ENERGY EFFICIENCY AND CIRCULARITY IN A POST PANDEMIC ECONOMY[1]

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1. PREAMBLE

- To contrast the global warming and mitigate the climate change it is necessary to set ambitious targets for the reduction of GHG emissions. Without ambitious emission reduction policies, the average global temperature is projected to increase between 1.5°C and up to 6°C over the course of this century, hampering the future of next generations.
- Limiting warming to 1.5°C implies reaching net zero CO_2 emissions globally by 2050 and concurrent deep reduction of non-CO_2 emissions, particularly methane.
- The model of economic development so far pursued needs to be reconsidered, decoupling the economic growth from emissions and **accelerating the transition towards a more sustainable, climate neutral, and circular economy,** in line with directions indicated in the UN SDGs and the European Green Deal.
- Recognising the role of the energy system in the temperature increase and climate change caused by the GHG emissions generated in combustion processes and of resources depletion linked with the ubiquitous energy uses, calls for deep decarbonisation policies of the energy system.
- The **energy system is key** in the path towards climate neutrality and net-zero emissions by 2050, according to the relevant plans adopted by the majority of G20 members and by over 120 countries world-wide.
- The SARS-Cov2 pandemic has caused a shock to economies at the global level but it represents an unprecedented opportunity to accelerate the transition towards a climate-neutral, and sustainable economy. The massive stimulus measures put in place for the recovery shall be clearly directed to support and accelerate the deployment of low carbon energy technologies with **renewable energy** sources and **energy efficiency** as main pillars, alongside promoting net-zero, **circular models** in all production sectors.
- It is possible to **reach the goals of a full decarbonisation** of the energy system by 2050, but a dramatic change in the entire system architecture needs to take place: replacing fossil-based power plants with renewables is a fundamental step but, to be sustainable and efficient, it needs to be accompanied by a profound transformation in the entire mass and energy flows in the system, transitioning from a linear system towards a more circular system.
- A **systemic view** is needed to ensure sustainable, resilient, accessible, and just energy system development: all layers must be considered.
- Energy and resource efficiency and circularity shall underpin the transition of the energy system: synergies across all energy carriers (e.g. electricity, gas, heat, water, etc.) are to be exploited, maximising process efficiencies to reduce losses and consumption.
- A climate neutral and sustainable energy system relies on the **integration of the different energy sectors** at any scale and considering the most cost-effective ways, leveraging a high degree of automated management and control and the efficient use of energy within all sectors (buildings, industry, mobility, ICT).
- A successful transition relies on an **active engagement of consumers** in the energy system as a prosumer, contributing to energy generation, distribution and use by means of distributed energy resources. Local communities can be powerful accelerators for the uptake of renewable energy, energy efficiency solutions and electric mobility, but affordability of low-carbon solutions is a key issue, in particular for low-income households.
- Global efforts must be deployed in **research and innovation** to accelerate the development of clean energy technologies that are instrumental for the energy transition. Continuous monitoring of the technological advancements and effective **knowledge sharing** processes are essential to foster the market uptake and facilitate the cost reduction of clean energy solutions, leveraging the **synergies between public funding and private investments**.

- Several **challenges and barriers** need to be overcome, including technological gaps, policy and regulatory entanglements, societal and economic models, users' expectations, and behaviour.
- Three pillars underpin the transition to a climate-neutral energy-system, namely: "**Sustainable Input**", "**Flexibility**" and "**Decentralization**".

2. PILLAR 1: SUSTAINABLE INPUT: THE FIRST STEP TO CIRCULARITY

Building a sustainable energy system for the future involves a substantial transition from what is in place today. Sustainability calls for processes that do not deplete natural resources in a significant amount, and renewable energy sources (RES) can fit this paradigm. A sustainable energy system is characterised by the efficient exploitation of all energy sources, fosters energy efficiency in the first instance, relies on renewable energy sources, adopts clean technologies and infrastructures for production, storage, distribution, integration, and use of different energy carriers. Excess electricity from RES converted into fuels will drive decarbonization of hard to abate industrial process and, converted to heat and stored, will enable further circularity and resource efficiency.
Improving efficiency relates not only to consumer-level energy issues, but also to upstream energy production/generation, transmission and distribution. It is an opportunity to accelerate the change from the traditional model of selling energy commodities to one of providing energy services based on innovation.

