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Inter-sectoral cooperation on cross-cutting issues:
Digital and data transformation in the energy sector

The twin transition in non-electricity sector [1]

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I. Introduction

1. The energy sector is undergoing a significant transformation, driven by the move towards sustainable energy. The pursuit of lowering emissions from the energy sector requires technological innovation to ensure operational efficiency for sustaining industrial competitiveness. Within this framework, digitalization emerges as an enabler, facilitating both innovation and enhanced productivity.

2. While electrification plays a major role in reducing emissions footprint from the energy use in the transport, industry, and residential sectors, the broader success of these efforts hinges on comprehensive modernization across the established sectors, such as oil and gas, alongside emerging areas like hydrogen. These sectors stand to gain substantially from the efficiencies, novel products and services, and innovative business models facilitated by digitalization. Additionally, on the demand side, digitalization enables energy-efficient behaviours, enabling better planning and more inclusive decision-making while accelerating the electricity system transformation.

3. Acknowledging the transformative role of digitalization across various energy sectors beyond electricity, the Task Force on Digitalization in Energy expanded its research to the theoretical application of digital technologies in sectors other than electricity, initially focusing on the oil and gas sectors, as well as on hydrogen, heating and cooling, cooking, and transport. The objective of this research track is to provide a comprehensive overview of the synergies and the current state of digitalization across the energy system.

4. This document, specifically, aims to raise the most pressing and important questions around the role of digitalization in energy sectors other than electricity. One

[1] The findings, interpretations and conclusions expressed herein are those of the authors and do not necessarily reflect the views of the United Nations or its officials or Member States. Mention of any firm, product, service or licensed process does not imply endorsement or criticism by the United Nations. The designations employed do not imply the expression of any opinion whatsoever on the part of the United Nations Secretariat concerning the legal status of any country, territory or area, or of its authorities.

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of the stated goals, is to raise awareness about research among the member States and the expert community across geographies, calling for more in-depth collaboration and analysis on matters of common concern.

II. Energy supply side and other energy vectors

Oil sector

5. The oil sector represents a major area within the global energy landscape, accounting for approximately 30% of the world's primary energy supply in 2023.[4] Despite its predominant supplier role across multiple industrial sectors, the oil sector is facing increasing environmental challenges and stricter requirements for fossil fuel investments. Such challenges highlight the need for technological innovation and digitalization across the entire oil value chain, which encompasses upstream (prospecting, exploration, and production), midstream (transportation), and downstream activities (refining), as well as distribution and consumption.

6. Historically, the oil sector has recognized relatively low levels of digitalization, with applications primarily restricted to upstream activities such as seismic data collection, reservoir modelling software, and pipeline transportation.[5] Although the sector's capital-intensive nature has contributed to this slow adoption, recent advancements in automation have enabled operations in previously inaccessible environments, such as deepwater and challenging land conditions. These innovations underscore the significant potential of digitalization in the oil sector, offering opportunities to reduce operational and maintenance costs by 10-20% and to increase technically recoverable oil resources by up to 5%.[6]

7. The opportunities presented by digitalization, combined with market competition, economic pressures to reduce costs across the oil supply chain, stringent environmental regulations, and declining investment in fossil fuels, are driving the sector's innovation and digital transformation. This shift is further accelerated by advancements in computational power, increased data collection, and the substantial expansion of digital technologies such as the Internet of Things (IoT), Big Data (BD), Artificial Intelligence (AI), robotics and automation, 3D printing, digital twins, and cloud computing.

8. These technologies are applied across various segments of the oil value chain, enhancing operations in distinct areas:

- In exploration and production:
  - IoT facilitates real-time monitoring and management of oil wells and critical equipment;
  - BD analytics enable accurate forecasting of reservoir behaviour during exploitation;

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[4] IEA (2023), World Energy Outlook 2023, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2023, Licence: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

[5] Al-Rbeawi, S. (2023). A Review of Modern Approaches of Digitalization in Oil and Gas Industry. Upstream Oil and Gas Technology, 11 (November 2021), 100098. https://doi.org/10.1016/j.upstre.2023.100098

[6] IEA (2017), Digitalisation and Energy, IEA, Paris https://www.iea.org/reports/digitalisation-and-energy, Licence: CC BY 4.0

  - AI optimizes drilling processes and enhances decision-making for reservoir selection;
  - Robotics and automation improve precision in drilling while reducing human exposure to hazardous conditions;
  - Additionally, 3D printing is employed for prototyping offshore platforms, and digital twins are used for predictive maintenance of essential equipment in the oil rig.
- In distribution and supply chain:
  - Technologies such as asset tracking and management, supply chain optimization, and inventory management enhance operational efficiency and reliability in distribution and logistics;
  - Cloud computing supports comprehensive data management and analysis, enabling more effective oversight and optimization of the supply chain.
- In health, safety, and environment, innovations in risk assessment and mitigation, environmental monitoring, and incident response and management bolster safety and compliance:
  - Virtual reality is utilized to prepare the workforce for hazardous conditions, improving training and safety protocols;
  - AI and BD analytics can be applied to detect methane emissions early and mitigate their global warming potential.

