Organising Committee:

Report on the key findings from the Theme Development Workshop “AI for Future Energy & Sustainability”

– May 2023 –

Executive Summary

The Joint Theme Development Workshop (TDW) co-organised by CLAIRE, TAILOR and VISION[1] on “AI for Future Energy & Sustainability” took place on the 23rd of February 2023 with the aim to develop and identify the most promising and emerging AI topics in the Energy sector. At this one-day workshop, experts from academia, industry and politics jointly developed initial input for the European Artificial Intelligence (AI) research and innovation roadmap. Inspired by introductory speeches and presentations from selected experts, the participants actively discussed a wide variety of topics during the breakout sessions and shared their main results in the subsequent plenary presentations. Furthermore, some initial ideas for follow-up activities and further collaborations have been identified.

This report contains a summary of the results from the Theme Development Workshop “AI for Future Energy & Sustainability”. To make the results available to a broader audience and the European AI community in particular, this report will be published via the organiser’s websites.

[1] In alphabetical order.

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Introduction

In September 2020, four new AI networks were established by the European Commission via the call "Towards a vibrant European network of AI excellence centres" (ICT-48-2020). The aim of these networks is to foster the collaboration between the best research teams in Europe, and to address the major scientific and technological challenges in the field of AI. These four networks are coordinated and supported by the VISION project to foster activities that reach critical mass and enable the creation of a world-class AI ecosystem in Europe.

One of these activities are so-called Theme Development Workshops (TDWs), an innovative format bringing together key players from industry, academia and politics to jointly identify the key AI research topics and challenges in a certain area or for a specific industry sector. In December 2020, an agreement was made between the respective coordinators and leadership teams of TAILOR, VISION, HumanE-AI-Net and CLAIRE to plan and execute a series of Joint (co-organised) Theme Development Workshops, starting in 2021. This report is a result of the fifth Joint TDW organised and executed within the framework of this series of workshops.

Keynotes and introductory presentations

The TDW was opened by the Co-Chairs Freek Bomhof (TNO) and Ghislain Agoua (EDF) on behalf of the Organising Committee (OC), which included further representatives from ABB, CLAIRE, German Research Centre for Artificial Intelligence (DFKI), EDF, NTT DATA, Tietoevry, Netherlands Organisation for Applied Scientific Research (TNO), University of Valencia (UPV) and Philips. The Co-Chairs outlined the objectives of the TDW as well as the agenda and programme, and introduced the invited keynote speakers to the participants.

The inspiring keynotes were provided by high-level experts from academia and industry. These introductory presentations served as a basis for the discussions about the value of data and the aspect of Sustainability in the Energy sector, and provided some interesting examples of application areas. Accordingly, these presentations stimulated the expert discussions in the following breakout sessions.

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Introductory presentations by Sherif El-Meshad, Dr. Adamantios Marinakis, Aliene van der Veen and Claire Lambert.

Sherif El-Meshad, ABB Electrification, gave his introductory keynote on the role of Artificial Intelligence (AI) in achieving a sustainable future in Energy. Starting his keynote, he outlined the current state and future assessment of AI and emphasised its immense potential. He also explained how it is likely to shape the future of technology with reference to a new forecast from the International Data Corporation's (IDC) Worldwide Artificial Intelligence Spending Guide. It shows that global spending on Artificial Intelligence (AI), including software, hardware, and services for AI-centric systems, will reach $154 billion in 2023, an increase of 26.9% over the amount spent in 2022. The ongoing incorporation of AI into a wide range of products will result in a compound annual growth rate (CAGR) of 27.0% over the 2022-2026 forecast with spending on AI-centric systems expected to surpass $300 billion in 2026. El-Meshad then moved on to the application of AI at its current stage, pointing out that AI is already present in almost every aspect of our daily lives, raising awareness of the importance of AI in the future. While raising the question of whether we should use AI to achieve our sustainability goals, examples of how AI can help address issues such as climate change and clean energy, water security and clean air, biodiversity and conservation as well as weather and disaster resilience were presented. For instance, in the area of climate change, AI can contribute to the integration of renewable energies, as well as supply forecasts and monitoring & prevention to sustainably contribute to water security and clean air.
The main question that was outlined was, “Is AI good or are there any downsides/negative aspects?” In this regard, he showcased the seventeen sustainability development goals set by the United Nations that ABB adheres to on its sustainability journey. These guidelines serve as a framework for responsible and sustainable AI development and deployment. Sherif El-Meshad also shared the results of a study that highlighted the importance of AI, with a positive impact of 79% in various ways. However, the study also revealed that the negative impact of AI is not negligible, with around 35% of targets being inhibited by AI. To address these concerns, he emphasised the need for responsible AI development and deployment that takes into account the potential negative impacts on the environment. This includes using efficient models that optimise energy usage and reduce waste, choosing cleaner energy grids, and mitigating AI bias by using complete and representative sets of data. Sharing best practices and leveraging collective intelligence is another key step in creating sustainable AI, as it enables organisations to learn from each other and work together towards a common goal. Finally, he stressed the need for researchers and policymakers to work together to develop regulations that encourage AI while also managing associated risks. By following these steps, he believes that we can create a sustainable and ethical AI ecosystem that benefits everyone and contributes to a sustainable future.

