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A B S T R A C T

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Science to guide EU energy transition policies on decarbonisation, energy security and affordability

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For more than two decades, the European Union has been adopting climate and energy policies and legislation on energy security, sustainability, and affordability. In 2015, the EU signed up to the Paris agreement to limit global warming to no more than 1.5^{0}C.

Since December 2019, stronger policies and legislation have been introduced under the EU Green Deal to deliver climate change commitments together with energy security and affordability. In June 2021, the EU adopted its Climate Law for net zero carbon emissions by 2050, and since the invasion of Ukraine in 2022, energy Directives been updated to strengthen energy security together with efforts to decarbonise energy demand in buildings, transport and industry.

Transport may be decarbonised by "avoiding" motorised transportation (eg: walking and cycling), "shifting" passengers and freight to more efficient transport modes (eg: buses, trains, ships), and "improving" the energy performance of vehicles (eg: reducing size and using more efficient powertrains).

The 250 million buildings in the EU produce about 25% of EU greenhouse gas emissions, and around 90% of these buildings will still be in use in 2050. Almost 80% of existing EU buildings are residential, and almost three quarters have poor energy performance. The EU has proposed a renovation wave to reduce building energy demand over the next 30 yrs. This would require annual renovation rates to increase from 1% to ~3%, which would challenge not only the building industry but also building owners (financing). In future, EU policies should focus on zero emission buildings, and on renovating neighbourhoods to increase property values and the quality of life. Investors may be encouraged by the health benefits of low emission buildings, which have less overheating, better ventilation, and better daylighting.

However, a cost-effective compromise must be found on a case-by-case basis between reducing final energy demand through renovations (insulate building envelope, heating systems, windows), and supplying renewable electricity for heat pumps, and solar and geothermal heat. Embodied emission reductions are also important, especially in foundations, floor slabs and structural components (steel and concrete). Existing buildings should be renovated not demolished, and materials reused and recycled. More timber should be used in place of carbon intensive materials (steel and cement).

Natural gas is not always cleaner than coal for power generation because of the methane leakage along its supply chain, so the Global Methane Pledge was launched at COP 26 in November 2021 to reduce methane emissions by 30% by 2030. Natural gas provides nearly 40% of energy used in buildings, so gas boilers must be phased out as soon as possible. As fossil fuels are phased out, policy makers must provide strategic support to key industries and SMEs (Small and medium-sized enterprises), and they must reduce energy poverty by supporting low-income groups.

Experts from European national science academies work through EASAC to provide independent science-based advice on climate and energy policies and legislation. EASAC reports on decarbonisation of transport and buildings, and on the Future of Gas with advice on addressing affordability, are freely available from the EASAC website. New work has recently begun to produce advice for policy makers on the security of sustainable energy supplies.
The main messages in these EASAC reports for policy makers will be presented.

Enviromental consequences of inaction

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Climate change is impacting all regions globally. Polar ice sheets are melting, and sea levels are rising. Some areas are experiencing an increased frequency of extreme weather events and precipitation, while others face more intense heat waves and droughts.

As global temperatures continue rising due to increased atmospheric greenhouse gas concentrations, the urgency to take action becomes ever more apparent. The environmental consequences of inaction on climate change are profound and far-reaching, with impacts that could reshape natural and human systems on a global scale.

Without significant efforts to reduce greenhouse gas emissions, the severity and frequency of extreme weather events will increase. These include more intense hurricanes, prolonged droughts, and unpredictable seasonal patterns that can devastate communities, disrupt food production, and lead to significant economic losses.

One of the most direct consequences of global warming is sea-level rise caused by melting ice sheets, glaciers, and the expansion of warming seawater. Coastal areas worldwide are particularly vulnerable, facing increased flooding, erosion, and saltwater intrusion into freshwater resources. This threatens habitats, agriculture, and urban infrastructure, displacing populations and creating climate refugees.

Inaction leads to the deterioration of ecosystems, which are critical in maintaining the balance of the Earth's environment. Biodiversity loss is a concerning not only because of the extinction of species but also because it affects ecosystem services that support life on Earth, including pollination, water purification, and carbon sequestration.

Climate change is a significant multiplier of existing social and health problems, exacerbating inequalities and exposing vulnerable populations to greater risks. Heatwaves can lead to increased mortality, while climate change affects water and food security, leading to malnutrition and conflicts over resources.

Certain impacts of climate change could be irreversible if thresholds are crossed. These include the collapse of ice sheets and the dieback of forests. Such changes not only have direct environmental consequences but also amplify global warming through positive feedback mechanisms, making it even harder to reverse the trend.

The environmental consequences of inaction on climate change are profound and far-reaching. Tackling climate change is not merely an environmental challenge—it is a societal imperative that requires urgent and concerted global action. Inaction not only exacerbates environmental degradation but also jeopardizes the ability of future generations to thrive on Earth. Every action taken to reduce emissions and enhance resilience moves us away from disastrous consequences, making the fight against climate change one of the most critical challenges of our time.

During the presentation, we will explore the possible consequences of climate change using different scenarios from the Intergovernmental Panel on Climate Change (IPCC). Each scenario describes varying degrees of warming and associated impacts. Furthermore, we will focus on the methodologies used to generate climate projections, both at global and regional scales. In particular, the latest climate projections for the Mediterranean region produced by ENEA and simulated with a state-of-the-art regional climate model will be presented.

Energy demand: current production methods and development prospects

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In the last century, a group of geologists, headed by King Hubbert, caused deep dismay by predicting that oil would run out around 1980.
Forty years later the authoritative "*Annual Energy Review*" stated that modern industrial activity is based on oil being its main activity the combustion. In fact, the contribution of fossil fuels reached approximately 80% of total energy production. All this, thanks to the development of technologies used in the extraction of hydrocarbons from the subsoil, taking advantage of geological and geophysical data managed through complex mathematical models. Therefore the demand for energy has increased over time, with consequent employment of oil and increase of the concentration of CO_2 in the atmosphere. As confirmed from the analytical data describing the evolution of its concentration in the atmosphere as a function of time.

Only hydrogen, produced through electrolysis and used as energy carrier, revealed to be of particular interest. By offering a perspective to the electrical energy obtained through renewable approaches, in the transport sector.

The use of nuclear fission instead, developed slowly, because it currently provides only 5% of total energy, while nuclear fusion is still the subject of research. On the whole also if the use of renewable energies, wind plus photovoltaic, has developed, at global level they do not exceed the 5.5% threshold.

