Energy-efficient solutions for industrial enterprises: modern technologies in the field of sustainable production

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Abstract. Industrial enterprises are increasingly embracing energy-efficient solutions to enhance sustainability in production processes. This shift towards sustainability is driven by modern technologies that aim to optimize energy usage and minimize environmental impact. Energy efficiency is a crucial aspect of sustainable production for industrial enterprises, given their significant role in global energy consumption and environmental impact. This article provides an in-depth exploration of modern technologies and approaches that industrial enterprises can adopt to enhance energy efficiency and promote sustainability. By embracing these energy-efficient solutions, industrial enterprises can achieve significant cost savings, minimize environmental impact, and contribute to a more sustainable future. The implementation of modern technologies in the field of sustainable production is essential for addressing global energy challenges and advancing towards a greener economy.

1 Introduction

The UN's sustainable development principles emphasize advancing civilization through innovation while meeting diverse populations' essential needs, including energy supply, while also safeguarding the environment. Recent global crises and heightened instability have spurred a reassessment of sustainable development priorities. While initial skepticism arose during the COVID-19 pandemic regarding adherence to the 2030 Agenda for Sustainable Development, attention shifted towards collective action to achieve the 17 Sustainable Development Goals (SDGs). Efforts span various levels, from states and their regional associations to municipalities, companies, and society as a whole.

The urgency of sustainable development has intensified due to worsening climate issues and the imperative of ensuring energy security. Balancing environmental preservation with providing widespread access to civilization's benefits through affordable energy resources

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remains a pressing challenge in today's rapidly evolving world. Transitioning to "green" energy emerges as a significant solution, involving energy sources with minimal greenhouse gas emissions.

Addressing climate change requires coordinated international action, involving active participation from countries, international organizations, and associations. International cooperation is crucial for making unified decisions across all levels, facilitating the transition to a low-carbon economy, and achieving climate neutrality.

The report primarily focuses on the contributions of regional integration associations, particularly in the post-Soviet space like the Eurasian Economic Union (EAEU) and the Commonwealth of Independent States (CIS), to global sustainable development efforts. It explores leveraging international standards and practices to develop and implement a "green" agenda in the Eurasian region.

The proliferation and significance of RIOs in recent decades have become central to discussions on sustainable development. Their growing influence suggests a potential role in shaping global regulatory frameworks, impacting the emerging world order.

The COVID-19 pandemic, beginning in 2020, not only exacerbated socio-political challenges but also underscored the enduring crisis of modernity - perpetual turbulence and instability. This crisis has become ingrained in human experience, shaping global political discourse. Assessments by the UN and other international bodies reveal the pandemic's detrimental effects on sustainable development indicators across all SDGs. Experts warn that progress achieved over the past five years, particularly in SDGs 12–15, may regress without decisive action to realign the global community with a sustainable development path. The full impact of the Russian-Ukrainian conflict and its associated crises on SDG achievement is yet to be fully comprehended and quantified.

2 Research methodology

The Paris Climate Agreement aims to achieve carbon neutrality by 2050, which entails eliminating CO2 emissions into the atmosphere. The International Energy Agency (IEA) identifies electric transport as a critical driver for achieving this goal. Forecasts suggest that by 2030, the world will produce 30 million electric vehicles, requiring new traction batteries with a total capacity of at least 1,800 GWh annually.

Additionally, renewable energy sources (RES) are gaining momentum due to the environmental agenda. However, stable energy supply from renewables requires backup sources and storage systems independent of weather conditions. By 2030, the combined capacity of wind and solar power is expected to reach around 950 GW. Backup solutions include stationary battery stations, power sources using "green" hydrogen, and pumped storage units.

Battery stations, known for their high efficiency and ease of integration into electrical grids, are vital for storing excess electricity and releasing it when needed. Estimates suggest that by 2030, 200–400 GWh of battery capacity per year will be needed to back up just a tenth of all renewable energy sources.

The battery market is projected to grow significantly over the next decade, reaching 2000–2200 GWh per year. Furthermore, the cost of hydrogen technologies for energy and transport is expected to decrease, with batteries and hydrogen fuel cells serving as complementary technologies. Batteries may be optimal for urban passenger transport, while hybrid installations combining batteries and hydrogen fuel cells could be used for long-distance freight transport and special equipment.

According to IEA forecasts, by 2030, leading countries like the USA, China, Japan, and South Korea may have around 1 million vehicles powered by hydrogen fuel cells, with a global total of 4.6 million. Recognizing the importance of energy storage systems across various sectors, the Russian government plans to collaborate with State Corporation Rosatom in developing this high-tech area.

