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Small Modular Reactor Safety-in-Design and Perspectives

Nuclear Power is Dead, Long Live Nuclear Energy!

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Cover:
Site layout for the SMR nuclear site complex by MOLTEX Energy. A feasibility report for Canada with the MOLTEX concept under review has just been published.

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2020-year-in review –
The NuScale Energy Exploration Center, Copyright NuScale

A Role for Nuclear in the Future Dutch Energy Mix

Findings of a Study for the Dutch Parliament

Bojan Tomic and Mario van der Borst

Introduction The EU is embarking on the European "Green Deal", with the target to be "climate neutral" by 2050. With majority of EU greenhouse gas emissions coming from production and use of energy, all possible energy sources warrant a new look. Facing the need for a drastic reduction of CO_2 emissions over the next couple of decades, while having limited back up options for VREs a potential role of nuclear energy for the Netherlands in 2050 has been raised by the Dutch parliament. Among seven questions raised by the Dutch parliament (motion Yeşilgöz-Zegerius/Mulder (2018/2019 35167NR15) of specific interest were prospects and costs of new NPPs including SMRs, comparison with other sources of electricity also considering CO_2 costs as well as potential scenarios including nuclear that are possible for the Netherlands. Consideration of the security of supply, reliability, and flexibility as well as new development including hydrogen cycle were important. To respond to the parliamentary motion, the Ministry of Economic Affairs and Climate Policy of the Netherlands launched a "meta- study" to critically assess and compile information from numerous reports while placing those in the specific Dutch perspective. Furthermore, the Study was to examine the cost of electricity from nuclear power plants and other low-carbon electricity sources specifically for the Netherlands.

In their reports, most international organisations, from IPCC over US EIA, OECD NEA, WEC etc. favour deployment of nuclear to cope with climate change. Moreover, many see little chance of full decarbonisation without a significant contribution of nuclear. This is in particular so for the countries like the Netherlands where there are no other possibilities (except fossil) to complement the VRE (variable renewable energy) sources. This highlights the need for a cost comparison that would not just be based on the headline LCOE (levelized costs of electricity) than rather consider all the cost drives, from the cost of financing a source of electricity over the operating costs including the system costs to the cost of decommissioning and waste. In this, the Study corrected some of previous cost comparisons that often excluded realistic system costs and/or other subsidies available to VREs such as grid connection, etc. Furthermore, the effects of the "priority access" to the grid were investigated. In particular, the notion of a "level playing field" was investigated, including sensitivity studies to account for uncertainties in some of the parameters.

Upon its publication and presentation of the result in the Dutch Parliament a lively debate commenced, in the Chambers (and its committees) but also in the media and among the public. As expected, some of the particular strong reactions came from entities and interest groups representing the VREs, which claimed that ENCO study reached "wrong conclusion", while falling to establish technically sound/justified arguments as what was wrong in ENCO Study's conclusion.

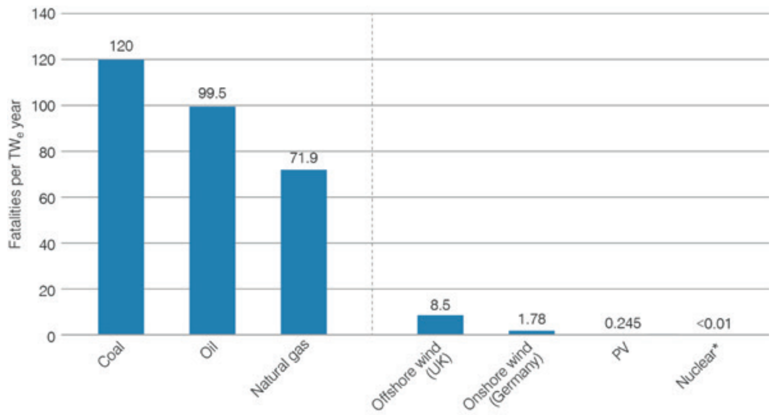
New nuclear power – where do we stand

As of May 2020, 441 nuclear reactors are operating in 31 countries, with 389,994 MWe total installed capacity. Further 54 nuclear power reactors are under construction, with a total of 57,444 MWe total net installed capacity. Developing nations with increasing energy needs and those heavily relying on coal (e.g. China and India) are leading the way in advancing nuclear construction, based on own and foreign technologies. Per IAEA, about 19 countries are starting or planning construction, and even countries that have never employed nuclear as an energy source, are reviewing their position (e.g. Australian Parliament's report). The world nuclear fleet generated 2,563 terawatt-hours (TWh) of electricity in 2018, a 2.4 percent increase over the previous year, which was essentially due to China's nuclear output increasing by 44 TWh (+19 %), but still 4 percent below the historic peak of 2006.