An energy transition has been promoted aimed at imposing the transition from energy sources with a carbon footprint to others with low emissions. However, the rate of the diffusion processes present in the gases tends to make the atmospheric composition of the entire planet uniform, creating an embarrassing situation for those who believe in the possibility of limiting the evolution of global warming by operating at local level. By evidencing that the reduction of the increase of CO_2 in the atmosphere can only be successful if based on international initiatives.

Therefore, it does not appear reasonable to believe that the use of technologies lacking innovation can save the planet from an evolution considered epochal. To conclude that only new approaches will be able to avoid the aforementioned dangers. Then it is necessary to explore possible turning points, with renewed technological content. Involving processes still subject of research, such as nuclear fusion and the applications of microbiology on the production of fuels obtained from biomass. This last aspect, resulting from the successes achieved in recent years in the synthetic biology, offers a promising approach, which has already led to important application, as confirmed by the production of fuels whose use is spreading in the aeronautical sector.

By promoting the beginning of a post-oil era.

Transition to renewable energies

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The transition from fossil fuels to renewable energy is the key instrument to combat climate change and avert catastrophic effects on human civilisation. Humanity has been relentlessly modifying its energy portfolio for over 200 years, but previous transitions (e.g. from biomass to coal) lasted about a century. We do not have as much time for the transition to renewables, because the global goal is climate neutrality by 2050. A momentous energy transition to be completed in a quarter of a century is a colossal technological, economic and social challenge. The process will see solar and wind power - in combination with various storage technologies - play a dominant role, thanks to a unique combination of technical and economic characteristics and an inherent seasonal and daily complementarity.

Topics discussed include the electrification of energy end-uses, the feasibility of a hydrogen economy, the prospects for nuclear power, and the availability of mineral resources for the production of converters and storage for renewable energy fluxes. The global picture highlights enormous opportunities for scientific and technological progress, but also suggests that the path to a just and sustainable transition is a narrow one, in a world with old and new tensions and already severely affected by the climate crisis. To act effectively, resources and time are now very limited.

Reference

N. Armaroli, Fossil fuels exit: challenges, perspectives, bottlenecks, *The Oxford Handbook on the Greening of Economic Development*, Oxford University Press, **2024**

The challenges of photovoltaics for the energy transition

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Photovoltaics (PV) is set to be a key player in the global transition towards clean and sustainable energy systems. The critical challenge is to accelerate the scale-up of the deployment of PV worldwide to meet the net-zero emission ambitions while the electricity consumption continues to grow. Useful strategies are to increase the conversion efficiency of the PV modules and promote approaches for ubiquitous PV deployment. While the established crystalline silicon (c-Si) PV technology experiences continuous advances and updated designs, a solution to significantly boost the efficiency is the application of one or more wider-bandgap solar cells on top of the Si device in tandem architectures for a better use of the solar spectrum. With a demonstrated high efficiency potential and prospects for further enhancements, in particular perovskite/silicon tandems are under intensive investigation and have recently entered the path toward commercialization. In parallel, in view of the considerable land resources needed, solutions that integrate PV with competing applications should be explored, as in agrivoltaics for optimal shared land use with agriculture.

This talk reviews the ways some of these scientific and technological challenges are tackled at the ENEA – Solar Photovoltaic Division, also discussing collaborative actions involving various national universities and other research bodies with the common aim of achieving the national target defined by the Integrated National Energy and Climate Plan (PNIEC) in terms of photovoltaic power installed.

Bioenergy and biofuels for energy and environmental transition in Net-Zero emissions 2050 scenarios

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In the context of the energy transition, the role of the biomass, bioenergy and biofuels supply chain represents an indispensable renewable and programmable energy resource. Estimates from the CRB Biomass Research Center, established in 2003 by the Ministry of Environment at the University of Perugia, estimate the availability of sustainable biomass in Italy to be 30 percent of all national energy needs by 2050 net of energy efficiency. From the latest 2021 forest inventory, it is clear that Italy has a huge untapped ligno-cellulosic biomass growth potential: our country uses only 30 percent of the wood it grows each year, particularly in coppice forests, compared to a European average of 75 percent. After all, Italy is a forestry country with an average of more than 35 percent forest area, and the development of supply chains based on this resource in regions such as Umbria, Abruzzo, Basilicata, and Trentino with forest areas over 60 percent of the territory would make it possible to create wealth and employment while avoiding depopulation of inland areas. Optimized forest management can allow for an increase in sequestered CO2 and the prevention of fires, which, due in part to climate change, are becoming more frequent and of ever-increasing extent depending on the intensity and persistence of winds.

Already today biomasses represent (Pellets, firewood, briquettes, wood chips etc.) about 50% of all renewable energy produced in Italy, much of this energy is used for thermal uses but in the future, thanks amodern technologies can be used for the production of Bio-Hydrogen and biofuels.

It is well known that the technological change related to the energy transition in the transport sector and electric mobility cannot be implemented immediately but must be achieved gradually in order not to destroy the production system of the energy technology industry. Heavy road transport, and for some sectors such as shipping and aero transport, still needs fuels or biofuels from renewable sources with integrated storage technologies.

In this regard, Italy has been pioneering in the past 15 years with the construction of ENI-Versalis biorefineries for the production of HVO biodiesel (at the Venice Porto Marghera and Augusta sites) aand bioethanol from residual lignocellulosic biomass (formerly Mossi and Ghisolfi's plant) built in Crescentino in the province of Alessandria.

Going forward, in addition to blending biodiesel and bioethanol with diesel fuel and gasoline, the hydrogen production chain from biomass should be considered. In fact, the technology of producing low-cost hydrogen from biomass appears to be economically viable for the next 15 years, and in particular more competitive than the hydrogen production chain based on electrolysis with electricity produced from renewable sources Photovoltaic or Wind.

At present, the two technologies to produce biohydrogen from biomass are steam reforming of biomethane (a mature and established technology) and steam gasification of wood chips, a technology that is being industrialized in light of Italy's bioenergy upgrading strategy to 2050. RSE and Enea have planned a special focus on the development of technologies for bioenergy and biomaterials supply chains for energy efficiency and sustainability in the next three-year system research plan 2025-2027.

