ARTIFICIAL INTELLIGENCE FOR NEXT GENERATION ENERGY SERVICES ACROSS EUROPE – THE I-NERGY PROJECT

ABSTRACT

Artificial Intelligence (AI) holds the premise to transform the energy sector and the underlying value chain; scarcity of AI expertise in the energy community, fuzzy and unclear regulations on access to data, standards' immaturity and uncertain business cases are hampering though the full exploitation of its potential. In this context, the goal of this paper is to present the I-NERGY project, an Innovation Action that targets to promote AI in the energy sector by reinforcing the AI-on-demand (AI4EU) platform service offering and ecosystem. To this end, the paper introduces the I-NERGY project concept, the domain challenges it addresses and the target audience towards which it is addressed, exposes the project technical solution and pilot use cases that respectively incarnate, and exemplify and validate it and emphasizes its open call mechanism for providing financing support to third SMEs for energy use cases and AI services proliferation.

KEYWORDS

Artificial Intelligence, AI-on-Demand, Energy, AI4EU, Open Calls.

1. INTRODUCTION

AI spreading in the energy sector is expected to dramatically reshape the energy value chain in the next years, by improving business processes performance, while increasing environmental sustainability, strengthening social relationships and propagating high social value among citizens. People's well-being, industrial competitiveness and the overall functioning of society are dependent on safe, secure, sustainable and affordable energy. AI is expected to radically transform the energy sector, redesign and shape the energy value chain and revolutionise the way through which Electric Power and Energy Systems (EPES) community is undertaking the business processes.

The use of AI is acknowledged to be of utmost importance for energy utilities to improve the performance of their business processes, and for power network operators to increase the stability of their operated network, within the renewable energy-based emerging decentralised paradigm. DeepMind AI managed to effectively achieve 40% energy savings for the Google Data Center operation (Yao, 2018). General Electric estimates that AI can enhance the production of a wind farm by 20% (GeneralElectric, 2019). AI transformation in the energy industry will directly influence international energy stability and economic prosperity (Nagy & Hajrizi, 2018).

At the same time, AI proliferation in the energy sector holds the premise for a larger environmental and social impact (Marinakis et al., 2020), by affecting environmental sustainability, strengthening social relationships among members of local communities and contributing to alleviate energy poverty. Energy fingerprinting might be leveraged to deliver different consumer-centred innovative AI-based services which bring high social value to individuals and/or local communities. Hence, AI can contribute to finding solutions to some of the most pressing societal challenges, such as the fight against climate change, environmental degradation and the challenges linked to sustainability. A large share of EPES stakeholders believe that AI will have a big impact on their business, since AI spreading will allow them to align their business processes to novel fine-grained near real time optimal energy system operation, within a context of rising share of deployed renewable energy. However, they are far to integrate AI in key business processes (Berger, 2018). Uncertain business cases, fragmented regulations, standards immaturity and low-technical SMEs workforce skills barriers are actually hampering the full exploitation of AI along the energy value chain.

In view of addressing these barriers in the European AI landscape and facilitate technology transfer from research to business, the first European Artificial Intelligence On-Demand Platform - AI4EU (EU, 2020) was launched in 2019 with the support of the European Commission under the H2020 program. The AI4EU platform[1] is a one-stop-shop for anyone looking for AI knowledge, technology, tools, services and experts. AI4EU aims at creating value, growth and jobs for Europe through a collaborative platform, which unites the AI community, promotes European values and supports research on human-centered and trustworthy AI. Nurtured within the AI4EU ecosystem, the I-NERGY project[2] specifically targets the promotion and support of AI in the energy sector with the following objectives:

- Reinforcing the AI-on-demand-platform for the energy sector with novel AI services and applications
- Reaching out to energy domain stakeholders to validate the developed applications and laying the foundation for a pan-European AI for energy ecosystem, boosting EU-scale data economy and use cases.