This collaboration aligns with Russia's strategic objectives in the energy sector and aims to strengthen its position in international energy markets. The report section provides insights into the current state and future prospects of electricity storage system technologies globally and in Russia. It includes an overview of research and development agendas, existing market solutions, and government support measures for this sector's development (Fig. 1).

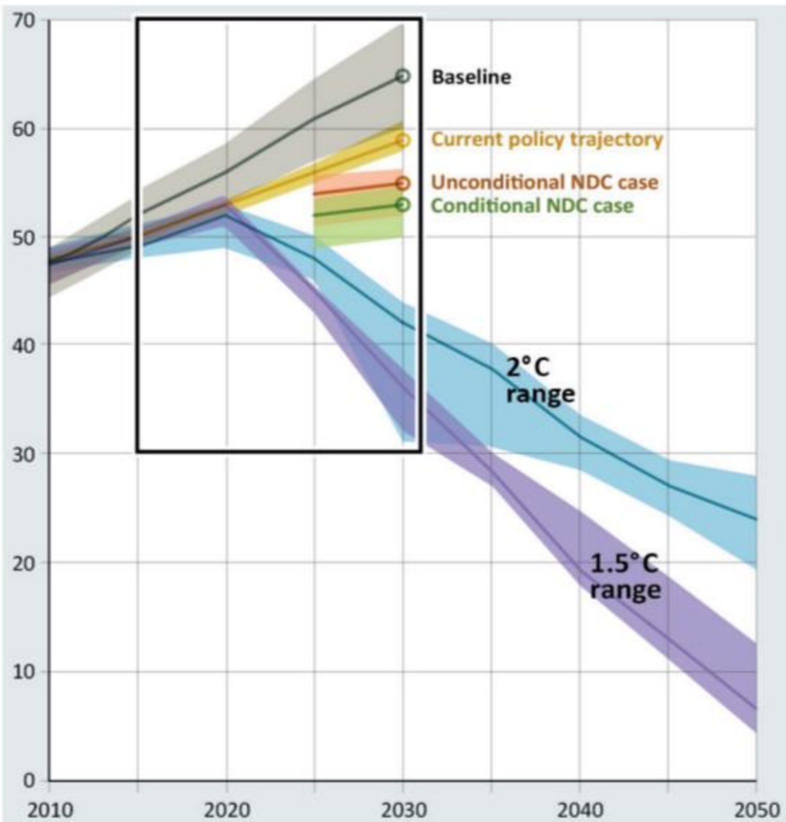

Fig. 1: Annual global GHG emissions (in Gt equivalent CO2) according to different scenarios. The emissions gap in 2030 is defined as difference between total global GHG emissions at implementation of the least costly scenarios corresponding to goals of a temperature increase of less than 2°C and less than 1.5°C, and expected global GHG emissions at subject to full compliance by states with their climate obligations.

3 Results and Discussions

The energy industry's state significantly influences a nation's economic competitiveness, societal development, and environmental quality. In Russia, ensuring the long-term sustainable and efficient development of the energy sector is essential due to its pivotal role in exports and government revenue generation. However, the industry faces challenges such as high inertia, long investment cycles, substantial financial and time investments in technology development, and the interdisciplinary nature of scientific research. Moreover, there are often multiple potential directions for scientific and technological advancement, and choosing the wrong path can lead to significant economic losses and falling behind more advanced countries.

Key conditions for shaping a post-industrial energy sector include the rapid growth of sectors with low energy intensity, diversification of energy sources, localizing production near consumers, implementing large-scale energy efficiency projects, and establishing smart energy networks and information systems.

The depletion of traditional hydrocarbon reserves in Russia is exacerbated by the fact that many of the world's oil reserves discovered in the past two decades are located in remote and challenging locations, leading to high resource and energy intensity in their extraction and infrastructure development. Additionally, global reserves of the uranium-235 isotope are expected to be depleted in 40-50 years, further driving up the costs of fuel and energy resource production and necessitating the development of non-traditional energy sources.

In response to tightening environmental regulations and climate change challenges such as rising temperatures, changing precipitation patterns, glacier melting, and sea-level rise, Russia must align its national energy legislation with international standards and implement economic and institutional measures to promote environmentally oriented development.

Economic growth in the Central and Eastern Europe, Caucasus, and Central Asia (CEECCA) region between 2000 and 2019 saw an average GDP increase of 6.5% per year, factoring in purchasing power parity (PPP). Despite this progress, environmental protection improvements vary across countries and sectors. While carbon dioxide emissions have declined in most nations, concentrations of fine particulate matter (PM2.5) have surged, posing health risks and economic losses, reaching their highest levels in two decades.

