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REVIEW OF TOP ENERGY TRANSITION INNOVATORS IMPACTING RENEWABLE ENERGY DEVELOPMENT

The list of TOP 100 energy transition innovators draws on Reuters Events' expertise as the world's leading provider of cleantech events. The main purpose of this review is to analyze the presented innovators and their main contributions towards energy transition as well as to emphasize those cases which are specifically dedicated to the renewable energy development, including solar systems, components and appropriate services. The main emerging trends shown and discussed in the review include Digital solutions, Decarbonization, Wind power, Just transition, Collaboration and partnerships, Hydrogen, Carbon capture, Novel technology, Green finance and Energy storage.

Keywords: *emerging trends; institutions and innovation ecosystems; solar systems; strategic innovations; technological changes; technological foresight; technology entrepreneurship; renewable energy; power electronics.*

Fig.: 8. References: 56.

Relevance of the research. Innovation is key to the energy transition as global greenhouse gas emissions continue to mount and the window for meaningful climate action closes. For the second year running, Reuters Events has wanted to recognize some of the many organizations innovating to save the planet from catastrophic climate change. The list of TOP 100 energy transition innovators draws on Reuters Events' expertise as the world's leading provider of cleantech events. The list divided into 10 categories with 10 organizations in each that have made notable contributions to the energy transition [1]. Many of the organizations listed have been attended the Reuters Events Global Energy Transition event in New York, United States, on June 07-08, 2023.

Problem statement. This study is performed in the frame of the research project "The maximum efficiency assurance of autonomous electrical power systems for special applications based on photovoltaic converters" #0123U100975 supported by the Ministry of Education and Science of Ukraine.

Research objective. The main purpose of this review is to analyze the presented innovators and their main contributions towards energy transition as well as to emphasize those cases which are specifically dedicated to the renewable energy development, including solar systems, components and appropriate services.

The statement of basic materials. The rest of this review, is structured as follows: Section I represents Digital solutions, Section II is devoted to Decarbonization, Section III is dedicated to Wind power, Section IV describes Just transition, Section V discusses Collaboration and

partnerships, Section VI is devoted to Hydrogen, Section VII tells about Carbon capture, Section VIII presents Novel technology, Section IX is devoted to Green finance, Section X describes Energy storage, Section XI represents power electronics in energy systems.

Digital solutions. GE Digital is a subsidiary of the American multinational conglomerate corporation General Electric. GE Digital's primary focus is to provide industrial software and services in four markets: Manufacturing applications serving discrete and process industries; Electric and Telecommunications Utilities; Oil & Gas industry; Power generation (gas, steam, solar, wind, hydro and related balance of plant operations and service support) [2].

Generating renewable energy depends on reliably forecasting the weather and its impact on wind and solar power generation. The IBM Environmental Intelligence Suite uses data and advanced analytics from The Weather Company®, an IBM Business, to create the most accurate weather forecasts in the world, which helps power companies to plan generation and maintenance schedules more effectively and efficiently [3].

IBM Environmental Intelligence Suite combines AI with weather, climate, and operational data into a single solution to provide more accurate information about the environment under study. In addition, the program allows you to gain insight into potential disruptions and prioritize mitigation and response actions [4].

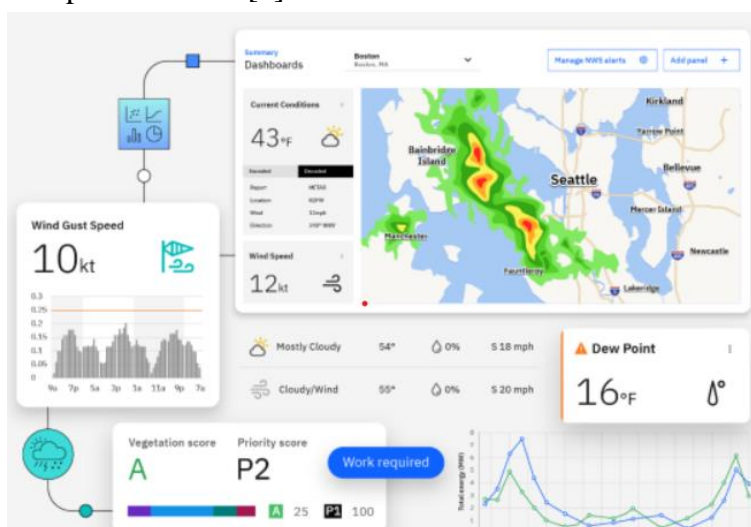


Fig. 1. SaaS platform to monitor, predict, and respond to weather and climate impact [4]

Octopus Energy Group is a British renewable energy group specializing in sustainable energy. Kraken Flex is a cloud-based platform that controls distributed energy assets with machine learning and artificial intelligence to match supply and demand. This helps the electricity grid deal with the natural volatility of renewable generation [5].

