or due to unforeseen safety problems).

The worldwide average load factor of nuclear reactors has been in a range between 76.7% and 82.4% over the years from 2003 to 2022, meaning that for more than 20% of the time, alternative power sources had to be available (IAEA 2024). One part of these unavailabilities is due to predictable reasons like the necessary fuel reload and obligatory safety inspections. But there are also other reasons.

The worldwide lifetime unplanned capability loss factor until 2022 was 5.8%, making clear, that the unavailabilities are not only due to planned routine shutdowns. The range of unplanned capability loss factors in different countries was between 1.2% for the relatively new fleet in China and 12.3% for the relatively old fleet in the United Kingdom, with an additional outlier of up to 36.3% for the very new and small fleet of Belarus (where the first Belarussian reactor had availabilities of only 59.7% and 45.8% in its first two years of commercial operation) (IAEA 2024).

The problem becomes even more evident, when one is looking at the yearly unplanned capability loss factors (instead of the lifetime values, which average out the large spread in the yearly values). For the years

- 2020 the national values show a spread between 0.0% (Japan) and 28.8% (United Kingdom) followed by 20.2% (Argentina),
- in 2021 between 0.0% (Slovenia) and 40.3% (Belarus) followed by 25.9% (United Kingdom) and
- in 2022 between 0.0% (in the Netherlands) and 33.9% (Belarus) followed by 22.5% (France).

For the case of France, (Mycle Schneider Consulting 2023) have compared the planned and total unavailability of reactors between 2019 and 2022, see Figure 3-1.

Figure 3-1: Total Unavailability at French Nuclear Reactors, 2019–2022 (in Reactor-Days)

Declared Type of Unavailability				
	"Planned"	Forced	Total	Average per Reactor
2019	5,273	316	5,588	96
2020	6,179	286	6,465	115
2021	5,639	172	5,811	104
2022	8,287	278	8,515	152

Sources: RTE and EDF REMIT Data, 2019–2023

Source: (Mycle Schneider Consulting 2023), Table 5

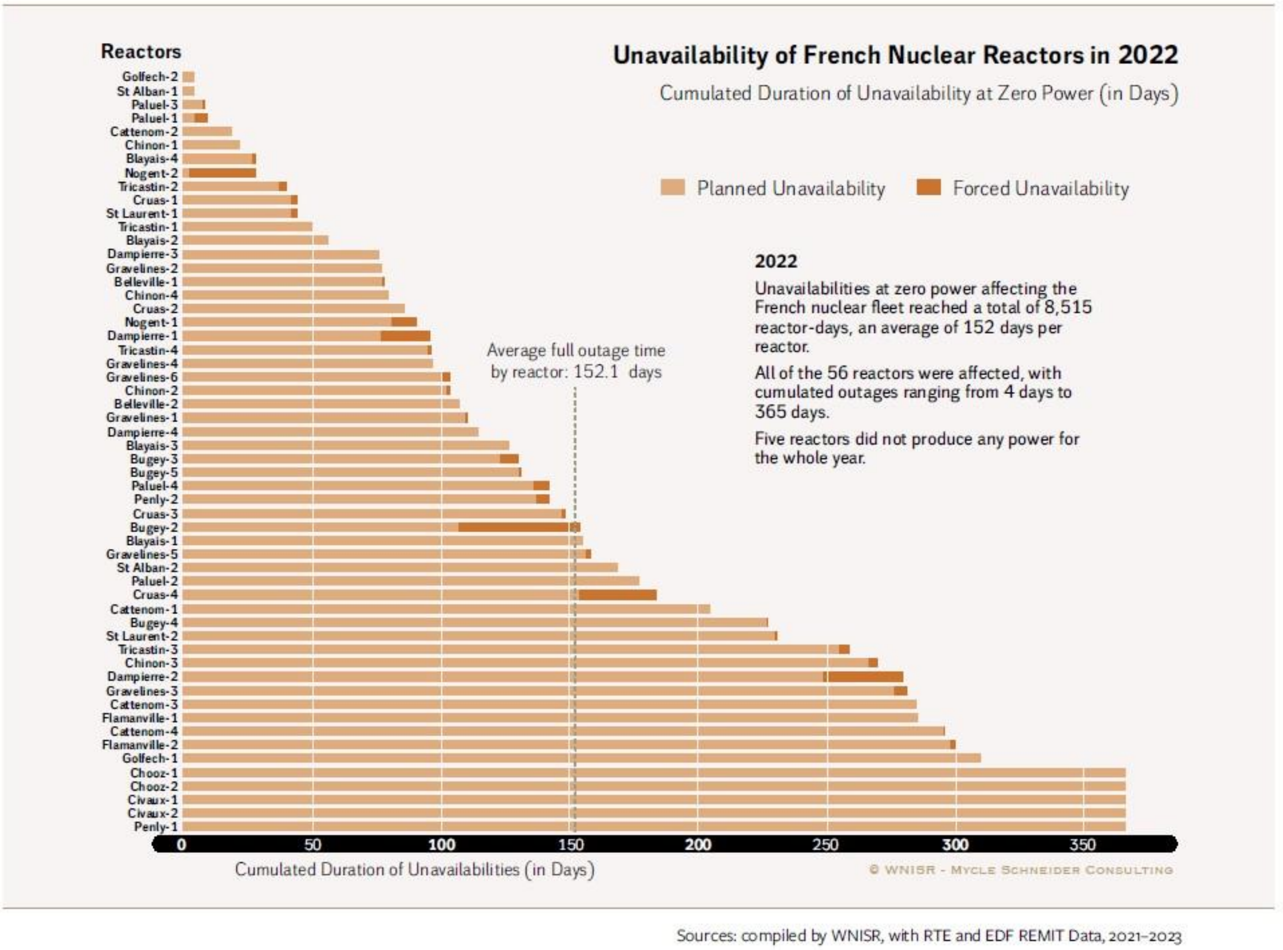
The authors conclude (Mycle Schneider Consulting 2023):

"The cumulated outage analysis over the four years 2019–2022 reveals the following …:

- *Four reactors were down half of the time or more (Flamanville-1 and -2, Chooz-1 and -2);*
- *26 reactors were generating zero power for 30 percent of the time, that is 109 days and more per year on average.*
- *39 reactors were off-grid for at least one quarter of the time, in other words, they did not generate any power for the equivalent of one in four years."*

Figure 3-2 shows the numbers of days of unavailabilities in France in 2022 on a reactor specific basis. It becomes evident, that large parts of the French fleet faced considerable unvavailabilities, some reactors even were unavailable for the whole year. Reasons for these unavailabilities range from planned shutdowns due to routine safety inspections, the need to shut down or reduce power of reactors in summertime due to insufficient cooling water and safety problems in the newest reactors of the French fleet due to unexpected findings of stress corrosion cracks in the vicinity of weld seams.

