EUROPEAN UNIVERSITY INSTITUTE

17 April 2023

Lecture

Nuclear energy: quo vadis?

Speakers: Ronnie Belmans and William D'haeseleer
(Professors at KU Leuven/EnergyVille)

Memo by Anca Radu
(Researcher, Law Department)

This event has been organised by the
Technological Change and Society Interdisciplinary Research Cluster

Ronnie Belmans received his MSc degree in electrical engineering in 1979 and a PhD degree in 1984, both from KU Leuven, Belgium. In 1989, he added a Special Doctorate from the KU Leuven and in 1993 a 'Habilitierung', from the RWTH, Aachen, Germany. **Ronnie Belmans** was Full Professor at KU Leuven, teaching techno-economical aspects of power systems, electrical energy, and regulatory affairs, among others. He became Emeritus Professor in 2021. His research interests include smart grids, security of energy supply and the techno-economic aspects of the liberalisation of the electricity market. Prof. Dr. Ir. **Ronnie Belmans** was co-founder and CEO of EnergyVille, a research collaboration in Genk specialising in sustainable energy in smart cities and buildings, in cooperation with VITO, UHasselt and imec. **Ronnie Belmans** is also Honorary Chairman of the board of directors of ELIA, the Belgian transmission system operator. He is member of the board of directors of SCK-CEN, the nuclear research centre in Belgium and niko NV.

William D. D'haeseleer is Full Professor in the College of Engineering of the University of Leuven (K.U. Leuven), Belgium. His research activities are situated in the areas of energy conservation and energy management, energy and environment, energy systems, and energy policy. He is Director of the University of Leuven Energy Institute. He is also Head of the Division of Energy Conversion and Applied Mechanics and co-founder of the Foundation Industry-University. **William D'haeseleer** obtained the degrees in Electro-Mechanical Engineering (option Energy; 5y program) and Nuclear Engineering from the K.U. Leuven in 1980 and 1982, respectively. In December 1983, he graduated as Master of Science in Electrical Engineering from the University of Wisconsin-Madison (UW-M), USA. He obtained his Doctoral Degree (PhD) at the same university UW-M in May 1988. From 1988 untill 1993, he resided in Germany, where he was a Scientific Staff Member of the NET Team at the Max-Planck-Institut für Plasmaphysik in Garching-bei-München. From 1993 untill 1996, he was active in the Belgian engineering consulting company Tractebel Engineering, where he was Manager of the Mechanical Design Section, and Research and Development Manager of the Nuclear Department. As of October 1996, he is a full-time faculty member at the K.U. Leuven. He has been a Fulbright Fellow, and in 1989, he has been Visiting Assistant Professor at the Rennselaer Polytechnic Institute in Troy, New York. Presently, **William D'haeseleer** is Chairman of Cogen Vlaanderen, the Flemish association for the promotion of high-quality cogeneration, he is Chairman of the Energy Section of the Royal Flemish Engineering Association (KVIV), and he is President of the Belgian Nuclear higher Education Network (BNEN). He was an active member of the Belgian AMPERE Commission, and at present, he is an active member of the Commission's Advisory Group on Energy (AGE) and its Strategic Working Group (S-WOG). **William D'haeseleer** is also Chairman of the EEI.

This lecture focused on the contributions of the nuclear power plants and evaluated the potential of the nuclear energy. In doing so, it sought to find answers to the following questions:

- How were the existing nuclear power plants integrated in the energy system of the seventies and eighties of the twentieth century? What was and is their contribution to the present overall energy supply in Europe?
- What is the distinction between existing nuclear power plants (and their long-term operation) and new build? Why is there so much difference in building large units in the Western world (FIN, FR, UK, USA) versus other places (UAE, CN, KOR)?
- What are the next steps in nuclear reactor technology? What are SMRs? How to distinguish between shorter horizon smaller light water reactors (comparable with present large reactors) and Generation IV or other so-called 'advanced' modular units?
- What can/should be the role of nuclear in the far-future electric power system, dominated by massive amounts of naturally fluctuating renewables and short-term storage, and by extension of the overall energy economy?
- What is the difference between 'safety' and 'reliability'?
- What could be the role of nuclear fusion as a possible 'ultimate solution'?

Professor **Belmans** started the lecture by recalling the triangle between regulation – economics – technology as an important and complex perspective one should bear in mind when trying to understand how to have nuclear energy in a future renewable energy-dominated power system. While nuclear is and will always be there, the real bulk of the electric energy will be delivered by renewables. So, the question that arises is what task/s could be performed by renewables in a system that is affordable, reliable, sustainable and CO2 neutral.

