Secure Systems Design and Technology Development. Veliko Tarnovo, Bulgaria
Proceedings of the International Scientific Conference, 2026. Volume II, 45-49

Intelligent Production and Business Processes: Application in the Mechanical Engineering Enterprises of Northeastern Region, Bulgaria

Siyka Demirova
Industrial Management
Technical University of Varna,
Bulgaria
s_demirova@tu-varna.bg

Mihail Ivanov
Industrial Management
Technical University of Varna,
Bulgaria
mihail.ivanov@tu-varna.bg

Sibel Ahmedova
Industrial Management
Technical University of Varna,
Bulgaria
sibel_ahmet@tu-varna.bg

***Abstract* - The article presents the application of smart manufacturing and digitalization of business processes in the mechanical engineering enterprises of Northeastern region. The aim is to study the impact of Industry 4.0 technologies on energy efficiency, productivity and return on investment. The applied methodology uses energy indicators such as energy intensity, energy per employee, return on investment, based on industrial data for the country and the region. The results have a huge potential for optimization, as even relatively moderate energy efficiency measures can bring tens of millions of euros in annual savings to the industry, which in recent years has been characterized by dynamic changes in both demand and supply of the service. The report emphasizes the regional strategic importance of digital technologies for the sustainable industrial development of the region, as according to recent data, Bulgarian industrial enterprises are on average 2.7 times more energy inefficient than enterprises from the same industrial sector in the EU.**

Keywords - business processes, Industry 4.0, smart manufacturing.

I. INTRODUCTION

Concerning global competition and accelerated technological development, industrial businesses face the challenge of reconciling high productivity, energy efficiency, and sustainable growth. Intelligent manufacturing, through proper management of business processes and achieving energy efficiency in enterprises, is one of the main fields of Industry 4.0.

Smart manufacturing incorporates the use of technology such as the Internet of Things (IoT), artificial intelligence (AI), and digital twins. IoT within manufacturing guarantees timely predictive maintenance and optimizes supply chains. Real-time data analysis provides for the identification of inconsistencies that can be used to streamline the production process and improve the final product. Digital twins are virtual copies whose advantages include increasing efficiency and optimizing resources, anticipating and preventing problems, emulation of several different scenarios, compatibility with new technologies, etc. AI is one of the technologies that are revolutionizing the world and is a crucial element in optimizing business processes, quality management, and increasing security in the industrial sector [1], [2].

Industry 4.0 brings about a change in industrial business processes along with a search for possible opportunities of enhanced productivity, sustainability, and competitiveness based on energy efficiency. Energy efficiency in mechanical engineering firms is among the most significant parameters for smart production and green development. Mechanical engineering firms' production lines use a lot of energy and resources and hence are highly dependent on regulatory and market requirements [3], [4], [5]. From the perspective of Industry 4.0, energy efficiency is seen as an active management process wherein digital technologies are utilized for the minimization of losses, optimization of production processes, and harmonization with the consumption of renewable energy sources. In this regard, Industry 4.0 and attaining energy efficiency are intimately linked and interdependent processes with the potential to transform not just mechanical engineering enterprises but even other industrial enterprises [6].

In the context of this study, intelligent manufacturing is understood as a production paradigm based on the integration of digital technologies, automation, cyber-physical systems, Internet of Things (IoT), artificial intelligence (AI), and real-time data analytics to optimize production processes, improve flexibility, and enhance energy efficiency [7], [8], [9]. Intelligent manufacturing enables adaptive and self-regulating production systems capable of responding dynamically to operational changes and resource constraints.

Furthermore, digital transformation is defined as the systematic integration of digital technologies into business and industrial processes with the aim of improving

Online ISSN 3044-7771
https://doi.org/10.68302/std2026.vol2.69

operational performance, productivity, sustainability, and decision-making [10], [11], [12]. In the industrial sector, digital transformation extends beyond simple automation and includes the redesign of organizational processes, predictive maintenance systems, digital twins, and intelligent resource management.