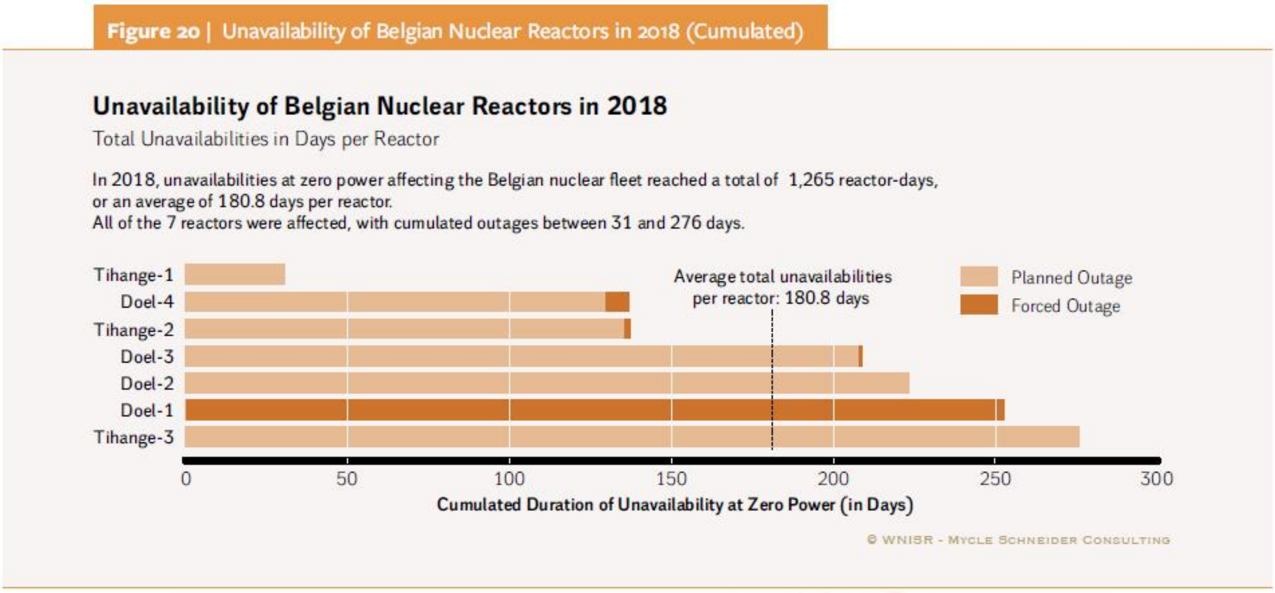
Figure 3-2: Unavailabilities of french reactors in 2022 in days.



Source: (Mycle Schneider Consulting 2023)

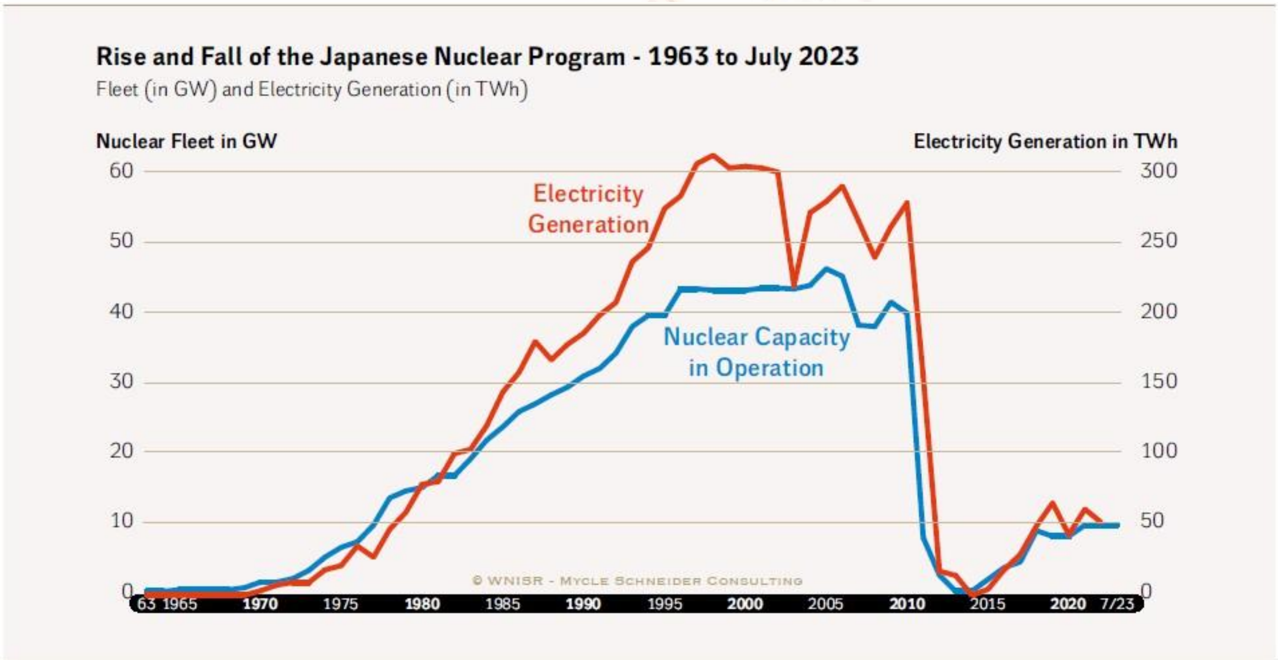
Other comparable examples for countries with very large, (unplanned) shutdown periods are Belgium, with all seven nuclear reactors being offline at some point and a cumulated outage between 31 and 276 days in 2018, compare Figure 3-3, and especially Japan, where large parts of the nuclear fleet were shut down after the catastrophic accident at the Fukushima Dai-ichi site in 2011 and have still not been restarted until today, see Figure 3-4.

Figure 3-3: Unavailability of Belgian nuclear reactors in 2018



Source: (Mycle Schneider Consulting 2019)

Figure 3-4: Japan's nuclear power production 1963-2023



Source: (Mycle Schneider Consulting 2023)

3.3.3 Conclusions

While the SESA claims nuclear power to by a reliable source of energy, based on the worldwide operational experience, nuclear power plants may face unplanned downtimes of considerable lengths. While nuclear power plants may be considered as a baseload source of electric energy, which does not depend on fluctuating natural resources like sunshine and wind, it still depends on a continuous supply of cooling water or may face unexpected safety issues. Nuclear power reactors or even larger parts of a nuclear power fleet may thus face unexpected downtimes for days, weeks and months, up to year-long unavailabilities.

3.4 Consideration of Alternatives

(NuPEA 2023, p. 33) defines as one of the tasks of the SESA:

> *"The main activities in the SESA study included:*
>
> *…*
>
> *Identification of alternative options and strategies, implementation of the Programme and time scale.*
>
> *…*
>
> *Identification of alternatives options and justification of preferred alternatives and linkages between any ongoing activities and proposed plan/ programmes."*

According to Chapter 10 "Conclusions" (NuPEA 2023, p. 270):

> *"The report also assesses the alternatives to the plan …"*

3.4.1 Claims made by the SESA

The SESA contains a Chapter 7 dedicated to the "Analyses of Alternative Options". Within this chapter, a subsection 7.2.3 analyses "Renewable Energy Technologies". The whole subsection consists of 88 words.