At the end of 2019, nuclear electricity constituted about 26 % of the EU's electricity generation. There are 126 nuclear power plants. There are active constructions of new NPPs in 3 EU Member states, and up to 6 MS are pursuing nuclear new built, of which Hungary expected to issue a construction licence for a new NPP in 2021. Regardless of massive investment in the VRE resources all across the EU, nuclear energy remains by far the largest (26.7 % in 2019) single source of low-carbon energy in the EU, ahead of hydro (12.3 %), wind (13.3 %), and solar (4.4 %).

As a possible contributor to the carbon-neutral future, small modular reactors (SMR) are receiving increased attention. This is due to the technological capability of nuclear to deliver on-demand electricity, coupled with a promise for great simplification and related cost reduction while applying industrial manufacturing and construction technologies at a factory rather than on site. The SMRs are expected to address the biggest obstacle for large nuclear power plants: long construction periods causing high capital costs. Active licensing activities with sites elected are underway in USA and Canada. Several EU countries expressed interest and as per news bulletins, some including Estonia and Poland started the negotiations with potential suppliers of SMRs.

One of the typical complaints regarding nuclear power is that it is unsafe. To the wider public, when considering with wide media coverage and public interest related with any nuclear accidents, and in particular Chernobyl and Fukushima, such a perception is understandable. However, the fact of the matter is that no one died from the radioactivity released during Fukushima accident (and as per UNSECAR report released on 21st March 2021 "Radiation-linked increases in cancer rates not expected to be seen"). As per multiple studies undertaken on the Chernobyl accident and its consequences, apart from several dozens of first responders who died shortly after the accident, there was a very limited number of deaths caused by the radioactive release. To put safety in the



* Gen II PWR, Swiss
Source: Paul-Scherrer Institut. Data for nuclear accidents modified to reflect UNSCEAR findings/recommendations 2012 and NRC SOARCA study 2015

Figure 1
Fatalities per TW of electricity generated for various sources.

perspective it is useful to assess the fatalities per unit of generated energy from various sources of electricity.

The fatalities caused by the nuclear industry in **Figure 1** reflect the GEN II nuclear plants. Integral to the GEN III and SMR reactors is the fundamental design requirement of a strict limit to any radiological release in a case of accident. GEN III nuclear plants as well as most SMRs are designed to be “inherently safe”, meaning minimisation of probability of accidents and exclusion of off-site consequences even in cases where a hypothetical accident is to occur. Deployment of such reactors would enable the construction also in highly populated countries, without concerns of the population in the vicinity of a plant. This applies even more to future GEN IV reactors, where innovative and/or revolutionary concepts might be expected to lead to fully inherently safe designs.

With that consideration, the notion of nuclear not being safe does not pass the scientific scrutiny. The energy that could have been produced in nuclear plants in Germany and instead was produced by burning coal, lignite and gas, affected the population and even much more the climate (in 2018 German CO_2 emission per capita was almost double of that in France or the UK) not just in Germany but also in the neighbouring countries.

Another criticism of nuclear power is that it generates radioactive waste that will remain dangerous for millions of years to come. While notionally true, it is also well known and often ignored that the amount of waste that remain dangerous for extended period of time is extremely small. Every other source of energy, even VREs generates waste that is dangerous to people and the environment and would need to be safely isolated, in quantities that are (much) larger than the radioactive waste generated in nuclear plants. Important advances have been achieved in the management of long-lived high-level radioactive waste. Disposal in special canisters in geologically stable layers in the deep underground is internationally regarded as a safe solution. Pragmatically-governed countries, in particular the EU Member states in Scandinavia, implemented solutions for long-lived waste that guarantees no effect to the public and environment for much longer periods that the humankind exist on the Earth. It is useful to put that in the perspective of currently non-recyclable PV panels, or ever increasing needs for exotic material including rare earth, cadmium or lithium, mining and processing of which leave enormous impact on the environment and its residues entering the water supply affecting the world’s population today. Furthermore, unlike any other sources of electricity, nuclear has from the very beginning been planned to require plant operators to make a provision for decommissioning and for disposing of any waste, thus these costs are ‘internalised’ as part of operating costs. No other source of electricity in the use today fully operates on such a principle.