Business processes are logically sequential, relevant activities that are formulated to produce value and a finished product through transformation, meeting the needs and desires of users. Industry 4.0 initiates the revolutionization of business processes through the Internet of Things (IoT) technologies, artificial intelligence (AI), Big data, digital twins and cyber-physical systems [13], [14].

Bulgarian machine-building enterprises, and enterprises of the Northeastern Region as a whole, represent strategic importance for the national economy. The fact that Northeastern is a transportation and industrial center (port, industrial parks, university potential) guarantees prerequisites for the integration of intelligent technology in production and logistics.

This study aims to assess the opportunities for improving business processes and energy efficiency in the mechanical engineering sector of the Northeastern Region through the implementation of Industry 4.0 technologies, including IoT monitoring, digital twins, predictive maintenance, and ERP systems, as instruments of intelligent manufacturing and digital transformation.

II. Materials and methods

The scope of the research is to assess the energy efficiency of the mechanical engineering businesses in the Northeastern District and provide an estimate of the savings when employing Industry 4.0 technologies.

1. The National Statistical Institute's value of industrial production and employed workers in Northeastern District (2023) was used, as well as national statistics regarding energy consumption in industry.

2. It is assumed that machine-building enterprises have a share of 3%, 6%, and 10% of the regional industrial economy (three variants).

3. Consumption of energy is estimated by proportional division to the value of production.

The present analysis is based on several methodological assumptions that should be explicitly acknowledged. First, due to the lack of disaggregated sectoral statistics for mechanical engineering enterprises in the Northeastern District, energy consumption was estimated proportionally according to the production value of the industrial sector. This assumes a relatively homogeneous relationship between production output and energy use, which may not fully reflect the technological heterogeneity of firms.

Second, three hypothetical scenarios (3%, 6%, and 10% sectoral share) were developed to account for uncertainty regarding the actual contribution of mechanical engineering enterprises to regional industrial production. These scenarios should be interpreted as indicative rather than exact measurements.

Third, the analysis assumes constant electricity prices and uniform implementation effects of Industry 4.0 technologies across enterprises. In practice, savings may differ significantly depending on production specialization, degree of automation, existing energy management systems, and company size.

Finally, the estimated savings percentages (5–20%) are based on findings from previous studies on Industry 4.0 adoption and industrial energy optimization and therefore represent achievable but context-dependent values rather than guaranteed outcomes.

4. The following formulas were used:

4.1. Energy Intensity (EI):

$$EI=E/Q \tag{1}$$

where E = energy consumption (kWh), and Q = value of production (BGN).

4.2. Energy per employee (Eemp):

$$Eemp=E/N \tag{2}$$

where N=number of employees.

4.3. Return on Investment (ROI):

$$ROI=(B-C)/C\times 100\% \tag{3}$$

where B = annual benefits and C = investment.

4.3.1. Annual benefits

$$B = \text{energy saved} \times \text{cost per kWh} \tag{4}$$

4. 3. 2. Repayment/redemption period

$$\text{payback period (years)} = C/B \tag{5}$$

III. RESULTS AND DISCUSSION

• Energy intensity (272 kWh/1000 BGN) is equal across all models because energy and production are distributed proportionally. This demonstrates the requirement of company data to capture existing differences.

• Per capita energy per employee (≈52.8 MWh/year) is relatively high for mechanical engineering, and the distribution from country data will likely overestimate existing sector consumption.

• The economic calculation shows that even a small decrease in the energy cost (5–15%) provides significant savings for enterprises. The payback period is extremely short, which provokes the implementation of smart technologies.

• Main limitation: the process uses summary national data, which can provide overestimation. For a more realistic assessment, a direct company energy audit is required.

TABLE 1 EVALUATION OF INDICATORS FOR MECHANICAL ENGINEERING ENTERPRISES IN NORTHEASTERN DISTRICT, 2023.

Scenario	**Production (million BGN)**	**Energy (TJ)**	**Energy (GWh)**	**EI (kWh/1000 BGN)**	**Busy faces**	**Energy / employee (kWh)**
Low (3%)	151.9	148.8	41.3	272	782	52,850
Basic (6%)	303.8	297.6	82.7	272	1564	52,850
High (10%)	506.3	495.9	137.8	272	2606	52,850

Table 1 examines 3 cases of the industrial economy of the Northeastern district with a relative share of 3%, 6%, and 10%. For the estimation purpose, production figures, temporary peak value of energy (TJ), total energy, energy intensity (EI), working people, and energy per employee are summarized in the estimates.