Decarbonization. Vattenfall is a Swedish multinational power company. As of 2019, renewables accounted for 35 % of the firm's total generation capacity, including wind, solar and hydro power [6].

Schneider Electric and Walmart Inc., the leaders in the digital transformation of energy management and automation. The groundbreaking initiative, called the Gigaton PPA (GPPA) Program, is designed to educate Walmart suppliers about renewable energy purchases and accelerate renewable energy adoption by participating suppliers through aggregate power purchase agreements (PPA) [7; 8].

Engie is a French multinational utility company, which operates in the fields of energy transition, electricity generation and distribution, natural gas, nuclear, renewable energy and petroleum. It is one of the few players in the sector to develop expert skills in both upstream (engineering, purchasing, operation, maintenance) and downstream (waste management, dismantling) activities [9].

Hitachi is co-creating global and local solutions to solve the global challenge of an inclusive and equitable carbon-neutral future. They are advancing the world's energy system to be more sustainable, flexible and secure. As the pioneering technology leader, they collaborate with customers and partners to enable a sustainable energy future – for today's generations and those to come [10].

TC Energy is a major North American energy company that develops and operates energy infrastructure in Canada, the United States, and Mexico. The company operates three core businesses: Natural Gas Pipelines, Liquids Pipelines and Energy. The company is expanding its energy division to include more renewable sources including pumped storage, wind, and solar generation [11].

Solar energy to power TC Energy renewable natural gas (RNG) interconnects – meter stations (Fig. 2), that measure the amount of gas being transported – is helping the company to work towards our net-zero commitment while also enabling the company to sell renewable energy to the local utility. The company uses multiple wind and solar PPAs to decarbonize operations [12].



Fig. 2. Meter stations that measure the amount of gas being transported

Wind power. Massachusetts Institute of Technology (MIT). Working with experts from turbine maker Siemens Gamesa and developer ReNew Power, MIT researchers have found a way to improve wind farm output by 1.2%—at no cost. The benefit can be achieved by modeling the wind flow of an entire collection of turbines and optimizing the control of individual units accordingly, the researchers found [13].

Acciona Energía is a company dedicated to providing solutions based on renewable energy, with the goal of contributing to the decarbonization of the planet [14].

GE Renewable Energy is a manufacturing and services division of the American company General Electric. They focus on the production of energy systems that use renewable sources. Its products include wind (onshore and offshore), hydroelectric and solar (concentrated and photovoltaic) power generating facilities. It is the world's largest wind turbine manufacturer [15].

As the world's top-class wind turbine manufacturer and clean energy integrated solution provider, Mingyang Smart Energy is dedicated to the green and intelligent energy to benefit the world. They engage in the wind energy and solar energy sectors, ranking the 40th among the World Top 500 New Energy Enterprises and the 1st in offshore wind innovation [16].

Siemens Gamesa Renewable Energy is a Spanish-German wind engineering company. The Services Commercial Office manufactures wind turbines and provides onshore and offshore wind services. It is the world's second largest wind turbine manufacturer. The company is notable for its SG 14.0-222 wind turbine, the largest variant based on the Siemens D7 Platform, as well as being the largest wind turbine in the world [17].

SSE Renewables is an energy company, which develops and operates onshore and offshore wind farms and hydroelectric generation in the United Kingdom and Ireland [18].

Vattenfall. As of 2019, renewables accounted for 35% of the firm's total generation capacity, including wind, solar and hydro power. Vattenfall also operates biomass and other power plants in Germany and the Netherlands [19].