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Overall, Sherif El-Meshads keynote speech underscored the importance of balancing the potential benefits of AI with its environmental impact. By following sustainable development practices and using AI responsibly, we can create a more sustainable and equitable future.

Dr. Adamantios Marinakis, Research Center for Energy Networks (ETH Zurich), gave a keynote about the role of AI in the future energy systems. Dr. Marinakis started his keynote by examining our ongoing energy system: Today, the triumvirate of gas, electricity, and liquids forms the bedrock of our energy matrix, each serving a specific industry sector or demand - be it heating, appliances, or mobility. Our energy system is vertical, top-down integrated - spanning from the source to the customer through transmission and distribution, characterised by centralised supply, and minimal cross-sector interactions. However, with regard to the future, changes are afoot. The legacy energy system is being disrupted and reshaped. The transition from fossil fuels towards more sustainable, renewable energy sources is no longer a matter of 'if' but 'when'.
In the second part of the keynote, Dr. Marinakis highlighted the main challenges and opportunities that this energy transition presents. Navigating through the complexities of the energy shift, we confront issues ranging from infrastructural changes, regulatory hurdles, to the need for new skill sets. Conversely, the opportunities are immense, providing avenues for innovation, job creation, and environmental sustainability. The third segment of the keynote was dedicated to exploring the role of AI in the future energy systems. For instance, AI is playing a pivotal role in smart grid management, predictive maintenance, energy storage, and optimization. It has the potential to revolutionise how we produce, distribute, and consume energy, making our systems more efficient, reliable, and sustainable.
Dr. Adamantios Marinakis continued his presentation by addressing the significant changes in the energy sector and the respective challenges and opportunities that they present. Firstly, he highlighted the electrification of new demand sectors. With the push towards electrification, legacy electricity systems face the challenge of adapting to new power demand patterns and controlling new sources of flexibility. However, this also presents an opportunity to redesign our systems for increased efficiency and resilience. Secondly, he discussed the rising dominance of renewable energy. While the intermittency and non-dispatchability of wind and solar power sources present challenges, they also open up new ways of power system operation, driving innovation in energy storage and management. Dr. Marinakis then moved onto the proliferation of distributed energy resources. As consumers morph into 'prosumers', contributing to the energy grid, it introduces dynamic behaviour that current electricity distribution grids are not dimensioned for. The surge in potential control points is a challenge but also an opportunity for decentralised, democratic power systems. The fourth change mentioned was digitalization and the advent of the Internet of Things (IoT). With millions of devices exchanging data, the challenge lies in controlling devices for various objectives and extracting knowledge from vast amounts of raw data. However, the opportunity lies in leveraging this data for informed decision-making and

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optimization. Finally, he touched on the advent of new technologies: While the absence of standardisation and the uncertainty around infrastructure investment present challenges, the development of new technologies offers enormous potential for innovation and progress.
Dr. Adamantios further outlined various applications of AI in the energy sector. He mentioned AI's utility in forecasting, increasing awareness, detecting abnormalities, coordinating systems, optimising operations, and supporting decision-making. Moreover, he highlighted the role of AI in autonomy, citing the AISOP project, an initiative focused on AI-assisted decision support for operational planning in distributed systems.
In the closing of his presentation, Dr. Adamantios identified four main challenges associated with the use of AI in the energy system: data privacy, data security, explainability or transparency, and accountability. Each of these challenges needs to be addressed to ensure that AI is used responsibly and effectively in the transition towards a sustainable and intelligent energy future.

Aliene van der Veen, Netherlands Organization for Applied Scientific Research (TNO)
In the keynote "Intelligent Agents in the Energy System and How to Make Them System Operators", Aliene van der Veen set the stage with a classical definition of AI from the textbook "Artificial Intelligence, A Modern Approach" by Russels & Norvig (1995): *"AI is about designing and building intelligent agents that receive precepts from the environment and take actions that affect that environment."* On the basis of this definition, she posed the question, "Where can we expect such intelligent agents in the energy system?" As we see it today, AI supports human agents and increasingly serves as an asset moderator, like with electric vehicles or storage assets. However, according to van der Veen, the evolution of AI into an intelligent agent is the next crucial step. The potential of AI as a system operator in the energy system is significant, but raises concerns about feasibility and safety due to the high responsibility involved. Nevertheless, as electricity and flexibility can permeate all grids, AI might offer powerful tools for system operation.
Furthermore, she emphasised the need for distributed system operation by AI, which was once viewed as a grand challenge in 2012 but is now considered a Social Grand Challenge in 2023. The building blocks for such a system, like the Clean Energy Package (EU Regulation) and the increasing body of knowledge, are already present. However, the transition to a smart grid is hindered by our centralised view on system operation and the lack of agreement on the distribution of system operation responsibilities.
Van der Veen cited a 2022 study outlining a taxonomy of coordination strategies for energy resources, which ranged from indirect control to implicit competition. While implicit competition, especially price-based, could align well with AI, there are still many unanswered questions. Moreover, market-based competition, which is prevalent in the energy system, poses its own challenges, including those related to the nature of intelligent agents. In some instances, the almost perfect rationality of intelligent agents has led to price spikes due to unstable evolutionary dynamics.