TABLE II. ECONOMIC APPRAISAL UNDER A BASE CASE OF 6%

Savings (%)	**Annual savings (million BGN)**	**Payback at 50k BGN (years)**	**Payback at 300k BGN (years)**
5	0.89	0.06 (~ 20 days)	0.34 (~4 months)
15	2.67	0.02 (~7 days)	0.11 (~41 days)

• Energy: 82.7 GWh

• Annual energy consumption (0.215 BGN/kWh): 17.8 million BGN

Table 2 gives sample ROI/payback for a base scenario, s=6%, price 0.21514 BGN/kWh.

For an investment of 50,000 BGN:

With the saving of 5% of energy consumption, the annual savings are equivalent to ≈ 889,158 BGN, and the payback period is approximately ≈ 0.056 years or ≈ 20 days.

For an investment of 300,000 BGN: At 5% saving of energy consumption, the annual energy saving is taken to be once again ≈ 889,158 BGN, for which the payback period comes out to be approximately ≈ 0.337 years or 123 days.

For an investment of 50,000 BGN

With a saving of 15% in energy consumption, the annual savings are ≈ 2.67 million BGN, and the payback period is approximately ≈ 0.02 years, or ≈ 7 days.

For the investment of 300,000 BGN: Through a saving of 1.5% in energy consumption, the energy savings per year are assumed to be once again ≈ 2.67 million BGN, while the payback period is approximately ≈ 0.11 years, or 41 days.

Main warning: these extremely short paybacks and high investment returns are due to the combined estimation (aggregation is the technique by which individual data is collected for statistical purposes and is expressed as a single number. This could be in the shape of an overall total or average value and the fact that our allocation relies on the total national "industry" energy usage). A number of energy-intensive sub-sectors within the national total (electric power, metallurgy, chemistry, etc.) skew the average "TJ/gr. product" when allocated directly by production value—possibly overestimating the real energy use of light engineering industries. The results are therefore estimates and show potential/order of magnitude but are not a substitute for company measurement.

Limitations: Cost of electricity for non-household clients (non-household/industrial) — representative (Eurostat / aggregated data): ≈ 0.11 EUR/kWh (December 2024, basis for calculation). (EUR→BGN: 1.95583).

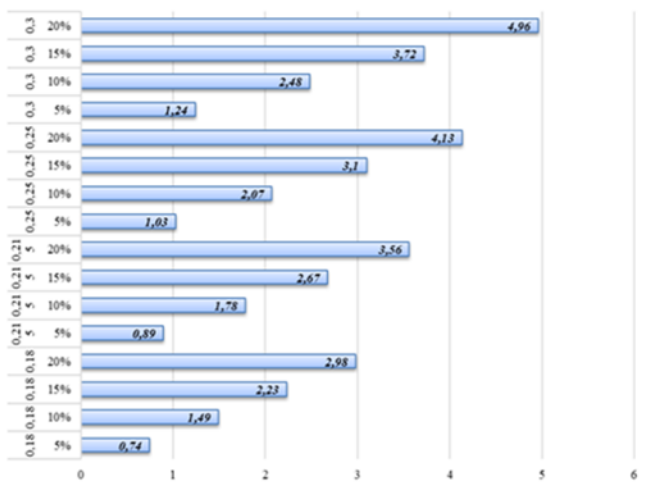

Fig. 1. Annual savings in million BGN

Sensitivity analysis (ROI)

1. Effect of electricity prices

• Based on a lower cost per kWh (0.18 BGN), the savings are lower—e.g., at 10% savings: ~1.49 million BGN/year.

• Premium price (0.30 BGN), and savings increase significantly—at identical 10% savings: ~2.48 million BGN/year.

This gives an impression that the effectiveness of investments is highly dependent on market electricity prices. The higher the electricity price, the greater the value of the introduction of energy-saving technology.