2. RELATED WORK

AI can unlock significant value for energy utilities, in terms of improving their business processes, increasing power networks' stability and essentially achieving significant energy savings. However, energy companies often lack ICT skills to catchup with AI potential causing high demand for AI experts. Also, there are several consolidated silos not willing to share data and processes. Combined with the lack of semantic and business interoperability across different energy utilities, this hinders the high data potential in the energy domain. Contradictorily, there are various scientific publications that exploit AI to create value-adding services, dealing with electrical load forecasting, predictive maintenance for power networks or building facilities, citizen patterns' anomaly detection in smart buildings and smart grids, energy flexibility and demand response (DR).

Regarding load forecasting (Guo et al., 2020), developed a short-term load forecasting model of multi-scale CNN-LSTM hybrid neural network that considers real-time electricity prices. The experimental results show that the proposed method has higher accuracy than other methods proposed in the literature. (Chen et al., 2018) focused also on short-term load forecasting. The authors developed a neural network forecasting method named NeuCast, enabling anomaly detection and forecasts under different temperature assumptions. Experiments in different datasets showcased considerable improvement over the state-of-the-art.

Concerning DR services, as the problem to be solved is more complex, there are different approaches. For instance, (Lu et al., 2018) and (Wen et al., 2015) formulate the problem of demand response as a reinforcement learning model. In the first case the proposed algorithm is price-based and adaptively decides the electricity price using an online learning process. In the second case, the proposed algorithm, named CAES, models both energy prices and residential devices usage as Markov decision processes and adapts to user preferences over time. On the other hand, (Baloglu & Demir, 2015) model the problem of demand response in a smart grid as a Bayesian game-theoretical model using a dynamic pricing scheme. Simulation results demonstrated that the proposed model evenly distributes the daily load in smart grid and therefore it is successful.

Furthermore, an example of predictive maintenance in building facilities is presented by (Bouabdallaoui et al., 2021), who propose ML and DL techniques, to identify failures in smart buildings. Their framework shows great potential to predict failures. Another example of ML-based predictive maintenance is presented in (Yeh et al., 2019). The goal is to predict the long-cycle maintenance time of wind turbines in a power company. The results of this approach reach high accuracy values and can be used for asset turbine maintenance.

Regarding anomaly detection, latest research has focused on detecting anomalies in citizen patterns in smart homes or smart grid installations. Different publications examine different types of anomalies. For instance, (Novak et al., 2013) use self-organised maps to identify anomalies, mostly based on sensors' data, (Yamauchi et al., 2020) use home appliances connected to the internet, to detect cyber-attacks based on user behaviour. (De Benedetti et al., 2018) predict anomalies in photovoltaic systems operation, based on the comparison between the actual and predicted AC power production, while the latter is predicted via an ANN, using solar irradiance and PV panel temperature measurements. The experimental results seem satisfactory. Moreover, as this approach can identify system deviations' trends from the normal operation behaviour, it is suitable for predictive maintenance in photovoltaic systems.

From the presented approaches it is observable that, the proposed solutions are tailored to specific business requirements with specific data schemas. while they mostly focus on specific and narrow subtasks, instead of a system level approach. Hence, they cannot be easily applied by multiple similar stakeholders, as there are no

[1] https://www.ai4europe.eu/

[2] https://i-nergy.eu/

commonly agreed interoperability procedures and usually measurements' metadata are not available. Therefore, the need for commonly accepted data interoperability standards among different systems should be priority, alongside a knowledge sharing culture across different stakeholders. I-NERGY aims at addressing this issue by providing reusable and interoperable data and AI models and setting standards for data and AI services interoperability in the energy domain and reinforcing AI4EU platform energy-related assets.

AI4EU project (Cortés et al., 2019) aims at reinforcing AI knowledge and resources sharing and bringing closer AI experts with different scientific domains. Other projects targeting to reinforce AI4EU assets are AI4Copernicus[3], aiming to bridge AI with earth observation and make AI4EU platform the digital environment of choice for users of Copernicus data; AIDIH Network[4], targeting to create a European Network of Digital Innovation Hubs with focus on AI; AIPlan4EU[5], aiming to bring AI planning to platform; BonsAPPs[6], focusing on SMEs digitalisation by facilitating access, implementation and make use of AI in an easy and affordable way; and StairwAI[7], aiming to ease low-tech users engagement to the AI-on-Demand platform.