Just transition. As part of the Powering Past Coal Alliance, the Canadian government has committed to banning new thermal coal mining and ending coal fired power generation. The Powering Past Coal Alliance (PPCA) is a group of countries, cities, regions and organizations aiming to accelerate the fossil-fuel phase out of coal-fired power stations, except the very few which have carbon capture and storage. The project was undertaken with financial support from the Government of Canada, through their environmental department known as Environment and Climate Change Canada [20].

Eni is a global energy company, active at every stage of the value chain: from natural gas and oil to co-generated electricity and renewables, including both traditional and bio refining and chemicals [21].

European Commission. The Just Transition Platform (JTP) provides a single access point to support and knowledge on Europe's transition to a sustainable, climate-neutral economy. The Platform is the EU's key tool to help Member States and regions unlock the support available through the Just Transition Mechanism, ensuring a fair and 'just' transition that leaves no person or region behind [22].

SSE is a leading generator of renewable electricity and one of the largest electricity network companies in the United Kingdom. They develop, own and operate low carbon infrastructure to support the zero-carbon transition. This includes onshore and offshore wind, hydro power, electricity transmission and distribution grids, and efficient gas-fired generation, alongside providing energy products and services for businesses [23].

Collaboration and partnerships. Hydrogen Import Coalition. This collaboration between DEME, Engie, Exmar, Fluxys, the Port of Antwerp, the Port of Zeebrugge and WaterstofNet has carried out important research into the feasibility of large scale imports of low-carbon hydrogen into Europe [24].

Asian Renewable Energy Hub (AREH), comprising 7.5GW of wind and 3.5GW of solar power generation capacities, is one of its kind and one of the most significant world hybrid power projects planned, and it's expected to generate 40TWh of clean electricity a year. A 14,000km² site with 8.2m/s average wind speed and 2,450kWh/m² solar power generation potential was selected for the hybrid energy project [25].

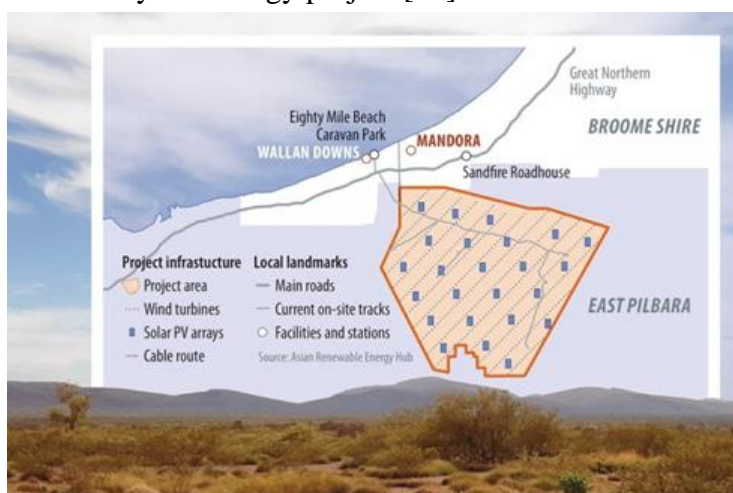


Fig. 3. AREH project map

Antwerp@C is a project dedicated to innovative CO₂ reduction. Together with seven leading chemical and energy companies, Antwerp@C are working on the transition to a circular and climate neutral port [26].

Siemens Gamesa wind engineering company manufactures wind turbines and provides onshore and offshore wind services. It is the world's second largest wind turbine manufacturer [27].

Hydrogen. Aqua Ventus' project sets standards and is unique in the energy landscape of Germany and Europe. The initiative is made up of highly innovative organizations and research institutions as well as leading international companies that are proclaiming a new era of climate-friendly energy with the production of green hydrogen at sea. The overarching goal of Aqua Ventus is to install 10 GW of green hydrogen generation capacity from offshore wind energy in the North Sea by 2035 and to establish an associated transport infrastructure [28].

HY2GEN AG develops, finances, builds, and operates plants for the production of green hydrogen, green ammonia, and hydrogen-based e-fuels worldwide. These products are used to create CO₂-free or CO₂-neutral and competitive fuels and industrial solutions. The first plants are being built in France, Norway, Canada, and Germany. Hy2gen's goal is to become the market leader in the production of green hydrogen, green ammonia, and green e-fuels for mobility, agriculture, and industry [29].

CWP Global is a leading renewable energy developer. The mission is to improve the environment for current and future generations by leading the transition to renewable energy [30].

