Towards a new generation of multi-disciplinary engineers in the energy sector : need for new knowledge, skills and competencies

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Tell me and I forget
Show me and I remember
Involve me and I learn

Confucius
(551–479 BC)

Chinese teacher, editor, politician, and philosopher

Abstract

Engineering Education and Training in the specific sector of energy relies on knowledge, skills and competences to be acquired through a mix of so-called hard sciences and soft sciences, to be taught in graduate schools and/or shared in continuing higher education programmes. A number of practical examples are given in connection with research and innovation needs in the framework of a typical Integrated Energy Plan considering all primary energy sources, all energy carriers, all technology options and all key policy imperatives. Conclusions are drawn in terms of values and ethics statements to be discussed in the engineer's sphere of action.

1 - Introduction – instruments to ensure lifelong learning and cross-border mobility

Both industry and research are increasingly looking world-wide for a new generation of multidisciplinary engineers. Science and technologies in the specific domain of Energy

Engineering should address, in a balanced and integrated manner, a number of issues pertaining to both hard sciences (e.g. mechanical, electrical, thermal and chemical engineering) and soft sciences (e.g. related to socio-economic and environmental aspects).

Reminder. Hard science and soft science are colloquial terms used to compare scientific fields on the basis of perceived methodological rigor, exactitude, and objectivity. Roughly speaking natural sciences (e.g. chemistry, physics, biology) are considered "hard", whereas the social sciences (e.g. economics, psychology, sociology) are usually described as "soft.

To face current and future challenges in Energy Engineering sciences, Education and Training programmes should better integrate the above hard and soft sciences while fostering lifelong learning and cross-border mobility not only within and amongst European Union (EU) countries but also world-wide. Remember that free movement of KNOWLEDGE is central in EU policy: it is the so-called "fifth freedom", complementary to the other "freedoms" of the "EU internal market" which are : PEOPLE, GOODS, CAPITAL and SERVICES.

At this stage, it is worth recalling a standard definition of Education and Training.

- <u>Education</u> is a basic and life-long learning process : it is broader than training, encompassing the need to maintain completeness and continuity of expertise across generations. Education is essentially a <u>knowledge creation process</u>, involving primarily academic institutions as "suppliers", and students as "customers"
  => it deals mainly with knowledge (and understanding)

- <u>Training</u> involves acquiring <u>specific skills and competences</u> required to properly perform a well-defined job or function, usually to an established standard. Training is a knowledge, skills and competence /KSC/ building process, involving primarily experts in continuing professional development /CPD/ (e.g. a mix of industry and academia experts) as "suppliers", and learners (e.g. professionals) as "customers"
  => it is mostly about skills and competencies, in addition to specific knowledge.

Not surprisingly, lifelong learning and cross-border mobility have been for decades at the heart of EU policies in continuing education and training, as it is demonstrated, in particular, in two high-level EU "Declarations" in 1999 and 2002, respectively:

(1) **Bologna Declaration on the "European Higher Education Area" in June 1999**, which fixed the rules for the "European Credit Transfer and accumulation System" /ECTS/, aiming at establishing mutual recognition of academic grades across all signatory States (namely: as of today, all 28 EU Member States + 20 other signatory States, bringing together more than 4 000 higher education institutions and numerous stakeholder organisations).

(2) **Copenhagen Declaration on "enhanced European cooperation in VET" in November 2002,** aiming at fostering lifelong learning and cross-border mobility through the "European Credit system for Vocational Education and Training" /ECVET/ (31 signatory States, namely: all 28 EU and 3 EEA-EFTA Member States). (*NB: EEA = European Economic Area // EFTA = European Free Trade Association*)

NB - Most of the Bologna action lines (such as ECTS, quality assurance, student and staff mobility, the European dimension in higher education, and the Diploma Supplement) have their origins in EU-funded activities under the Erasmus programme ("EuRopean Action Scheme for the Mobility of University Students", 33 Members, 1.5 % of total EU budget in 2017). Overall, by the end of the academic year 2013-14, the Erasmus programme had supported 3.3 million Erasmus students and 470 000 staff since its launch in 1997-1998.

An important concept in the EU ECVET policy and in our discussion on lifelong learning and cross-border mobility is **Learning Outcomes** *(LOs)*:

> *Definition : Learning Outcomes are the set of **knowledge**, **skills** and/or **competences** an individual has acquired and/or is able to demonstrate after completion of a learning process, either formal, non-formal or informal.*

Remember the ECVET definition of knowledge, skills and competences in connection with learning outcomes :

- **Knowledge** and understanding (Learning to know and understand – usually related to the "cognitive domain" and acquired through higher education programmes)
  Knowledge is the outcome of the assimilation of information through learning.
  In other words, knowledge is the body of facts, principles, theories and practices that is related to a field of work or study.

- **Skills** (Learning to do – i.e. : know-how - e.g. Teamwork ; Time management ; Adaptability ; Problem solving ; and Presentation - usually related to the "psychomotor domain" and acquired in particular when undertaking apprenticeships)
  Skills are the ability to apply knowledge and use know-how to complete tasks and solve problems.

- **Competences** or attitudes (Learning to live together – e.g. practical behaviours and attitudes which impact the way you operate in working life - usually related to the "affective domain" and acquired during on-the-job experience)
  Competence is the proven ability to use knowledge, skills and personal, social and/or methodological abilities in a defined context (e.g. at work or in study situations ; at professional or personal development courses).