He then showed us the picture of the Tihange Nuclear Power Station to prove the extremely small footprint of nuclear power. We were looking at 25% of the electricity production in Belgium, deriving from only 3 nuclear power plants. Thus, nuclear is a compact source. Then, we looked at how nuclear power created a very high voltage grid for supplying the demand at longer distance. The map we were shown was built in the 60s to the 80s. Further, we saw where nuclear power is today in the European countries – the ones who produce nuclear electricity, in a descending order, are France, Sweden, Spain, Finland, Belgium, Czech Republic, Slovakia, Bulgaria, Romania, Hungary and the Netherlands.

Professor **Belmans** further showed us what happens on the energy market once renewables are introduced. In sum, we can see that the peak generators will become out of service, the same will happen also to mid loads, and if even more renewables are introduced, the same thing will happen with the base load too, but flexible controllable generation resembling somewhat peak load of the past, will return. And this is the current challenge. Normally, the nuclear production is dictated by the demand. This led to giving lower prices to electricity during the night in order to encourage people use more electricity at night, thus allow power plants to operate on a constant basis. This is called demand side management that gives an equilibrium and is similar to the non-flexible generation of renewables. This makes renewables quite resembled nuclear, in the sense that their outputs cannot be controlled.

Whereas in the classical energy model, demand sets generation, the new developing system looks completely different. To prove this, Professor **Belmans** showed us data he generated from the Belgian's Electricity System Operator – Elia, where we could see the real data of different generation schedules, as well as the base load that completely covered by nuclear power. The same site also provides wind and solar forecasts, and then compares them to the measured real wind. The reason why wind and solar outputs need to be as accurate as possible, is to better deal with unbalances between demand and supply, which otherwise would cost a lot. Therefore, accurate weather forecasts allow for a smooth transition towards the future power system, where generation will set the demands. Professor **Belmans** showed us that the wind is in the North Sea (growing towards 300 gigawatts), and what will be needed for the grid is to bring these 300 gigawatts to the countries where it is needed most, for instance Germany, Switzerland, Czechia, Poland, etc. Eventually, nuclear may be part of the game plan, but will be living in a completely different surrounding compared to the past.

Lastly, Professor **Belmans** exemplified us a model designed by EnergyVille imagining a CO_2 neutral Belgium by 2050. There is a central system, where the industrial product demand is stable, and the technical renewable potential is as follows: 104 GW rooftop PV, 20 GW onshore and 8 GW offshore wind. Then, there is a variation of this, if going deeper into the sea and tap in another 16 GW of offshore wind together with allowing a certain small nuclear reactor by 2045 at an assumed investment and operation cost. A third variant is when we have clean molecules hydrogen supposedly costing 1,7 EUR/kg. Such models allow us to see what is the most societal lowest cost system that results. By 2030, 4 times more PV in Belgium and 2 times more wind onshore and offshore. By 2050, eFuel turbines grow to a capacity of 8 GW in the central scenario to provide peak power, and additional 16 GW offshore and 6 GW nuclear SMR's halves investments in solar PV and onshore wind in Belgium in the second model. From 2040 onwards, the need for demand flexibility grows drastically under all assumptions: smart charging, heat pump with buffers, battery storage, hydrogen electrolysers.

Professor **Belmans** concluded by saying that indeed, nuclear can be part of the future, however that future will not look the same way as we have seen nuclear so far. The base load of nuclear will disappear, the demand setting generation will also disappear. Instead, we will have massive amounts of renewables, and must understand how to work with nuclear which no longer will run constantly, and the impact on how investments will go if there is no need to operate 8760 hours per year. Therefore, the most important message is in figuring out a totally different way for nuclear to exist in the future.

Professor **D'haeseleer** started his presentation by introducing us to an overview of relevant references, including with regard to Small Modular Reactors (SMRs). Then, he gave us some preliminaries.