Regarding the energy domain, there are also a few projects acknowledging the need for setting up interoperability standards as well as the fact that combining different types of data can unlock significant added value. For instance, BD4NRG[8]aims to enable improved operations for all stakeholders in the energy value chain by leveraging the potential of big data in the energy sector. Contrary to I-NERGY, BD4NRG focuses mostly on big data. On the other hand, MATRYCS[9]aims at reinforcing decision support operations in smart buildings through big data, AI and analytics technologies.

3. I-NERGY CONCEPT

Lack of EPES stakeholders' workforce ICT background is the reason they are far from integrating AI in key business processes. Moreover, lack of tools for capturing the real time dynamics, scarcity and competition for AI experts, the need for knowledge transfer to new contexts and accordingly for training new AI for each context, as well lack of optimal ways to explore and exploit cross-domain data, which are now being generated at an unprecedented rate, still incommode the complete introduction of AI in the energy sector.

In essence, I-NERGY's main objective is to capitalise on state-of-the-art AI, IoT, semantics and data analytics technologies and deliver an open modular framework for supporting AI-on-Demand in the energy sector. I-NERGY vision is to enable edge-level, AI-based, cross-sector, multi-stakeholder analytic tools for integrated and optimised smart energy management and to evolve, scale up and demonstrate an innovative energy-tailored AI-as-a-Service Toolbox, which will help towards achieving a techno-economic optimal management of the EPES value chain, especially when it comes to SMEs and non-tech industries, while leveraging on and complementing the AI resources and tools made available by the AI4EU platform. The project aims essentially at strengthening European-wise Research and Innovation on AI, through synchronizing, liaising, contributing, and extending the AI4EU Platform service and research across a variety of cross-fertilisation activities.

I-NERGY main stakeholders cover the entire energy value chain, including Transmission System Operators (TSOs), Distribution System Operators (DSOs), Energy Services Companies (ESCOs), Policy makers (e.g., EC Directorates and Units, Ministries and Governments, or Regulatory Agencies), Facility Managers, Investors, National and local governments, Citizens and Designers (e.g., architects).

4. I-NERGY TECHNICAL SOLUTION

Figure 1 illustrates an initial version of the I-NERGY architecture. I-NERGY technical solution consists of several service layers, ranging from data management services (ingestion, storage, harmonisation etc.) to AI-

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[3] https://ai4copernicus-project.eu/
[4] https://ai-dih-network.eu/
[5] https://www.aiplan4eu-project.eu/
[6] https://bonsapps.eu/
[7] https://cordis.europa.eu/project/id/101017142
[8] https://www.bd4nrg.eu/
[9] https://matrycs.eu/

enabled energy analytics applications and services. Specifically, it consists of the Data Services', the AI Trained Models', the Energy Analytics' Applications, and the I-NERGY – AI4EU Interconnection Layers.

The **Data Services Layer** will allow the ingestion, pre-processing and querying of heterogeneous data. Its most important components are the services for interoperability, data ingestion, data cleansing curation and preparation, as well as a common data model which secures that all data, being stored to I-NERGY platform adhere to predefined standards. With this approach the data can be used also by other stakeholders and services that use the same standards with little to no modifications.