For over 30 years, Toyota has invested significantly in its world-leading fuel cell technology. Instead of using power from electricity stored in a battery, hydrogen fuel cell electric vehicles (FCEVs) generate their electricity through a chemical reaction between hydrogen and oxygen in a fuel cell stack. It's a process that leads to zero emissions apart from water. Fuel cell electric vehicles (FCEVs) powered by hydrogen have a unique role in the decarbonisation of transport and the wider economy [31].

U.S. Department of Energy. The HydroGEN Advanced Water Splitting Materials consortium aims to accelerate the research, development, and demonstration of advanced water splitting technologies for clean, sustainable hydrogen production. HydroGEN is a consortium of six U.S. Department of Energy (DOE) national laboratories that will address advanced water splitting materials challenges by making unique, world-class national lab capabilities in photoelectrochemical, solar thermochemical, and low- and high-temperature electrolytic water splitting more accessible to academia, industry, and other national labs [32].

Carbon capture. Baker Hughes Company is one of the world's largest oil field services companies. The company provides products and services for oil well drilling, formation evaluation, completion, production, and reservoir consulting. They design, manufacture and service transformative technologies to help take energy forward [33].

Aker Solutions delivers integrated solutions, products and services to the global energy industry. They enable low-carbon oil and gas production and develop renewable solutions to meet future energy needs. By combining innovative digital solutions and predictable project execution, they accelerate the transition to sustainable energy production [34].

C-Capture was founded as a spin-out company from the School of Chemistry at the University of Leeds. C-Capture has patented a unique, solvent-based technology that offers a safe, low-cost way to remove carbon dioxide from emissions using a post-combustion capture approach [35].

Chevron Corporation is an American multinational energy corporation predominantly in oil and gas. Within oil and gas, Chevron is vertically integrated and is involved in hydrocarbon exploration, production, refining, marketing and transport, chemicals manufacturing and sales, and power generation [36].

Saipem is an Italian multinational oilfield services company and one of the largest in the world. Saipem is an advanced technological and engineering platform for the design, construction and operation of safe and sustainable complex infrastructure and plants. Saipem has always been oriented towards technological innovation and is currently committed, alongside its clients, on the frontline of energy transition with increasingly digitalised tools, technologies and processes that were devised from the outset with environmental sustainability in mind [37].

Novel technology. Twelve is the carbon transformation company. Their technology is a new breed of electrochemical reactor that works like industrial photosynthesis. Just like a plant uses CO₂, water and sunlight to make useful carbon-based products, they use CO₂, water and renewable energy to make chemicals, materials and fuels that are made from refining fossil fuels [38].

Shell uses blockchain to track the source of renewable energy and allocate sustainable aviation fuel purchases for air travel. Shell Energy partners with AMPYR Australia on a 500MW/1000MWh battery located in Wellington. It will be support renewable generation and contribute to improved reliability for the grid and consumers (Fig. 4) [39].



Fig. 4. Wellington battery energy storage system (BESS)

Heineken has committed to grow the proportion of renewable energy it uses to 70% by 2030 via renewable energy initiatives around the world. Now they have 12 biomass projects in operation around the world, together supplying over 6% of HEINEKEN'S global energy demand for production [40].

Norwegian Crystals manufactures ultra-low-carbon monocrystalline ingots, brick, and wafers for PV. Using a high-precision process, cylindrical silicon ingots are cut into bricks, then processed by partners to create silicon wafers. The process is fully powered by hydro with the addition of natural cooling water from the local glacier, Svartisen [41].

Studio Mom developed the LAVO bike, a compact modular transport concept powered by green hydrogen. They designed it as a toolkit for a new emission-free mode of transport. LAVO developed the 1st commercial home hydrogen system. It fills small tanks with hydrogen using water and solar energy [42].

Green finance. Union Bancaire Privée (UBP) have a responsibility and great potential to contribute to the global effort to tackle environmental problems through their investment decisions. At the same time, UBP strives to lead by example, managing the environmental impact of their own operations [43].

Bluefield Solar Income Fund is an investment company focused on the acquisition and long term management of a diversified portfolio of low carbon assets in the UK. This is the first investment company focused on solar PV to be listed on a major stock exchange [44].