Societal costs of nuclear

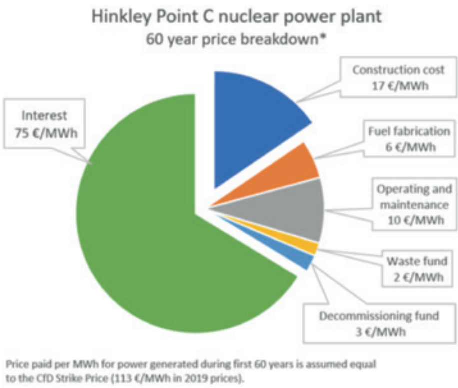
Every source of electricity (or indeed practically any other human activity) has external impact that are not fully reflected in the price, but which society as a whole must bear. The best example is the cost of emissions, which may (and in reality already is) cause damage to those who are not related nor benefitting from the activities. In the case of electricity generation, the external costs of interest are those related with three components: emissions of CO_2 and resulting climate change; damage/impact such as on health and crops associated with air, water or environmental pollutants and other non-environmental social costs.

External costs to the society from the operation of nuclear power could assumed to be negligible as there are no emissions from the operation, and the cost of management of waste and decommissioning are internalised, meaning included in the price. Nevertheless, one might argue that a serious accident causing damage which is beyond the insurance limit might become the societal costs. However, for modern nuclear plants the probability of such an accident is extremely low and societal costs might be expected not to exist for the Gen III or inherently safe SMRs.

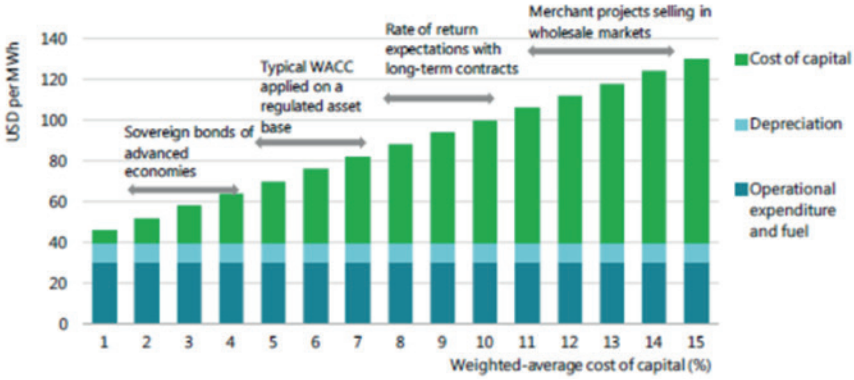
Electricity generation from fossil fuels is not regulated in the same way, and therefore the operators of thermal power plants do not to internalise the costs of greenhouse gas emission or of releases in the atmosphere. In some countries this is being addressed through the CO_2 pricing. For VREs the impact of the decommissioning and waste management are not even known, effectively making the future societal cost.

Externalities of electricity production are not limited to environmental and health related impact, but may be related with macro-economic, policy or strategic factors not reflected in market prices, such as security of supply, cost stability and broad economic impacts including employment. Although those externalities generally have not been subjected to systematic assessment and comparison, some qualitative analysis established high advantage for nuclear as compared with any other sources of electricity on the majority of the parameters of interest.

One further aspect for consideration is in relation to the social impact is the land utilisation. For this aspect, the extremely high energy density of nuclear (up to about a 1000 times) is a great benefit compared to VREs. Due to its low energy density, VREs require lots of space. This is particularly relevant for solar PVs, where the installations are competing with land available for agriculture and/or encroaching the preserved nature, and for onshore wind, where increased opposition due to noise (on



| **Figure 2**
The cost breakdown for Hinkley point C NPP.



| **Figure 3**
Cost of nuclear electricity in relation with WACC.

shorter distance), drop shadow and intrusions into natural settings is becoming omnipresent.

Especially in densely populated parts of Europe, such as the Netherlands, enormous needs for space for some of the technologies is becoming increasingly a limiting factor in the deployment. Further to this, the disturbance of the landscape complains are on the raise everywhere. Although the “NIMBY” phenomena affects any intervention, a much higher energy density of nuclear plants, the number of people affected is only a fraction of those affected by the low energy density VREs.