References

1)Temporim, R.B.L., Cavalaglio, G., Petrozzi, A., Coccia, V., Iodice, P., Nicolini, A., Cotana, F., Life Cycle,Assessment and Energy Balance of a Polygeneration Plant Fed with Lignocellulosic Biomass of Cynara cardunculus L., (2022) Energies, 15 (7), art. no. 2397, DOI: 10.3390/en15072397

2) Carmona-Cabello, M., Sáez-Bastante, J., Barbanera, M., Cotana, F., Pinzi, S., Dorado, M.P., Optimization of ultrasound-assisted liquefaction of solid digestate to produce bio-oil: Energy study and characterization, (2022) Fuel, 313, art. no. 123020, DOI: 10.1016/j.fuel.2021.123020

3) Frota de Albuquerque Landi, F., Fabiani, C., Castellani, B., Cotana, F., Pisello, A.L., Environmental assessment of four waste cooking oil valorization pathways, (2022) Waste Management, 138, pp. 219- 233, DOI: 10.1016/j.wasman.2021.11.037

4) Aiello, D., Sannino, C., Giannoni, T., Fabbrizi, G., Gelosia, M., Nicolini, A., Turchetti, B., Cotana, F., Buzzini, P., Triacyl glycerols from yeast-catalyzed batch and fed-batch bioconversion of hydrolyzed lignocellulose from cardoon stalks, (2021) Fermentation, 7 (4), art. no. 315, DOI: 10.3390/fermentation7040315

5) Comodi, P., Zucchini, A., Susta, U., Cambi, C., Vivani, R., Cavalaglio, G., Cotana, F., Correction to: Multiscale minero-chemical analysis of biomass ashes: A key to evaluating their dangers vs. benefits(Sustainability 2021, 13, 6052), (2021) Sustainability (Switzerland), 13 (22), art. no. 12634, DOI:10.3390/su132212634

6) Cavalaglio, G., Gelosia, M., Giannoni, T., Barros Lovate Temporim, R., Nicolini, A., Cotana, F., Bertini, A., Acid-catalyzed steam explosion for high enzymatic saccharification and low inhibitor release from lignocellulosic cardoon stalks, (2021) Biochemical Engineering Journal, 174, art. no. 108121, DOI: 10.1016/j.bej.2021.108121

2) Carmona-Cabello, M., Sáez-Bastante, J., Barbanera, M., Cotana, F., Pinzi, S., Dorado, M.P., Optimization of ultrasound-assisted liquefaction of solid digestate to produce bio-oil: Studio e caratterizzazione energetica, (2022) Fuel, 313, art. n. 123020, DOI: 10.1016/j.fuel.2021.123020

3) Frota de Albuquerque Landi, F., Fabiani, C., Castellani, B., Cotana, F., Pisello, A.L., Environmental

assessment of four waste cooking oil valorization pathways, (2022) Waste Management, 138, pp. 219- 233, DOI: 10.1016/j.wasman.2021.11.037
4) Aiello, D., Sannino, C., Giannoni, T., Fabbrizi, G., Gelosia, M., Nicolini, A., Turchetti, B., Cotana, F., Buzzini, P., Triacyl glycerols from yeast-catalyzed batch and fed-batch bioconversion of hydrolyzed lignocellulose from cardo stalk, (2021) Fermentation, 7 (4), art. no. 315, DOI: 10.3390/fermentation7040315

Hydroelectric power: an indispensable resource

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Hydroelectric power in Italy and throughout the Western world has reached its maturity in terms of utilization of the resource of water and land, its development understood as growth consists essentially in the conversion or upgrading of pumped storage plants but much work is needed to keep the operating stock efficient and safe

Existing plants are an essential asset for the energy system, which is evolving toward an increasing presence of nonprogrammable renewable sources, and no program envisions their replacement

The sustainability of plants conceived on average 80 years ago is the subject of a major effort aimed at prolonging their use as much as possible to defend their undoubted benefits that are often taken for granted in the face of increasingly cogent regulations

In many cases a hydropower facility has become more important for its environmental, tourism, irrigation, drinking, flood defense, and firefighting benefits than for the energy it produces; burden sharing follows largely outdated rules

Issues such as the coexistence of animal and plant species with infrastructure or the management of sediment accumulated in artificial reservoirs are the subject of a wide-ranging international technical debate in which Italy remains at the forefront

The age of infrastructure presupposes new investments to safely preserve the existing, and the expiration and duration of existing concessions poses major problems in planning activities for the long term

Hydroelectric power development in both the world and Italy is focused on new pumped-storage facilities that are needed to store renewable energy produced at times when it is redundant.

Maximising the use of geothermal energy for a sustainable energy transition

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The increase in global energy demand has emphasised the importance of developing urgent strategies to support low-carbon resources and technologies. The urgency of shifting to more sustainable energy sources is heightened by the threat posed by the global geopolitical backdrop to the addiction to traditional energy sources. Under this framework, achieving independent and sustainable energy management in accordance with EU goals requires a greater use of renewable energy.

Among the prospective choices, the development of geothermal energy emerges as a crucial component. Geothermal energy represents the thermal energy extracted from the Earth’s crust and exploited both to produce electricity and in direct thermal uses. The direct uses may include district heating, geo-exchange and use in many production processes such as milk pasteurisation, cheese production or food drying. Low-temperature geothermal resources (<100°C) are generally employed in direct thermal applications, while the heat from medium (100-150°C) and high (>150°C) temperature resources is typically utilized indirectly for geothermal power generation. Generally, resources used for direct uses are located at depths of tens to hundreds of meters, whereas those suitable for electrical production are hosted at depths on the order of kilometers.

Despite historically having a limited role in global energy scenarios, geothermal energy can play a significant role at the local level, satisfying energy demands extensively. This concept becomes particularly relevant for countries characterized by high geothermal potential such as Italy, where unfortunately, there is currently minimal utilization and development relative to the existing potential. Italy, abundant in geothermal resources, has demonstrated and continues to demonstrate excellence in the sector by transferring its knowledge internationally and maintaining historical geothermal plants operating in Tuscany, in the fields of Lardarello, Travale-Radicondoli, and Monte Amiata. These fields, with their 37 plants, manage to satisfy 30% of Tuscany's energy needs and currently cover 2% of the national demand. Italy represents one of the most powerful countries in the geothermal market, with an estimated production potential exceeding 100 TW/year by 2050. Maximizing the use of geothermal energy and especially integrating it with other renewable energy resources would significantly contribute to sustainable energy transition, stimulating local economies through both traditional and innovative applications.

To optimize the maximization process, various actions are necessary. These include allocating investments in research, not only to identify and characterize resources but also to promote technological advancement and understanding of potential risks associated to the exploitation, along with mitigation practices. Additionally, it is important to expedite bureaucratic authorization procedures and intensify energy dissemination and education activities to create an informed and aware young and adult population regarding the energy choices proposed by their country. This would potentially prepare individuals for critical participatory actions aimed at achieving energy, economic, and social sustainability.