Besides this, the SESA states (NuPEA 2023, p. 190) about the "current" status of electricity production in Kenya:

> *"Kenya's current effective (grid connected) electricity capacity is 2,600MW. Electricity supply is predominantly sourced from hydro and geothermal sources. This generation energy mix comprises 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from biogas cogeneration and 0.4% from wind, respectively. The current electricity demand is 1,600 MW and is projected to grow to 2,600-3600 MW by 2020 hence will need to be developed further to accommodate the project nuclear power injection."*

In the SESA, only very limited and obviously outdated information on the development of alternatives to nuclear power can be found. (NuPEA 2023, p. 60) estimates:

> *"According to reference capacity fast-tracked/expansion case arising from the committed 5000 MW+ generation in the period until 2018, the additional capacity to be developed will include geothermal 2,095MW, natural gas 1,058MW (including conversions), wind 630MW and coal 1,920MW, thermal 163MW, cogeneration 18MW and imports 400MW. This will improve the status of power supply in the country."*

Correspondingly, (NuPEA 2023, p. 209) claims:

> *"The programme aims at promoting development and use of renewable energy sources to create a reliable, adequate and cost-effective energy supply regime to support industrial development. Key programmes and projects are prioritized for implementation to increase additional electricity installed capacity to 5,221 MW by 2022 from the following sources:*

- *93MW from Hydro Power Projects*
- *913MW from Geothermal Power Projects.*
- *800MW from Wind Power Projects.*
- *157MW from Biomass Power Projects.*
- *442MW from Solar Power Projects.*
- *328MW from Coal Power Project, and*
- *400MW from Imports."*

According to (NuPEA 2023, p. 106):

> *"The optimal development programme is dominated by geothermal, nuclear, coal, imports and wind power plants."*

With respect to the cost of nuclear power, (NuPEA 2023, p. 190) states that:

> *"From the financing point of view, nuclear plants have some special features that should be considered. The principal ones are:*
>
> - *Large investment.*
> - *Long lead and construction times.*
> - *Complex technology.*
> - *Regulatory risk; and*
>
> *Nuclear plants are capital-intensive compared with alternative energy sources."*

And it continues:

> *"… As to the renewable options (wind, solar, biomass, etc.), costs to produce equivalent amounts of energy are, as a rule, considerably higher than for nuclear plants."*

No data or sources are given by the SESA to prove these claims and no further discussion related to renewable energies as alternatives to the introduction of nuclear power can be found in the SESA.

3.4.2 Discussion

According to Statista the total installed electric capacity in Kenya is 3300 MW in 2022[4]:

> *"As of 2022, Kenya registered a total installed capacity to generate roughly 3,300 megawatts of electricity. It was the highest total installed capacity registered in the country since 2017. Geothermal power made the largest contribution to the total capacity, followed by hydro and thermal power sources"*

[4] https://www.statista.com/statistics/1240951/installed-capacity-of-electricity-generation-in-kenya/, last accessed 16.02.2024

Renewable sources contributed 2191 MW to this according to Statista[5]:

> *"The installed electricity capacity from renewable energy in Kenya remained stable at 2,191 megawatts in 2020. Overall, the capacity increased during the period in analysis, improving from 1,040 megawatts in 2010. As of 2020, renewable sources accounted for over 70 percent of the electricity capacity in the country."*

Of this, large parts were due to hydropower:

> *"As of 2022, Kenya registered an installed capacity to generate 839 megawatts of electricity from hydropower. The capacity slightly increased from the previous year, after keeping constant between 2017 and 2019."*[6]

as well as geothermal energy:

> *"As of 2022, Kenya registered an installed capacity to generate 950 megawatts of electricity from geothermal energy."*[7]

Based on these numbers, Kenya already today has a strong baseload capacity based on renewable sources like geothermal and hydropower, but only marginal capacity in the form of wind or solar photovoltaics.

The whole discussion of possible alternatives to nuclear power in the form of "Renewable Energy Technologies" is included in Chapter 7.2.3 and comprises 88 words. It lists possible future measures but does not contain any comparison of social or economic impacts of renewable energies instead of nuclear energies.

Additionally, subsection 7.2.4 on "Energy Technologies Development Programme" in two bullet points lists two research centres, one on renewable energy research and one on oil and gas extraction. Finally, subsection 7.2.7 also lists programmes on multipurpose dams, with a total of 100 MW hydropower.

Globally, a different picture can be drawn. The worldwide development of renewable energy production capacity is shown in Figure 3-5. It is clearly evident, that there is a very strong growth in production capacity, dominated by solar photovoltaic and onshore wind. Figure 3-6 shows the corresponding electricity generation over the time period 2010-2022, a nearly 100% increase in production from 4.2 Mio. GWh in 2010 to 7.9 Mio. GWh in 2022.

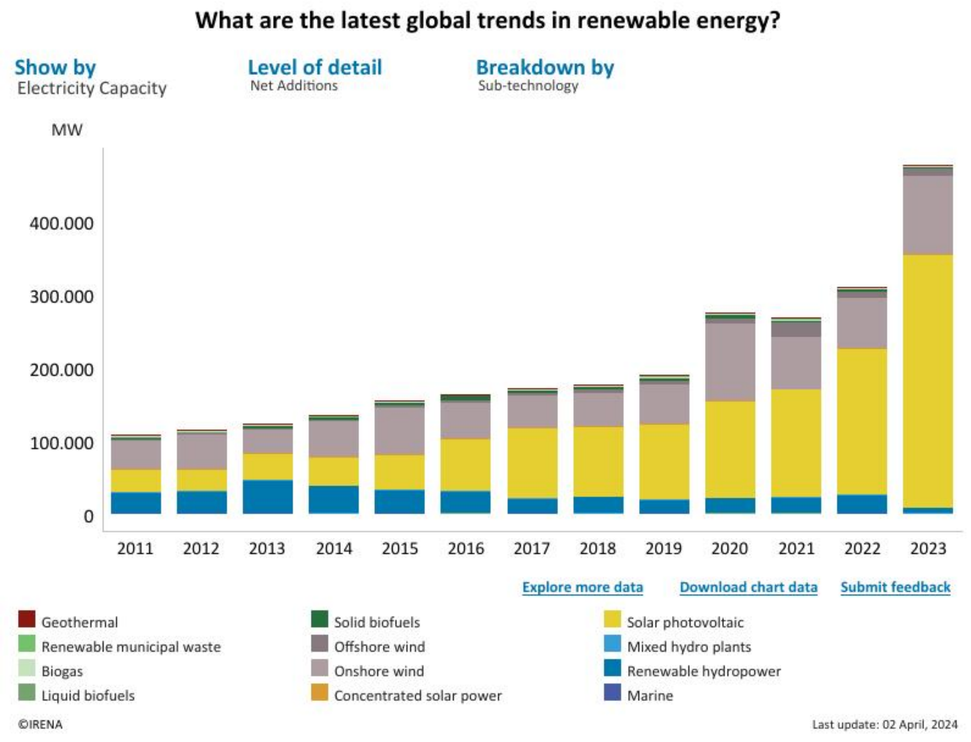
A comparison of the global investment decisions for renewable energies and nuclear power is given in Figure 3-7, clearly showing that since 2004 there is an unmistakable trend to invest in renewable energy production. Correspondingly, as shown in Figure 3-8, the cumulated electricity production of solar and wind since several years exceeds those of nuclear power. Wind alone will shortly outpace nuclear power production.