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Van der Veen concluded her keynote with key takeaways towards distributed responsibilities in energy systems. System operation responsibilities need to be explicit and modular, thus making distribution possible. Additionally, the governance of distributed energy system operation needs to be defined. Addressing the question of how this should be done, she stressed that it should not be seen merely as a game design challenge for AI. Instead, it should be treated as an organisational challenge where AI handles responsibilities. Interoperability is also essential; designs should contribute to the broader picture instead of focusing on isolated systems.

Claire Lambert, EDF, gave her keynote on the challenges for reliable Artificial Intelligence (AI) in the energy industry. She presented EDF's goal to develop innovative solutions around the world to produce clean energy and guarantee access to electricity for all. She explained why AI is an important lever that will be activated to achieve this goal. Firstly, AI can help improve the process of energy production (nuclear, hydro, renewable) by providing powerful tools for process monitoring, fault detection and diagnosis, uncertainty quantification, etc. Secondly, AI can also help in the operation of distribution networks. It can provide more accurate forecasting models for load, demand and prices. It can provide faster and more efficient optimization and risk management tools. It can also help improve knowledge of consumer behaviour to help reduce electricity consumption and prepare for e-mobility. Finally, AI tools are crucial for customer relationship management, as they provide tools for text and voice processing (transcription, synthesis, anonymization), chatbots, Q&A, or load curve analysis. Lambert emphasised that all these activities in the energy industry require trustworthy AI solutions due to their importance and criticality, and has posed two ongoing challenges that have been addressed at EDF: The first challenge was how to build a generic and trustworthy AI model for time series data, which is useful for several applications such as peak load estimation, flexibility management, network balancing and monitoring, and customer consumption analysis. Besides the operational constraints of data quality, an important regulatory constraint is the European GDPR, as individual load curves are classified as private information. Therefore, it is imperative to build models that are generic, privacy preserving, and robust against attacks all while maintaining good performance levels. The second challenge was how to build explainable AI models when dealing with multimodal data. The data collected can be either structured (tables, time series, contract information) or unstructured (emails, audio transcriptions, power plant photos, drone photos, etc.). The goal is to build an AI model that can handle all this variety of data, while being able to explain how the output is obtained. The use case of identifying new reasons for dissatisfaction with both textual and tabular data is an example.
Overall, Lambert's keynote emphasised that AI is a key tool that is helping and will help the energy sector build a net-zero energy future with electricity and innovative services. Its trustworthiness and ability to respect regulatory constraints will favour its widespread use.

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Key results from the Breakout Sessions

AI for Energy Efficiency

The focus of this session was on how to achieve improved energy efficiency using software solutions in general, and in particular the AI-enabled ones. The session began with an introductory presentation by the invited expert Juha Mäntysaari from ABB Process Automation. Firstly, it was pointed out that there are standard indicators for energy performance, and then stated that it all starts with access to data. Furthermore, the importance of energy consumption anomaly detection and time-series forecasting was stressed. The capabilities of machine learning for time-series forecasting were illustrated by comparing multiple forecast methods for a real scenario.

It should be possible to obtain significant energy savings in many applications by applying machine learning solutions. For example, in any transportation system, be it on land, air or sea, there is room for **energy optimization**. In particular, with the current **clear shift towards electrical vehicles and vessels**. Similarly, in traditional heavy industries, such as mining & metals, pulp & paper, power utilities, and chemicals, there is also a **shift towards electrification with large savings possibilities**. Other applications mentioned were heating & ventilation, data centres and energy storage (battery as well as hydrogen-based).

In order to increase energy efficiency with machine learning, there are, however, several challenges, e.g. coming up with suitable business models giving the proper customer incentives since there are often conflicting objectives, such as, e.g., carbon neutrality and cost minimization. There is also a need to understand that **industry deals with large and interconnected systems,** which poses a challenge in itself. Other important challenges include **data availability & quality**, the **need for explainable & accurate models** and paying attention to the entire AI life cycle, including **ML model quality monitoring**.