9. Despite the advantages of digitalization, the oil sector faces barriers to its adoption, categorized into technical, organizational, and sector specific. Technically, insufficient IT infrastructure and a shortage of skilled personnel impede the effective use of digital technologies – much like the digitalization challenges in the electricity sector. High initial costs, cybersecurity risks, and complexities in data integration and regulatory compliance further complicate implementation.

10. Organizationally, conservative management culture and risk-averse decision-making result in delays and hinder the timely integration of innovative technologies. Sector-specific challenges include the industry's fragmented structure, which disrupts the coordination of digital initiatives, and the slow pace of large-scale capital projects relative to rapid technological advancements, compounded by outdated infrastructure that inadequately supports innovations.

Natural gas sector

11. The natural gas industry has played a vital role in the global energy sector, offering a more environmentally sound option compared to coal and oil. Nevertheless, the industry encounters obstacles that span from market conditions to heightened regulatory scrutiny aimed at mitigating carbon emissions, while also being subject to geopolitical dynamic. In order to maintain competitiveness and to address the increasing environmental requirements, the natural gas industry is increasingly exploring the implementation of digitalization.

12. Over the years, the natural gas sector has witnessed advancements in digital technologies. Early digital tools primarily focused on process automation and basic data management. However, the sector has experienced additional transformation due to the emergence of advanced technologies such as IoT, AI, and BD analytics. Key milestones include the adoption of digital twins for real-time system simulation, predictive

analytics for maintenance, and AI-driven optimization in both exploration, production, and downstream operations.

13. IoT devices offer real-time monitoring of natural gas critical infrastructure, providing early detection of leaks or technical anomalies. AI and machine learning are used to optimize drilling operations and reservoir management, while big data analytics unlock more informed decision-making processes. As for preventive maintenance, digital twins simulate entire systems to optimize operations. Other automation tools are also playing a significant role in reducing downtime and enhancing operational efficiency.

14. Digitalization is positively impacting the various stages of value chain. In exploration and production, AI-driven seismic data and reservoir modelling are improving the accuracy of resource identification and extraction. Liquefied Natural Gas operations are also benefiting from process optimization and predictive maintenance, reducing downtime and energy consumption.

15. Digitalization in the gas sector also faces significant challenges, such as:

- High initial investment costs for upgrading infrastructure and integrating advanced technologies can deter companies to adopt these solutions;
- Skill gaps and the need for workforce training, as employees may lack the digital expertise required for modern technologies;
- Data integration and management are also complex due to the vast amounts of information generated from various sources, and poor data governance can limit the benefits unlocked by digital tools and platforms.

Hydrogen

16. Hydrogen can contribute to fast-pacing the energy transition process, especially in hard-to-abate sectors.

17. Key among the drivers advancing digital transformation in the sector are the competitive pressures and economic constraints that industries face, prompting the need for even more cost-efficient operations. Environmental regulations are also a significant driver, as hydrogen operators aim to meet sustainability targets.

18. Advances in AI, IoT, and BD have contributed to operational efficiency and cost reduction, through real-time data analytics and process automation. Additionally, safety and risk management are crucial, as hydrogen production and distribution require precise control and monitoring.

19. Digital technologies play a critical role in optimizing hydrogen production. For instance, electrolysis, the most common method for green hydrogen production, benefits significantly from process monitoring, control systems, and predictive maintenance tools. These technologies help in maximizing uptime and ensuring that the electrolysis process is as energy efficient as possible, which is crucial because energy costs make up a large part of the total production cost of hydrogen. Moreover, as policy objectives are supporting clean hydrogen solutions, such as green hydrogen that uses renewable generation, digitalization supports the integration of renewable into the hydrogen production processes, increasing predictability.

20. Digitalization also supports the storage and transportation of hydrogen by providing complex solutions for pipeline and tanker management, helping to effectively manage safety risks. Automated systems monitor the integrity of storage facilities and

transportation infrastructure, minimizing the risk of accidents and enabling quick responses to any potential hazards.