Offshore Renewable Energy: an opportunity for the energy transition of our Country?

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Abstract:
The use of Marine Renewable Energy, with particular attention to Offshore wind farms and floating solar islands, seems to be an unavoidable step towards a well-defined energy transition strategy for our Country. However, the deep water condition in our Mediterranean sea poses several challenges, both technological and strategic (e.g. missing infrastructures and missing clear rules for the permitting process) that must be addressed to favorite a full development of the technology, possibly based on the use of a national chain value. Novel scenarios, such as that of the Floating Energy Archipelago (first example of a floating city) can be envisaged in a long-term perspective, as part of a sustainable use of the marine space.

The imperative social challenge of achieving environmental sustainability for the containment of climate change, requires, on the one hand, important actions to increase efficiency in the use of energy sources and recover energy waste and, on the other an important strengthening of infrastructures for exploitation of renewable natural energy (wind, sun, waves, etc.).

According to the strategic energy scenarios envisaged by the EU Commission, the European energy system, both production and consumption, must quickly adapt to the sustainability criteria, already foreseen in the Green Deal, which include:

A) Reduction in energy consumption
B) Increase in the share of energy from renewable sources
C) Cutting (drastic) the use of fossil fuels
D) Implementation of the circular economy concept (reuse of materials, extension of the use time of materials)
E) Energy independence

The EU would thus like to facilitate the reduction of greenhouse gas emissions, paving the way for the implementation of climate neutrality by 2050.

Point E) is an indisputable element of resilience. In 2020, approximately 60% of the energy consumed in the EU was imported. Russia had a dominant role as an energy supplier, with 29% of crude oil, 43% of natural gas and 54% of solid fossil fuels, mostly coal. This has resulted in vulnerability to energy shortages, particularly for those EU states more dependent than others on Russian energy.

To achieve this ambitious prospect, the growth of renewables and related infrastructures plays a fundamental

role
- compared to a current European generation capacity from solar PV of around 200 GW, it is expected to double to 400 GW by 2030 and reach 1,400 GW by 2050;
- the current wind capacity will need to increase by 100 GW, reaching 300 GW by 2030 and 1100 GW by 2050;

These infrastructures, however, are relatively large in terms of land consumption and landscape impact, such as to arouse possible resistance from the local population.

In this context, the hypothesis of moving such infrastructures into the sea at a sufficient distance from the coast is a solution to be pursued with determination, despite the greater complexity of the system.

If one were to think about a classification of marine renewable technologies (i.e. wind, wave, tidal and current, solar) based on their level of technological maturity, offshore wind and current and tidal devices would certainly have a leading position. first level, followed by floating solar PV and then sea waves. In fact, a "winning" mechanism for the exploitation of energy from waves has not yet been found, a winner that can use a substantial part of the enormous quantity of energy available in sea waves. On the other hand, current and tidal devices, although efficient, do not find great applicability in some EU basins and in particular in the Mediterranean, given the reduced extension of areas with a significant resource.

In such a context, the EU presents itself as a world leader for marine renewable energy and in particular for offshore wind technology, destined to have a dominant role towards energy independence with over 60GW by 2030 and 300GW in 2050.

Following the virtuous path which has led, in the case of offshore wind with fixed foundation, to the reduction of installation and maintenance costs to the point of estimating an LCOE for 2030 below 7 ct€/kWh, EU wants to propose with the same role and with the same strategy to try to reduce the cost also in the case of floating wind power platforms. This technology becomes an obligatory step to guarantee a rapid diffusion of offshore wind power in marine environments very different from the North Sea, such as those typical in the Mediterranean Sea and/or the Atlantic Ocean. In these contexts, the much deeper seabed makes technologies based on the use of floating structures necessary and sustainable. The path that has now been outlined for a rapid ecological transition sees the use of increasingly larger turbines in power (we are currently at 15 MW and the objective of 20 MW is being reached) and specifically designed for application in the marine field. This will allow a reduction in the maintenance and operation costs of the plant in the short term, allowing us to predict an LCOE of around 12 €ct/kWh in 2030 (SET-Plan).

As highlighted in the SET Implementation Plan, there is a general consensus on the need for new offshore areas to go beyond the shallow water regions of the North Sea, where the fixed-bottom wind turbine is a well-established technology. Deeper seas, which require the use of floating technology, must be exploited for the full deployment of wind energy. Within these perspectives, the Mediterranean Sea is a very attractive alternative. Despite the lower average wind speed compared to the North Sea, the milder sea conditions and greater stability of the wind resource provide advantageous conditions for lower investment and maintenance costs and facilitate an expected reduction in LCOE, a key factor for a full deployment of floating wind turbine technology.

Due to the new challenge of the great depth of water, the Mediterranean Sea still lacks offshore wind turbines. However, very recently, the first prototype of an innovative floating wind turbine designed by Saipem was built and installed by the CNR at sea in front of the port of Naples, at the MaRELab site. The activity was part of a joint collaboration between CNR and Saipem, with the aim of taking a step forward in revealing and understanding the main issues related to the use of innovative solutions for floating technologies applied to offshore wind. This is just one of the objectives of the Research Project "System Research, Theme 1.8: Electric Energy from the Sea" (RdS), financed by the Ministry of Economic Development/Ministry of Ecological Transition and coordinated by the National Research Council (CNR) with the contribution from “University of Campania” (Unicampania) and “University of Roma Tre” and “Sapienza”.

More generally, the RP RdS aims to develop a consolidated scientific approach to study innovative technological solutions for marine renewable energy (from wind, sun, waves, current) leading to higher TRL, up to 8-9, with a reduced investment effort.

This is achieved through an interdisciplinary and comprehensive investigation strategy that combines: i) a set of fully integrated numerical models with variable complexity (depending on the design phase) for the aerodynamics, hydrodynamics, structural, control and electrical of the system marine energy; (ii) model-scale experiments in inland laboratories emulating real conditions at sea; iii) experiments at sea (at the MaRELab site) on a larger scale prototype (up to full scale) of the marine energy device considered.

A new strategy for the collection of marine renewable energy was theorized for the first time since 2015 by the CNR-INM and published for the first time as one of the three strategic lines of Trajectory 5 (Marine Renewable Energy) in the action plan of BIG Cluster: the Floating Energy Archipelago (FEA). Conceived for deep-water marine areas, typical of the Mediterranean, the FEA is a prototype of a floating and modular smart-city, energy independent, capable of collecting marine renewable energy (sun, wind, geothermal, waves) and using it to human and industrial activity in situ.