The cost of nuclear power

Often raised drawback for nuclear power is that it is just “too expensive”. Clearly, judging from the headline numbers, e.g. the price of two large GEN III nuclear units under construction at Hinkley point in the UK is above 24 billion Euros, or multiple costs increases for similar units in France (Flamanville 3) or Finland (Olkilouto 3), the cost are very high. Furthermore, many were astonished with so called” strike price” for the electricity from Hinkley point C being 94 GBP per MWhr when comparing that with currently traded price of about 50 to 60 GBP MWhr. However, the comparison with the strike price of about 140 GBP per MWhr for *non-dispatchable* offshore wind sources provides a bit of perspective. To assess the cost of nuclear it is important to understand its background. The cost comparison with other sources using the “levelized cost of electricity” (LCOE) provide interesting insights.

The construction of a nuclear plant is a large and extremely complex undertaking. While at the time of the most intensive deployment of nuclear plants in late seventies and eighties of the last century, typical construction period was in the order of 5 or so years. With fewer nuclear plants being built nowadays, the construction duration extended dramatically, beyond 15 years and counting for the EPR reactors in Finland and France. Given the high costs of a plant itself, just the cost of deployed capital over such a long period significantly contributes to the overall cost. However, this is not unique to nuclear plants. Other large and complex infrastructure projects experienced similar extension of the construction periods and resulting effects on the costs, e.g. an airport (BER, a factor of 3 cost increase) or a railway (Crossrail, factor of 3.5 cost increase and counting). The difference to those is in the financing costs.

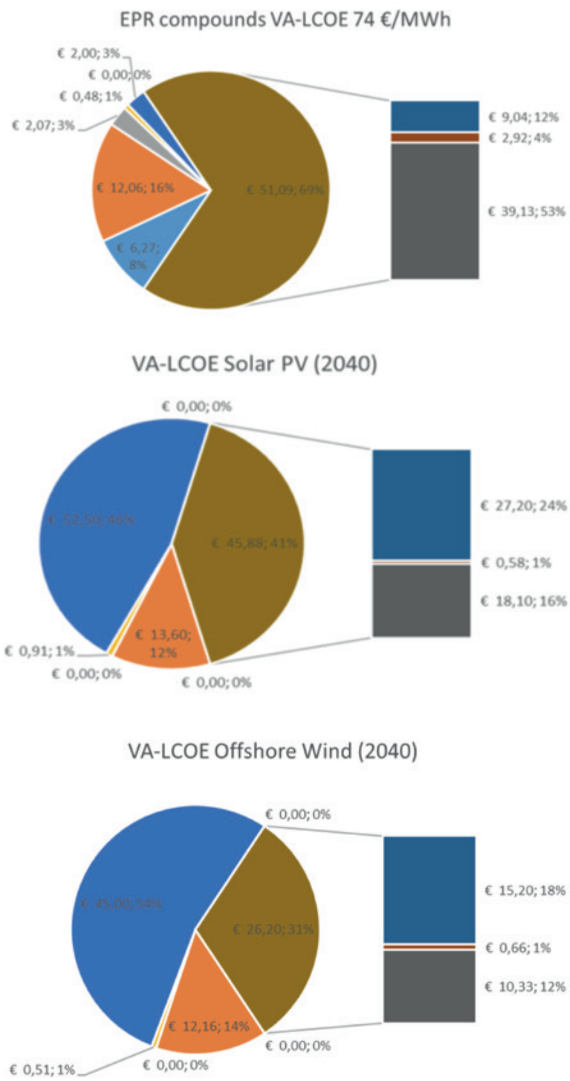
The cost of capital

Where the nuclear plants are really penalised, and which is the dominant cause of their high price, is the costs of the capital. While infrastructure projects such as BER and Crossrail attract the capital with very low costs, due to a perceived risk related to nuclear projects, the cost of capital encompasses a risk premium. In the costs profile of new nuclear the majority is indeed the costs of capital, i.e. interest and risk premium. For Hinkley point C, about 65 % of the total cost of the plant is associated with interest payment.

It is obvious that with the cost of capital as it is in the EU today (zero or negative interest rates), an investment model where two thirds of the cost is to cover the interest is not sustainable. With the weighted cost of the capital (WACC) in the range of 4 %, simular to what is used in VRE projects, nuclear becomes fully cost competitive with other sources of carbon free electricity.