21. As safety is a priority in hydrogen operations, digital tools are supporting continuous risk assessments and ensure proper incident response and mitigation strategies, while also facilitating continuous monitoring of safety parameters.

22. Despite its potential, the hydrogen sector faces challenges in digitalization, with high initial investment costs being the primary concern.

III. Energy demand side

23. Digitalization plays a crucial role in optimizing energy demand across various sectors by improving efficiency, reducing costs, and promoting sustainability. Overall, digital technologies contribute to significant cost savings, enhanced energy security, and reduced carbon emissions, making them essential for meeting the growing global energy demand sustainably.

24. Non-electricity energy demand refers to such key sectors as heating and cooling, cooking, and transport, all of which face unique challenges and limitations. In heating, the reliance on fossil fuels such as natural gas and oil remains high. Similarly, in cooking, many households and industries depend on non-electric energy sources, although such fuels as liquefied petroleum gas, natural gas, biogas, solar, alcohol, and biomass (classified as Tier 4 or 5 for PM2.5 emissions and Tier 5 for CO emissions) that power stoves, constitute clean fuels and technologies).[7] In the transport sector, the challenge is even higher, as it continues to be heavily dependent on oil-based fuels despite significant and growing efforts to shift toward alternative, cleaner mobility solutions.

Heating and cooling

25. The heating and cooling is increasingly being shaped by digitalization, which enhances energy efficiency, reduces operational costs, and integrates renewable energy sources.

26. Digitalization is argued to have the potential to reduce global residential and commercial buildings' energy use by around 10% by 2040.[8] A sizeable portion of global energy consumption occurs in buildings, digital technologies in heating, ventilation, and air conditioning (HVAC) systems may offer numerous benefits in driving sustainability and improving indoor climate management. Among the benefits brought by digital solutions, cost efficiencies arising from more informed energy consumption or informed decision-making on the maintenance and service operations of heating and cooling assets.

27. The integration of IoT with HVAC systems is another important aspect. IoT devices enable real-time monitoring and control of HVAC components, facilitating seamless communication between different system parts. This connectivity allows for better data collection and increased energy management efficiency.

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[7] https://www.who.int/tools/clean-household-energy-solutions-toolkit/module-7-defining-clean

[8] Asif, M., Naeem, G., & Khalid, M. (2024). Digitalization for sustainable buildings: Technologies, applications, potential, and challenges. Journal of Cleaner Production, 450, 141814. https://doi.org/10.1016/j.jclepro.2024.141814

28. The information sourced through digital tools can be used manually by end users or their utility companies for modifying consumption patterns and favouring energy efficiency initiatives, or autonomously via smart thermostats and automated control systems based on AI and model-based control. For instance, smart thermostats are a key digital tool, which uses advanced algorithms and machine learning to optimize temperature settings based on occupancy, weather forecasts, market conditions, or user behaviour.

29. Data analytics and predictive maintenance further enhance the efficiency and reliability of this infrastructure. By continuously collecting and analysing operational data, these technologies can identify inefficiencies, forecast potential equipment failures, and schedule maintenance proactively. This approach reduces downtime, extends equipment life, and lowers maintenance costs.

30. Digitalization also supports the use of renewable energy sources for HVAC systems. To this end, dual-energy systems – which combine two energy sources – are gaining importance in the pursuit of energy resilience and sustainability.[9] These systems often pair traditional energy sources, like natural gas, with renewables such as solar or wind power, providing flexibility and reliability in energy supply. Digital solutions enable seamless transitions between these energy sources based on real-time demand and availability, ensuring continuous operations while optimizing energy costs and reducing environmental impact.

31. In the context of district heating and cooling, digital technologies enable more efficient and flexible energy distribution. By utilizing real-time data, advanced controls, and predictive analytics, district heating and cooling systems can optimize the generation and distribution of heat and cold across urban areas, balancing supply and demand more effectively. This leads to reduced energy waste, lower greenhouse gas emissions, and enhanced reliability of heating and cooling services.

Cooking

32. Digitalization is transforming energy consumption in cooking by introducing smart technologies that optimize energy usage, through smart cooking appliances equipped with automation and remote control. Moreover, as digitalization continues to advance, it is playing a critical role in creating more energy-efficient and sustainable cooking environments.

33. Smart cooking appliances can adjust cooking settings based on real-time data, reducing unnecessary energy use and lowering utility bills. Additionally, digital solutions such as IoT-enabled kitchens allow for advanced integration of appliances, further enhancing energy management. IoT-enabled kitchens can automate tasks such as cooking, inventory management, and energy consumption tracking, making kitchens more efficient and reducing manual effort. For instance, smart refrigerators can monitor their contents and suggest recipes, while connected ovens can adjust settings based on the cooking progress.