[5] https://www.statista.com/statistics/1277030/installed-electricity-capacity-from-renewable-energy-in-kenya/ last accessed 16.02.2024

[6] https://www.statista.com/statistics/1240891/installed-capacity-of-electricity-generation-from-hydropower-in-kenya/ last accessed 16.02.2024

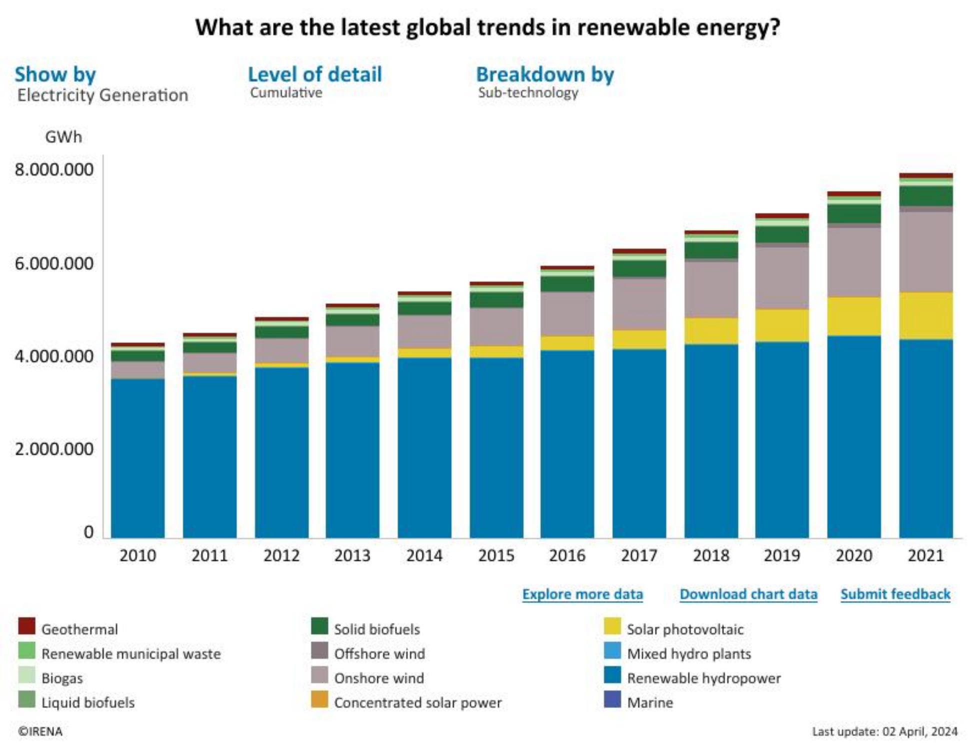
[7] https://www.statista.com/statistics/1240949/geothermal-power-electricity-installed-capacity-in-kenya/ last accessed 16.02.2024

Figure 3-5: Renewable electricity capacity worldwide 2011-2023



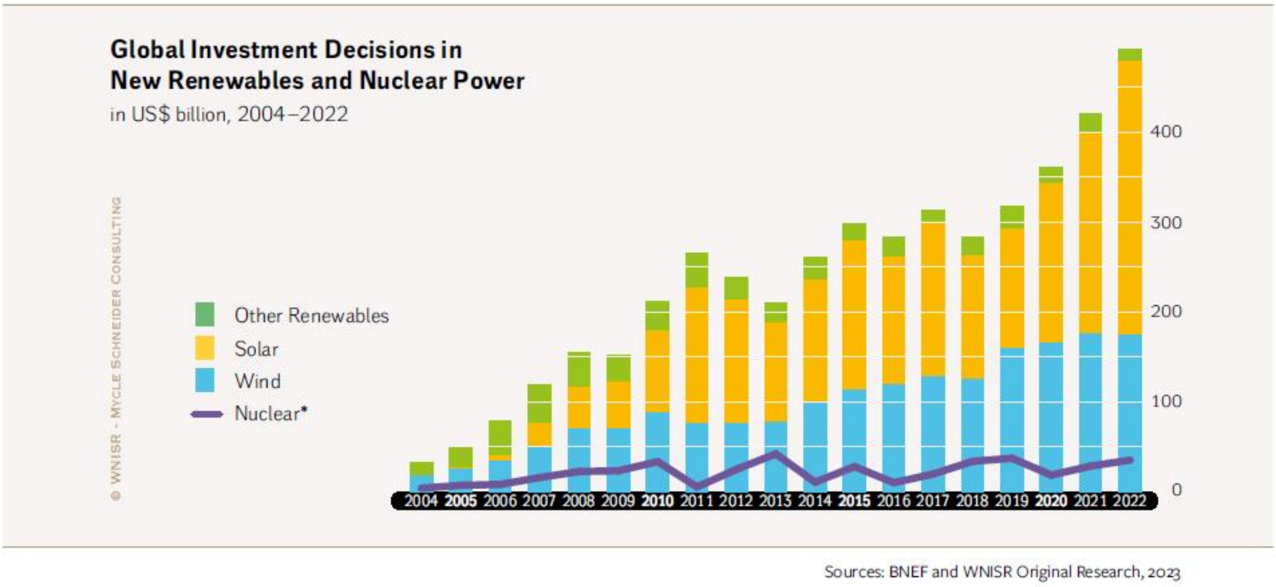
Source: (IRENA 2024)