The system cost

Apart from the costs of investment (construction) and operating costs (fuel, operation, maintenance) various



| **Figure 4**
The contributors to cost of electricity, comparison between nuclear, solar and wind.

energy technologies would have specific costs related to the integration into the electricity supply system. The system costs typically include the balancing costs (deviations from the planned production and extra cost for investment in reserves), the profile cost (technology dependant, i.e. anti-cyclicals able to achieve higher prices) and the grid cost (extra cost of expanding the grid). The system costs are highly dependent on the configuration of the electrical system – the energy mix. The system costs is what differentiate between reliably dispatchable energy sources being able to supply agreed electricity to the grid and non-dispatchable ones, being dependant on external influences like weather and therefore requiring backups. For the VREs, the system costs are also dramatically increasing with the penetration, while dispatchable technologies might be credited with system benefits due to being able to vary their outputs to support system stability.

The further point of attention is the electric potential (in installed MW) that is needed to guarantee the supply of electricity in dispatched MWh. This is best explained by comparing solar and nuclear. Because of the capacity factor of about 10 % for solar and 90 % for nuclear, the installed capacity for solar to generate the same amount of electricity needs to be 9 times larger. The LCOE cost calculation takes this into the account only as far as the expected production of electricity from different sources is concerned (i.e. capacity factor). However, the grid costs and in particular the balancing and profile costs to assure reliable supply of electricity, are (much) higher for VRE, and dramatically increasing with the higher penetration. The system costs strongly depends on the geography i.e. whether large hydro is available. Typical studies addressing the system costs always take into the account a certain proportion of hydraulic plants, which is not the case in countries such as the Netherlands.

Another important consideration is that the deployment of a large share of variable-electricity generating sources with (nearly) zero marginal cost has a profound impact on the functioning of electricity markets and on the operation of the generating capacity. In the short term, reduced load factors (the compression effect) and lower prices affect the economics of all dispatchable generators. Above certain level of penetration of VRE and at specific weather conditions, there would be no other generators on the market, leading to a necessity of shutting down some of the VRE producers. At that time the implicit promise (i.e. the state guarantee) that all electricity that would be generated by VREs will be taken by the grid and delivered to the consumers suddenly disappears, further increasing system cost but also the LCOE due to lower overall utilisation.

The system costs for the dispatchable sources such as nuclear or coal/gas are very small, in the order of 2 Euro/MWh. With a low penetration of VRE, the system costs remain small, as there are enough reserves to balance the grid when VREs are not generating. With an increased penetration of VRE, and in particular above about 50 %, the system costs become a dominant contributor, as documented in the research of the IEA in the **Figure 5**.

The decarbonation of electricity supply with VRE only leads to the situation of both very high costs (due to electric potential, needs for grid development, etc.) AND accepting regular blackouts as there will be periods when none of the VREs would generate electricity. Availability of VREs is internally closely related, i.e. non redundant: doubling the amount of PV panels will not add to overnight supply; all windmills would stand still when there is no wind.

The studies analysing VRE role in the electric supply often significantly underestimate system cost by projecting upwards from the current situation where there is 10-20 % penetration. Sometimes the "low" system costs are justified with the assumption that electricity will be unavailable for certain amount of time, which is very likely not acceptable to today's society. Furthermore, typically advertised "low cost of VRE" often exclude the grid connection cost, which in a case of offshore wind becoming a dominant contributor. On the contrary, nuclear is constantly dispatchable, able to balance the grid and its investment costs already include the grid connection.

It should be highlighted that some nuclear plants are now being approved to operate for 80 years, while the wind generators and solar panels have projected lifetime up to a maximum of 25 years (with discernible degradation over the lifetime for solar PV). Typically, after about 25 years, the investment in a nuclear plant is already paid off. For VRE, this is exactly the time when the new investment cycle is needed.

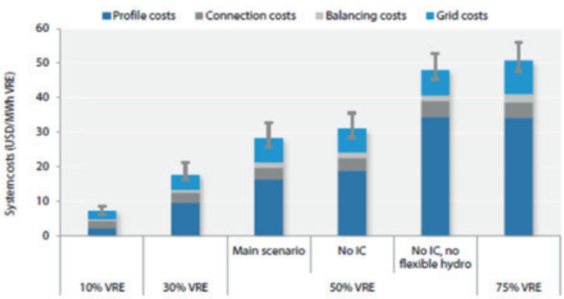


Figure 5
The relation of system cost to the penetration of VREs.