RENEWABLES AND THEIR CONTRIBUTION TO LIMIT GHG, WHILE ENSURING SECURITY OF SUPPLY

Renewable energy sources (RES)[2] have already significantly contributed to reduce the greenhouse gases emissions (GHG) of the energy system and will play a major role, together with end-use efficiency and the integration of innovative technologies (storage, CCUS, H_2) to pave the way towards a climate-neutral energy system, ensuring security of supply and the promotion of domestic employment. In sharp contrast to all other primary energy sources, renewables used for generating electricity grew by almost 7% in 2020. The renewables industry has adapted quickly to the challenges of the Covid-19 crisis, and hadn't it been for policy and market uncertainties, their development could have been even more important. In fact, while policies and regulatory frameworks remain critically important to provide long-term revenue stability for renewables deployment, competition will continue to drive contract prices down. **Electrification** will be a central pillar of the clean energy transition: while in the IEA Sustainable Development Scenario (SDS) to 2070 the share of renewables in the global power generation mix needs to reach 86%, the share of primary energy dedicated to electricity generation needs to jump from 38% today to over 60%.

THE KEY ROLE OF ELECTRIFICATION

Electrification across all energy sectors is the key to achieving decarbonisation targets by 2050. Indeed, it is a viable and cost-effective pathway for decarbonization of the energy system: in fact, electrification of end-use sectors will account for almost 30% of the annual CO2 reductions in 2070 according to the IEA SDS. Low-carbon electricity shall extensively replace fossil fuels. A major part of GHG reduction from electrification relates to the transport sector, particularly through the uptake of electric vehicles. Significant CO_2 reductions from electrification need to occur also in the industry and building sectors, led by the continued electrification of low-temperature heat applications through heat pumps.

HOLISTIC APPROACH BEYOND ELECTRIFICATION

Ambitious climate neutrality targets and commitments require an integrated approach to decarbonisation across all different sectors, such as **electricity, heating, cooling, transport and industry**.

- Decarbonisation of the energy system is driven by the penetration of renewables in all end-use sectors, but it requires a cost-effective mix of electricity and different low-carbon energy carriers, where direct electrification is not feasible.

[2] more specifically the term usually refers to the following forms: hydroelectricity, wind energy, solar energy, biomass energy, tidal energy, wave energy, geothermal

- Exploiting synergies coming from the interplay of different energy carriers ensures higher flexibility for the whole system, increased efficiency in the energy resources and reduced curtailment of RES, while reducing the need to reinforce existing network infrastructures.
- **Power-to-Gas** and **Power-to-X** technologies allow **circularity** into the energy system: excess electricity from RES converted into fuel as hydrogen or synthetic methane can be used on site or stored for later use, as well as re-converted again into electricity when renewable electricity supply is not sufficient to satisfy the loads.
- **Power-to-Heat** technologies, such as heat pumps, lead to cost-effective and efficient heating and cooling of buildings and industrial process heat production, allowing for lower primary energy consumption. Combined with thermal storage, they will allow thermal energy production to be shifted when renewable electricity is in excess thus closing the loop and enabling a **circular** approach.

ACTIONS NEEDED TO PROMOTE RES ALONG ALL ENERGY SECTORS

Decisive **technological and socio-technical actions** need to be taken jointly to promote the potential of renewable energies to meet electricity, mobility, heating and cooling needs, and to manage the transition from fossil-based economies.

- **Research activities** are urgently needed to bridge technological gaps still existing in several fields. The IEA indicates, in its Tracking Clean Energy Progress[3] that, among the 13 power generation technologies considered, only 2 (i.e. PV and biomass) are on the adequate track towards the achievement of sustainable development scenario goals[4], while 5 need more effort and 6 are dangerously lagging behind.
- Dimensions related to technologies, RES potential, infrastructure are to be considered and addressed in a sustainable perspective, taking into account the existing conditions in individual countries or regions.
- Essential technological actions include the deployment of renewable electricity for all sectors, the development of flexible and interconnected smart grids and systems, large-scale and distributed energy storage systems and demand response and energy management through digitalisation.
- Among the main socio-technical actions we recognise the fundamental role played by the involvement of consumers and the active participation of all actors in the energy transition, and by the public acceptance of low-carbon and carbon-free technologies.
- In order to maximise the sustainability of RES installations and energy system infrastructures, as well as landscape integration, local communities need to be involved in a transparent and inclusive way through a multi-level governance approach.