2. Impact of rate of savings

• With a 5% reduction in energy, savings are high, but the payback is longer (~0.11–0.34 years on 50k/300k investments).

• With a 20% reduction, savings are 4 times greater, and the return becomes very short-term (within a month for minor investments).

The implication is that the more integrated and holistic the energy efficiency improvements are, the quicker the investment pays back.

3. Payback periods

• Even on the most conservative assumption (5% savings and 0.18 BGN/kWh), the payback of an investment of 300k is ~0.34 years (about 4 months).

• In case of high energy prices and strong measures (20% savings and 0.30 BGN/kWh), the period falls below 1 week.

This is a very rare case of extremely high ROI, which makes energy-saving measures practically "obligatory" for the competitiveness of enterprises.

4. Strategic conclusions

• For mechanical engineering companies in Northeastern District, Industry 4.0 technologies implementation (IoT monitoring, digital twins, and AI optimization) can realize quick and significant financial effects.

• Best outcomes occur when combining:

• high rates of savings (10–20%);

• the adaptation to electricity market prices;

• balancing the initial investment (50k–300k BGN).

The outcome of the analysis of energy efficiency and return on investment sensitivity for Northeastern district's mechanical engineering companies presents a variety of significant trends and relationships. To begin with, the following fact manifests itself: despite relatively moderate rates of energy saving, companies achieve sizable annual savings, which amount to more than hundreds of thousands of leva. It obviously testifies to the high energy intensity of production procedures and potential for optimization.

The impact of electricity prices on investment efficiency is increasingly becoming significant. As market prices rise per kWh, the payback period for energy-saving interventions becomes very low, even below a month in some cases. This means mechanical engineering companies in the region are very sensitive to energy market prices but at the same time enjoy a strong incentive to implement sophisticated optimization technologies.

Another striking feature is how the saved energy relates to the financial result. While with 5% reduced consumption, companies have tangible savings, with 15–20%, the effect is magnified and totals millions saved yearly. This means that partial measures have only an incremental effect, whereas integrated Industry 4.0 solutions—i.e., smart sensors, automation technology, and artificial intelligence for predictive maintenance—can drive a fundamental revolution in efficiency.

Sensitivity analysis confirms again that even under the most adverse circumstances (unfavorable electricity prices and small savings), the return on investment occurs within months, not years. This is rare in industrial practice and proves that economic logic substantiates energy-saving measures firmly. In the context of the European Green Transition and increasing demands for decarbonization, these results are also of strategic relevance.

By the way, one should mention that the research is based on aggregated data and is making a proportional assumption of energy consumption. This can have some distortion from the real picture since each company has some degree of technological modernization and various energy profiles. Hence, the subsequent step should be to conduct company energy surveys that would give a more accurate picture.

The obtained results demonstrate a clear relationship between energy efficiency improvements and economic performance in mechanical engineering enterprises. Across all modeled scenarios, reductions in energy consumption generated measurable financial benefits and short investment payback periods. The sensitivity analysis further confirmed that the economic effect becomes more pronounced under higher electricity prices and greater energy savings. These findings suggest that Industry 4.0 technologies may serve not only as instruments for production optimization but also as strategic mechanisms for strengthening industrial competitiveness and sustainability in the Northeastern District. However, given the aggregated nature of the dataset, the results should be interpreted as indicative estimates requiring validation through firm-level empirical studies.

IV. CONCLUSIONS

This study examined the potential for improving business processes and energy efficiency in mechanical engineering enterprises in the Northeastern Region through the application of Industry 4.0 technologies. The findings indicate that the integration of intelligent manufacturing solutions—including IoT monitoring, digital twins, predictive maintenance, and ERP systems—creates favorable conditions for improving operational performance and supporting more efficient resource utilization in industrial enterprises.

The analysis suggests that investments in digital technologies may contribute not only to reducing energy-related costs but also to strengthening industrial competitiveness and long-term sustainability. In the context of increasing energy market uncertainty and growing environmental requirements, the transition toward intelligent manufacturing should be viewed as a strategic development opportunity rather than solely as a technological modernization process. In this regard, the implementation of Industry 4.0 technologies can support both economic resilience and compliance with sustainability objectives in the industrial sector.