First, he explained us the three distinct meanings of the concept of *baseload*:

- Original meaning, which is based on gradually filling up the load-duration diagram. We have already seen the chronological electricity demand curve for one day, and this can also be done for a year. From this, we can construct the 'load-duration' diagram, then satisfy the load duration curve with electric-power delivering units. By using continuously operating power plants, the so-called *base-load plants* deliver electrical output to the grid. This is sometimes referred to as 'continuous full rated electrical output' (REO), but to make it even more specific: full REO injected into the grid. However, in a future world, with ample variable renewable energy (VRE) installed capacity, the classical baseload generation no longer makes sense. And the justification is simple, VRE will have zero marginal cost, whereas the marginal cost of nuclear is not zero.
- Industrial electric-power demand in process industries, 24/7, meaning that those industries do need constant electrical power, without caring where the electrons come from. All they need is a guaranteed constant delivery of electrical power. To stress the caveat here, Professor **D'haeseleer** gave the example of the Finish TVO that has its own power plant and have a contractual agreement with the power plant, and referred to what they might do, prefer the electrons from their own power plant or rather buy cheaper ones if available on the market.
- For economics, nuke operators will *prefer* to keep producing valuable output. This means keeping reactor's thermal output constant, but not necessarily generating electricity. Sometimes, it is also referred to steady full rated thermal power (RTP), meaning that they will need to use that heat output as alternative valuable product (i.e., desalination, cogeneration, assist electrolysis, high-temperature heat storage).

Another alternative is to produce electrical power without injecting it into the grid if electrical storage is cheap.

Further, Professor **D'haeseleer** clarified that nuclear power plants (NPPs) do not need to constantly operate, as they can participate in 'load following'. For instance, the German and the French NPPs were originally designed to participate in load following, provided that they want or need to. Also, other plants designed for baseload can participate in load following too. But for safe load following, there is a need for studies, maybe even refurbishments need to be implemented, and for sure, the approval from Nuclear Regulators is necessary.

In regard to the lifetime of a NPP, the systems do not have an *a priori* lifetime, components (which must be qualified) do. Thus, as a rule, the components (such as valves, motors, pumps, steam generators, turbines, alternators, transformers, etc) can be replaced. One component that cannot be replaced is the reactor vessel, for instance, because it is too difficult/expensive. Thus, the technical lifetime can be said to be determined by the lifetime of the reactor vessel, and it is informed by monitoring brittleness via metal samples closer to the reactor core to capture more neutron flux. It can be predicted 10-15 years ahead. Related, safety is crucial and should never be compromised, meaning that the Nuclear Regulators should define non-negotiable safety levels. Thus, non-safe plants can and must be shut down at the right time.

While NPPs do have a design life, it does not constitute a determining factor for the actual lifetime of an NPP. In some countries, NPPs have a pre-determined license lifetime. This is typical for the U.S. – the first operational license is for 40 years, and to extend it, upgrades are needed. The practice in the U.S. shows us that there are some NPPs which got their license lifetime extended to 60 years, and two of them up to 80 years. However, this is not the case in Europe. For instance, until 2003, France and Belgium did not have license lifetime, which means that every 10 years a major structured 'overhaul' happens. Thus, after each upgrade, another 10 years are granted and so on and so forth. More importantly, the original license lifetime (if applicable) does not constitute an *a priori* reason for shut down. However, Professor **D'haeseleer** stressed that the all-overruling lifetime of NPPs is the political lifetime. Meaning that, regardless of democracies or autocracies, politics does have the last word. Of course, this does not mean that politics cannot change, but it does raise awareness that whenever politics is involved, there is a certain level of uncertainty.

Regardless, it seems that Long Term Operation (LTO) is a valuable option. It refers to the extension of nuclear plants' lifetime as an indispensable part of a cost-effective path to net zero by 2050. However, LTO nuke is not silver bullet, in the sense that NPPs are fine for Security of Energy Supply (SoES) if they are available to run. For this, we analysed four different examples. Further, to define a Long-Term Objective, Professor **D'haeseleer** underlined the importance of first defining the problem and then the objectives. So, what is needed to achieve is the decarbonisation by mid-century.

The results over the next 20-30 years will depend on geography/meteorology and country policies. A reasonable expectation would be the reduction of cost of PV, wind, and batteries, even in a fragmented non-global world with technological 'strategic autonomy'. Another reasonable expectation is that more renewables will be pushed into the energy system, there will be huge installed VRE capacities, and we will move towards increased electrification. To achieve these, there are 'flexibility' options, such as: flexible thermal generation (CCGT or OCGT with CCS, or biogas, etc), electrical transmission, active demand response/participation, energy storage (PHS, batteries, etc). Moving towards thinking realistic constraints (permitting, licensing), the long-term VRE shares in different countries will vary between 70-90%. Because of the long-term storage, most analyses find a gap-filling technology, which could be combat cycle gas turbines (CCGT) with CCS, or hydrogen, or geothermal, and so on. Therefore, the future of nuclear will largely depend on investment cost.