The discussion led to the following key recommendations: It is important to **combine machine learning and optimization**, and to focus on business models and use co-innovation with multiple stakeholders involved (universities, automation suppliers and industry end-users), i.e., to have **cross-domain collaboration**. Moreover, it became clear from the initial presentation how important the **energy consumption anomaly detection** and **time-series forecasting** aspects are. Finally, active participation in the on-going legislation activities in Europe is important from both industry and academia.

AI for Collaborative Sustainable Buildings

This breakout session focussed on AI solutions for buildings, interactions and the formation of Human-AI-Ecosystems. In order to meet the climate sustainability goals, existing smart building systems need to be improved on the level of interaction and collaboration. Solutions

go into deliberation between buildings and interactions with humans in order to reach collaborative goals, such as e.g. peak shaving and insights into various forms of flexibility.
In order to achieve a resilient grid infrastructure powered by renewable energy sources, the focus must **shift from individual systems and isolated intelligence to fostering interaction and collaboration** among them. This **requires the integration of energy management and distributed smart buildings systems, as well as a mutually beneficial partnership between humans and smart energy systems**.
Therefore, the challenges of energy transition and AI must be approached in a cross-disciplinary manner. While simple systems can sometimes suffice, the key lies in **facilitating effective interaction between various systems**. The overarching idea builds upon human-AI ecosystems where humans and machines work together in teams with a shared objective, characterised by collaboration and mutual support. The aim is to create an environment where machines are not seen as mere tools, but rather as collaborators working towards a common goal, much like an ecosystem.
Within this breakout session the group identified several challenges. The first is the **need for semantic dataspaces to facilitate data communication**. On the technical AI level, there are self-optimization problems, and questions about decision-making, ranging from regression to supervised and reinforcement learning. In the field of human-machine interaction, **researchers must consider human requirements and provide explainable solutions**, including preference elicitation and aggregation. Privacy and conflicts of interest arise when private data is shared to enable AI-based decision-making, scheduling, and other data-driven solutions. Additionally, the agility of AI-based solutions must be considered.
The domain opens up for an interdisciplinary research discipline, containing topics that require contributions from individuals in various fields. There are similar initiatives happening in parallel, which should be tailored and discussed in follow-up activities, such as workshops, hackathons and show-case presentations. We should further encourage participation and refine the projects and participants.
The group discussion resulted in several recommendations. First, it's important to consider the objectives of various parties, including building occupants and building owners. Second, **key domain challenges must be addressed**, in addition to AI challenges. Third, rooms or buildings must be properly connected to the IoT ecosystem to enable **trustworthy information sharing**. Finally, explainable AI is crucial for i**ncreasing reliability and ensuring that the partnership between humans and algorithms** remains on the right track.
Moreover, **scalability** is a crucial factor to consider. Currently, data streams still need to be analysed to link them to the AI model. There is a need to explore how AI can carry out this step without human intervention.

Energy at the Edge

The session about energy at the edge of the grid started with a short introduction by moderator André Meyer-Vitali (DFKI), followed by an inspiring presentation by expert Kim Bybjerg (Tata Communications). Bybjerg explained how the Internet of Things (IoT) lays the foundations for the buildings of the future with several important examples. The examples mentioned were two of the world's most sustainable buildings: Edge in Amsterdam and Berlin's 10-storey Cube. The buildings are equipped with multiple sensors that measure and collect vast amounts of behavioural and environmental data using the Internet of Things (IoT) and 5G wireless Internet. Using these data and anticipating future states allows for **precisely controlling the buildings for optimal energy efficiency**. It's important to move from merely collecting data to **understanding their value, e. g., data for climate management**. Resources can be saved in parts of the buildings that are currently unused or unoccupied. This can be scaled from buildings to neighbourhoods and cities and also involves traffic management to avoid congestions.

An important concern is the **privacy of collected data**. Some data can be aggregated and anonymised and a lot of data can be processed locally. For example, image data can be processed for face recognition or motion detection and deleted afterwards. This is not always the current practice, such as for car driving behaviour data that is continuously sent to the manufacturer. **Reducing the amount of transmitted data** is also beneficial for the mobile networks, which are expensive to set up and maintain. Edge devices, however, such as smart meters, are inexpensive and can be upgraded for up-to-date functions.

Regarding the **value of data**, it is essential to **improve predictions**, for example, for the charging schedule and duration of electric vehicles. **Fair use of such prediction results** should guarantee that all users are served sufficiently. The main issue is that efficient and fair scheduling cannot be performed on local data only. With only local optimisations the overall scheduling may become inefficient. Therefore, it is **necessary to include global data** - at the cost of increased complexity. The **advantages of processing at the edge** (and thereby saving communications and avoiding central control) **need to be balanced by smart decentralised coordination mechanisms** to exchange only the information that is necessary for all local nodes to achieve global optimisation. **Smart AI systems** can help dealing with uncertainties and negotiations among users. They **need to be human-aware**, i.e., understandable and controllable with personal preferences.