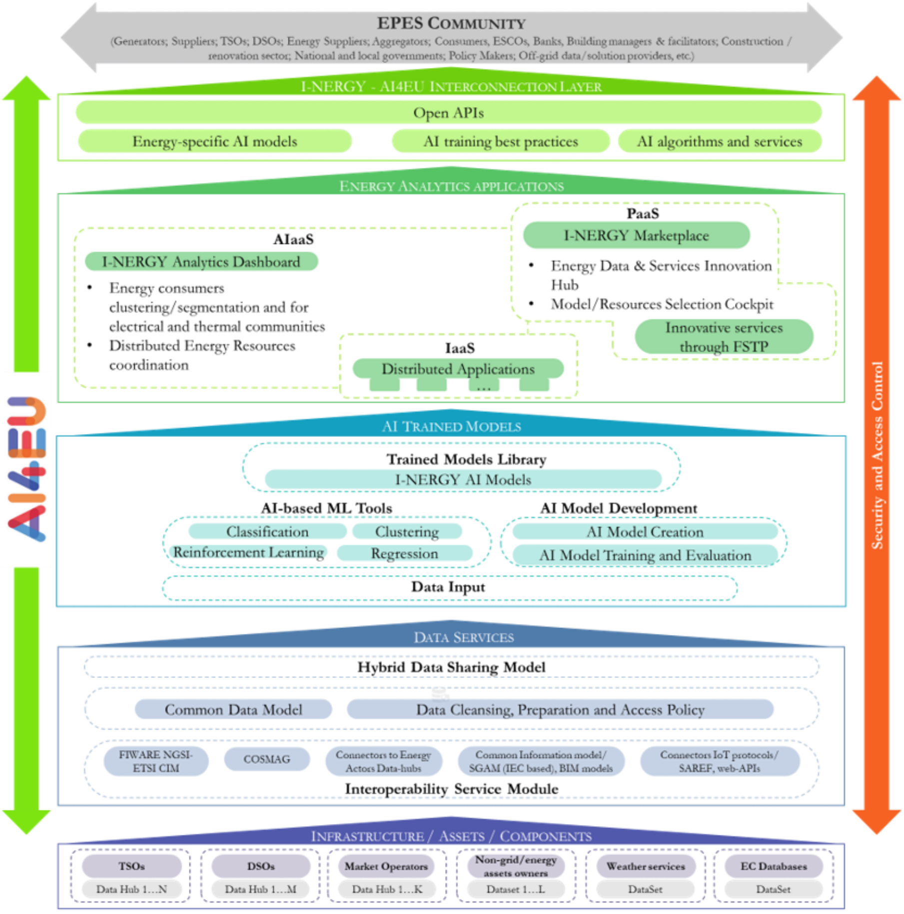

Figure 1. I-NERGY conceptual architecture

The **AI Trained Models Layer** will provide several functionalities that facilitate the development, creation and testing of new AI models. Moreover, it will be responsible for storing I-NERGY AI models. Some services to be provided in this layer are the ML models development toolbox, a trained models library and an AI model training and evaluation environment. The former will provide a library of state-of-the-art methods for AI model development, including several ML and DL technologies (e.g. scikit-learn, TensorFlow, Apache Spark MLib etc.), as well as transfer learning capabilities, whereas the latter will provide resources for efficient model training, and model evaluation utilities that monitor the accuracy of developed models over time and provide recommendations for improvements. The trained models library will be the marketplace of all I-NERGY trained models, to facilitate reusability and knowledge exchange among different stakeholders.

The **Energy Analytics Applications layer** is the closest layer to end users, providing them with energy analytics services (AI as a service) and applications that are stored in the AI trained models' layer. Moreover, visual analytics tools will be provided, to facilitate exploratory analyses on specific datasets. The analytics services will be served through APIs to end user applications and business intelligence systems, to provide them with accurate predictions, and facilitate enhanced decision making on critical issues, such as power network reliability and DR. Contradictorily, energy analytics applications will be mostly focused on digital twin applications creating physical systems' (e.g. networks, buildings and energy systems) digital representations, to perform simulations and tests for physical assets of I-NERGY pilots. Some energy analytics services and applications to be provided by this layer are electrical load forecasting, demand response, predictive maintenance for circuit breakers, anomaly detection in citizen patterns, digital twin for distributed energy resources (DER), prioritisation and risk assessment of energy efficiency investments, digital twin for electrical communities.