SUSTAINABILITY ASSESSMENT AND METHODS (LCA, LCC, ETC,)

- All proposed energy solutions need to be assessed considering the effect on the cost of energy-using services, employment, externalities, welfare and justice and, of course, the environment. As concerns environmental impacts, the assessment methods should not be limited to climate change impact but should include pollution, effects on human health, effects on ecosystems and biodiversity. New energy solutions should enable the reduction in primary raw material needs, the promotion of secondary raw material use, the reduction of waste and the increase in energy efficiency, as well as the increase in device life-span thus increasing the level of **circularity**. In this framework, a life-cycle approach should be adopted. Evaluation should include all the phases of the value chain of energy solutions.
- Different **life cycle assessment techniques** are already available to assess the impact of energy pathways and production methods along different aspects of the value chain. An (Environmental) life cycle

3 https://www.iea.org/topics/tracking-clean-energy-progress
4 https://www.iea.org/reports/world-energy-model/sustainable-development-scenario

assessment (LCA) looks at potential impacts on the environment as a result of the extraction of resources, transportation, production, use, recycling and landfilling of products. Life cycle costing (LCC) allows to assess the cost implications over the life cycle and can also include externalities; social life cycle assessment (S-LCA) examines the social consequences of the different portions of the lifecycle of products and services. The combination of these techniques, the Life Cycle Sustainability Assessment or LCSA, should be adopted in energy strategies to avoid trade-offs among the three pillars of sustainability and among communities and generations. A dynamic approach to LCA is recommended: assessment shall take into consideration the foreseeable evolution of both the technology concerned and the overall further increase in energy and resource efficiency due to the transition itself.

FROM RECYLING TO CIRCULARITY

- Appropriate **management of waste from end-of-life** components of the energy system is a circularity pillar of an energy system. The definition of the adequate end-of-life management of RES components (e.g., waste photovoltaic modules, wind turbine, batteries, etc.), the adoption of **eco-design strategies** to increase the amount and value of materials that can be recovered and reused, and new supply chains for their possible repair/reuse for different applications will have to be properly explored, **strengthening a circular economy.** These strategies will have to be adequately supported until technological evolution makes them accessible.

A KEY ENABLER: DIGITALISATION

- The **digital transformation is a key factor to accelerate and enhance a sustainable transition of the energy system.**
- Digitalisation improves the observability of the power system for stable and **secure operation in the presence of higher variability due to RES** and allows the **integration of energy carriers** with the electricity system, improving system balance and resilience at all time scales.
- Interoperable, standardised data architectures and related communication are necessary to achieve higher levels of efficiency in managing energy resources and unlock the **full potential of customers.**
- Digitalisation should be accompanied by important cybersecurity measures to prevent threats and to ensure citizens' privacy.

3. PILLAR 2: FLEXIBILITY: PAVING THE WAY TO CIRCULARITY

Along the pathway towards carbon neutrality of the energy system, variable renewable energy sources (vRES) such as solar and wind will play a major role together with the electrification of several compartments of energy uses. The electric power system will play an increasingly important role and will be the backbone of the carbon neutral energy system. The power system, however, to work properly, needs at all times a perfect balance between the power entering each portion of the system and the connected load (including losses). Any unbalance between equivalent generation and load generates disturbances, fluctuations and transients that can jeopardise the reliability and quality of supply and lead to blackouts. Now, being the type of considered renewable energy sources variable by nature and being the load intrinsically stochastic, the required balance is obtained through a series of features comprised under the concept of "flexibility".

DEFINING FLEXIBILITY

- System flexibility is the ability of a power system to **manage the variability and uncertainty of demand and supply across all relevant timescales**. In fact, the integration into power systems of high shares of vRES poses significant challenges to the system operation and increases a lot the flexibility requirements. Lack of flexibility could hinder the system security and result in inefficient system operation (e.g., vRES curtailments, congestions). Dispatchable fossil-fuel based power plants (especially the most rapid in changing their power output, e.g. gas turbines power plants), together with reservoir based hydro power plants (including pumped storages), are controllable resources used as a major source of flexibility. However, in the wake of energy transition, innovative options able to ensure the full environmental sustainability need to be implemented. Several solutions for flexibility services to the system are available or are being developed, namely:

1. Supply side flexibility (e.g., provided by the vRES themselves, prosumers empowerment, hydrogen as vector etc.)
2. Demand side flexibility (e.g., demand side management, demand response programs)
3. Storage considering all the different technologies: from batteries to seasonal storage (e.g., hydro, thermal and chemical; hydrogen as storage)
4. Network & System flexibility (increasing grid capacity through the reinforcement of the network structure or the improvement of the network utilization through advanced control solutions)
5. Market (e.g., new rules for unleashing vRES flexibility and enabling prosumer and consumer participation in flexibility markets).