Impax Asset Management is a specialist asset manager based in London, England. Impax is one of the longest established private markets managers in the large and rapidly growing renewable energy sector. The firm manages three new energy funds that follow an industrially-focused value-add strategy, investing in renewable power generation and related assets [45].

S&P Global is an American publicly traded corporation. Its primary areas of business are financial information and analytics. The S&P Global Clean Energy Index is designed to measure the performance of companies in global clean energy-related businesses from both developed and emerging markets, with a target constituent count of 100 [46].

Energy storage. Polar Night Energy. The project embraces renewable energy by providing stable and affordable heat storage for district heating and industrial applications. A heat transfer system was built inside the sand, which ensures a long storage period, from hours to months, with minimal heat loss. There is a heat storage system with a thermal capacity of 2 MW with a capacity of 300 MW/h or 10 MW with a thermal capacity of 1000 MW/h.

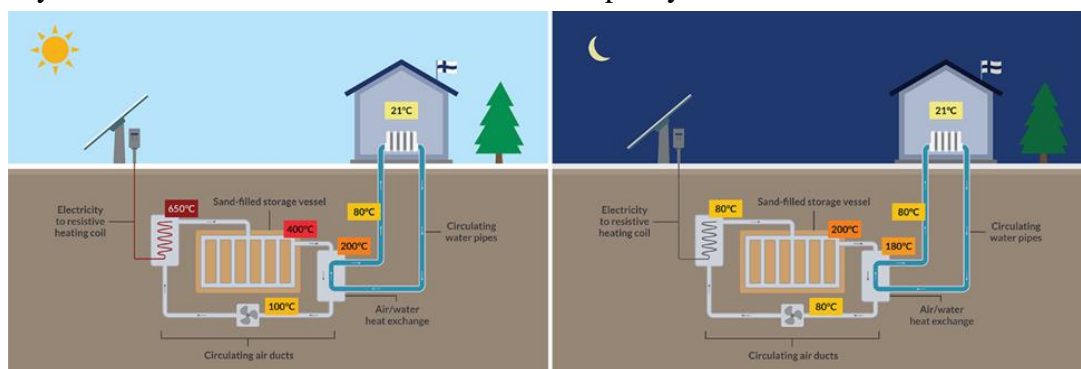


Fig. 5. A schematic of the components and operating cycle of the Polar Night Energy system [47]

Hydrostor provides grid-scale electricity storage by storing renewable energy as compressed air. The technology offers the same services as a natural gas plant while having zero emissions using surplus electricity as fuel [48].

Mission ESS is to accelerate global decarbonization by providing safe, sustainable, long-duration energy storage that powers people, communities and businesses with clean, renewable energy anytime and anywhere it's needed. As more renewable energy is added to the grid, long-duration storage is essential to providing the reliability and resiliency when the sun is not shining and the wind is not blowing [49].

The Tesla Megapack is large-scale rechargeable Li-ion battery stationary energy storage product, intended for use at battery storage power stations, manufactured by Tesla Energy. Designed to be deployed by utility companies, Megapacks can be used to store energy generated by intermittent renewable power sources, such as solar and wind. Tesla Energy also offers smaller battery energy storage devices: the Powerwall, intended for home use, and the Powerpack, intended for use by businesses or on smaller power utility projects [50].

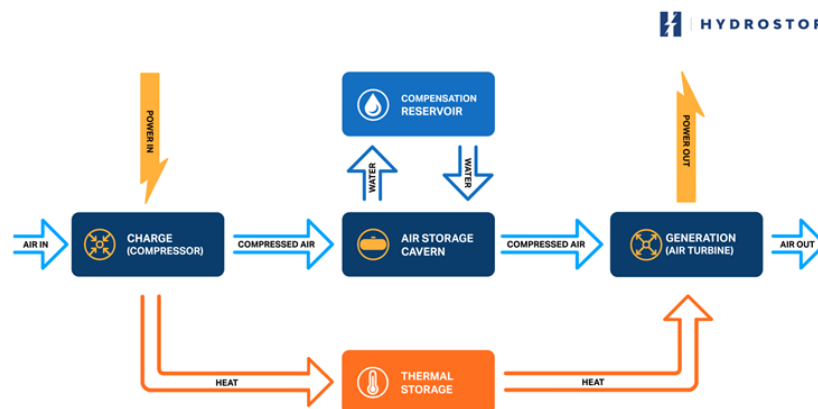


Fig. 6. The diagram of the A-CAES Process Flow

Power electronics. Paper [51] describes the role of power electronics, future trends in terms of power semiconductors, reliability, advanced control, grid-forming operation, and security issues for renewable energy integration.