As reinforcing the AI4EU On-Demand platform, through utilisation, distribution and enrichment of the existing AI resources in the energy domain is a key I-NERGY objective, the **I-NERGY – AI4EU Interconnection Layer** is responsible for the bilateral communication between I-NERGY and AI4EU platforms. Additionally, it is responsible to make AI4EU trained models, data and other assets available to I-NERGY services, as well as to publish I-NERGY assets (services, datasets, documentation etc.) to AI4EU catalogue and onboard I-NERGY models and services to AI4EU Experiments for sharing AI knowledge and resources with a wider range of interested parties.

I-NERGY data, services and other assets will be available to users provided that they are authenticated and given authorisation to access the requested resources. Hence, I-NERGY platform has its own **Security and Access Control Module**, which is responsible for user authentication and authorisation. This module provides mechanisms which ensure that security standards are holistically met during I-NERGY operation.

5. PILOT USE CASES

The I-NERGY analytics framework will be applied, demonstrated and validated in real-life pilots involving 9 pilot hubs and 15 different use cases, distributed across three domains: (i) **AI for energy networks, aiming at the optimised operation of electricity and district heating networks.** Services relating to this domain will focus on grid asset management, predictive maintenance and enhanced reliability as well as electricity demand forecasting; (ii) **AI for Renewable Energy Sources (RES) generation in buildings, districts, communities.** These services will involve the forming and management of Virtual Power Plants (VPPs) functioning as flexibility providers, through the successful matchmaking of prosumers and green energy marketplaces; (iii) **AI for enabling synergies and implications on other energy and non-energy domains** such as heating, transport, water management, personal safety, finance and Ambient Assisted Living (AAL). Here, applications will focus on dynamic energy-efficient and end-user comfortable building-scale management, financial risk assessment and management of renewable investments, optimal energy management in buildings, and cross-sector energy-driven services including personal safety and care management services for the elderly.

Pilot sites will be accompanied by two testbed facilities and simulation-enabling digital twins (Boschert & Rosen, 2016), spanning across 8 European countries (Greece, Latvia, Italy, Portugal, Spain, Croatia, Slovenia and Germany). The large geographical coverage of the demo sites aims to support the EU-wide replicability and market take-up of AI-driven solutions in different socio-economical contexts, to maximise the I-NERGY services impact across Europe. The planned use cases are briefly described below.

AI for network assets' predictive maintenance, integrating off-grid data with condition-based monitoring. This pilot aims at assessing the condition of grid assets and specifically circuit breakers inside the Portuguese transmission network. DL techniques will be deployed to determine the failure probabilities of each asset based on historical oscillography data of circuit breaker tripping incidents and to provide answers to the challenges of predictive maintenance and effective maintenance plans implementation.

AI for network load forecasting towards efficient operational planning. This pilot's goal is to provide forecasts of aggregated and disaggregated electrical load timeseries for the Portuguese transmission system. Applying state-of-the-art ML and DL-based short-term load-forecasting techniques on historical data, a load forecasting framework of various timesteps and forecasting horizons will derive, leading via self-monitoring and iterative learning to operational planning optimisation, and grid operations' reliability improvement.

AI for District Heating and Cooling Network (DHCN) load forecasting and optimisation of the production mix. This pilot consists of two use cases. The first regards the provision of accurate demand forecasts for a large DHCN managed by a Spanish facility manager by matching production with demand through energy demand predictions. Available data range from cooling and heating demand and production to RES production and weather forecasts. State-of-the-art ML will be applied to provide estimations of day-ahead future values of the energy demanded by the DHCN, aiming at decreasing its energy consumption and GHG emissions. The second one will leverage the produced demand forecasts, to investigate demand response schemes for matching demand with production. Given the RES stochasticity, this optimisation task will lead to a "greener" production mix.

AI for energy saving verification, increasing the trust on energy performance contracts (EPCs). This pilot will act as a decision support system for a Spanish ESCO by establishing a workflow to measure and verify energy and economic savings after energy efficiency related building renovations. Following, simulation and digital twins will be employed, leveraging the available historical data from smart meters and two natural gas boilers for heating and domestic hot water of a large building community, with the ultimate goal of improving the ESCO's business model through energy efficient refurbishments and reliable EPCs.