The LCOE estimates for the Netherlands for the year 2040

The key request by the Ministry of Economic Affairs and Climate Policy was to estimate the LCOE for several electricity generation technologies for the year 2040, on a comparable basis specifically for the Netherlands. The study considered the following emission free sources of electricity:

- Large nuclear GEN-III plant
- Nuclear SMR
- Off-shore wind
- On-shore wind
- Large solar PV
- Hydrogen Power

To make this comparison meaningful with expected higher (50 %) penetration of VREs, the adjusted "LCOE*" was calculated to include the system effects, as defined by the OECD NEA.

A full utilisation was assumed for all sources of electricity, meaning that each source would be allowed to deliver to the grid when it is capable to deliver, independent of electricity-exchange-market or other prioritization mechanisms. For the stability of the electrical grid with the higher VRE penetration rates, VRE units would also be obliged to shut down or reduce the output at certain moments, like now is the case with the dispatchable plants. This will result in the utilisation rates being lower than 100 %. As those are not driven only by economic considerations, rather by political and other issues, the Study did not elaborate further on the expected utilisation rate. The basis assumption for the assessment is included in the list in the following table.

The findings could be best illustrated by the summary **Figure 6**.

The results are pretty obvious: even limiting the VRE penetration rate to 50 %, the system costs became so dominant that the dispatchable sources are visibly cheaper than the VREs. Compared with the offshore wind, onshore wind and solar PV, two nuclear options remain cheaper when realistic system costs are considered in the LCOE*. The Hydrogen Round trip is very costly. The explanation is in the low efficiency, between 25 % and 39 % for the electrolyser and the turbine, meaning that 60 % to 75 % of the energy is lost in the process. The hydrogen storage is assumed to be in the salt-caverns. When storage in high pressure casks is selected, the LCOE* for this option could be 5-10 times higher.

As with any prediction for the future in a dynamic and changing environment, the point values might be far off if the assumptions change. All such estimations, and in particular those that are addressing the more distant future, could only be made on the basis of a set of assumptions, covering wide range of issues, from the technology development to the cost of financing and learning curves. While the projections of the LCOE* are considered the best estimate, it was highly interesting to assess how those estimates would be influenced by changes in the assumptions and/or relevant parameters. The Study undertook a series of sensitivity analysis, covering the following:

- Construction times (duration)
- Learning effects consideration
- Impact of the lifetime of a plant
- Utilisation rates of a plant
- Interest-rate (WACC) sensitivity
- System costs sensitivity
- Sensitivity cases for hydrogen utilisation

The results are depicted in the **Figure 7**, indicating the effects of uncertainties.

The example sensitivity case for the VRE penetration rate of 75 % shows an interesting correlation. The increased penetration of VREs from about 50 % to about 75 % leads to approximately doubling of the system costs for every technology. However, for the technologies with lower system costs, this effect is barely visible while for the non-dispatchable sources of electricity it dominates, as in the **Figure 8.**

ENCO report caused quite a stir in the Dutch media and politics

The prevailing public opinion in the Netherlands is that nuclear indeed contributes to lowering the emissions, but that the costs would be many times higher than solar and wind energy. Reference is often made to the cost overruns of the new construction projects in Finland and France. As a result, enthusiasm for nuclear energy decreased even among the most interested parties.

The ENCO report made it clear that nuclear energy can compete with solar and wind energy in the future, if the system costs are allocated to the energy source causing those. This message did not please the renewable energy interests and many articles appeared in the media contradicting the Study conclusions. Most of the articles lacked factual arguments and attempts were made to discredit the authors of the ENCO report.

The consultancy firm Kalavasta, which had previously published a report on the "Costs of Nuclear Energy", wrote a negative assessment report, mainly focusing on the fact that" system costs are not that high". The conclusion and arguments used have been thoroughly refuted by the Dutch journal Kernvisie.

Reflecting Kalvasta criticism of the ENCO report, questions were asked in the Dutch parliament. The Parliamentary committee organised a round table discussion on December 2nd 2020 attended by the members of the Parliament and a variety of experts from energy companies, NGOs, consultancies and universities. Unsurprisingly, this discussion ended in a draw.

In the meantime, EPZ, the operator of the nuclear power plant Borssele, announced that it is preparing the extension of its lifetime after 2033 and consideration for the expansion of Borssele site with two new large nuclear power plants. Several Dutch provinces, such as Zeeland and Brabant, do not rule out nuclear energy as a solution for achieving a 100 % CO_2 neutral economy by 2050.