The Energy Archipelago proposal, the subject of an important collaboration between CNR and Fincantieri, aims to overcome the technological obstacles connected to the offshore construction of energy generation plants from marine renewable sources (wind, wave motion) integrated with photovoltaic systems, to the point to create demonstrative prototypes of energy islands, whose modularity will allow the construction of archipelagos i) of adequate energy production for the different geographical locations, ii) with a combination of energy harvesting systems and technologies appropriately optimized for the energy resource available on the site and iii) with possible in situ use of the stored energy.

Point iii) involves the integration of the capacity to produce fresh water from seawater desalination, hydrogen and oxygen from electrolysis; the first suitable for making the archipelago a floating city for human activity as well as a possible water reservoir for a community of small nearby islands, the second as a refueling site for hybrid naval units. Furthermore, the stored energy can be used to power aquaculture and mussel farming plants to be built nearby. The wide availability of electricity can also make the archipelagos suitable places for the location of Data Centers and unique sites for monitoring marine waters and marine life, which - as is known - are particularly energy intensive. This plant integration - impossible in land-based infrastructures - will make it possible to increase overall efficiency and improve the economic investment plan.

The archipelago plant will, first of all, be functional to the energy autonomy of isolated coastal urban settlements (islands, peripheral villages with respect to the national electricity infrastructure), and then, with the increase in production power, to be able to provide an important contribution to the system national electricity.

In other words, the increase in the planet's energy needs, combined with its overpopulation and the consequent, generally insufficient availability of territories, suggests the need for the development of an alternative paradigm that increasingly shifts certain activities currently concentrated onshore towards the oceans.

In this context, we intend to study the sustainability of the integration between multiple energy sources and its uses for industrial purposes concentrated offshore, with the logic of sharing the necessary support infrastructures and therefore evaluating possible synergies.

With a further analysis we intend to verify whether the idea of a multifunctional energy archipelago that favors a "symbiosis" between different disciplines can create the conditions for overcoming some potential conflicts between different categories such as wild fishing and production of offshore energy.

Renewable Hydrogen: a green energy vector for decarbonization of industry and sector coupling

Francesco Sergi
CNR Institute of Advanced Energy Technologies

Currently, the main options for reducing climate-changing gas emissions can be summarized in three crucial actions: fossil fuels phase-out, use of renewable energy sources and electrification of consumption. However, the decarbonization of the industrial sector cannot be achieved only with this approach because large portions of heavy industry supply chains make use of carbon in their processes (e.g. steel making process, refining, chemicals production, etc.) and require high enthalpy heat. Commonly, these industries belong to the so-called *hard-to-abate* sector, due to the fact that it is difficult to reduce carbon dioxide emission in their manufacturing process.

Hydrogen produced by renewables, is a green energy vector that can be used for hard-to-abate industry sector, energy storage, energy transportation and sector coupling to achieve a more resilient, decarbonized and integrated energy system.

This presentation will explore green hydrogen production and utilization advantages and disadvantages, limitations and opportunities, cost related issues, and raw materials supply needed.

Future prospective in electricity storage

Pier Paolo Prosini

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With the increase of renewable sources in the energy mix, electricity storage is becoming increasingly important. To further the deployment of renewable energy, a progressive increase in our storage capacities is necessary. In fact, since renewable energies are discontinuous, it is necessary to compensate for the discrepancies between production and demand peaks. Among the various storage systems, batteries represent the most efficient one as they allow electricity to be directly stored and released.

What we will have to take into greater consideration for the near future is the development of sustainable batteries, i.e., batteries that use highly available raw materials and for which we know effective methods of recycling at the end of their life.

This topic will be addressed in the presentation: not only valid alternatives for the creation of efficient storage systems with low environmental impact will be shown but also strategies for the recovery of end-of-life batteries will be illustrated.

Motivation for the construction of Advanced Modular Reactors cooled by lead

Luciano Cinotti

***New*cleo**

The abundance of low-cost fossil fuels has created difficulties for the development of nuclear energy which

(i) has not developed new technologies, limiting itself to the construction of water-cooled reactors and

(ii) has relied on economies of scale in an attempt to reduce costs increasing the unit power output.

The exclusive adoption of water-cooled reactors has not led to progress on the fuel cycle characterised by poor use of natural uranium resources and production of long-lived waste. The increase in size, together with the decline in manufacturing capabilities, has increased production times/costs.

The small, modular, water-cooled reactors (SMR) being developed by various companies focus instead on simplicity, economies of series, standardisation, reduction of manufacturing times, and safety, but do not improve the fuel cycle. In an electricity system dominated by renewables, small nuclear reactors will have the function of stabilising the grid.

The US Department of Energy (DOE) launched the Generation IV initiative in 2000 to explore new technologies and the 2002 Roadmap selects 6 of them.

Of these, 4 exploit a fast neutron flux and offer:

- the possibility of reducing uranium consumption by over 100 times, making nuclear power a practically inexhaustible source of energy;

- drastically reduce the production of long-lived waste using as fuel some of those materials that would represent waste for water-cooled reactors.

*new*cleo focuses on the development of liquid lead-cooled fast reactors and in 2023 it was included in the *France 2030* initiative by Bpi France. *new*cleo intends to build a first 30 MWe reactor in France and a series of 200 MWe Advanced Modular Reactor (AMR) in Europe. It is also conceivable to build water-cooled reactors whose plutonium and other long-lived fissile materials are then used by *new*cleo lead-cooled reactors with an appropriate mix between the two types of plant.

Nuclear fusion energy: from basic research to commercialization

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Research on nuclear fusion aims to develop energy production facilities with extremely limited environmental impact (not giving rise to direct release of climate-altering gases or high-activity nuclear waste), independent of weather conditions, using widely available and virtually inexhaustible raw materials. Current studies focus on the D-T reaction between the isotopes deuterium (D) and tritium (T) of hydrogen, which fuse into a helium nucleus (alpha particle) and release a neutron and energy. Deuterium is extracted from seawater, while tritium, found in nature only in trace amounts, can be produced by irradiating an appropriate 'blanket' containing lithium with the neutrons from the DT reaction itself. A 1000 MW electric reactor will only require 100 kg of deuterium and 300–600 kg of lithium each year.

