Foreword by Professor Andris Piebalgs, Former EU Commissioner for Energy

In recent years, the world has been characterized by dangerous divisions, both politically and ideologically. Yet, amidst these tumultuous times, 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) emerged as a beacon of hope. Held in Dubai, this pivotal conference marked a significant shift in the international approach to climate change, symbolizing a convergence of opinions and commitments that many thought impossible just a few years ago. COP28 will be remembered as a historic event, where all participating nations unequivocally confirmed their dedication to a critical and urgent cause: accelerating emission reductions with the aim of achieving net-zero by 2050. This commitment was not just a declaration of intent; it was a promise for immediate action within this critical decade. The agreement to reduce global emissions by 43 % by 2030, in line with the best available science, was a bold and necessary step to keep the increase in global temperature within 1.5° Celsius—a target that is not just desirable but essential for the survival of our planet.

The most groundbreaking aspect of the COP28 resolutions was the unanimous agreement to transition away from fossil fuels. For many years, the reliance on oil and gas has been a contentious topic, with numerous countries heavily dependent on these resources for their economic stability. This consensus marks a dramatic departure from traditional energy policies and signifies a collective acknowledgment of the urgent need to embrace alternative energy sources. For nations whose economies are deeply rooted in fossil fuel production and use, this transition represents a monumental challenge. Moving away from oil and gas necessitates a complete transformation of the economic structures. However, this challenge also presents a unique opportunity for innovation and growth.

The shift towards renewable energy sources and increased energy efficiency is not just an environmental imperative but an economic one, offering new avenues for development and prosperity. The commitment at COP28 to drastically increase the installation of renewable energy capacity to at least 11 terawatts (TW) and to double the rate of global energy efficiency improvements from roughly 2 % to 4 % annually by 2030 is a clear indicator of the world's resolve. This ambitious goal reflects a deep understanding of the role renewable energy and efficiency improvements play in combating climate

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change. The focus on renewables, such as solar, wind, and hydroelectric power, paves the way for a sustainable and resilient energy future.

The global energy landscape is experiencing a significant transformation, with electrification emerging as a key factor. This shift affects both the demand and supply of energy and is defined by advancements in technology as well as substantial changes in business models. Electrification involves the transition from fossil fuel-dependent technologies, such as internal combustion engines and gas boilers, to electric alternatives, for example, electric vehicles and heat pumps. These alternatives are typically more efficient, leading to a reduction in overall energy demand. Additionally, as electricity generation moves towards decarbonization, the impact of these changes on emissions becomes increasingly consequential.

Electrification not only unlocks efficiency but also has the potential to lower consumer bills. However, these benefits take time to materialize, as electrification must be supported by the development of infrastructure, including public chargers for electric vehicles, strengthened distribution grids, and the rapid deployment of smart metering. A surge in electrification is crucial across all sectors, particularly in transportation.

To fully harness the decarbonization potential of electrification, it's essential that electricity generation transitions to low-carbon sources, especially renewables. This transition is complex, faced with challenges such as public perception, land use issues, lengthy and cumbersome permission procedures, and political divisions. In addition, power grids must enhance their capacity and adaptability to meet the growing electricity demand, and the need for increased energy storage solutions must be addressed. The deployment of digital technologies and smart grid management, along with storage solutions, such as pumped hydro storage, vehicle-to-grid (V2G) systems, and both prosumer and utility-scale batteries, can lead to lower costs and improved reliability of energy systems with high levels of variable renewable energy (VRE), such as solar photovoltaics (PV) and wind.

Political decisions heavily influence this transition. The fair distribution of risks and benefits, adequate investment signals for necessary assets, and incentives for anticipatory investments largely depend on the frameworks established. Consensus has been reached on some actions based on current experiences, such as redesigning short-term wholesale markets to integrate large shares of VRE, creating investment frameworks and policy instruments to facilitate the deployment of low-carbon electricity generation and new technologies in the markets, and introducing carbon pricing to account for the costs of greenhouse gas (GHG) externalities. As electricity systems move away from fossil fuel generation to higher shares of VRE, ensuring secure system operation will require a different configuration of components.