- The energy system balance must be maintained at all times and therefore requires flexibility measures with different intensities and acting along different timespans, and namely:
  - ***Short-term flexibility*** (seconds to minutes time scale): is essential to ensure the stability and controllability of the system with respect to the short-term vRES variability and sudden imbalances caused by contingencies allowing network operators to manage the overall system efficiently and securely.
  - ***Mid-term flexibility*** to cope with the natural variability of vRES and load/supply forecast errors from several minutes to several hours.
  - ***Long-term flexibility*** to deal with low wind and solar energy availability lasting several days and involving a vast geographical area and to cope with vRES seasonal variability.

THE NEEDS TO SUPPORT SYSTEM ADEQUACY

- The extensive integration of vRES in the power system generation portfolio shall not happen at the expense of the reliability and quality of supply. It is therefore important that power systems rely on **adequate levels of resources** (i.e., installed power, storage, flexibility and network transport capacity) to meet the expected electricity demand profile at all times, including a reserve margin able to cope for forecasts errors (of load and generation) as well as consequences of possible grid failures and other contingencies. This means that to be reliable, an energy system must be dimensioned with a certain degree of overcapacity to ensure that all users are supplied with adequate power quality whatever the variation of energy sources over time. This overcapacity shall be managed efficiently to avoid losses and wastes: in this context, sector coupling enables the conversion of excess renewable electricity generation into other forms of energy, thus closing the energy loop in a circular approach. Supporting renewables with the introduction of new solutions such as services provided by electrochemical storage and the possible exploitation of demand response would be important to comply with the adequacy and quality of supply standards. To guarantee that these new solutions will be supported by relevant investments, innovative markets and regulatory framework evolutions are needed.

INTERCONNECTIONS TO SUPPORT TRANSMISSION CAPACITY AND FOSTER RES INTEGRATION

- **Interconnections** will play an increasingly important role while the level of vRES penetration in the system will increase. Harvesting renewable energy from remote areas and transferring excess of available power to regions where power production is low will be a key factor to reliably operate the future power systems. Interconnections have always played a pivotal role in power systems fostering system strength against variability, transients and contingencies. Powerful interconnections, with special reference to **high voltage direct current (HVDC) systems**, leverage the potential of different renewable energy sources, technologies, time zones, load characteristics, also located far from one another thus ensuring the overall balance along the entire energy system. Lack of production in one area can be compensated by surplus in another one; overnight wind generation can be exploited in areas with daytime thus leveraging time zone differences, etc; In a future dominated by weather-dependent and intrinsically variable sources, such as wind and solar, this type of flexibility will be important since it will average the generation intermittency over long distances thus helping to reach a smoother production behaviour.

- Interconnections **support the system also in case of contingency**: relying on power import in case of local issues avoids local blackouts, while the stronger transfer capacity among different power system areas allows to overcome severe transients without the need to isolate portions of the power systems.
- Advanced power system solutions (such as HVDC and other power electronics technologies) can greatly contribute to the overall system efficiency and circularity **reducing possible local power flow congestions** and avoiding the curtailment of renewables.

VALUE STORAGE IN ALL FORMS: FROM BATTERIES TO SEASONAL STORAGE (HYDRO, THERMAL AND CHEMICAL)