Professor **D'haeseleer** then showed us an MIT report on different countries' evolution with regard to NPPs construction and maintenance, as well as graphics from the Nuclear Energy Agency where we could observe the overnight cost and constructions times for a few selected recent nuclear projects. Thus, we could conclude that the 'competitiveness of nuclear in relation to other power generation technologies is determined by the value of its output as well as its cost of production'.

Last, the lecture focused on the 'modular' in Small Modular Reactors (SMRs), and Professor **D'haeseleer** clarified that it states for two things:

- Many small identical reactor units, sited next to each other as independent modules, making a power plant with bigger output. Many of these identical modules could be placed at different sites at different locations around the world (an extreme example would be a reactor fitting in a container);
- The major parts of a particular reactor of whatever size are built in a workshop that will be brought to the site and assembled there. This entails much less onsite work.
- While SMRs may provide a potentially interesting nuclear technology, it is up to the fusion community to prove that they can make it.

Professor **D'haeseleer** concluded by emphasising the determining factor, which is the cost. In turn, it will be assisted by technical flexibility and characteristics, and this represents its value. Overall, the cost/value balance will determine the future of nuclear.

Questions and answers

A Ph.D. researcher asked whether the sustainability value of nuclear – more precisely, the problem of its waste – and whether it is included as an externality in the cost. Professor **D'haeseleer** answered that the external cost of waste is minimal compared to megawatt hour. Also, companies and governments have predicted this issue and there are certain funds for dealing with waste.

An EUI Professor referred to how geopolitics of energy is playing a quite dramatic role, and he was wondering how nuclear energy could help us achieve more stability in the generation of energy, and as a consequence also in terms of geopolitics. For example, Italy is currently looking for alternative to gas, so to what extent nuclear energy can become a key element. Professor **Belmans** wanted to first clarify the amount of energy referred to in the examples he gave during the lecture. The potential contribution from nuclear can be around 10-20%, He does not believe this to be the critical answer sought for the time being. The reaction needed from the part of nuclear cannot happen in the short timeline we need it for responding to the present challenges. Also, he stressed the need to get organised and to plan accordingly with regard to renewables as the build out is not sufficient to even reach the Fit for 55 targets.

Another EUI Professor refered to transmission as an important element in terms of a stabiliser of tensions, meaning that if there were more grids, there would also be less problems. Professor **D'haeseleer** answered by making a distinction between existing plants and new plants. He does not believe it is wise to prematurely shut down plants, instead he stressed the need for existing plants to complement the gas crisis. As regards geopolitics, the security problem cannot be answered by the creation of new plants due to the timeline needed for that to happen. Then, given the massive overflow of renewables that is about to happen, getting the transmission correctly is necessary. A good lesson from the gas crisis is to always diversify, and not to rely only on one resource. He then referred to the three German power plants that were closed priorly to the lecture, and he believed this to be non-understandable given the gas crisis and the overall demand in Europe. Professor **Belmans** then also referred to the importance of transmission, and the omission of a European view of transmission. Although there is currently a 10-year development plan at the level of the EU, it is totally inefficient, there is a need to act more coordinate and to look at what needs to be done in accordance with the resources and needs we have towards 2050. That is, to diversify on the European scale on the sustainable resources.

Another EUI Professor emphasised that a common element from both lectures refers to a lot of evidence of requirements and challenges with the scientific and economical perspectives, however the political environment is so volatile and often evidence is not necessarily regarded. His first question was whether China is using nuclear as a base load model or a low salary model. And the second question was with regard to the distinction between the grid's transmission and the generation, and the fact that both lecturers referred more to the grid's transmission rather the generation. Professor **Belmans** reiterated that, while indeed there are costs involved in building wind turbines for example, the difficult part is the legislative one. He then referred again to the need of having a European view, because otherwise it is not possible to convince, for instance, Belgium to build a high voltage line to supply Germany. Professor **D'haeseleer** answered that when they addressed transmission is because they assumed that the renewable investment in Europe will happen, and it will happen differently in different parts of Europe. Further, the better the transmission grid is, the fewer holes to be plugged. In sum, a better transmission grid implies optimisation. As regards China, it runs many of its power plants in baseload, and the reasoning is that electricity demand is still growing. However, in certain locations they will have to do load following.