Cross-functional AI predictive analytics for integrated DSOs asset management and network operation. This use case's goal is to support a condition and risk-based maintenance of power components, owned by an Italian DSO. Data-driven predictive analytics will be applied on datasets relating to operational data, acquired from distribution network assets such as transformers and lines, as well as historical data on replaced assets. The expected result is the anticipated failure prediction at the low voltage side of secondary substations, leading to efficient infrastructure management, equipment's lifetime increase, and service interruption times' reduction.

AI-based consumption and flexibility prediction for local community optimal aggregation and flexibility trading. This pilot comprises two cases. The first aims to assist an Italian aggregator and DSO in forming and validating a decentralised VPP consisting of residential, commercial and industrial customers. Exploiting the availability of weather data and smart meter data, AI techniques will be used for load profiling, clustering and forecasting, seeking to form flexibility clusters amongst end-users. Based on such predictions, the aggregator will be accordingly selecting the appropriate flexible loads and consumers which better fit with the flexibility request, conveyed by the flexibility trading market. The second use case aims at coordinating with the local water network operator seeking to follow specific activation priority models for smart water pumps according to the electricity flexibility needs, hence realizing the synergy between electricity and water.

AI-based IoT-enabled PV module-level portfolio optimal predictive maintenance and PV-enhanced industrial plant optimal operation. This use case focuses on predictive maintenance of multiple utility and industrial scale PV plants in Italy, managed by an O&M and designer company of RES generation plants. Exploiting the abundance of near-real-time grid measurements, weather data, SCADA data and maintenance records from PVs, I-NERGY will employ ML and DL models for the prediction and detection of malfunctioning at decentralised module level. Major expected outcomes include improvement in operational efficiency of PV assets through the combined effect of optimised maintenance and increased assets efficiency and increased self-consumption from local RES leading to electricity cost reduction.

AI in EV charging infrastructure. This use case aims at optimizing the operation of EV charging stations owned by a Greek energy supplier. Given the data availability from publicly accessible charging stations relating to EV charging cost, duration and demand, ML-based predictive algorithms will enable load profile extraction and availability prediction of public charging stations based on timely distributions and average duration of charge transactions. Additionally, through AI-based variable pricing algorithms, the use case will allow for more efficient operation of charging stations and smooth load distribution amongst them.

AI for peer-to-peer renewable energy trading in virtual energy community. This use case will contribute to the establishment of a VPP, consisting of multiple households, distributed within multiple geographical areas of Croatia and managed by a local RES cooperative. In terms of datasets, PV generation measurements within each household and historical demand and generation are available alongside weather measurements collected across the grid. In this context, AI techniques will be employed, to enable community participation in the ancillary services market, and peer-to-peer energy trading within it, hence leading to innovative prosumer business models and their promotion across the citizens.

AI for the Ambient Assisted Living and personal safety/security at home. This use case focuses on the development of services for personal safety, security and AAL in an elderly care house, managed by a Slovenian energy supplier in the context of a peer-to-peer energy trading platform. Available data include residential smart meters, ambient sensors, operational data from site assets (PV, heating, heat storage) and meteorological variables. Electricity fingerprinting methods will be applied for modelling the behaviour of specific devices, individuals and activities. Based on unsupervised ML techniques caregivers will be supported via alerts in case of anomalies, as well as living conditions, habits, and behaviour changes' monitoring.

AI for de-risking energy efficiency investments. This use case focuses on reducing the uncertainty linked to energy efficiency investments managed by a Latvian municipal energy agency. Historical heating and hot water consumptions along with meteorological variables and internal real-time ambient measurements will be collected for a small number of buildings, prior and following their renovation. Accordingly, AI will enable the extraction of knowledge regarding energy savings based on a few buildings and then its generalisation to other buildings with similar constructional characteristics leveraging knowledge from external databases. Hence, EPCs and other energy investments will be more reliable, cost-effective and of better quality.