- Energy storage can provide multiple services to the electric grid by **storing the energy produced in excess and delivering it on demand**. It can smoothen the variability of vRES, making them reliable and flexible, also enabling a wide range of different services, such as the frequency regulation support and the improvement of the quality of supply.
- **Battery energy storage** systems are considered among the best suited technologies for short and mid-term flexibility services, such as frequency regulation, spinning reserve, peak shaving, vRES power smoothing etc.
- Long term storage services, including **seasonal storage** (with a maximum duration of some months), are necessary in presence of a high penetration of solar and wind energy production. They are generally supplied by bulk energy storage systems, such as pumped-hydro plants or mechanical storage facilities (e.g., Compressed Air Energy Storage (CAES), Liquid Air Energy Storage (LAES), electrochemical energy storage systems or sector coupling.
- **Thermal storage** solutions can be used in several industrial applications as well as district heating, power to heat, industrial processes, etc. Besides, they represent a strong support to heating and cooling electrification. These applications are cornerstone to enhance **the energy system circularity**, thanks to their characteristics of closing energy cycles without energy waste: storing excess electricity that would, in an open cycle, cause the curtailment of renewables, by converting it to other forms, enables new energy streams bending over the cycle towards useful ends, thus increasing circularity.

THE POTENTIAL OF SECTOR COUPLING

- In order to achieve ambitious objectives of climate neutrality and zero net emissions, among the different possible future energy mix, the one based on the **integration of energy systems** (Sector Coupling) is of great interest because of its expected outstanding features, namely: i) efficiency and a more “circular” energy system, ii) greater direct electrification of end uses and iii) use of renewable energies and low carbon emissions fuels (including hydrogen) in all those sectors where direct electrification is not feasible (hard to abate).
- **Sector coupling**, through the integrated use of different energy infrastructures and carriers, both on the supply side (e.g., by converting (surplus) electricity into other forms, e.g. hydrogen), and at the demand

side, (e.g. by using residual heat from power generation processes for district heating), will be crucial for achieving climate-neutrality. Sector coupling provides the energy system with greater flexibility to cope with fluctuations in energy demand and renewable energy supply and will allow avoiding vRES overcapacity. Converting electricity into other forms (Power-to-X) can act as a sink for surplus electricity, using the available energy in a cost-effective and circular manner. The integration of the electricity and gas/hydrogen sectors (Power-to-gas, Power-to-hydrogen) will make it possible to leverage and refurbish existing gas infrastructure to transport renewable energy, reducing the need to expand electricity transmission systems, and to store gas to cope with seasonal variations in demand and supply of renewable energy. Renewable gas will provide low-carbon back-up capacity to generate electricity in power plants or fuel cells when other RES are not available.

- A special form of sector coupling consists in **the re-use of the heat produced by the digital infrastructure**, so important for the integrated energy system. Strong action to improve the energy efficiency of the digital infrastructures by making them climate-neutral and highly energy-efficient with the possible re-use of their waste heat is essential. Coordinated actions will be needed to introduce measures to reduce energy demand from data centres for storing, processing and distributing data, from transmission networks for transferring data between connected devices, from connected devices for generating data.
- **Hydrogen** as a vector allows to decouple the dynamics of energy generation from that of demand. Thanks to its chemical storage properties, hydrogen is becoming a key enabler for the integration of vRES in the power system. RES-based electrolytic hydrogen can be produced by the excess in vRES and has a load levelling effect. Hydrogen can then be deployed in a multitude of processes both as an energy vector and as feedstock, providing the opportunity to link and operate different sectors and networks.

4. PILLAR 3: DECENTRALISATION

The increasing availability of cost-effective renewable energy technologies is accelerating a paradigm shift of the energy system from centralized energy generation (largely dependent on fossil-fuelled power plants) to decentralized generation, relying on small-scale generation capacities from RES and Combined Heat and Power (CHP) units not connected to the high-voltage or gas grid, usually small-scale plants that supply electricity to a building, industrial site or community, potentially selling back surplus electricity.

DECENTRALIZED ENERGY OFFERS THE OPPORTUNITY TO REDUCE THE CARBON INTENSITY OF ENERGY USE

- **Energy is generated close to where it is used**, exploiting renewable energy resource available locally (wind, solar, biomass, biogas, geothermal, wave or tidal energy, hydro, waste) or small CHP plants. Decentralized energy allows for more circularity, sustainability and a more efficient use of energy.
- Achieving a shift in resource efficiency contributes to decoupling economic growth from environmental impact due to the reduction of the carbon footprint of power generation, to a broader availability of RES, and to the exploitation of marginal feedstock such as biogenic waste. For example, bio-methane produced from organic waste can be injected into gas networks at a local level; waste heat from CHP can be used for district heating and cooling, closing the loop and achieving a major resource-efficiency.
- Energy and climate benefits are due to **increased conversion efficiency** (capture and use of heat generated, reduced transmission losses); increased use of renewable, carbon-neutral and low-carbon sources of fuel; more flexibility for **generation matching local demand patterns** for electricity and heat; reduced exchange of energy on large distances that contributes to delay the need of new infrastructure.