The scientific challenges to be addressed concern heating the reacting fuel, in the plasma state, to a temperature of about 100 million degrees, much higher than that at the centre of the Sun, and its 'confinement', i.e., maintaining it in reaction conditions, isolated from the reactor structure, for a sufficiently long time. For this purpose, two alternative schemes are used, magnetic confinement and inertial confinement, each with numerous variants. In the presently best performing magnetic machines, the 'Tokamaks', a rather tenuous plasma is contained within a toroidal vessel, around which powerful electromagnets are wound. Furthermore, a dedicated circuit induces a current in the plasma, heating it and generating a magnetic field that adds to that generated by the magnets, resulting in magnetic forces that keep the plasma in equilibrium. The plasma is further heated by the injection of electromagnetic waves and energetic particle beams. In inertial confinement, powerful pulsed laser beams irradiate a millimeter-sized 'target', causing implosion, compression, and heating of the fuel, with the aim of triggering 'nuclear combustion' in a small portion of the fuel, which propagates throughout the entire target.

In the past three years, significant progress has been made in both avenues. In magnetic confinement, which historically received more resources (especially in the European Union and Japan), the European Tokamak JET machine has produced approximately 60 MJ of energy in 5 seconds and, in other experiments, achieved an energy amplification Q = 0.67 (the ratio between fusion energy and energy supplied to the plasma). Tokamaks with superconducting magnets have maintained plasma equilibrium for 1000 seconds. A historic milestone has been obtained in inertial fusion: experiments with the NIF laser at the Lawrence Livermore National Laboratory (Livermore, California) have achieved thermonuclear ignition for the first time (initiation of a 'self-sustained' reaction wave, caused by the energy deposited in the plasma by fusion alpha particles), and Q = 1.9 has been obtained: a target irradiated with 2 MJ laser pulses produced 3.8 MJ.

These are significant results in both cases, but beyond technological aspects (related to reliability, availability, costs), further scientific progress is necessary. In the field of magnetic fusion, the European Roadmap primarily involves participation in the construction of the experimental reactor ITER, under construction in France within a larger international consortium, with the goal of producing 500 MW of thermal power in pulses of about ten minutes, with Q = 5–10, and concurrently experimenting with a range of technologies necessary for a subsequent commercial reactor. ITER will be operational in a few years, but full operation with DT is only expected by 2038. Activities are already underway on DEMO, the subsequent prototype of the commercial reactor. In inertial fusion, it is necessary to verify the feasibility of schemes (widely studied theoretically but only tested on a small scale) that can achieve Q values on the order of 100. Additionally, laser, optical, and thermomechanical technologies must be developed to enable repetitive, efficient, and cost-effective operation of the process. At present, there are no institutional roadmaps, but some start-ups, including Focused Energy, have outlined programs that extend to the construction of prototype reactors and are studying and developing all necessary technologies.

It is worth noting the entry of private companies into the fusion sector aiming for rapid commercialization and having collectively received investments exceeding $4 billion globally. The establishment of such companies has been followed, especially in the USA and Germany, by a positive reaction from public institutions. In the USA, Private-Public-Partnership programs have been initiated under the auspices of the Department of Energy. In Germany, the Federal Government has launched an ambitious program to support collaborative initiatives (among private companies, academia, and research centres), open both to magnetic fusion and, for the first time, to inertial fusion. Additionally, the SPRIND [(German) Federal Agency for Disruptive Technologies] has established a company for the development of laser technologies for fusion, which will operate in collaboration with (and in support of) Focused Energy and another start-up.

Sustainable mobility and industrial policy

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The green transition and digital innovations are causing a radical change in the automotive sector and in the "car" product. The “Fit for 55” package (2023), a series of legislative proposals aimed at reducing EU greenhouse gas emissions by at least 55% by 2030 to reach zero in 2050, includes among other things the ban on the registration of petrol or diesel powered vehicles in member countries from 2035. The European industry has been caught unprepared and risks losing ground to Chinese competition. In fact, thanks to a far-sighted public policy, which has long subsidized the growth of the sector, supporting the creation of the entire supply chain, China has become the main producing and exporting country of electric cars. Dynamic and scale economies give it a huge advantage over competitors.

The threat to European industry has led the European Commission to review its "liberal" philosophy, adopting various measures to defend the national industry. Geopolitical concerns have also led to the evaluation of policies to reduce the risk deriving from excessive dependence on foreign sources.

The new European policy must deal with several problems. A protectionist policy carries the risk of retaliation, which could cut off European industry from inputs, raw materials and technologies fundamental to the green transition. Furthermore, a de-coupling with Chinese industry could damage the competitiveness of European companies, to the extent that it prevents them from benefiting from lower costs and China's enormous advantage in green and digital technologies. Finally, opening the European market to Chinese products could reduce costs and accelerate the adoption of electric vehicles, favoring the decarbonisation process, but at the cost of undermining the EU's industrial base. Therefore, opening up to China poses a trade-off between employment and decarbonisation and a conflict of interest between Western car manufacturers, interested in defending their global market shares, and their governments, interested in defending employment.

A delicate balance is therefore required between protection and competition, with the introduction of measures capable of accelerating the production and adoption of green vehicles. An important aspect concerns the financing of the transition. A European sovereign fund, like the American IRA, to finance the new industrial policy agenda is strongly opposed by some European governments. The new European industrial policy, therefore, has left the task of financing the transition to individual states. With the renewed Stability Pact, this implies a very different margin of maneuver between countries in granting aid aimed at attracting the investments necessary for the construction of the new electric car supply chain, safeguarding employment and mitigating the effects of massive employment transitions across sectors, job profiles and regions caused by industry restructuring. Short-term costs and long-term benefits distributed very unequally between and within states risk slowing down the green transition process.

A different model of development and industrial policy - based on the role and ability of the State to set the direction and path of change, shaping markets and coordinating investment decisions at European level, and attentive to social cohesion - could transform the green transition from challenge to opportunity.

Sustainable mobility in the renewable energy sources and climate change contexts

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The demand of energy, and in particular of electrical energy, is continuously increasing since more than one century. There are so many new applications and sectors where energy is essential and demanded to represent one of the most significant challenges in the search for a safer and healthier environment (net-zero target). For instance, air-conditioners at industrial as well as at residential level have dramatically raised the demand of electric energy. In order to cope with the above target, national and international regulation and legislation bodies largely opted for moving towards different sources of energy, which were environmentally friendly and with no-impact on health of earth and people. Renewable and distributed energy sources have than seen as a robust and solid solution toward a carbon-free environment.

A parallel issue contributing to threaten the health of environment and people is represented by vehicles for mobility, particularly mobility in cities. In parallel with the evolution of new-renewable energy sources, all big efforts oriented to make mobility far more environmentally affordable and sustainable led to replace, in vehicles, traditional internal-combustion engines with electric motors, supplied with electric batteries as well as with Hydrogen-based energy sources (either fuel cells or fuel).