Explainable AI for Energy

This session dealt with the importance of Explainability in the use of AI in the energy sector. There are many critical industrial applications in this sector, both downstream (from production to delivery) and upstream (from delivery to services to customers). The **acceptability of AI solutions** for the management of these systems depends not only on

their ability to be explained to decision-makers or industrial operators, but also on their **ability to respect regulatory constraints** (European AI law, audits by control authorities, privacy, etc.). For example, the **black box effect** of many tools/models (Deep Neural Networks) **limits their acceptability and widespread use**.
Explainable Artificial Intelligence (XAI) tools are crucial to convince decision makers of the developed AI technology or method. Currently available tools or packages for XAI models are unsatisfactory because they are too data-oriented, can require difficult mathematics and, for some, lack strong theoretical demonstrations/proofs. They also do not cover the whole chain: feature interpretability - model interpretability (either in-situ or post-hoc) and decision interpretability.
It is therefore important to be cautious about off-the-shelf tools for XAI, and **to consider explainability aspects at the beginning of AI technology development and throughout the development process**. The level of explainability required should be discussed between industry experts and algorithm developers to build a fit-for-purpose tool. This co-construction allows tools to benefit from domain-specific recommended practices. Explainability methods/frameworks that enable interoperability of data and features should be privileged. **Verification and Validation** of the algorithms/tools could follow a systems engineering approach: guarantee the behaviour of the models/tools even if a component is not fully explained/understood.

Data-driven Microgrids powered by renewable energy - Group A

This breakout session was centred around the concept of **data-driven microgrids powered by renewable energy**. The discussion highlighted the **importance of balancing, storing, and flexibly utilising renewable energy within microgrid systems** to optimise their performance.
Leveraging artificial intelligence (AI) and machine learning (ML) was deemed crucial in achieving the functional microgrid capabilities necessary for optimal system-level performance. In this regard, one aspect that needs to be considered is the **Weather Prediction and Energy Storage**. The participants emphasised the **need for more localised and accurate models** to predict weather conditions specific to microgrid areas.
Additionally, **understanding energy storage mechanisms** within the grid was considered essential for efficient utilisation of renewable energy resources, including inertia and battery systems.
Followed by this, the breakout session delved into the **importance of robust data governance frameworks** and **consent handling protocols for data collection** within microgrids. Addressing data privacy concerns while enabling effective steering of assets was a crucial aspect of data-driven microgrid operations.
Furthermore, there is also a **need for appropriate data legislation**, specifically discussing Automatic Meter Reading (AMR) information. Establishing **legal frameworks** for data

sharing and utilisation within microgrids was a key consideration.
Beyond that, **detecting abnormalities and identifying potential cyber-attacks** were identified as areas where AI-powered solutions could **enhance the security and resilience of microgrid systems**. Simulations, including simulated attacks on communication lines, were also discussed as a part of this topic.
AI and Machine Learning were seen as valuable tools when it comes to **smarter management of various energy resources,** such as hydro, solar, and wind. **Optimising energy production and consumption based on environmental conditions could significantly enhance the efficiency and sustainability of microgrid operations**.
Moreover, AI-driven solutions were highlighted as potential enablers of enhanced resilience against extreme weather events. By leveraging real-time data and predictive algorithms, microgrids can adapt and respond to adverse weather conditions, ensuring reliable energy supply during challenging circumstances.
The session also touched upon the legislative aspects of microgrid operations, emphasising the need for **appropriate frameworks governing microgrids** and enabling seamless integration with larger energy infrastructure. APIs (Application Programming Interfaces) for effective communication between microgrids and external organisations were also discussed.

Data-driven Microgrids powered by renewable energy - Group B

Microgrids with a primary energy source from their own renewable production require balancing, storing and flexibility of usage to work at an optimal level. The balancing needs an asset level forecasting and steering of all connected assets. AI and ML will play a crucial role in achieving a functional microgrid capable of providing optimal microgrid system level performance.
There are multiple challenges in this area that have been identified by the participants like the **proper modelling of the aggregation level**. In larger grids, the variability of behaviour is large (buffers, industries, shopping malls) and this is harder to regulate. However, the **law of the large numbers** also plays a role which can actually make regulating larger grids easier and more challenging for smaller grids. Additionally, taking into account border conditions like thermal loads of heat pumps is a challenge that is closely related.
With regard to **exploiting storage capacity of EVs**, the challenge is to **train AI to take end user requirements into account,** like minimum battery level and expected travel range. Excessive interaction with the user should be avoided, which in turn would need to be automatically optimised. This may involve personal data which is a challenge in itself. Other aspects discussed within the session include battery life and warranty.
Furthermore, business models for companies and end users are an aspect that is not yet elaborated in terms of the business ecosystem, including **regulation**. Specifically, there is a challenge to **address the changing role of prosumers**, which will be given a larger role. A

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better understanding of the economical and psychological incentives is also considered very important.
Social interactions in smaller communities play a role; besides pricing being an incentive, also behaviours and norms will be important. Agent-based modelling can help understand such dynamics in a better way.
Furthermore, there is a **need for AI-supported system design for future energy systems**, especially **integrated systems** that make use of flexibility of subcomponents. This also involves **knowledge management and knowledge transfer** from experts.