DISTRIBUTED ENERGY RESOURCES AND ACTIVE ROLE OF THE CONSUMER

- A decentralized energy system architecture makes the system more sustainable and triggers more inclusive and circular processes, for example in waste and water management, through adequate territorial planning.
- In this model, the **consumer plays an active role** contributing to the energy supply. Decentralization involves households, small communities, or businesses that own and operate energy generation and storage assets available locally, including solar photovoltaic (PV) panels, wind turbines, biomass, waste, CHP, and battery storage (e.g., in electric vehicles, e-bikes, e-scooters).
- Main drivers towards a decentralized energy system are: local energy communities as an organizational model enabling consumers/prosumers play an active role; the increasing availability of distributed energy resources including storage from electric mobility (EV). Digitalization and a proper governance and market design are key enabling factors.

OUTSTANDING ROLE OF LOCAL ENERGY COMMUNITIES

- Energy communities, as a cooperative, bottom-up model to produce and consume energy, are expected to play an important role in the transition. In a decentralized system relying on RES, consumers shall contribute to energy production: energy communities are a **means to enable consumers to participate actively** in the energy system, leveraging distributed energy resources and providing the energy system with flexibility.
- Comprising a **variety of local energy actors**, such as private households, small businesses, energy producers and distributors and local authorities, energy communities can make a substantial contribution to the development of renewable energy generation and distribution. Consumers may engage in generation from RES, distribution, aggregation, energy storage, or provide energy efficiency services to its members. The aim is mainly to maximise self-reliance in energy generation to **match energy local demand and supply**, but energy communities can eventually sell excess energy to the grid, by power purchase agreements with electricity suppliers or 'peer-to-peer' (P2P) trading arrangements.
- A community-based energy system allows to aggregate and exploit energy resources at the local level, contributing to a more sustainable and inclusive transition. This brings multiple benefits as regards:
    - Energy self-sufficiency and resource-efficiency: development of local energy generation contributing to achieve energy targets.
    - Addressing energy system vulnerability: local production/consumption of energy increases the energy security in terms of lean development and optimal use of local resources, reduction of losses, congestions, reduction or delay in infrastructural investments.
    - Social acceptance of RES: citizen engagement and community ownership of energy resources can overcome resistance to infrastructure development.
    - Social and environmental benefits, as well as creation of local jobs and growth, new entrepreneurial forms and bottom-up innovation.
- In both developed countries and emerging economies, energy communities can be regarded as a model to help achieving carbon reduction goals, foster consumer engagement in the energy transition and to **address energy poverty**. Since energy is generated locally, profits remain in the community helping to bring down the cost of energy in the long run, whilst also inducing the emergence of local value chains addressing energy poverty, in particular in low income, inhabited or marginal areas.

TRANSITIONING TO EVs MOBILITY

- Given the significant share of GHG emissions of the transport sector, it is decisive to implement measures to reduce the use of fossil fuels shifting to very low or zero carbon-based technologies. **Electric mobility** plays an important role in accelerating carbon neutral transition: a proper transition to

EVs mobility, supported by higher deployment of RES, contributes with multiple benefits to the sustainability of the transport system.

- EVs are expected to play a key role in the decentralized energy system:
  - as a driver for increasing RES integration in the buildings – so far, the dominant charging points - to meet the additional power demand coming from EVs.
  - offering support to the grid to enhance grid stability and continuity of supply.
- EV batteries connected to the network constitute a huge reserve of energy that can operate as distributed resources. **Vehicle-to-grid (V2G)** technologies use batteries in parked electric cars to store electricity that is produced in excess or as an electricity reserve to power the grid or a home network when needed. This solution, among others, helps make the most of the renewable electricity that is produced by vRES, and to better manage fluctuations on the electricity grid, operating the batteries as an active storage by feeding power back into the network during high demand periods or disturbances.
- To achieve this, **smart charging** stations are to be deployed to complement V2G, along with smart meters and smart grid technologies: a dynamic management of decentralized energy and storage resources requires a massive digitalization of the energy system.