> Source: CEDEFOP glossary 2008 – "Terminology of European education and training policy - http://www.cedefop.europa.eu/EN/Files/4064_en.pdf

The ultimate aim of applying a number of hard and soft sciences in Engineering Education and Training in the energy sector is to contribute to the development of modern energy services as they are requested by society (households and industry) - see Sections 2 and 3 below. The concept of energy service is central, particularly when defining the purpose of an energy system as it is illustrated in Figure 1 below (valid for any country). It is important to realize that the use of energy is no end in itself but is always directed to satisfy human needs and desires. Energy services are the ends for which the energy system provides the means.

2 - <u>Hard Sciences</u> in the energy sector - challenges in Education and Training

Hard sciences in engineering education and training in the energy sector refer principally to two types of technology (see Figure 1): conversion technologies and end-use technologies.

The focus in this Section 2 is on research and innovation needs in technologies to convert primary energy sources into energy services (see Figure 1). The successive steps of energy conversion are discussed, i.e. from primary to secondary energy sources and then to energy services. Other important technologies are not treated, such as those related to :
(1) primary energy sources- see column 1 in Figure 1 - e.g. mining and/or extraction of fossil fuels / coal, crude oil and natural gas / and of nuclear fuels / uranium / and design and construction techniques related to renewable energy sources / solar, wind, hydro /),.and
(2) secondary energy carriers – see column 3 in Figure 1 – e.g. transport and/or storage of electricity, heat, refined petroleum products (or hydrogen as it is discussed further down).

Figure 1 provides a complete picture of the energy value chain in a modern country (South Africa). It covers the full spectrum of scientific disciplines and engineering technologies from primary energy sources (i.e. renewables, fossil and nuclear) to demand for energy services. This Figure 1 is particularly useful to structure our discussion on research and innovation in hard sciences as they are needed in engineering educational programmes in the energy sector.

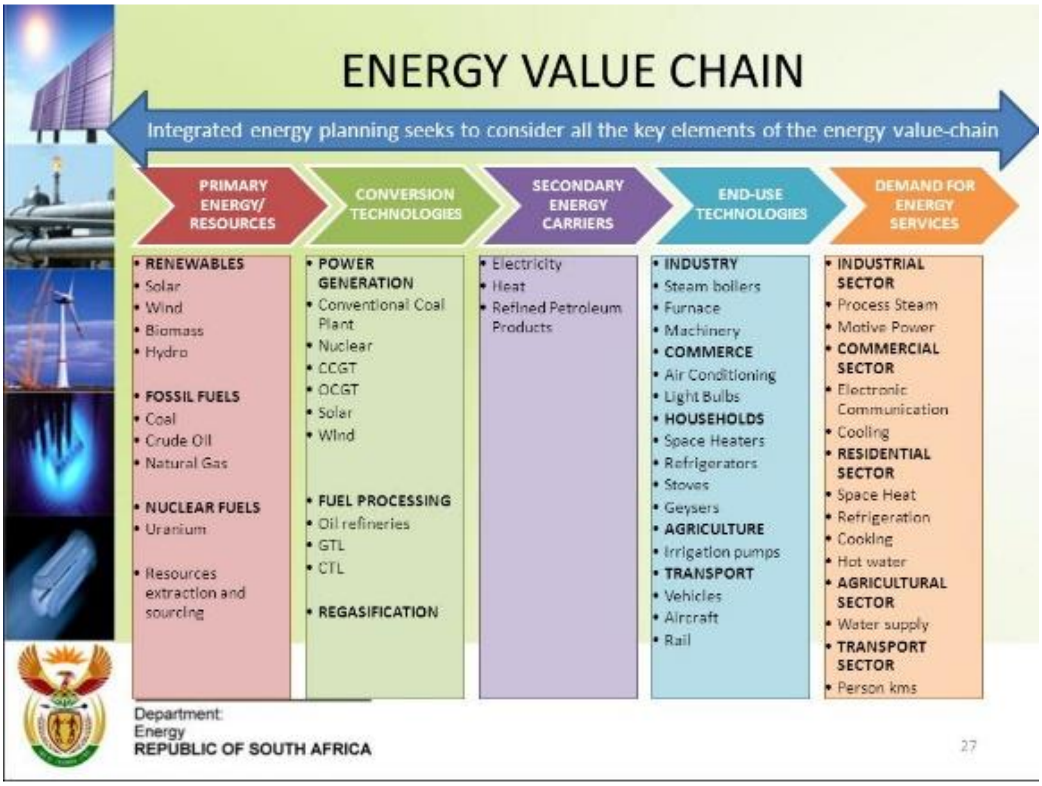

Figure 1 – “Energy Value Chain” in Integrated Energy Plan (IEP)
Republic of South Africa 2016 – (approach valid for any country)

Source : INTEGRATED ENERGY PLAN (IEP), Republic of South Africa, Dep't of Energy, 22 November 2016 - http://www.energy.gov.za/files/IEP/presentations/Integrated-Energy-Plan-22-Nov-2016.pdf

The following items will be treated successively, corresponding to columns 2, 4 and 5, respectively, in above Figure 1:

- *2.1 Hard sciences in Energy Conversion Technologies*
- *2.2 Hard sciences in End-use Technologies*
- *2.3 Hard sciences related to the development of modern Energy Services.*

Figure 1 is taken from the Integrated Energy Plan (IEP) of the Republic of South Africa, elaborated in 2016 under the auspices of the International Energy Agency (IEA), located in Paris. It is worth recalling that the Integrated Energy Planning Framework generally considers all energy carriers, all technology options and all key national policy imperatives and proposes an energy mix and policy recommendations which ensures that the energy sector can help achieve these in the most optimal manner. It also considers the national supply and demand balance and proposes alternative capacity expansion plans based on varying sets of assumptions and constraints. The IEP focuses on determining final demand for all forms of energy and the cross linkages of different energy carriers to meet those energy needs across different sectors (see also IEA recommendations in their yearly "World Energy Outlook").

2.1 Hard sciences in Energy Conversion Technologies

Hard sciences in Energy Conversion Technologies refer principally to power generation in connection with electricity production. Most engineering applications in this domain rely on thermodynamic cycles, that is: basic cycles such as Rankine (as in fossil or nuclear steam-fired power plants) and Brayton (as in combustion- or gas-turbine based power plants) ; combined cycles such as Rankine/Rankine and Brayton/Rankine (as in gas turbine-steam combined cycle power plants) as well as advanced cycles such as CO_2 gas turbines. On the more innovative side, other Energy Conversion Technologies are for example integration of gas turbine and waste incinerator, and industrial cogeneration (i.e. Combined Heat and Power generation /CHP/) – remember : nearly two-thirds of the energy used by conventional electricity generation is wasted in the form of heat discharged to the atmosphere.

NB : Remember that in 2016 while total world energy came from 80% fossil fuels, 10% biofuels, 5% nuclear and 5% renewable (hydro, wind, solar, geothermal), only 18% of that total world energy was in the form of electricity. Most of the other 82% was used for heat and transportation. As far as long-term horizon in the EU is concerned, it is also worth recalling that all scenarios of the EU Energy Roadmap 2050 show electricity will have to play a much greater role than now (almost doubling its share in final energy demand to 36-39% in 2050) and will have to contribute to the decarbonisation of transport and heating/cooling (source : https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:52011DC0885, Dec. 2011).

Hard sciences in Energy Conversion Technologies refer also to fossil fuel processing in connection with refined petroleum products (see above Figure 1). Most engineering applications in this domain rely on research and innovation in chemical processes. The aim is to transform crude oil in oil refineries into useful products such as liquefied petroleum gas (LPG), gasoline (used in internal combustion engines in automobiles) and fuel oil (produced from the burnable liquids derived from crude oil and also called kerosene, home heating oil or diesel fuel). Natural gas processing plants also play an important role in the energy value chain. Natural gas applications are needed, for example, for industrial heating, for operation of public and industrial power stations, for household applications (cooking, heating and providing hot water) as well as for internal combustion engines (in environmentally friendly compressed or liquid natural gas vehicles). Natural gas can also be used as raw material for chemical synthesis.

2.2 Hard sciences in End-use Technologies

Hard sciences in End-use Technologies refer first to the industrial sector, as this sector uses more delivered energy than any other end-use sector, consuming about 54% of the world's total delivered energy. The industrial sector can be categorized by three distinct industry types, each requiring specific research and innovation actions and appropriate higher education programmes (source : https://www.eia.gov/outlooks/ieo/pdf/industrial.pdf) :

- energy-intensive manufacturing, e.g. food ; pulp and paper ; basic chemicals (inorganic and organic) ; iron and steel manufacturing (including coke ovens) ; non-ferrous metals (primarily aluminium and other non-ferrous metals, such as copper, zinc, and tin) ; non-metallic minerals

- non-energy-intensive manufacturing, e. g. other industrial manufacturing (including machinery, computer and electronic products, transportation equipment, and electrical equipment) and other chemicals (including pharmaceuticals, miscellaneous chemical products)

- non-manufacturing, e.g. agriculture, forestry, fishing ; mining (coal mining, oil and natural gas extraction, and mining of metallic and non-metallic minerals) ; construction (residential and commercial buildings), heavy and civil engineering construction, industrial construction.

Second, hard sciences in End-use Technologies refer to the commercial sector. Commercial buildings include a variety of building types such as institutional and private sector offices, hospitals and healthcare facilities, schools, warehouses, hotels, and shopping malls. Different commercial building activities have unique energy needs, but as a whole, space heating / cooling accounts for most of the total energy use in commercial buildings. Most individual commercial buildings and households have their own heating and cooling systems.

What are the types of energy used in commercial buildings and in households ? Electricity, fuel oil and natural gas are the most common energy sources used. Renewable sources of energy (biomass, geothermal, solar, and wind energy) are also used.

Energy efficiency is of course crucial in all sectors : industrial and commercial sectors as well as households. As far as buildings are concerned, special attention is dedicated to upgrading Heating, Ventilation, and Air-Conditioning systems (HVAC) or replacing insulation. In this context, lighting controls (including in both public street and highway lighting) are often relatively easy, accessible and affordable changes. Large investments are made, in particular, in new lighting control technologies aiming at providing the appropriate level and type of lighting, thereby saving on electricity costs.