At the same time, the interpretation of the results should consider the methodological assumptions underlying the analysis. Due to the absence of disaggregated sectorspecific energy data, the study relied on proportional allocation of industrial energy consumption according to production value and scenario-based estimates of the mechanical engineering sector's regional share. Consequently, the presented findings should be regarded as indicative estimates of potential effects rather than precise measurements of enterprise-level performance. Variations in technological maturity, production specialization, and firm size may significantly influence actual outcomes.

Future research should therefore focus on firm-level empirical investigations, including direct energy audits and company-specific performance assessments. Additional studies involving digital twin simulations and artificial intelligence applications in predictive maintenance may further improve understanding of the practical effects of Industry 4.0 on industrial energy efficiency and business process optimization.

REFERENCES

[1] M. Gu, L. Luo and P. Li, "Study and Development of Intelligent KPI Management System for Discrete Manufacturing Enterprises in Industry 4.0," 2023 4th International Conference on Mechatronics Technology and Intelligent Manufacturing (ICMTIM), Nanjing, China, 2023, pp. 19-25, doi: https://doi.org/10.1109/ICMTIM58873.2023.10246680.

[2] T. Hristova, I. Stoyanov, I. Mitev and R. Aleksandrov, "Automated Tracking of Electrical Engineer Competencies through Blockchain Technology," 2023 4th International Conference on Communications, Information, Electronic and Energy Systems (CIEES), Plovdiv, Bulgaria, 2023, pp. 1-8, doi: https://doi.org/10.1109/CIEES58940.2023.10378781.

[3] H. Beloev, I. Stoyanov and T. Iliev, "Good Practices in Implementing Energy Efficiency Measures in "Angel Kanchev" University of Ruse," 2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 2022, pp. 1-4, doi: https://doi.org/10.1109/EEAE53789.2022.9831424.

[4] L. D. Mashapu, P. S. P. Eboule and J. -H. C. Pretorius, "The Need for Artificial Intelligence for Energy-Efficiency Management: A Review," 2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 2022, pp. 1-6, doi: https://doi.org/10.1109/EEAE53789.2022.9831359.

[5] V. Koval, Y. Sribna, O. Mykolenko, N. Vdovenko, "Environmental concept of energy security solutions of local communities based on energy logistics," 19th International Multidisciplinary Scientific GeoConference SGEM 2019, 19(5.3), pp. 283-290, doi: https://doi.org/10.5593/sgem2019/5.3/S21.036

[6] Q. Liu, X. Guo, Y. Lei and M. Wang, "Manufacturing Execution System Driven by Industrial Big Data," 2021 4th World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM), Shanghai, China, 2021, pp. 543-546, doi: https://doi.org/10.1109/WCMEIM54377.2021.00117.

[9] L. Da Xu, E. L. Xu, and L. Li, "Industry 4.0: State of the Art and Future Trends," Int. J. Prod. Res., vol. 56, no. 8, pp. 2941–2962, 2018.

[10] A. Gilchrist, Industry 4.0: The Industrial Internet of Things. Berkeley, CA, USA: Apress, 2016.

[11] F. Tao and M. Zhang, "Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing," IEEE Access, vol. 5, pp. 20418–20427, 2017.

[12] S. Wang, J. Wan, D. Li, and C. Zhang, "Implementing Smart Factory of Industry 4.0: An Outlook," Int. J. Distrib. Sens. Netw., vol. 12, no. 1, 2016.

[13] J. Su, Y. Zhang, Y. Zhou and A. Wang, "Optimization for Intelligent Manufacturing Quality Inspectio," 2025 5th International Conference on Mechanical, Electronics and Electrical and Automation Control (METMS), Chongqing, China, 2025, pp. 645-648, doi: https://doi.org/10.1109/METMS65303.2025.11047662.

[14] X. Zhang, "Design and Implementation of Intelligent Manufacturing Workshop Management System Based on BOM," 2022 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Hengyang, China, 2022, pp. 686-689, doi: https://doi.org/10.1109/ICITBS55627.2022.00149.