AI for improved Energy Performance Certificates Reliability. This use case focuses on reinforcing the reliability of Energy Performance Certificates and is led by a Spanish municipal energy agency. Available data range from energy performance certificate and energy efficiency project databases to historical actual energy consumption data of buildings. AI algorithms will be tailored to detect patterns from real energy consumption data, distinguishing among the consumption derived from the energy fabric, energy systems and user behaviour. This will be contrasted to existing Energy Performance Certificates and raise alarms when AI-inferred energy values greatly differ from them.

AI for predicting the climate change impact in RES and energy demand at regional level. This use case is also led by a Spanish energy agency. AI methods will be applied on publicly available data such as Copernicus C3S (Buchwitz et al., 2018), aiming at producing an accurate climate change impact model for the region of Asturias. The model will enable predictions of future changing conditions derived from climate change related to the energy demand and RES, hence enabling the effective planning and deployment of RES.

6. I-NERGY OPEN CALLS

I-NERGY will significantly contribute to spreading and adoption of the AI along energy sector through the launch and management of two Open Calls, facilitating the access of energy vertical SMEs to finance while further validating I-NERGY use cases, promoting the development of new AI-driven technology components and energy services, and ultimately enriching the AI4EU resources and tools catalogue. The above will be achieved through the provisioning of Financial Support to Third Parties (FSTP). FSTP amounts to 2 M€, to be distributed to up to 25 bottom-up projects within a time period of 17 months for each call.

The selected projects will cover various application domains besides the energy sector (e.g. environment, society and economy), a wide range of experimentation areas, including AI applications in energy, Data governance and valorisation for energy services, Analytical applications in energy, Monitoring, energy usage optimisation, Predictive maintenance, and Demand forecast, and numerous challenges, enumerating network assets predictive maintenance, network loads and demand forecasting towards efficient operational planning, energy demand and supply prediction, energy storage management decisions, integrated TSOs / DSOs asset management, consumption and flexibility prediction, solar energy and photovoltaic applications, electric vehicles, trading in energy communities, energy efficiency investments and decision support systems, energy performance, energy savings and contracts, climate change and business environmental impact transformation, reinforcement learning in energy systems.

7. CONCLUSION AND NEXT STEPS

This paper presented I-NERGY, a project that aims to deliver an energy-specific open modular framework for supporting AI on demand in the energy sector and reinforce the AI4EU platform with new energy related assets (AI models, datasets and more), through state-of-the-art AI, IoT, semantics and data analytics technologies. The project motivation and the challenges to be addressed were presented in detail, alongside the project objectives and its relation to the AI4EU platform. A literature review on related approaches and projects on energy analytics services was also performed, to showcase the I-NERGY added value. The paper further presented the proposed technical architecture alongside the main services to be developed as well as the I-NERGY pilot use cases. The Open Calls, another important project aspect, were also described as they are expected to enrich the project know-how. As the project is in its first steps, there are no concrete results yet. However, several energy analytics services will be launched in the following months. The latter will be thoroughly evaluated, so as to refine technical developments and improve I-NERGY functionalities. Lastly, several assets will be published to AI4EU, enabling interested stakeholders to gain significant know-how and experiment with real data and state-of-the-art AI models.

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REFERENCES

Baloglu, U. B., & Demir, Y. (2015). A bayesian game-theoretic demand response model for the smart grid. *International Journal of Smart Grid and Clean Energy*. https://doi.org/10.12720/SGCE.4.2.132-138

Berger, R. (2018). *Artificial intelligence: A smart move for utilities*.