Hydrogen, produced by electrolysis, plays a controversial but potentially vital role in decarbonizing sectors where direct electrification is not feasible. It could be crucial for long-duration flexibility, adequacy, and resilience in decarbonized energy systems. Regardless of the scale of hydrogen use, a holistic system perspective is necessary to establish an energy-efficient and infrastructure-efficient energy system.

A critical challenge is the lack of electricity access for a significant portion of the global population. In 2022, the number of people without access to electricity rose for the first time in decades, reaching 760 million. This increase, reverting back to 2019 levels, is largely attributed to the repercussions of the COVID-19 pandemic and geopolitical upheaval following Russia's invasion of Ukraine. Most of this increase is observed in Sub-Saharan Africa, home to 80 % of the electricity-deprived population and possessing some of the world's best renewable energy resources.

The need to accelerate electrification is clear, yet progress is slower than anticipated. In Europe, despite ambitious climate targets, the electrification rate has remained stagnant at around 20 % for the past 15 years. To decarbonize Europe and achieve long-term energy independence from fossil fuels, a threefold increase in electrification is necessary by 2050. However, this goal faces significant challenges unless Europe implements enabling factors for tangible action.

A major advancement is the consensus on a new electricity market design in Europe. This framework aims to establish a renewable-based energy system, reduce energy costs, and protect consumers from price fluctuations. It encourages the use of long-term contracts for clean power production and incorporates non-fossil fuel-based flexible solutions, such as demand response and storage. This reform empowers consumers, including businesses and public authorities, to actively participate in the energy system as prosumers. They can invest in renewable energy sources, such as wind or solar and sell surplus energy. Additionally, the reform mandates that all public support for new capacity in renewable and low-carbon electricity generation must take the form of two-way Contracts for Difference (CfDs) or equivalent mechanisms. This approach ensures revenue stability for power producers and protects industries from price volatility. Furthermore, the new design enhances the integration of renewables and improves predictability for electricity generation through increased transparency and real-time trading deadlines.

Europe's experience demonstrates that technological developments need to be accompanied by new regulatory approaches and economic models. In many cases, the technologies advancing energy transition towards carbon neutrality are disruptive in nature, and existing energy regulatory frameworks need to be adapted or substantially revised.

Europe demonstrates another opportunity coming with electrification. Cooperation between countries provides lower prices for consumers and more security of supply. Most European neighboring countries are well connected by transmission lines, and one country might have cheaper generation units available for export. In a neighboring country, meanwhile, more expensive units will not be needed to meet demand. Still, even in Europe's common electricity market, congestion is a problem, and it is not constant over time. The frequency of congestion and its impact on markets depend on the changing demand-supply balances in connected markets. Building new transmission lines is often the most expensive option to increase capacity. Better management of existing transmission assets, for example, through more integration of grid operation

between countries or the use of advanced technologies to monitor grid capabilities, can free up significant value at a much lower cost. Too little cross-border transmission capacity implies higher generation costs, more emissions, and less effective deployment of new generation than necessary. Maximizing transmission capacity within the current infrastructure and setting incentives to build out additional power lines will be crucial for a cost-efficient net-zero transition.

The energy system is evolving, and so is energy research. Multidisciplinary research is advancing our understanding and providing a basis for solutions to the challenges ahead. Despite all the difficulties on the way forward, there is a basic consensus that electrification based on renewable energy sources is a no-regret option and provides the least cost for society.

The "Handbook of Electrical Power Systems" serves as a guide to the complex changes in energy systems brought about by the transition, with electrification at its core. It consolidates knowledge and experiences from various research areas worldwide.

Riga, June 2024 Professor Andris Piebalgs