Figure 3-6: Renewable electricity generation worldwide 2010-2022



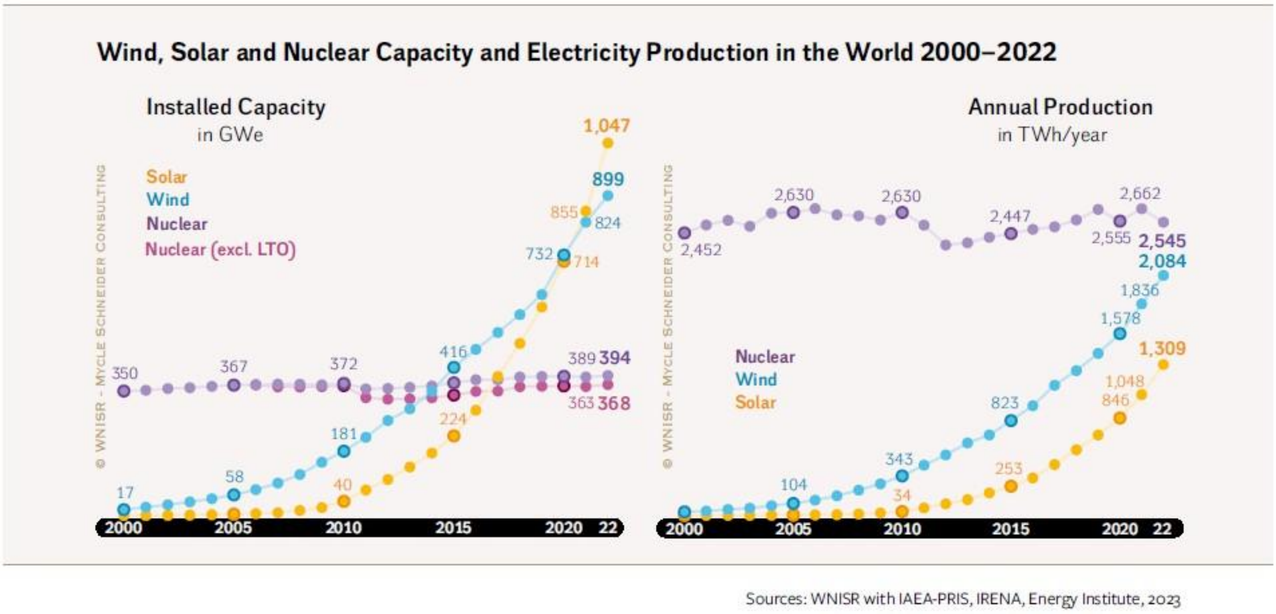
Source: (IRENA 2024)

Figure 3-7: Global Investment Decisions in Renewables and Nuclear Power, 2004–2022



Source: (Mycle Schneider Consulting 2023), Figure 62

Figure 3-8: Wind, Solar and Nuclear Installed Capacity and Electricity Production in the World



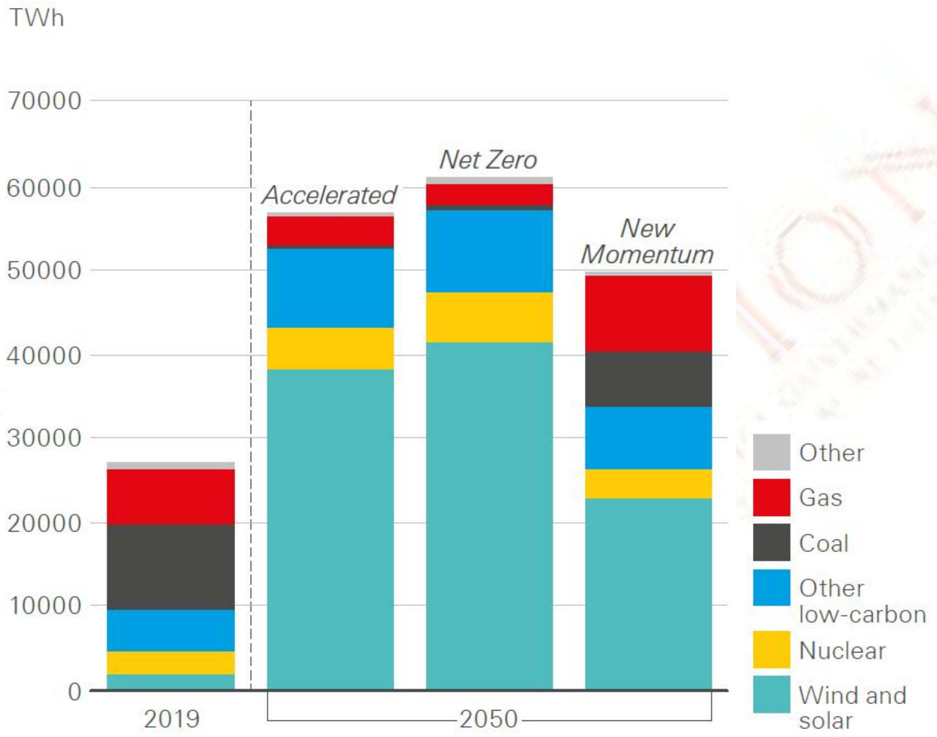
Source: (Mycle Schneider Consulting 2023), Figure 65

With respect to the future development of electricity production and renewable energies, the World Energy Outlook (BP 2023) concludes:

> *"The global power system decarbonizes, led by the increasing dominance of wind and solar power. Wind and solar account for all or most of the growth in power generation, aided by continuing cost competitiveness and an increasing ability to integrate high proportions of these variable power sources into power systems. The growth in wind and solar requires a significant acceleration in the financing and building of new capacity."*

This becomes evident in the projected worldwide electricity production 2050, compare Figure 3-9

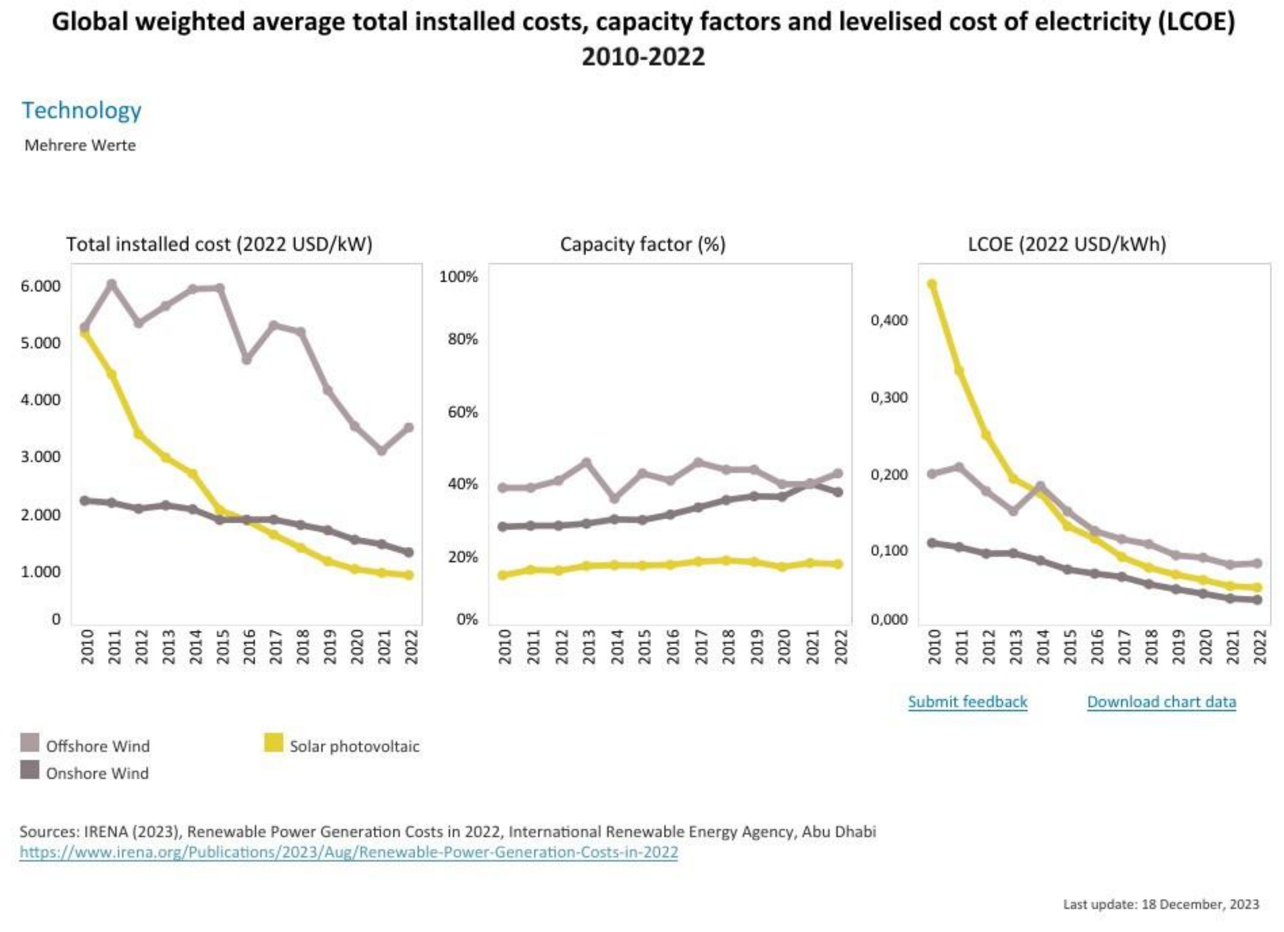
Figure 3-9: Worldwide electricity generation by fuel 2019 and estimated values for 2050