Boschert, S., & Rosen, R. (2016). Digital Twin---The Simulation Aspect. In P. Hehenberger & D. Bradley (Eds.), *Mechatronic Futures: Challenges and Solutions for Mechatronic Systems and their Designers* (pp. 59–74). Springer International Publishing. https://doi.org/10.1007/978-3-319-32156-1_5

Bouabdallaoui, Y., Lafhaj, Z., Yim, P., Ducoulombier, L., & Bennadji, B. (2021). Predictive maintenance in building facilities: A machine learning-based approach. *Sensors (Switzerland)*, *21*(4). https://doi.org/10.3390/s21041044

Buchwitz, M., Reuter, M., Schneising, O., Bovensmann, H., Burrows, J. P., Boesch, H., Anand, J., Parker, R., Detmers, R. G., Aben, I., Hasekamp, O. P., Crevoisier, C., Armante, R., Zehner, C., & Schepers, D. (2018). Copernicus Climate Change Service (C3S) global satellite observations of atmospheric carbon dioxide and methane. *Proceedings of the International Astronautical Congress, IAC*, *2018-October*(1), 57–60. https://doi.org/10.1007/S42423-018-0004-6/FIGURES/4

Chen, P., Liu, S., Shi, C., Hooi, B., Wang, B., & Cheng, X. (2018). *NeuCast: Seasonal Neural Forecast of Power Grid Time Series*.

Cortés, U., Cortés, A., & Barrué, C. (2019). Trustworthy AI. The AI4EU approach. *Proceedings of Science*, *372*. https://doi.org/10.22323/1.372.0014

De Benedetti, M., Leonardi, F., Messina, F., Santoro, C., & Vasilakos, A. (2018). Anomaly detection and predictive maintenance for photovoltaic systems. *Neurocomputing*, *310*. https://doi.org/10.1016/j.neucom.2018.05.017

EU. (2020). White Paper On Artificial Intelligence - A European approach to excellence and trust. In *European Commission*.

GeneralElectric. (2019). *General Electric GE Launches the Next Evolution of Wind Energy Making Renewables More Efficient, Economic*.

Guo, X., Zhao, Q., Zheng, D., Ning, Y., & Gao, Y. (2020). A short-term load forecasting model of multi-scale CNN-LSTM hybrid neural network considering the real-time electricity price. *Energy Reports*, *6*, 1046–1053. https://doi.org/10.1016/J.EGYR.2020.11.078

Lu, R., Hong, S. H., Zhang, X., Ye, X., & Song, W. S. (2018). A Perspective on Reinforcement Learning in Price-Based Demand Response for Smart Grid. *Proceedings - 2017 International Conference on Computational Science and Computational Intelligence, CSCI 2017*, 1822–1823. https://doi.org/10.1109/CSCI.2017.327

Marinakis, V., Doukas, H., Tsapelas, J., Mouzakitis, S., Sicilia, Á., Madrazo, L., & Sgouridis, S. (2020). From big data to smart energy services: An application for intelligent energy management. *Future Generation Computer Systems*, *110*. https://doi.org/10.1016/j.future.2018.04.062

Nagy, K., & Hajrizi, E. (2018). Beyond the Age of Oil and Gas – How artificial intelligence is transforming the energy portfolio of the societies. *IFAC-PapersOnLine*, *51*(30). https://doi.org/10.1016/j.ifacol.2018.11.307

Novak, M., J.F., & L.L. (2013). Anomaly detection in user daily patterns in smart-home environment. *Journal of Selected Areas in Health Informatics*, *3*.

Wen, Z., O'Neill, D., & Maei, H. (2015). Optimal demand response using device-based reinforcement learning. *IEEE Transactions on Smart Grid*, *6*(5), 2312–2324. https://doi.org/10.1109/TSG.2015.2396993

Yamauchi, M., Ohsita, Y., Murata, M., Ueda, K., & Kato, Y. (2020). Anomaly Detection in Smart Home Operation from User Behaviors and Home Conditions. *IEEE Transactions on Consumer Electronics*, *66*(2). https://doi.org/10.1109/TCE.2020.2981636

Yao, W. (2018). *Analysis on the Application of the Artificial Intelligence Neural Network on the New Energy Micro Grid*. https://doi.org/10.2991/macmc-17.2018.144

Yeh, C. H., Lin, M. H., Lin, C. H., Yu, C. E., & Chen, M. J. (2019). Machine learning for long cycle maintenance prediction of wind turbine. *Sensors (Switzerland)*, *19*(7). https://doi.org/10.3390/s19071671