On March 17th the elections for the Dutch parliament took place. Nuclear energy was one of the major discussion topics during the campaign, including the argument that there is not sufficient space in the Netherlands to rely on wind and solar energy for decarbonisation. The opponents claiming that nuclear energy is too expensive. The political parties that believe in a role for nuclear energy to tackle the climate problem represent the majority in the new Dutch

General assumptions LCOE assessment	Nuclear	VRE	Hydrogen P2P
WACC	7 %	4,3 %	4,3 %
Technical Lifetime (years)	60	25	20, electrolysers limiting
Depreciation period	technical lifetime	technical lifetime	technical lifetime
Utilisation factor	100 %	100 %	50 %
Decommissioning costs	15 % of capital costs, discounted at 3 %	5% of capital costs, discounted at 3 %	5% of capital costs, discounted at 3 %
Waste costs	Spent fuel disposal and storage, decomm. waste included in decomm. costs and operational waste in O&M costs	Decommissioning waste included in decomm. costs and operational waste in O&M costs	Decommissioning. waste included in decomm. costs and operational waste in O&M costs
Construction time (years)	7	0,5 – 1,5	3, CCGT limiting

Table 1
The relation of system cost to the penetration of VREs.

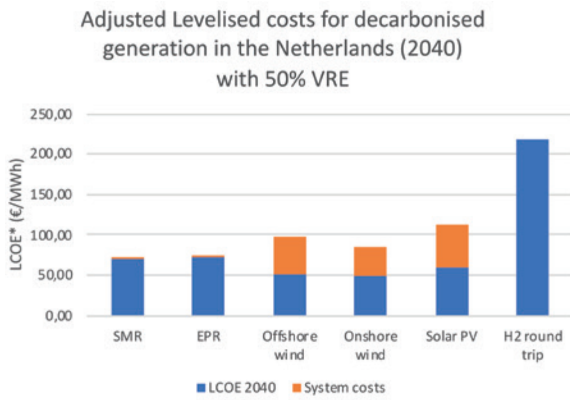


Figure 6
LCOE* for the decarbonised generation for the Netherlands in 2040.

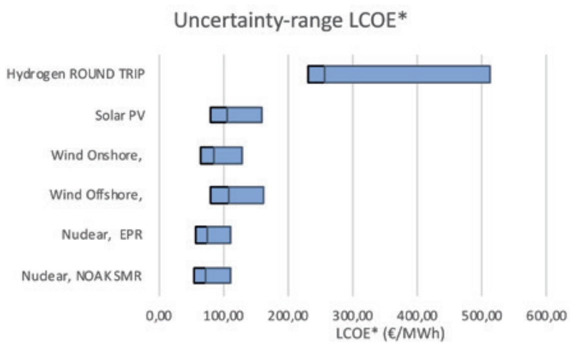


Figure 7
The results of sensitivity analysis on the LCOE*.

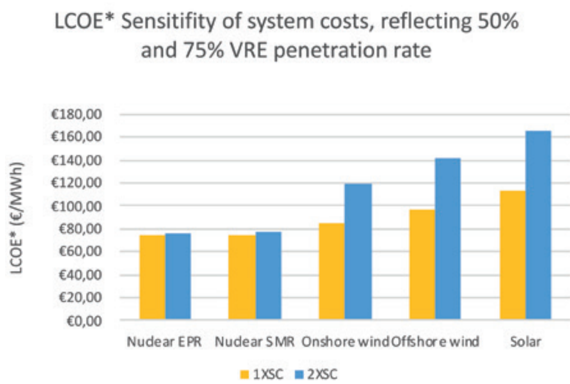


Figure 8
The results of sensitivity analysis on the LCOE*.

parliament (80 out of 150 seats). It is expected that the nuclear option will be the topic for the Dutch political discussions for the coming years.

From financial standpoint it is recognized that system costs are the discriminating factor between nuclear and the VRE. Numerous institutes, including PBL, TNO but also Berenschot/Kalavasta, involved in the development of the Dutch energy scenario studies all consider system costs in their analysis. However, the system costs as projected for VRE are (by far) too optimistic and systematically fail to consider obvious uncertainties. The extrapolation from the present situation to the one where VREs predominate is obviously impossible, because in the present world the VRE caused system costs are absorbed by the still-available margins in the electrical system. Some studies consider arrangements to moderate system cost including smart grids, load rejection, car-loading systems and decentralised generation enable short transport trajectories. All these solutions have their limitations and many are not established and their technical merits and general acceptance is uncertain. Furthermore, zero curtailment (100 % utilisation) is assumed for the VRE, and 50 % to 70 % curtailment for nuclear. With higher VRE penetration this becomes impossible and furthermore it obviously does not establish a level playing field, where all CO_2 free generators should have the same priority to the grid.