Source: (BP 2023)

This development is clearly driven by environmental but also economic reasons. The cost of nuclear electricity production has already been discussed in Chapter 2.1. The development of cost for renewable energy production by wind and solar photovoltaics is given in Figure 3-10. It is evident, that in 2010 production cost for electricity from solar photovoltaic were extremely high and even wind power was still comparatively expensive. But this picture has completely change during the corresponding time period. Today, onshore wind and solar photovoltaics are the least expensive means for electricity production, even in comparison to gas or coal production, compare Figure 2-5.

Figure 3-10: Global development of LCOE for wind and solar photovoltaic from 2010-2022

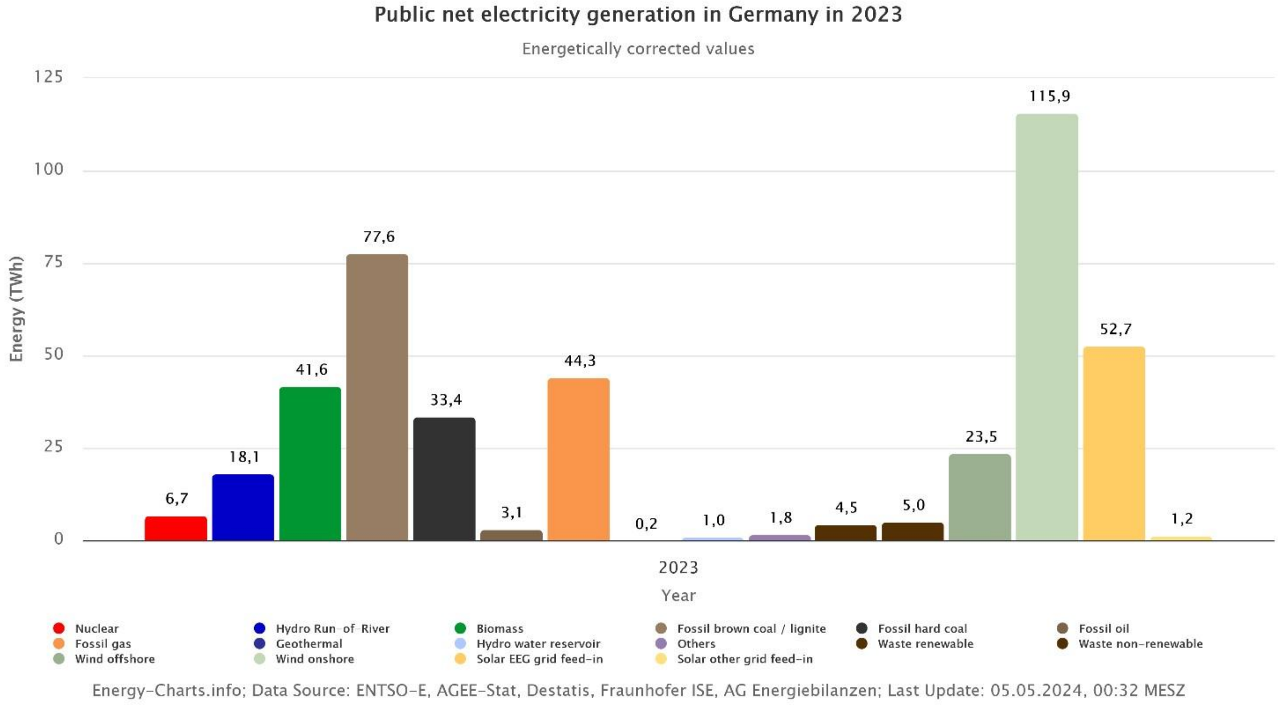


Source: (IRENA 2024)

Concerning the question of the feasibility of integrating high levels of renewable electricity into an electricity system, several studies have shown, that systems based on 100% renewable electricity production are feasible (Breyer et al. 2022).

High shares of wind and solar power production are already feasible. As an example, the case of Germany will be discussed. In 2023 solar photovoltaic produced approx. 54 TWh of electric energy, compare Figure 3-11. The maximum solar capacity fed into the grid was approx. 40.1 GW on 7 July 2023 at 13:15. The maximum share of total electricity generation at this time was 68% and the maximum share of total daily energy from all electricity sources was 36.8%. Wind power plants produced approx. 140 TWh in 2023. Wind energy was the strongest energy source of the year, followed by lignite, solar, natural gas, biomass, hard coal, hydropower and nuclear energy. The maximum wind power generated was approx. 53 GW on 21 December 2023 at 11:00 a.m. In total, the renewable energy sources solar, wind, water and biomass produced approx. 260 TWh in 2023. The share of renewable energy fed into the public electricity grid in Germany in relation to the load, i.e. the electricity mix that actually comes out of the socket, was 56.9% compared to 50.2% in 2022 (ISE 2024).