34. This connectivity enhances user experience by providing greater control and reducing energy, as well as food, waste, making kitchens smarter and more responsive to user needs. By using these tools, homeowners can track and optimize energy

[9] https://www.hydroquebec.com/residential/customer-space/rates/rate-dt.html

consumption, while also understanding their environmental impact and adopting certain energy behaviours.

Transport

35. Given the extent of the transport sector, as well as the negative externalities generated by it, digitalization is crucial for enhancing efficiency, reliability, and environmental protection.

36. By implementing advanced digital tools such as real-time monitoring systems, predictive maintenance, and automated control mechanisms, the conventional transport sector can optimize the flow of energy across vast networks, reduce operational costs, and minimize environmental impact. These advancements help meet the growing demand for energy while supporting global efforts to reduce carbon emissions and transition to cleaner energy solutions. Several innovative solutions have been tested and are now considered for scale utilization.

37. Telematics systems have become a cornerstone of modern fleet management, blending telecommunications and informatics to enhance vehicle tracking and operational efficiency. These systems provide real-time data on vehicle location, driver behaviour, and engine diagnostics, enabling better decision-making and proactive management. Key benefits of telematics include route optimization, which minimizes fuel consumption by selecting the most efficient paths, and predictive maintenance that helps schedule vehicle servicing, reducing downtime. This data-driven approach allows fleet managers to improve fuel efficiency and vehicle longevity while maintaining compliance with regulations. Moreover, the findings can also lead to the development of new business models for insurance providers or car manufacturers, among others.

38. Vehicle-to-Everything (V2X) communication is another emerging technology that connects vehicles to their surroundings: other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the grid (V2G). The tool plays a crucial role in enhancing transportation efficiency and safety by facilitating real-time data exchange. It can support traffic management by providing vehicles with information about traffic lights and congestion, thus enabling better routing.

39. Smart infrastructure is key to supporting efficient and modern mobility across various transport modes. Digital infrastructure such as smart traffic lights and dynamic routing systems help manage traffic congestion and improve fuel efficiency by adjusting signals based on real-time traffic data. Real-time data analytics provided by these systems support urban mobility by enhancing route planning, reducing travel time, and minimizing environmental impact.

IV. Key areas for further analysis and consideration

40. Digital transformation process plays a paramount role in ensuring the technical and environmental efficiency of conventional energy sectors, while also facilitating a seamless transition to cleaner alternative solutions.

41. Comprehensive inter-disciplinary research is needed to deeply explore the role of digitalization in the aforementioned sectors. Additionally, sector-coupling focused R&D can help to map the benefits and challenges of energy system digitalization for other sectors of the fuel and energy complex.

42. The Task Force on Digitalization in Energy further suggests the following questions to be addressed in framework of its future activities within the mandate for 2025-2026:

General digitalization process challenges

- *What are the most significant barriers to digitalization in non-electricity sectors, and how can they be addressed through policy? What is the role of business operators in ensuring that the right public policy framework is being developed?*
- *What are the cybersecurity risks associated with increased digitalization in non-electricity sectors, and how can these be mitigated?*
- *What role does regulation play in advancing digitalization efforts in non-electricity sectors? What are the incentives needed for a higher-pace adoption of digital tools?*

Sector specific challenges

- *What new digital innovations can further reduce the environmental impact of oil and gas operations?*
- *How can digital technologies support the green hydrogen production process, and what is needed to make it more cost-effective and scalable?*
- *How can digitalization in district heating and cooling systems be scaled, and what are the case studies to learn from?*
- *What are the potential environmental, social, and economic benefits of highly digitalized cooking systems, and how can they be made accessible to both developed and developing regions?*
- *How can digital infrastructure support the decarbonization of conventional transport sectors, while also ensuring a smooth transition to alternative mobility options, including through location efficiency?*
- *How can digital applications facilitate decarbonization, cost-effectiveness, and resilience of the industrial sector?*
- *How can digital solutions help increasing the systemic efficiency of the energy system transformation across energy carriers (to expedite an efficient integration of renewable energy sources)?*

Advanced digital integration solutions

- *What cross-sectoral synergies can be unlocked through digitalization?*
- *How can digitalization support the integration of renewable energy across non-electricity sectors?*
- *What emerging digital technologies hold the most promise for transforming non-electricity sectors? How will advancements in AI, blockchain, and IoT shape the future of fuel and energy sectors in the context of the energy transition?*