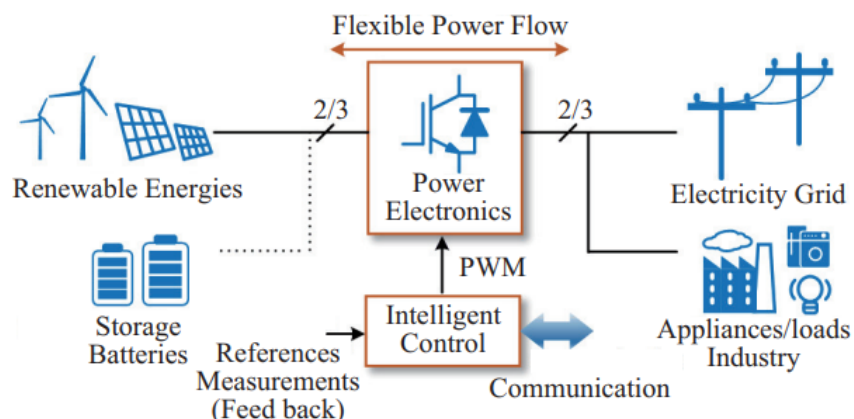


Fig 7. Configuration of a typical grid-connected RES with power electronics converters and intelligent control

In article [52] describes the evolution of power semiconductor devices technologies, general types of power converters for Large-Scale renewable energy generation such as: two-level inverter and three-level neutral-point clamped inverter, Typical configurations of large-scale for PV and wind turbines power generation systems.

Study [53] is to present a comprehensive review of wind-solar hybrid renewable energy source, such as power architectures, mathematical modeling, power electronic converter topologies, and design optimization algorithms.

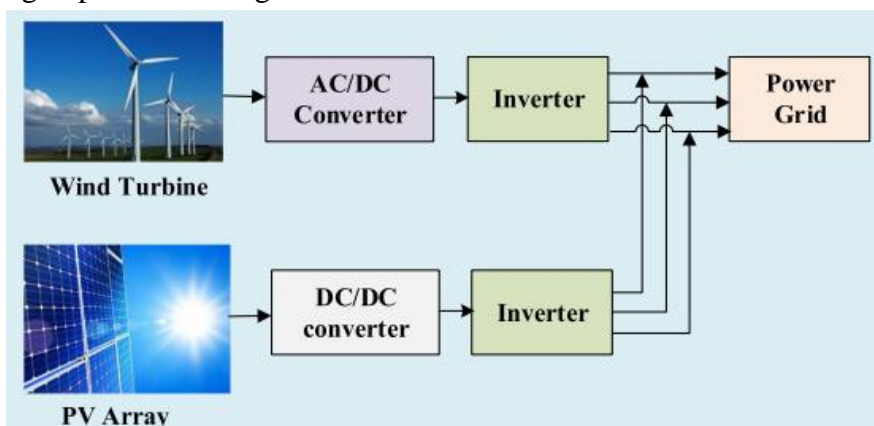


Fig 8. Scheme diagram of power architectures for hybrid renewable energy source

Article [54] describes the hybrid energy storage systems in photovoltaic energy sources and analyzes the important aspects of capacity sizing, power converter topology and strategies management. This paper focuses combine two storage technologies energy: high energy and high power.

Paper [55] describes energy systems with variable photovoltaic power source. Controls that trade off energy production against variability are presented.

Publication [56] characterizes the general development of power electronics, emerging trends, and aspects that will be important in the future when designing converter systems. In addition to an increase in energy conversion efficiency and CO₂ emission reduction, there is a problem of waste leading to the need of designing converter subsystems also for "Repairability and Circularity". The reduction of wasted energy and the environmental impact is taken into account by considering the entire life cycle of the converters. This can mean a new approach to design and converter optimization.

Conclusions. The representatives of the TOP Energy Transition Innovators and their contributions were analyzed in this review. It was found, that most of the presented institutions and innovation ecosystems are directly dedicating their efforts to the renewable energy development. Some of them have specific interests and achievements in the field of solar systems as well as their components and services.