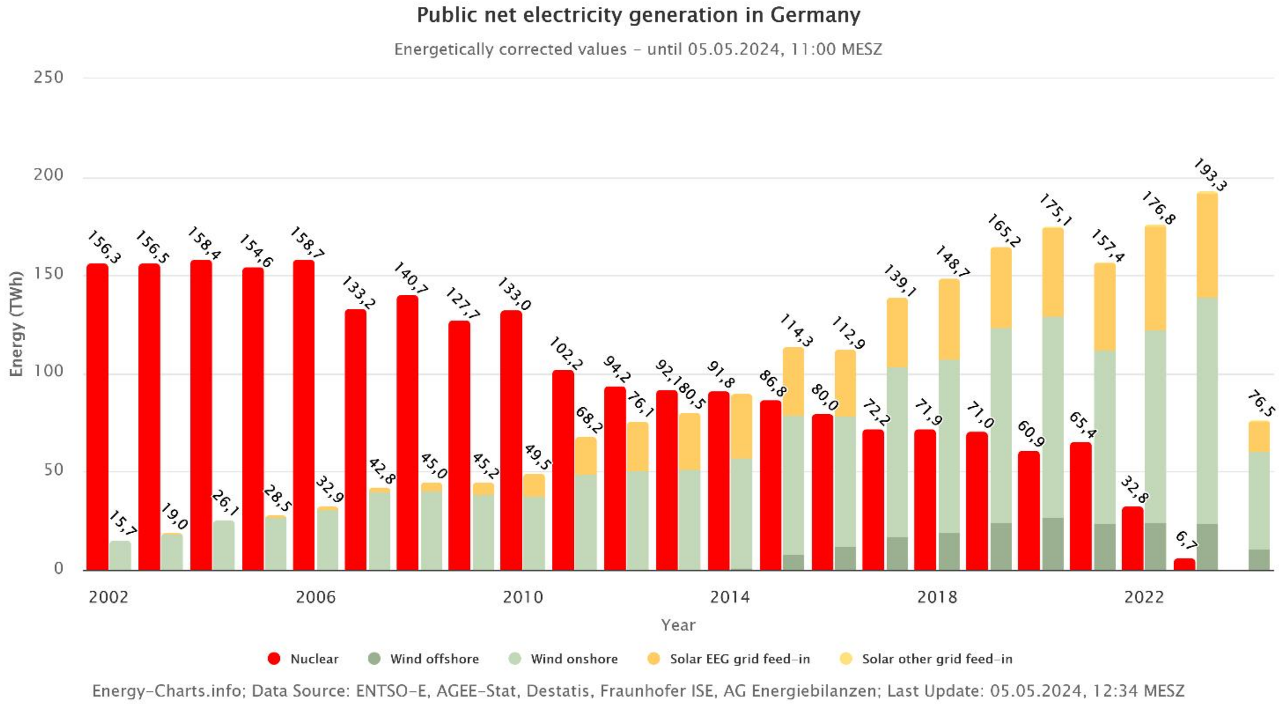
Figure 3-11: Public net electricity production in Germany 2023



Source: (ISE 2024)

Figure 3-12 shows the public net electricity generation in Germany from nuclear power in comparison to solar photovoltaic and wind power in the time period from 2022 to 2023. While nuclear power was phased out on 15 April 2023, electricity generation from solar and wind grew from initially 15.7 TWh in 2002 (about 10% of the nuclear generation in that year) to today nearly 200 TWh (120% of the maximum nuclear generation of that time period in the year 2006).

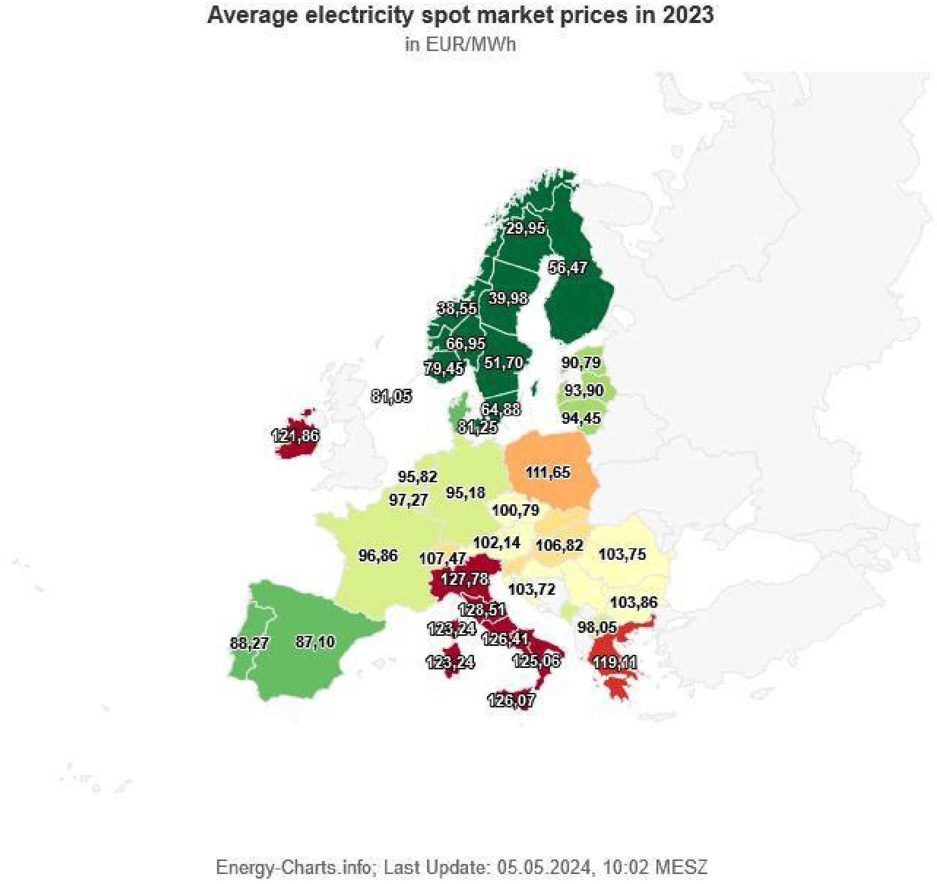
Figure 3-12: Public net electricity generation in Germany 2002-2023 (2024)



Source: https://www.energy-charts.info/charts/energy/chart.htm?l=en&c=DE&chartColumnSorting=default&interval=year&year=-1&sum=1&legendItems=0010000000000000011110&stacking=stacked_grouped

Despite this development, the average day-ahead spot market prices of electricity in Germany in 2023 were in the lower range of the average prices in Europe, compare Figure 3-13.

Figure 3-13: Average day-ahead spot market prices in Europe in 2023



Source: https://www.energy-charts.info/charts/price_average_map/chart.htm?l=en&c=DE&interval=year&year=2023

3.4.3 Conclusions

The SESA falls short of identifying alternative options and justifying the preferred alternative. Without giving any evidence and contrary to the international data available, it claims that cost of renewable energies as a rule are considerably higher than for nuclear plants. The SESA does not give any comparison of the possible economic or ecologic consequences of the preferred alternative to other alternatives. It does not compare the possible negative impacts of nuclear power (with respect to severe accidents, the generation of highly radioactive wastes or the security issues related to nuclear proliferation) with those of renewable energies like wind and solar photovoltaics (both of which do not face these important environmental issues). Therefore, the SESA does not fulfil one of its most important tasks: to present a clear and convincing basis for a political decision on the future electric power system of Kenya.