As far as transport technologies are concerned, there are many studies on air transport versus high-speed rail (see for example Shinkansen in Japan, TGV in France and ICE in Germany). Regarding long-distance air transport, the next generation of twin-engine jet liners is of particular interest: Boeing 787 Dreamliner and A350-900 ULR (for Ultra Long-Range), where fuselage, wings, stabilizers and turbine housings are manufactured primarily (more than 50 %) from Carbon Fiber Reinforced Polymer (CFRP) - rather than using conventional aluminium construction techniques.

In the automotive market, companies hoping to win and survive must reinvent themselves as the car industry experiences turbulence. Lots of research and innovation is dedicated to autonomous driving, e-cars, digital services and (electro-)mobility platforms. Innovative technologies are investigated in connection with large-scale multimodal transport systems, including the comprehensive assessment of new emerging transport modes.

2.3 Hard sciences related to the development of modern Energy Services

Research and innovation contribute directly to help cities and communities, business and civil society to improve a variety of services while reducing energy and resource consumption, greenhouse gas (GHG) and other polluting emissions. Infrastructure services (such as telecommunications, transport and electricity), in particular, are crucial for the efficiency, competitiveness and growth of an economy.

Industries use a large amount of energy to power a diverse range of manufacturing and resource extraction processes. Many industrial processes require large amounts of process heat and motive power, most of which is delivered as natural gas, petroleum fuels, and electricity. In addition, some industries generate fuel from waste products that can be used to provide additional energy. Various industries also generate steam and electricity for subsequent use within their facilities. When electricity is generated, the heat that is produced as a by-product can be captured and used for process steam, heating or other industrial purposes. Conventional electricity generation is about 30 percent efficient, whereas combined heat and power (also called co-generation) converts up to 90 percent of the fuel into usable energy.

Energy efficiency in automobile transportation is high on the agenda. There are several ways to enhance a vehicle's energy efficiency. Using improved aerodynamics to minimize drag can increase vehicle fuel efficiency. Reducing vehicle weight can also improve fuel economy, which is why composite materials are widely used in car bodies. More advanced tires, with decreased tire to road friction and rolling resistance, can save gasoline.

As far as energy efficiency in air transportation is concerned, there are several ways to reduce energy usage, from modifications to the planes themselves, to how air traffic is managed. As in cars, turbochargers are an effective way to reduce energy consumption. Air traffic management systems are another way to increase the efficiency of not just the aircraft but the airline industry as a whole. New technology allows for superior automation of take-off, landing, and collision avoidance, as well as within airports, from simple things like HVAC and lighting to more complex tasks such as security and scanning.

Finally, green construction requires particular attention. Europe's homes, businesses and public buildings sap up about 40% of all energy in circulation, more power than in either the industrial (32%) or transport (28%) sectors. This translates into about 20 exajoules of energy per year - the rough equivalent of 3.5 billion barrels of oil - and means our buildings are responsible for about 36% of the continent's carbon emissions. In response to tough EU and national policies, the green-building sector has taken off. The European efficiency-related construction market is expected to double to Euro 140 billion by 2020. The most dynamic patenting areas in green construction are: HVAC ; Energy-efficient insulation ; "Green" lighting ; Incorporating renewable energies.
Source (2018) : https://www.epo.org/news-issues/technology/sustainable-technologies/green-construction.html

Shift from fossil to renewable energy sources : challenges for modern energy services

As it is mentioned in the introduction of this Section 2, transport and storage of energy are not considered in this note. It is worth, however, mentioning briefly some challenges facing energy services in the new context of liberalisation of energy markets and sustainability of energy systems from an environmental and economic point of view. Lots of research and innovation is needed to address changing political preferences, such as the shift from fossil to renewable energy sources and the reduction of anthropogenic CO_2 emissions.

Intermittent energy provided by renewable sources has introduced particular challenges in the domains of transport and storage of energy. In electricity networks (aiming at transporting electrical energy), it is worth mentioning the many innovative technological opportunities especially in the fields of Information and Communications Technologies (ICT) and power electronics aiming to support the requested system changes. Moreover, the arrival of renewable energy resources on the grid architectures has led to the inapplicability of the "production follows consumption" principle which has been applied for decades to the conventional centralised energy generation systems with one-way power flows. Demand Side Management (DSM) will be one of the most important parts of future decentralised smart power grid systems with multiple actors and multi-layered energy and information flows.

As far as energy storage is concerned, remember that storing excess energy to use it at high demand time has great importance for applications at every scale because of irregularities of demand and supply. Many energy storage approaches are currently investigated in the electrical, electrochemical, chemical, mechanical and thermal domains. Hydrogen is of particular interest - hydrogen should be added in column 2 of above Figure 1 as a potential "secondary energy carrier" for the future. Hydrogen is a promising (man-made) fuel and energy storage solution. Indeed, hydrogen can function as an energy storage medium, effectively storing (for example, renewable) energy until a fuel cell or engine converts it back to electricity. Hydrogen can also be recombined with captured CO_2 to produce a synthetic natural gas that can be used in power plants or transportation applications.

3 – Soft Sciences in the energy sector - challenges in Education and Training

Soft sciences in engineering education and training cover a variety of perspectives such as social and political sciences, law and governance, ethics, cross-cultural management and leadership, education science (pedagogy) as well as business and economics.