AI for Optimal Prosumer Management

The presence of intermittent renewable energy sources requires an increased flexibility of the generation in the energy system. One way to balance the stochastic availability of renewable energy is to **foresee significant reserves and to cover for the uncertainty by generation**. Another way is to optimally schedule both producers and consumers of energy while accounting for uncertainty. This breakout session focused on the use of AI to optimally schedule industrial generation and consumption of energy. In this session, challenges and relevant industrial applications were discussed, identified, and concluded with some recommendations and concluding remarks.
The session started with a talk by Dr. Marija Zima, who has many years of experience in the relevant field from ABB.. The presentation "*How is AI related to relativity?*" addressed the three keywords for a successful renewable proliferation: space, time and mass (energy). It was demonstrated how AI can help to firstly design the *space* optimally accounting for the grid topology, to provide possibilities to identify the potential sources of waste and, in real time, optimise the generation as well as the consumption of *energy*: Defining power and energy ratings of resources, forecasting the conditions, optimising planning and scheduling— including uncertainty—, considering the asset health, and maintenance and finally fulfilling the production schedule with an optimal energy consumption.
Following the valuable input from the opening presentation, several challenges were discussed. In this regard, a cluster of challenges around **data quality**, **availability**, and **accessibility** as one of the major challenges were identified. Another big challenge is the **necessity for developed models to fulfil the sufficient level of trustworthiness, explainability, scalability and maintainability** during their lifecycle. The complexity of the objectives in this context was raised for discussion. The distributed nature of the energy management problem, with **limited certainty of forecasting the future load** together with the intermittent nature of the renewable energy sources on one hand and increasing demand on energy resilience and security on the other hand, makes the problem even more challenging. It was emphasised that the **need for expertise and staff with sufficient know-how** at different levels will be an increasingly urgent matter. Considering the industrial applications where AI for optimal prosumer management would play a role, **three clusters**

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of applications, from industrial plants to grid operation and private sites were covered. In all these three areas, AI can provide different smart solutions and services, such as **price prediction on hourly basis**, **sustainability support and guidance**, **design optimization**, **optimised usage of self-generated energy**, **using industrial plants as intelligent nodes in a grid**, etc.
Finally, it was concluded that there is a **need to ensure access to high quality data through a structured data acquisition** to get the most out of AI in service for an optimal prosumer management. It is **necessary to have a tight integration between design tools and optimization configurations**. Here, there is an emerging **need for standardisation and legislation** for both data as well as the developed models. **Trustworthiness, ease-of-use,** and **Explainability** are the key features for the models developed in this context. Last but not least, competence and know-how in this emerging area are necessary.

AI for the Integration of Renewable Energies

The power feed-in of distributed renewable energy sources and the demand for electrical power increase on the distribution level and confront low-voltage grids by challenges like unmonitored overloads or violations of the voltage range. Additionally, the volatility of loads and renewable energies makes it challenging to predict future grid states and plan and apply preventive measures. The breakout session focused on essential building blocks for integrating renewables, such as AI-based forecasting algorithms, and how to train them.
Initially, some key challenges in the field of renewable energies like **Thermal Load Integration** and how they can be overcomed were discussed. Cold countries face the unique challenge of providing enough thermal load to a significant amount of end-user demand. The potential of converting excess renewable energy into heat and storing it in thermal storage systems, which provide a cost-effective solution, were discussed. However, determining the optimal share of energy conversion depends on factors such as generation capacity, load profile, and expected thermal demand. The session also explored the development of AI models to effectively address this challenge. The **production of green hydrogen as a storage medium** posed another challenge with regard to the technical and economic aspects of producing green hydrogen from renewable sources. Furthermore, the potential solutions were elaborated to ensure its usability in energy systems. Finally, the goal was to identify ways to use AI in optimising the production and use of green hydrogen.
In addition, another challenge defined by the participants related to the **Energy Equilibrium in Hybrid Renewable Energy Systems**. Integrating multiple renewable energy sources into a hybrid system requires maintaining energy equilibrium. To address this challenge, **AI models for optimising energy distribution and achieving a balanced hybrid grid** were explored. These models are able to intelligently allocate energy resources by analysing real-time data, including energy demand, generation capacity, and weather conditions.
For effective energy management, **accurate forecasting is crucial**. During the session, the

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importance of data availability and generation for both regular and extreme conditions was emphasised. AI models are capable of processing real and simulated scenarios, including rare events, which can significantly improve forecast accuracy supporting decision-making processes.