Product life cycle management (PLM) in the context of smart factories entails fully automated production processes controlled in real time and adapting to changing conditions. This is achieved through the integration of Internet of Things (IoT) technologies, big data analysis (including data from IoT devices), and information systems for managing production and business processes (such as MES, ICS, ERP, EAS, etc.). Cyber-physical systems create virtual replicas of real production facilities, oversee physical processes, and make decentralized decisions, sometimes being self-learning and self-adjusting. These systems can be interconnected into a network. The realization of the Industry 4.0 concept relies on well-established processes for acquiring, analyzing, and exchanging data. Smart factories also leverage robotics (including collaborative robots), additive manufacturing (3D and 4D printing), industrial avatars controlled through neural interfaces, and other innovative solutions. After-sales service, now considered a separate value proposition and revenue stream, adopts a service business model ("product as a service") and predictive maintenance based on data analysis from user experiences and IoT devices. The digital transformation of the industry culminates in the establishment of flexible and highly efficient distributed network production based on digital platforms that integrate all stakeholders into a single ecosystem. Industry 4.0 represents the widespread integration of cyber-physical systems into manufacturing processes. Key concepts related to this transformation include: - Factory of the future: A business process system that combines digital platforms, digital product and production process models, and the digitalization of product life cycles. - Digital Factories: Integrated technological systems facilitating the design and production of globally competitive products, from research and planning to creating digital twins and prototypes. - Smart factories: Systems ensuring the production of high-quality products with high levels of automation and robotization, minimizing human errors and intervention. - Virtual factories: Integration of digital and smart factories into distributed networks, potentially spanning global supply chains and production assets. - Service business model: Offering comprehensive product and service packages throughout the product's lifecycle, adding value during sales and ongoing service.

- Predictive maintenance: Anticipating equipment maintenance needs based on empirical data and predictive models, optimizing maintenance schedules and component replacement.

The digital transformation of industry not only results in cost reduction and increased labor productivity and product quality but also enables faster time-to-market for products, facilitates mass customization, and allows for flexible production that can quickly adapt to external changes. Compared to traditional methods involving physical prototypes and full-scale testing, utilizing digital twin technology in product development reduces design errors and can significantly decrease time and resource costs by up to 10 times or more. Digital modeling and digital twins also enhance product competitiveness, meet high consumer demands, and elevate customization levels.

Industrial VR testing optimizes development time and costs while enhancing product quality. For instance, implementing virtual aircraft testing at the United Aircraft Corporation reduced on-board system debugging flights by nearly half. Similarly, Nortec utilizes virtual simulation to monitor tire quality and predict potential damage. Employing digital twin technology in production processes minimizes failures, prevents downtime, and optimizes enterprise operations. It enables accurate prediction of equipment responses to operational loads with 95% accuracy and reduces operating costs of industrial complexes by 5–10%.

Gazprom Neft PJSC, for instance, implemented digital twins for refining units, yielding economic benefits exceeding 700 million rubles annually. Big data analysis, including data from IoT devices, enhances decision-making, boosts industrial production and logistics efficiency, and enables predictive maintenance of fixed assets. Industrial robots reduce personnel costs, maintain consistent product quality, and enhance production flexibility. The Philips razor plant, equipped with 128 robots and only nine workers, exemplifies this efficiency.

Integrating 3D printing in industry accelerates production and prototyping, conserves raw materials, and minimizes waste. For example, UEC JSC has been utilizing 3D printing for large-sized parts of industrial gas turbine engines since 2019. Future growth areas for 3D printing include new material creation and metal-based 3D printing.

4 Conclusions

In conclusion, I would like to emphasize the importance of energy efficient solutions for industrial enterprises and their significance in the context of sustainable production. Modern technologies in this area play a key role in reducing energy consumption, optimizing production processes and reducing negative environmental impacts.

The use of energy efficient technologies not only reduces energy costs and increases the competitiveness of enterprises, but also contributes to the reduction of greenhouse gas emissions and environmental improvement. This is especially important in the context of global climate change and the growing need for sustainable development.

In addition, energy-efficient solutions stimulate innovation and technological progress, boosting economic growth and creating new jobs in the clean technology sector.

In general, the introduction of modern energy-efficient technologies in industrial production is not only economically feasible, but also contributes to the achievement of sustainable development goals, ensuring a more favorable future for our planet and future generations.

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