However, this transition is still controversial in some circumstances. From one side, electric mobility in cities does not produce any local pollution; on the other side the production of electric vehicles generates pollution in some other places and requires special rare elements. However, there are so many advantages associated with the transition to electric-based mobility in terms of quality of health, efficiency, noise, weight, etc. to make such evolution as on-way. Furthermore, it fully matches with the definition reported in the European strategy on sustainable development approved in 2006 by the European Council, which requires to ensure that transport systems correspond to the economic, social and environmental needs of society, while simultaneously minimizing the negative impacts on the economy, society and environment.

The presentation will focus on main features of electric vehicles compared with conventional ones. Challenges and changes brought by electric mobility will be highlighted (new power networks for renewable and distributed energy sources, energy communities, charging stations, vehicle-to-grid (V2G) concept, supply-chain, new worker skills, refurbishing of production and testing facilities, etc.) with particular attention to the effects on society and on lifestyles.

When the wind blows harder
The impact of climate change on maritime transport

Emilio Fortunato Campana
CNR

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Sea transport is the hidden engine of globalization. In fact, 90 percent of the world's goods transport is by sea: without it, half the world would starve, the other half freeze to death.

However, the spread of marine transport is linked to no small part of the release of CO2 into the atmosphere. To limit and then solve the problems posed by climate change and ocean pollution and degradation, the focus of international institutions is therefore increasingly on technologies for decarbonizing maritime transport, and scientific and technological research is focusing on new fuels, on-board alternative energy production, self-driving ships, electrification, and new digital technologies, with a horizon reaching 2050 for a complete achievement of the goal.

For the time being, and in the coming years, greenhouse gas emissions will continue to push up global temperatures: as a result, we can also expect stronger winds, and a consequent increase in mean sea states and the frequency of extreme events (rogue waves), thus requiring new and more advanced design methods, based on advanced simulation models, integrated with multidisciplinary optimization methods. Even mathematically, the problem in fact is not trivial: the ship is a (large) elastic object traveling at the interface of two fluids in a strongly turbulent regime, and the (free) boundary between the two also has a shape that depends on the solution of nonlinear PDEs with stochastic boundary conditions.

Energy Transitions Amid an Economic Transformation

Arunabha Ghosh,

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Countries undergoing traditional transformations witness economic prosperity before undergoing an energy transition. However, this trajectory looks much different for emerging economies like India, where multiple energy transitions are occurring concurrently with rapid economic growth. Emerging markets are key to the global energy transition, with 88 per cent of the growth in electricity demand between 2019 and 2040 expected to come from them. If they do not shift, or "leapfrog", to renewables and other clean energy sources, there will be no global energy transition. This is the leapfrog decade, with emerging markets like India shifting to cleaner energy at a rapid pace.

India has a short time horizon from peaking fossil fuels by 2040 to reaching its net zero target by 2070. For this, all of India's energy vectors will have to grow to meet growing energy demand, conventional fuels will need securing before phasing down, and newer fuels will need nurturing and support to scale up. In line with this, India is currently going through four central energy transitions – traditional to modern sources of energy, rapid urbanisation, growth of sustainable energy infrastructure, and deeper integration into global energy markets. Through these transitions, India is witnessing large-scale shifts in its energy demand, energy access, and energy efficiency.

These energy transitions have impacts on other SDGs (Sustainable development goals), from gender equity to new jobs to sustainable cities to responsible production and consumption to reduction in poverty via clean energy-driven livelihoods. India is also promoting global initiatives, such as the International Solar

Alliance and the Global Biofuels Alliance.

At the same time, three challenges persist. Financing for clean energy continues to be high cost for emerging markets. Clean energy supply chains are highly concentrated, impacting materials, minerals and intermediate and finished products. And new markets for green hydrogen are also limited by lack of common standards across jurisdictions. For rapid growth of renewables in the decade of leapfrog, the more structural problems in the energy transition must be resolved.

This presentation will present data from India's multiple energy transitions, discuss in more depth the challenges associated with investment and low-cost financing, showcase innovative approaches for technology co-development and new business models to deploy clean energy, and delve deeper into how global supply chains need to become more resilient to respond to energy security challenges for the fuels of the future.

International perspectives on the contribution of nuclear power to a just and sustainable energy transition

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Nuclear power is and has been a key contributor to the decarbonization of the energy sector. The IAEA estimates that over the last five decades, nuclear power has avoided around 70 Gt of CO2 emissions. Though only 31 countries operate nuclear power today, it represents in some countries or regions (the European Union or the United States) the leading source of low-carbon electricity, and globally, nuclear power is still the second source of low carbon electricity behind hydropower. Lack of favourable policies and investments over the last two decades including as a fallout from the Fukushima Daiichi accident, have meant that nuclear generation has not progressed - nuclear generation in 2021 was at the same level as in 2006 - while generation from other low carbon sources such as wind or solar power has greatly increased. Consequently, the share of nuclear electricity has been steadily decreasing from nearly 18% in the mid-1990s to just over 9.2% in 2022.

Increasing concerns about climate change, as well as for security of energy supply, has led to a rediscovery of nuclear power's attributes: the smallest carbon footprint among low C technologies, its contribution to security of energy supply as well as to the stability of electricity grids, but also, its dispatchability and flexibility that make it an attractive partner to variable renewables. Furthermore, though it is more costly than wind and solar on a LCOE (levelized cost of electricity) basis, it can contribute to lowering the overall cost of the transition by reducing the need to overbuild renewable and storage capacities. The International Energy Agency (IEA) recently concluded that "without additional nuclear, the clean energy transition becomes more difficult and more expensive".

At COP28 in Dubai, nuclear power was listed in the First Global Stocktake as one of the low-emissions technologies needed for deep, rapid and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways of the Paris Agreement. New nuclear technologies coming onto the market – such as Small Modular Reactors – are increasingly being considered as options to substitute fossil power plants for electricity or heat production. Macroeconomic benefits of nuclear investments, including job creation and technological spillovers, can help ensure that transitioning away from fossil fuel activities does not leave communities behind.

Capacity building support in infrastructure development provided by the IAEA to dozens of newcomer countries are also reshaping the prospects for nuclear power. The IEA's Net Zero roadmap foresees more than a doubling of nuclear capacity by 2050, in line with the IAEA's own nuclear capacity projections. The presentation will shed some lights on the Agency's global and regional projections, drivers and challenges.