Of particular interest in the energy sector is the set of requirements related to economy, society and ecology, that impact energy and climate policies in modern countries (not only in the EU but also world-wide). EU's energy policy, in particular, is aiming to ensure that European citizens can access affordable, secure and sustainable energy supplies (see "Energy Union" strategy adopted by the EU in February 2015 - https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union).

This is summarized in a holistic manner in the EU Energy Triangle (Figure 2 below). The primary energy sources (i.e. renewables, fossil and nuclear), illustrated in both Figures 1 and 2, are the very basis of the energy mix that each country should decide upon in a democratic manner, keeping in mind the satisfaction of the end-user. Soft sciences definitively can help in the implementation of above requirements, e.g. by identifying the pros and cons of various energy systems in terms of economy, society and ecology.

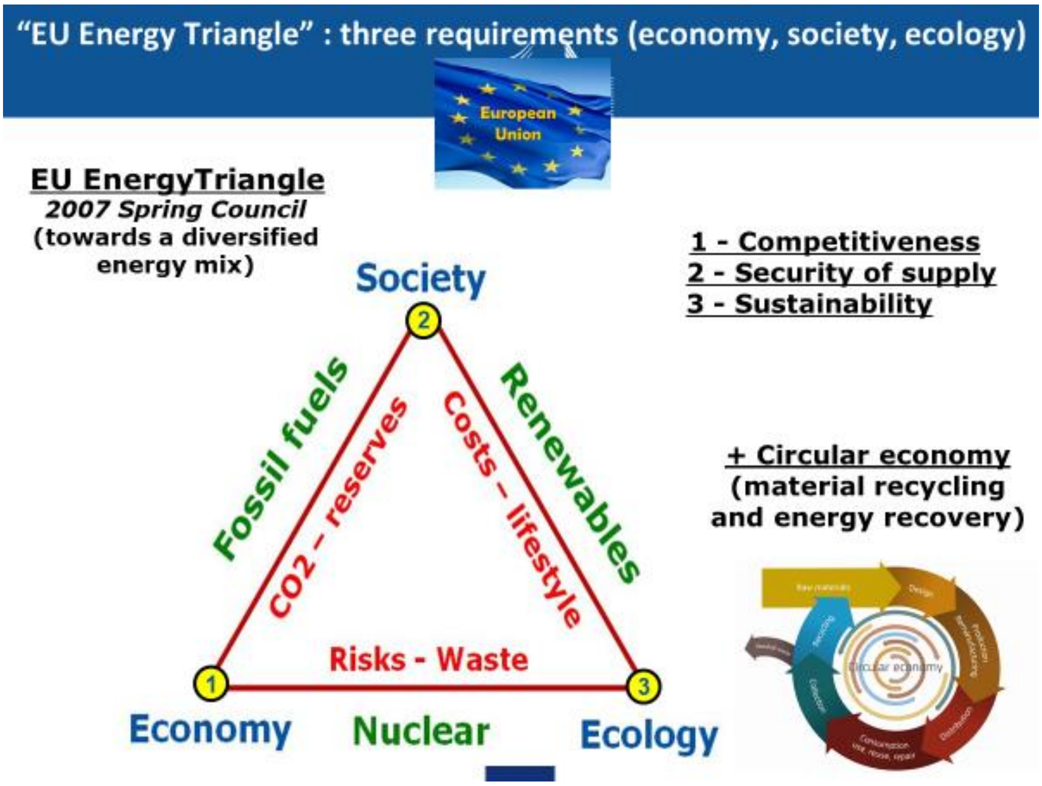

Figure 2 - EU Energy Triangle (2007 Spring Council)
Towards a diversified energy mix satisfying 3 requirements (economy, society and ecology)

EU's energy and climate policy has set targets for 2020, 2030 and 2050. These cover emissions reduction, improved energy efficiency, and an increased share of renewables in the EU’s energy mix. The Energy Roadmap for 2050 is aiming at achieving its goal of reducing greenhouse gas emissions by 80-95%, when compared to 1990 levels, by 2050. Together, these goals aim at providing the EU with a stable policy framework on greenhouse gas emissions, renewables and energy efficiency, which gives investors more certainty and confirms the EU's lead in these fields on a global scale.

NB – as far as EU Strategy for Energy and Climate Change is concerned, remember in particular Article 194 of the Lisbon Treaty (2009) : "Union policy on energy shall aim, in a spirit of solidarity …: .. Such measures shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply”. (http://europa.eu/lisbon_treaty/index_en.htm)

The following items will be treated successively, corresponding to vertices 1, 2 and 3, respectively, of the EU Energy Triangle in above Figure 2:

- 3.1 Economy – soft sciences aiming at optimising overall costs of electricity
- 3.2 Society – soft sciences aiming at fostering energy consensus amongst people
- 3.3 Ecology - soft sciences supporting transition towards a low-carbon energy future.

3.1 - Economy - soft sciences aiming at optimising overall costs of electricity

Soft sciences are needed in the engineer’s sphere of action to develop, in particular, new techniques for estimating the full cost of electricity provision, that is : plant-level production, grid-level and external costs (see Figure 3 below). Choosing how this electricity is generated – whether from fossil fuels, nuclear energy or renewables – affects not only economic outcomes but individual and social well-being in the broader sense.