Conclusions

The outcome of the Study for the Netherlands lead to some interesting insights. When the system costs are properly accounted for, two nuclear options are markedly cheaper than the offshore wind and significantly cheaper than photovoltaic. This is even before other (positive) externalities are considered, e.g. the lifetime of nuclear plants being 60 or even 80 years, while the VREs at best last for 25 years, the spatial impact of nuclear is a minuscule fraction of that for the VREs, or that the cost of nuclear already include provisions for decommissioning and safe disposals of all of its waste.

The positive vision on future developments is affecting all technologies, though mainly the offshore wind and nuclear SMR. For large nuclear significant saving could be achieved by reducing the duration of the construction; it is however uncertain whether nuclear industry would be able to erect a NPP in Europe in less than 7 years. A much more dramatic impact is observed with the reduction of the capital costs for a nuclear plant. When the WACC is reduced from 7 % to 4,3 %, the resulting decrease of LCOE* is around 25 %. With some EU governments being able to borrow at negative rates, low WACC for nuclear by implementing risk-sharing instruments becomes a pretty logical consideration.

When the design lifetime of nuclear plant is being extended from 60 to 80 years, the impact of this change on LCOE* appears low. This is because of the devaluation of money, the impact of the last 20 years on the LCOE* in relation to the full lifetime is not that significant (due to the constant value calculation).

The LCOE* of all electricity generation sources is driven by capital costs. All sources have roughly the same dependence on the utilisation, as all need to operate to generate income. The impact from 100 % to 60 % is moderate. Below 60 %, the LCOE* increases fast.

The LCOE* of Hydrogen Round trip units is extremely high, especially affected by lower utilisation factor of electrolysers. At the UF of 20 %, a typical utilisation factor of a "Peaker" unit, the LCOE* will increase to above 700 €/MWh.

Nuclear power emits no greenhouse gases. The complete nuclear power supply chain, from uranium mining to waste disposal, including the construction and operation, is estimated to emit only 2–6 grams of CO_2 per kilowatt-hour generated. This is less than even wind and solar, and up to two orders of magnitude fossil fuels. Nuclear should not be viewed as being in competition with "renewable" sources of energy, such as wind or solar. As the reduction of carbon emissions becoming a top priority, both nuclear and renewable sources have both roles to play.

Possibly the most relevant finding from the Study is that with the level playing field for all non-carbon emitting sources for electricity, nuclear is fully competitive and even dominates other sources in several areas. The current situation where VREs are effectively subsidized by having guaranteed income (i.e. all VRE generation is taken by the grid and paid for at a predetermined price, regardless of the need for such electricity) will became impossible with higher penetration of VREs, as some will have to periodically shut down. This, together with system costs, further undermines the competitiveness of VREs. On the contrary, nuclear with its guaranteed dispatchability and reliability of supply, when financed with capital costs that are prevailing in the markets today, becomes the most affordable non carbon emitting source of electricity.

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Bojan Tomic has more than 35 years experience in the nuclear sector internationally. He started his career as the designer of nuclear plant safety systems at Combustion engineering in USA. He was a First officer at the IAEA's Nuclear safety division, with responsibilities for probabilistic safety assessments and operational safety. He continued his career as a consultant with ENCO, advising clients on various aspects of utilisation of nuclear and radiological technologies worldwide. He was engaged in numerous modelling and analytical studies, including due diligence assessment for new nuclear units. Bojan has been involved with many nuclear safety initiatives at the EU level, most notably in the EU Post Fukushima Stress test activities, where he led the peer review team assessing national stress tests in several countries including Germany. More recently he was on the Board of ENSREG's Topical peer review on Ageing management of NPPs. Mr Tomic is a member of the Borssele Benchmark committee.

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Mario van der Borst started his career in R&D at TNO in the Netherlands. In 1984 he entered the Nuclear Industry. He specialized in Thermo-Hydraulics and Probabilistic Safety Assessments. He was responsible for major back-fitting and O&M projects at the NPP Borssele. From 2003 till 2010 he was the Technical Director of this plant. In 2010 he entered the RWE New Build Team to be responsible for Technology, Authorization and Regulation. At that time RWE was involved in NNB projects in the UK, Netherlands, Romania and Bulgaria. He is president of the Dutch Nuclear society. At the moment he is principal consultant.