The main emerging trends shown and discussed in the review include Digital solutions, Decarbonization, Wind power, Just transition, Collaboration and partnerships, Hydrogen, Carbon capture, Novel technology, Green finance and Energy storage.

It is worth noting that solar energy was not directly included in the list of selected directions. Although it is one of the main types of renewable energy sources, along with wind and hydrogen energy. At the same time, a significant part of representatives of innovators are directly involved in the field of solar energy in their activities.

The presented companies provide their services and distribute technologies on the European, North American, Australian and Asian continents. Each of them strives for the efficiency of its activities by reducing emissions, new methods of energy storage and transmission, the latest digital solutions, energy management and increasing the efficiency of power electronics. As a result, only the technological and functional solutions that were presented remain on the world market.

For the purposes of future research and as further technological forecasting, it is worth emphasizing that the development of tools and services for solar energy and the construction of photovoltaic power supply systems is practically impossible by itself without taking into account and integrating such fields of innovations as Digital solutions, Decarbonization, Collaboration and partnerships, Novel technology, Green finance and Energy storage. Further work will be devoted to research on the construction of highly-efficient power supply systems based on photovoltaic converters, in particular, taking into account the further joint development of the mentioned innovative areas.

This study is carried out within the framework of the research projects “The maximum efficiency assurance of autonomous electrical power systems for special applications based on photovoltaic converters” #0123U100975 and “Multi-agent system for the protection of critical infrastructure based on a swarm of multi-copter drones” #0123U101819 supported by the Ministry of Education and Science of Ukraine. This research is also partially supported by the program “Excellence initiative – research university” for the AGH University of Krakow.

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ОГЛЯД КРАЩИХ ІННОВАТОРІВ В ЕНЕРГЕТИЦІ, ЩО ВПЛИВАЮТЬ НА РОЗВИТОК ВІДНОВЛЮВАНОЇ ЕНЕРГЕТИКИ

Список кращих новаторів у галузі енергетики базується на досвіді «Reuters Events» як провідного світового постачальника відновлюваних технологій. Проаналізувавши внесок наведених у цій статті новаторів, можна підкреслити їхню значущість у сприянні декарбонізації та зменшенні викидів парникових газів та розвитку відновлюваної енергетики. Основна мета даної оглядової статті — проаналізувати представлених новаторів та їхній основний внесок у перехід до енергетики, а також підкреслити ті випадки, які спеціально присвячені розвитку відновлюваної енергетики, що сприятиме просуванню даного напрямку в сучасному світі.

Серед найважливіших тенденцій варто відзначити такі: цифрові рішення, які сприяють оптимальному використанню ресурсів та зменшують негативний вплив на навколишнє середовище.

Декарбонізація, передбачає заміну використання вугілля та інших вуглеводнів на більш екологічно чисті джерела енергії, такі як енергія сонця, вітру та гідроенергетика. Це дозволить значно зменшити викиди парникових газів в атмосферу та зменшити негативний вплив на глобальне потепління.

Енергія вітру та сонця або розвиток вітро- та сонячної енергетики також є важливими напрямками у сучасній енергетиці. Нові технології та масове виробництво дозволяють зробити їх більш ефективними та доступними для ширшого кола споживачів.

Співпраця та партнерство стають все більш важливими для успішного вирішення складних проблем сфери енергетики. Співпраця між компаніями, керівництвом країн та кінцевими споживачами є важливими для успішного впровадження інновацій в енергетиці. Спільні зусилля можуть забезпечити стабільну роботу та постійний розвиток енергетичної системи.

Водень та водневі технології є перспективними напрямками розвитку, які можуть значно розширити перспективи використання енергії та зробити її більш ефективною.

Зберігання енергії дозволяє ефективно розподіляти ресурси – накопичувати, коли є надлишок генерації і віддавати електроенергію, коли виникає дефіцит.

Силова електроніка дозволяє ефективно перетворювати отриману енергію з відновлюваних джерел для використання її кінцевими споживачами.

Ключові слова: нові тенденції; інститути та інноваційні екосистеми; сонячні системи; стратегічні інновації; технологічні зміни; технологічне передбачення; технологічне підприємництво; відновлювальна енергія; силова електроніка.

Рис.: 8. Бібл.: 56.