DIGITALIZATION TO FOSTER DECENTRALISATION

- The increasing electrification and more decentralized deployment of renewable power generation require the development of **reinforced and smarter electricity networks**, able to accommodate both centralized and decentralized elements. The massive integration of smart meters and a meter interface with the user's devices and Home Energy Management Systems allows the implementation of new business models and aggregation schemes (e.g., energy communities) that exploit the flexibility of the end-users.
- Digitalization is also key to unlock the **full potential of customers** having a flexible energy consumption to contribute to the effective integration of higher levels of RES. Peer-to-peer electricity trade can enable local energy communities and their interconnection to the electricity system.
- Digitalisation paves the way for **virtualization and digital representation** of systems and devices enabling flexible ICT architectures with increased resilience and recovery strategies. IT techniques, including semantic data models, Big Data management and Artificial Intelligence, will enable the optimization and automation of processes and support operators' decisions. Through digitalisation, it will be possible to **facilitate services** and achieve full integration throughout the energy system.

GOVERNANCE AND MARKET DESIGN

In a decentralized energy system, governance and market design play a pivotal role to drive the transformation of the energy system and support the integration of increasing shares of RES. The energy system, largely designed for conventional and centralized power generation, requires now fundamental changes to adapt to the rise of distributed generation, increased reliance on variable sources, emerging role of storage and active role of consumers in the energy market.

These adaptations concern all actors of the energy system, including policy makers, regulators, grid operators, utilities, consumers, and new energy operators such as aggregators. A decentralized system requires **different market schemes and actors' role** with respect to the traditional approach. Existing network services should be re-thought, and **new regulatory schemes** must be developed in order to ensure stability and security of the energy system on all timeframes.

From this perspective, **market design** should be based on current and new system's needs, considering short-term markets, minimizing distortions, and providing **clear long-term investment signals** to support the deployment of cost-effective carbon-neutral technologies. **Regulatory sandboxes** should be largely used to introduce new schemes into the market.

Important challenges are to be considered:

- Fair and transparent remuneration schemes. In some cases, a remuneration for the capacity should be defined in order to deliver a proper signal for medium/long term investments;
- Clear and stable support schemes, the impacts of which should be monitored for fine tuning;
- Aggregation of small users' needs simplified contract schemes;
- Standards and networks codes, also to set a level playing field for all customers and operators;
- Simplification and transparency of the authorization procedures.

5. CALL FOR ACTIONS

- No single fuel or technology can enable the entire energy sector to reach net-zero GHG emissions. Success depends upon a **deployment at scale of a wide range of low-carbon solutions and technologies**, tailored to individual parts of the energy sector and to country-specific circumstances.

- Planning strategies shall **consider the energy system-as-a-whole**, so that new developments can help minimizing the cost of transition to a carbon-neutral system. An **integrated planning approach** ensures that all energy sectors receive the necessary share of investments to bring the enabling technologies at a market maturity level.

- The development of **smart energy networks** with adequate rules of operation provides an important opportunity to enhance the synergy among technologies, thereby enhancing the cost-effective penetration of the broadest range of low-carbon technologies and assuring energy security, improving the resilience of the energy system while fostering circularity.

- **Global collaboration** is needed also in the field of research, development and innovation to accelerate the market uptake of clean technologies, leveraging the experience of more advanced countries to help developing economies leapfrog towards sustainable, efficient and circular solutions. Governments have a fundamental role to play sustaining innovative solutions to become competitive and leveraging the synergies between the public and private investments.

- Significant **investment along the entire energy value chain** (from research and innovation to deployment) is essential to integrate renewables, leading to more efficient, flexible and economically and environmentally sustainable system. Meeting long-term energy security and climate goals requires the design of **more effective innovation models** that are able to mobilise additional investment to deliver more rapidly competitive clean energy technologies.

- The **regulatory framework shall be adapted** to enable the clean energy transition according to an integrated and technology neutral approach; particular attention shall be given to energy storage ownership and management, sector coupling, self-consumption and energy communities.

- Enabling the evolution of the energy system towards a more sustainable, efficient and circular configuration needs a specific attention also at **governance level to facilitate the development and market uptake of clean energy technologies** through adequate legislation, tax regimes and support schemes.

- Collective action is key to addressing climate change. **International cooperation and multilateral action shall continue** providing a platform to share best practices, align ambitions, harmonise standards, maximize and capitalize R&I efforts and support investment at scale.

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