The energy transition and sustainable industrialisation: perspectives from developing countries

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[the views expressed in this short abstract are those of the author and do not necessarily reflect those of the Organisation]

Energy has turned into the next development frontier. Accelerating the energy transition is crucial to achieve net zero and to limit global warming to 1.5^{0} C by 2050. But not all countries bear equal responsibility for the current climate crisis, nor do they possess the same options and capabilities to navigate the transition. The energy transition is not only imperative to save our planet and human life on it, it entails major geopolitical implications. If properly handled, it could be a game changer for developing countries and redefine their role and position in global trade, industrial and innovation networks.

Renewable energies represent a major development opportunity for developing countries. They offer solutions to pressing needs as providing energy to remote and sparsely populated areas. But especially, if coupled with well-crafted and smart industrialization strategies they could offer higher opportunities for local value creation than what was possible under the fossil fuels paradigm. Developing countries have natural endowments which make them key players in the energy transition. They host the vast majority of known deposits of key critical minerals essential for the energy transition, as lithium, nickel, cobalt and others. Non-OECD countries account for 90% of the supply of platinum, graphite, cobalt and nickel. Access to these critical minerals is crucial to ensure security and sustainability of the supply chains to effectively advance and accelerate the energy transition. In some cases, developing countries also have strategic advantages in terms of location for solar radiation, wind, and biomass.

However, developing countries are, and should aim to be, more than just suppliers of raw materials if they want to fully reap the benefits of the energy transition and turn it into an opportunity to transform their economies, diversify trade, increase local value addition, and reduce dependency on external shocks. The energy transition represents a great opportunity to activate new forms of sustainable industrialization in developing countries.

The shared global goal of the energy transition should help changing the mindset of advanced and developing countries in their trade, investment and industrial strategies. It should foster new forms of partnerships balancing the aspirations of developing countries and the needs of advanced ones. Failing to do so bears high risks. It can sensibly slow down the peace of the energy transition, it could limit exploration and prematurely lock the world economy in given energy pathways, and it could contribute to increasingly fragment the world economy. For developing countries on top of these dangers, it would represent a major missed opportunity to transform their economies and their role in the global economic order.

The pace and direction of the energy transition are and will deeply shape international relations, government and business partnerships and ultimately growth and development opportunities in the coming decades. Today, it is in the interest of developing countries, and of the global economy, to treat the future of energy as an open frontier. The big energy players are essential partners in shaping the possible futures of energy; it is equally important to create the conditions for new players to emerge, both in advanced and in developing economies. Chief among the urgent actions is the identification of effective mechanisms, funding models and the preservation of the policy space for developing countries to partner and co-invest in science, innovation, industrial development, and infrastructure.

Is the current EU regulatory framework on energy fit for purpose in view of the EU 2040 Green House Gas targets?

Clara Popletti

(ARERA)

The ambitious European GHG reduction targets require a radical change in energy production, transportation and consumption. The transformation of our energy systems must balance the urgency of decarbonization with the need to ensure security of energy supply as well as affordability. Such a profound and accelerated transformation will carry significant cross sectorial implications not only for the energy sectors, but for the European economy as a whole and, ultimately, for the European citizens.

The European legal and regulatory framework, progressively developed since the late 1990s and still evolving today, has proven effective in ensuring the integration of national markets. The cooperative approach adopted in setting up the European agency ACER has been a cornerstone of the integration process. However, the current regulatory framework needs to be adapted and further improved to address the upcoming challenges.

Thus far it is not clear which technological solutions and market arrangements will prevail in the future, especially for the so-called "hard-to-abate" sectors and industries. On one hand, we observe an increasing push towards the deployment of decentralized energy sources and the utilization of local platforms (or energy communities) to match demand and supply. This trend will be enabled by the fast-growing availability of new ITC tools and smart solutions even for small consumers and families. On the other hand, a more robust cross border integration, supported by additional big infrastructural interconnections, is considered necessary to fully exploit the potential of additional renewable sources, given their uneven geographic distribution and volatility. Greater resource sharing would increase system resilience and most likely reduce costs. These two frameworks are not necessarily alternatives to each other; however, they are somehow in competition. The discussion is ongoing on how to ensure consistency and avoid duplication of costs. Similarly, regarding retail markets, there are diverging views on the role domestic customers can play. If high retail prices might be needed in order to properly reflect environmental externalities and system constraints, they can be very detrimental for affordability. While there is a push towards more active customer participation, there is also a strong need to protect consumers, especially the vulnerable ones.

In seeking a balance between seemingly conflicting objectives, the debate among regulators, institutions, and various stakeholders is now very open, although some themes are consistently identified as crucial: how to improve the regulation of electricity transmission and distribution services, given the prospects for electrification of our systems to support decarbonization; how to ensure the flexibility necessary to cope with the variability of renewable sources; and how to protect customers, especially the vulnerable, from price increases.

Several future regulatory challenges arise from the need to efficiently deploy a new wave of investment in energy infrastructure within a short period of time, both cross-border and within each Country. These investments will particularly concern distribution networks, as the increasing distributed generation and expected growth in self-consumption will result in huge network stress. Regulators will need to leverage new technological solutions, building a framework increasingly focused on performance (an output-based approach) to ensure efficiency in investments. Furthermore, infrastructure planning should increasingly be based on joint scenarios integrating multiple energy vectors (electricity, natural gas, renewable gases) with enhanced coordination between European and national levels, as well as between transmission and distribution. This involves selecting appropriate infrastructure developments and maximizing the utilization of existing assets through capital-light interventions.

While grid investments can increase the European system's capacity to support the deployment of intermittent renewable sources, they are not sufficient alone. The flexibility of the electricity system, defined as the ability to adjust generation and consumption patterns across the different market timeframes, must improve. This is central to the future electricity system. In addition to interventions aimed at enhancing energy supply flexibility through network upgrades and storage development (which are capital investments, nonetheless), demand-side flexibility can also be enabled by both the wholesale and retail markets. However, it remains crucial to clarify that demand enablement (reduction and modulation of consumption), while important, cannot be the main pillar on which to rely for the transition, starting from the fact that it is unlikely to affect a significant customer segment such as the vulnerable or those in energy poverty.

In conclusion, the challenges facing the energy system require an upgrade of the regulatory framework, which must preserve and enhance cross border integration while also being flexible and accommodating tailored solutions for each country. Alongside technical and implementation complexities, improvements in the way infrastructure needs are identified and cross border costs are shared among countries deserve careful consideration.