Only certain costs of electricity provision are perceived directly by producers and consumers. Other costs, such as the health impacts of air pollution, damage from climate change or the effects on the electricity system of small-scale variable production are not reflected in market prices and thus diminish well-being in unaccounted for ways. Moreover, in the specific case of intermittent renewables, special attention should be devoted to the costs of energy storage.

Energy (be it electricity, heat or refined petroleum products) is a vital commodity which consumers need for heating/cooling their homes or powering their appliances as it illustrated in column 5 of above Figure 1. However, millions of consumers in the EU are struggling to pay their energy bills. For example, in 2017 in the EU, electricity prices for household consumers involving all taxes and levies, were as follows (in Euro/MWh) : 305 in Germany ; 280 in Belgium ; and 169 in France (Eurostat 2018). Moreover, energy markets are undergoing profound changes with more renewable energy and smart technologies and services starting to emerge, which are creating new opportunities but also new challenges for consumers for instance in terms of complexity and privacy protection.

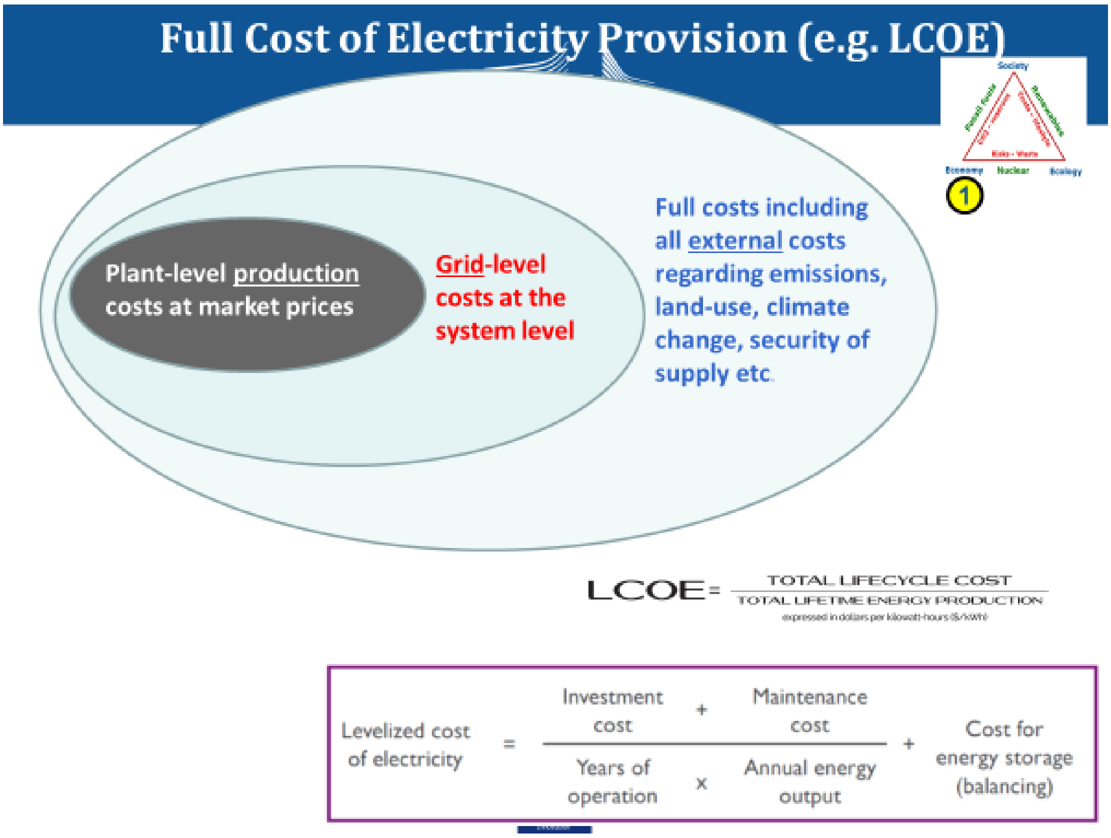

Figure 3 : full cost of electricity provision (plant-level, grid-level and external costs)

In this context, it is worth recalling the long-term electricity price that was recently agreed upon in the UK amongst all parties concerned as a consequence of the UK "Electricity Market Reform". UK government indeed adopted a level playing field approach for low-carbon technologies such as renewables and nuclear fission (contract for difference /CfD/ or top-up payments), that is : the UK government will pay the difference between the wholesale electricity price and the minimum it has promised (x Euros per MWh for xx years). Regarding nuclear EPR construction in Hinkley Point C, the following commercial deal was achieved : *the UK government will provide loan guarantees for the project. The CfD, signed on 29th September 2016 will guarantee EDF Energy a price of GBP 92.50/MWh (in 2012 pounds, index-linked) for 35 years for the power from the plant. NB : 1 GBP = 1.15 EUR (Oct 2018).*

Source : "A long and winding road?", 17 November 2016, in Nuclear Engineering Int'l - http://www.neimagazine.com/features/featurea-long-and-winding-road-5671917/

3.2 - Society - soft sciences aiming at fostering energy consensus amongst people

Soft sciences are needed to understand, for example, why public is protesting to new energy projects: wind energy, biogas installations, transmission lines, carbon capture and storage, shale gas, natural gas, gas storage, solar fields, nuclear fission and so on (see Figure 4 below).