Automation and Autonomy

The topic was first introduced by the moderator with a mind map of themes related to automation and autonomy with a preliminary definition of these terms relating to the **dilemma of AI, moving from the automated repetition of procedures to the delegation of tasks to autonomous agents, and the resulting reduction in (direct) control**. This general theme can be applied to urban scenarios, including the production, distribution and consumption of energy.
It was mentioned that **trust in autonomous systems requires human-machine interaction**. However, it may be the case that trust does not require deep understanding. Much of the discussion revolved around **experimenting in simulated environments** (including **virtual reality**) with **synthetic data (digital twins)** as a means to achieve trust in autonomous systems by experience. Among the various examples, the case of **autonomous drilling** for oil or gas on a full-scale test rig was discussed (a system capable of taking its own decisions by evaluating the current conditions and adapting to them while considering multiple horizon strategies to fulfil the drilling operation goal). While such **test environments** are of great help, it is important to stress that they also have their **limitations**, such as the quality of sensors (resolution, latency, accuracy, reliability, etc.). **Interactions of humans with robots** in a factory were also discussed as a case where experience can be gained in a relatively well-controlled environment.

AI for e-mobility integration onto the grid

In the context of climate change and stricter regulations on greenhouse gas emissions, electric mobility (e-mobility) offers a sustainable response to urban pollution. The technological performance of batteries makes Electric Vehicles (EVs) a key element in the development of e-mobility, with almost 9 million EVs expected on Europe's roads by 2030. This growing number of EVs is challenging for both grid operators and energy providers. AI can help facilitate the integration of EVs into the grid by balancing the needs of the grid/energy resources, providing flexibility services and grid stability, and accelerating smart charging.
More specifically, AI models could be used to **better understand user habits** in terms of driving and charging patterns. In fact, energy demand for vehicle charging overlaps with other electrical uses, making it **important to have predictive models (load, charging point occupancy)** to anticipate and meet demand. Moreover, **AI optimisation** or

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reinforcement tools could help develop smart charging solutions: These solutions help to manage EV charging power in an efficient, flexible and economical way. With smart charging solutions, EV batteries can be viewed as energy reservoirs that can be used to feed energy back into homes (V2H), buildings (V2B) or electricity grids (V2G). AI could also help optimise the sizing and location of charging infrastructure for different uses such as residential, commercial and public.

A specific focus was on the Smarter Mobility Data Challenge which aimed to predict the occupancy of charging points in Paris. This challenge highlighted issues such as the **lack of publicly available datasets**, the **quality of the available datasets**, the **difficulty of modelling user behaviour**, and **evaluating the predictions**. One important point is the lack of a complete dataset including state of charge information, mobility data, EV connections, traffic data, etc. **Networking activities brought by TAILOR**, challenge organisations could help to fill this gap..

In summary, this session highlighted the **transformative potential of AI in addressing the challenges associated with integrating EVs into the grid**. By leveraging AI capabilities such as **predictive modelling**, **optimisation**, and **reinforcement learning**, it will be possible to develop efficient and intelligent charging solutions that meet the demands of a growing EV market, while **ensuring grid stability and maximising the benefits of EVs as an energy resource**. However, it is critical to **address data challenges** and continuously **improve model accuracy** to enable effective decision making and planning for EV deployment and grid integration.

Individual energy contracts based on AI

Within this breakout session it was discussed how AI can be used to tailor energy contract offers for each consumer or consumer group, e.g., based on energy consumption profiles, demand forecasts, demand-side management options, and energy price forecasts. Furthermore, risk-sharing models based on price guarantees and minimum charges could also be tailored based on consumer knowledge.

Concerning the idea of AI-based energy contracts, however, it is questionable whether and how these can be applied in the future and which challenges need to be overcome or reconsidered. For instance, one of these challenges in evaluating if **micro-contracts** (peer-to-peer or agent-based) or **individual contracts** are performing best.

In addition, another important aspect of the discussion was to determine who holds the authority in designing energy contracts - whether it is the retailer or the consumer. Addressing this potential conflict of interest requires thoughtful auditing to **maintain fairness** and **avoid any exploitation of consumers**.

Furthermore, the **impact of EU regulations on energy contract tailoring** was discussed, particularly regarding **social aspects**. The participants raised concerns about ensuring equitable access to favourable contracts, regardless of consumers' means. Reducing the

energy loads of high-energy consumers with greater resources became a priority.
The breakout session also explored the **potential of newly rising community-based models for tailored energy contracts**. By **fostering collaboration** and shared benefits within local energy communities, these models aimed to **enhance resilience, efficiency, and social cohesion**.
Another discussed challenge related to **data exchange** when consumers switch energy retailers. Ensuring the **seamless transfer of historical data** while **protecting consumer privacy** was crucial in facilitating transitions between energy providers. Continuing the idea of **transparency**, namely making AI algorithms **transparent and accessible,** could **enhance trust among stakeholders** and **promote understanding** of how tailored energy contracts are created. To implement this, the applicability of an open-source foundation could be the key.