4 Summary and Conclusion

The SESA is written by SGS Kenya Limited for Nuclear Power and Energy Agency (NuPEA). The aim of the NuPEA is to promote and implement nuclear power in Kenya, therefore, the NuPEA cannot be seen as a neutral organisation with respect to a balanced assessment of nuclear power. Thus a thorough analysis of the SESA with respect to missing or inadequately discussed positive or negative impacts of an introduction of nuclear power in Kenya and a communication of these aspects to the general public as planned by CJGEA must be recognised as an urgently needed task.

The SESA correctly lists major cost factors of nuclear power like large investment needs, long lead and construction times, complexities, and risks. But without further justification, the SESA claims nuclear power to be cost competitive to conventional technologies like coal or gas and does not even give any reasonable comparison to renewable energies at all.

International analysis clearly shows that nuclear new build is one of the most expensive electricity production technologies today, more expensive than the use of coal and far more expensive than the use of renewables, even if storage cost is included.

The SESA furthermore claims that nuclear power is a predictable energy source. While this is certainly true with respect to its independence from intermittent energy provision like with solar or wind, nuclear power might also face relevant unplanned downtimes due to different reasons like cooling water shortages or safety issues.

Therefore, the SESA falls short of adequately identifying and assessing the economic consequences of introducing nuclear power in Kenya.

With respect to nuclear safety and the consequences of severe accidents in nuclear power plants, the SESA report refers to a very limited amount of scientific literature, which does not provide a comprehensive assessment of different consequences of severe accidents. While admitting different consequences of severe accidents, the SESA only discusses two indicators with respect to severe accidents – the number of fatalities and only to a very limited degree the cost of accident –, that are clearly an insufficient risk metric to fully represent the consequences of severe accidents.

The SESA report does not discuss other indicators with respect to severe accidents – like the number of people evacuated or relocated, the area of land contaminated for decades or even centuries nor the economic consequences of a severe accident – although they are relevant and there exists scientific literature making clear that these indicators must be taken into account.

Severe accidents in nuclear power plants can happen and they do have significant consequences for human health and the environment. Therefore, the SESA falls short of adequately identifying and assessing the possible safety consequences of introducing nuclear power in Kenya.

The SESA report does not fully assess the risks of nuclear proliferation when assessing the possible impacts of nuclear energy production in Kenya. Any use of nuclear weapons would have catastrophic impacts on human health and the environment. The SESA report evades the complex history and an in-depth discussion of the use of nuclear energy and nuclear proliferation. But nuclear technologies have a dual-use characteristic and therefore carry a potential for misuse. Any discussion of nuclear energy not covering nuclear proliferation is thus incomplete.

While the SESA recognises the possibility of terrorist attacks on a nuclear facility, if fails to assess possible consequences of a potentially successful terrorist attack. Thus, it also fails to fully assess the corresponding risk, nor does it compare this risk with possible alternatives to nuclear power.

Therefore, the SESA falls short of adequately identifying and assessing the possible security consequences of introducing nuclear power in Kenya.

According to the SESA, it is not clear which nuclear fuel cycle and hence which waste management strategy Kenya is aiming for. The former will have an impact on the latter, though, since an open cycle will entail different waste streams than a so-called closed cycle.

All options will necessarily require final disposal of high-level radioactive waste. In the SESA, neither option is discussed in a realistic manner, brushing aside difficulties that have been experienced elsewhere. Various countries have been struggling to find a site for a deep geologic repository for decades, so the SESA answer 'we burry it' is grossly misleading with respect to the technological and political complexity of the process of high-level waste disposal.

Reprocessing, while not fundamentally changing the problems associated with nuclear waste disposal, will bring additional proliferation risks, increase the cost of the nuclear fuel cycle and enhance the amount of low and intermediate level waste to be disposed of.

Therefore, the SESA falls short of adequately identifying and assessing the possible consequences of introducing nuclear power in Kenya with respect to nuclear waste management.

The SESA does not discuss possible environmental impacts of uranium production in Kenya, as it claims nuclear fuel to be purchased from abroad, while at the same time admitting that an exploration of uranium reserves in Kenya is planned for.

Therefore, the SESA falls short of adequately identifying and assessing the possible consequences of introducing nuclear power in Kenya with respect to uranium production for nuclear fuel.

While the site selection process in principle follows international recommendations on how to perform a site selection, several aspects of the site selection process are not explained in the SESA to a degree making it possible to reproduce the decisions taken by the responsible site selection team.

Even after execution of the screening and ranking process described in the SESA, many of the remaining possible sites, including the ones by far best ranked in the site selection process, are removed from the further process without convincing reasoning.

Therefore, the SESA falls short of making the site selection process transparent and comprehensible for the general public.

In the current version of the SESA, a very unclear picture of the future electricity demand, and the corresponding nuclear share is given. The introduction of a nuclear power programme in a country has to be recognised as a century-long commitment. For this whole timespan, the state will have to ensure sufficient expertise and infrastructure. Thus, there should be a clear and unambiguous picture of a future electricity demand justifying the introduction of nuclear power before such a commitment is made. Given the unclear picture painted by the SESA concerning the future electricity demand and nuclear's role in Kenya's electricity system, it is highly questionable whether such a decision should be taken on the current state of knowledge.

The current electricity grid in Kenya is not designed to support nuclear power plants with today's typical output of 1000-1750 MW. Substantial grid upgrades would be required before even individual nuclear power plants in Kenya could be connected to the grid. The SESA is discussing the use of SMRs as an alternative. However, despite intensive international discussion of SMR concepts, these are currently not a technologically available and commercially competitive option. According to current knowledge, the cost of SMRs would be significantly higher than that of large nuclear power plants.

While the SESA claims nuclear power to by a reliable source of energy, based on the worldwide operational experience, nuclear power plants may face unplanned downtimes of considerable length. While nuclear power plants may be considered as a baseload source of electric energy, that does not depend on fluctuating natural resources like sunshine and wind, it still depends on a continuous supply of cooling water or may face unexpected safety issues. Nuclear power reactors or even larger parts of a nuclear power fleet may thus face unexpected downtimes up to yearlong unavailabilities.

The SESA falls short of identifying alternatives options and justifying the preferred one. Without giving any evidence and contrary to the international data available, it claims that cost of renewable energies as a rule are considerably higher than for nuclear power. The SESA does not give any comparison of the possible economic or ecologic consequences of the preferred alternative to other alternatives. It does not compare the possible negative impacts of nuclear power (with respect to severe accidents, the generation of highly radioactive wastes or the security issues related to nuclear proliferation) with those of renewable energies like wind and solar photovoltaics (both of which do not face these important environmental issues).

Therefore, the SESA does not fulfil one of its most important tasks: to present a clear and convincing basis for a political decision on the future electric power system of Kenya.

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