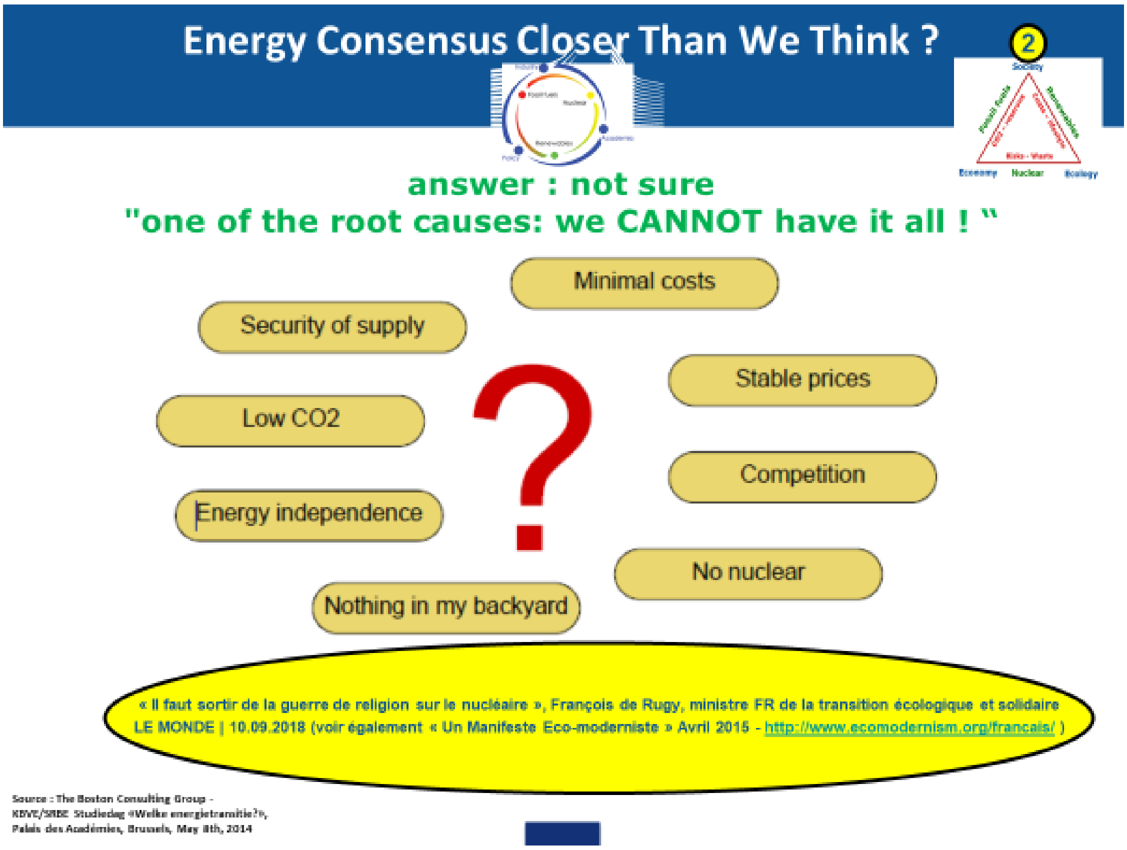

Figure 4 – Energy consensus closer than what we think ? Answer : not sure !

Despite there being a near consensus in the scientific community that the primary driver of the acceleration of climate change is anthropogenic GHG emissions, and that we need to cut those emissions if we are to keep global warming to a minimum, the public remains divided on the issue. Across the full range of technological options in the energy transition (fossil, nuclear and renewable), we observe social conflict posing a significant challenge for the energy transition. Energy systems are becoming more and more decentralized, relying on technology with a significant spatial impact (e.g. wind parks, solar parks). This will continue to raise conflicts, for instance related to what can be considered fair distribution of burdens and benefits, fair decision-making procedures, and fair representation of individuals and their viewpoints.

In a democracy, we hope that science can help to inform the public about its problems, thereby fostering consensus amongst people in particular in the energy – climate debate.

3.3 - Ecology - soft sciences supporting the transition towards a low-carbon energy future

Soft sciences are needed to evaluate the ecological footprint of various energy technologies (Figure 5 below). The ecological footprint is defined as being the developed method in which humanity measures the way in which Earth is affected by the human activities which use resources (materials and energy) in comparison to the amount of waste that accumulates (see also below discussion on circular economy, i.e. : Material Recycling and Energy Recovery).