Input for the roadmap

Based on the results summarised in the previous section, the Organising Committee identified several topics which could be a valuable input to a European AI research and innovation roadmap. These topics will be presented to and further discussed with experts from TAILOR, VISION and CLAIRE in order to enrich the respective roadmap activities.

The below topics stood out most prominently and will thus provide the 'core' of the input. However, during the actual development of the roadmaps, all inputs from the Theme Development Workshop will be considered.

Energy sector specific

- **Energy efficiency using AI**: Focus on achieving improved energy efficiency through AI-enabled software solutions. This includes energy consumption anomaly detection and time-series forecasting.
- **Machine learning applications**: Explore the application of machine learning solutions for energy optimization in various sectors such as transportation (land, air, and sea), heavy industries, heating and ventilation, data centres, and energy storage.
- **Business models and incentives**: Develop suitable business models that align with conflicting objectives such as carbon neutrality and cost minimization to promote the adoption of AI solutions for energy efficiency.
- **Collaboration and cross-domain innovation**: 2BFoster collaboration among stakeholders, including universities, automation suppliers, and industry end-users, to combine machine learning and optimization approaches for energy efficiency.
- **Integration of energy systems**: Focus on the integration of energy management and distributed smart building systems to achieve a resilient grid infrastructure powered by renewable energy sources. Emphasise the partnership between humans and smart energy systems.
- **Scalability and decentralisation:** Consider scalability as a crucial factor for AI solutions in energy systems, especially when dealing with large and interconnected systems. Explore the potential of edge computing and decentralised coordination mechanisms.
- **Interdisciplinary research and knowledge transfer**: Encourage interdisciplinary collaboration and knowledge transfer among experts in various fields to address the complex challenges at the intersection of energy and AI.
- **Integration of electric vehicles (EVs) into the grid**: Leverage AI models to manage the integration of EVs into the grid effectively. Focus on predicting user behaviour, optimising charging infrastructure, and using EV batteries as energy reservoirs for grid stability and flexibility.

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More general topics not limited to the Energy sector

- **Explainable AI and Trustworthiness**: There is a need for AI models and systems to be explainable, transparent, and trustworthy, which is of importance across all domains. It is crucial to address the black box effect of AI models and develop tools and methods for explainable artificial intelligence. This involves considering interpretability at different levels, including feature interpretability, model interpretability, and decision interpretability.
- **Human-AI Collaboration and Interaction**: The concept of human-AI ecosystems and collaborative sustainable buildings highlights the importance of effective interaction and collaboration between humans and machines. AI should be designed to work together with humans as collaborators in teams, aiming for shared objectives and mutual support. The field of human-machine interaction, including preference elicitation, aggregation, and understanding human requirements, plays a significant role in achieving successful human-AI collaboration.
- **Data Quality, Accessibility, and Privacy**: There is a need for high-quality data, structured data acquisition, and semantic dataspaces for facilitating data communication. Additionally, privacy concerns regarding the collection, processing, and sharing of data as well the importance of data anonymization and local processing should be taken into account.
- **Optimization and Decision-Making**: AI's role in optimization and decision-making processes is important for AI in the energy sector particularly in the context of energy management, EV charging, and industrial generation scheduling. AI can provide smart solutions for optimising energy consumption, designing efficient systems, and achieving global optimization.

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Summary and Conclusion

The high international interest that was expressed in response to the announcement of the AI for Future Energy & Sustainability Theme Development Workshop translated into excellent attendance of the event. Forty-seven participants joined the TDW, ranging from a diverse set of backgrounds. Nineteen (predominantly EU) countries were represented, with thirty participants indicating that they are affiliated with industry, whilst forty-one participants indicated that they are affiliated with academia (three participants indicated “other”). The participation of major industry representatives, with companies like ABB, EDF, Huawei Deutschland Technologies GmbH, Stromnetz Hamburg GmbH and Tietoevry is particularly noteworthy and testifies to great interest on the part of industry. The TDW, therefore, caught the attention of some of the most important actors in the field of Future Energy and Sustainability and brought together representatives from key companies, supra-national institutions, and academia. The workshop thus successfully provided a platform for discussions between representatives from academia, industry and politics: Discussions that are key in unlocking the full potential of AI in Europe.

The Organising Committee would like to express its deep gratitude to all experts for their valuable input and contributions to this Theme Development Workshop! Their active participation in the workshop and engagement in the breakout session discussions paved the way for the excellent results presented in this report.

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In addition to this list, three participants of the TDW preferred not to be mentioned publicly by name and affiliation.

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