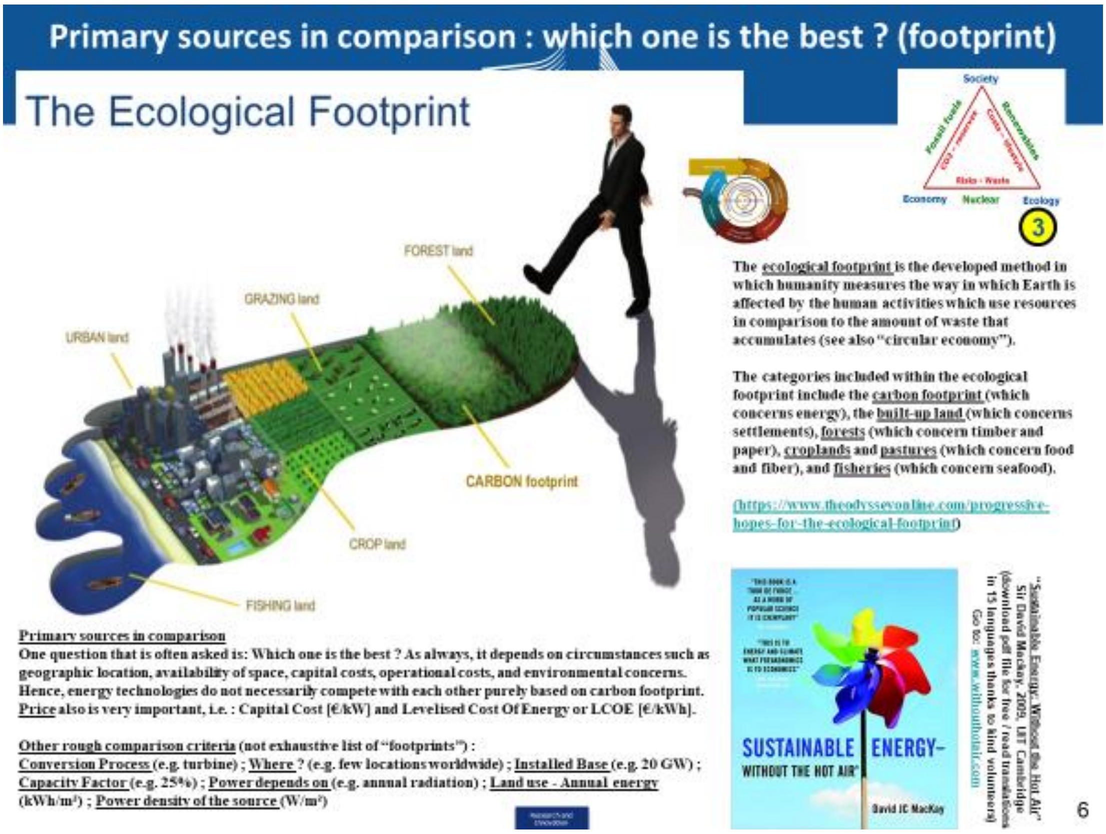

Figure 5 - Ecological footprint (carbon footprint ; built-up land ; forests ; croplands and pastures ; and fisheries)

The categories included within the ecological footprint include the carbon footprint (which concerns energy), the built-up land (which concerns settlements), forests (which concern timber and paper), croplands and pastures (which concern food and fibre), and fisheries (which concern seafood). To shrink the human footprint is also at the heart of challenging ecological movements such as ecomodernism ("An Ecomodernist Manifesto", April 2015, https://thebreakthrough.org/index.php/voices/michael-shellenberger-and-ted-nordhaus/an).

Circular Economy (i.e. Optimizing Material Recycling and Energy Recovery) is particularly important in this context : it is high on the political agenda of most industrialised countries, as it is demonstrated by impressive research and innovation programmes. In a circular economy, the intention is to produce no waste or pollution. Instead, products, parts, and materials are used, cared for, repaired, reused, and recycled as much as possible. This is intended to be the preferred alternative to the dominant economic development of "take, make, and dispose". The circular economy is best known for the so called 3R Principles:

- Reduction : reduce resource consumption and energy use
- Reuse : facilitate reuse of product components
- Recycle : extent the product lifetime.

The advantages are not just related to environment and health, but can also include economic growth and employment.
(see EC "Closing the loop-An EU action plan for the Circular Economy," 2015, http://eur-lex.europa.eu/legalcontent/EN/TXT/?qid=1453384154337&uri=CELEX:52015DC0614)

4 – Conclusion : values and ethics statements in the engineer's sphere of action

To conclude, let us recall a number of challenging Values and Ethics Statements that reflect the collective values to which engineers and scientists should aspire. Inspiration can be found in Charters of Ethics as they are proposed in some higher education engineering schools, e.g.:

> *"It is necessary to explain and engage in a society, which certainly does not refuse progress, but is wary of possible devilry.*
> *... On top of the two traditional vocations of the engineer, to innovate and manage in industry, we must add a third vocation: to explain and possibly to reassure. ...*
> *Information, transfer of knowledge, only takes full effect in dialogue. ..."*

Source: « Manifeste pour la technologie au service de l'homme », Institut National Polytechnique (INP) de Grenoble, Octobre 2000, Hubert Curien (1924 – 2005, ancien ministre français de la Recherche et de la technologie 1984 – 1993 et président de l'Académie des Sciences), published in « Charte d'éthique des ingénieurs de l'INP Grenoble » 2004 http://chamilo2.grenet.fr/inp/courses/PHELMAA13PMCETH9/document/ethique/charte_fr.QXP.pdf

Also worth mentioning is another engineers' charter containing an ambitious ethics statement:

> *"The engineer is a responsible citizen ensuring the link between science, technology and the human community; he is involved in civic actions for the common good."*

Source : « Charte d'éthique de l' ingénieur », Conseil National des Ingénieurs et des Scientifiques de France » (CNISF), 2001- https://www.iesf.fr/752_p_49680/charte-ethique-de-l-ingenieur.html

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Towards a new generation of multi-disciplinary engineers in the energy sector : need for new knowledge, skills and competencies

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